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(54) **Title**: METHOD FOR CAPTURING THERMAL AND SPECIFIC RADIATIVE SPECTRUM VISIBLE, AND DEVICE FOR IMPLEMENTING SAID METHOD

(57) **Abstract**: This invention relates to a method and to a device for the implementation of said method, for selectively picking up some frequencies of a radiative spectrum, for a first use and, at the same time, to use the residual frequencies for thermal purposes. The method is characterized in that it includes the following steps: • to pick up said electromagnetic radiation; • to induce the reflection of said one or more frequencies using a reflector coloured by colours corresponding to said one or more frequencies; • to receive said one or more frequencies reflected by said coloured reflector; • to convey said one or more received frequencies towards a user device; • to use said residual frequencies for increasing the temperature of said coloured reflector; • to take the thermal energy produced by said coloured reflector. The device (A) is characterized in that it includes: - first means (3), fitted to reflect said one or more frequencies and to absorb said residual frequencies, in such a way to produce thermal energy, said first means (3) being coloured by one or more colours corresponding to said frequencies to be reflected; • second means (5), fitted to receive said one or more frequencies reflected by said first means (3) and to transmit them to a user device.

METHOD FOR CAPTURING THERMAL AND SPECIFIC RADIATIVE SPECTRUM VISIBLE, AND DEVICE FOR IMPLEMENTING SAID METHOD

DESCRIPTION

This invention refers to a method and to a device for the implementation of said method, for selectively picking up some frequencies of a radiation spectrum, for a first use and, at the same time, to use the residual frequencies for thermal purposes.

It is strongly felt the need to have effective systems for recovery of thermal energy, to feed heating systems and processes in general. This need is particularly felt in the low enthalpy systems, by the ever more widespread use of heat pumps, to exploit environmental resources (Renewable Energy Sources). The efficiency of thermal solar panels is compromised by the insulating structures used to draw from environmental resources, and are mainly aimed at picking up the portion of energy deriving from the only irradiation. Even for the not glazed panels, they were not developed specific strategies to exploit the natural dynamics of the convective motions that are generated to the heat taking in front of the vertical or anyhow inclined surfaces. Another need, strongly felt, is the possibility to have specific components of the visible spectrum, selected and in appropriate assortment for specific processes (for example for biological ones).

In summary, in the current state it is not possible to selectively pick up some frequencies of the radiation spectrum and, at the same time, to use the residual frequencies for thermal uses. Moreover, it is not optimized the taking of the environmental energy simultaneously with the one of the radiant energy.

In particular, it is not possible, by a single device, to pick up some specific frequencies for a purpose and to use the residual frequencies to produce thermal energy for another purpose.

The object of this invention is to propose a method and a device to implement said method, respectively conform to claims 1 and 2, to selectively pick up one or more frequencies of an electromagnetic radiation, at least in part visible and to use the residual frequencies to produce thermal energy.

The method is characterized in that it includes the following steps:

- to pick up said electromagnetic radiation;
- to induce the reflection of said one or more frequencies using a reflector coloured by colours corresponding to said one or more frequencies;
- to receive said one or more frequencies reflected by said coloured reflector;
- to convey said one or more received frequencies towards a user device.

According to a preferred embodiment, the method is further characterized in that:

- to use the not reflected part of said electromagnetic radiation to increase the temperature of said coloured reflector;
- to take the thermal energy produced by said coloured reflector.

The device is characterized in that it includes:

- first means (3), fitted to reflect said one or more frequencies and to absorb said residual frequencies, in such a way to produce thermal energy, said first means (3) being coloured by one or more colours corresponding to said frequencies to be reflected;
- second means (5), fitted to receive said one or more frequencies reflected by said first means (3) and to transmit them to a user device.

Other characteristics, such as for example the possibility to pick up the environmental energy, will be the subject of the dependent claims.

The use of a device according to the invention allows, for example, to pick up the frequencies that are useful for the growing of certain crops and, simultaneously, to heat the environment in which said crops are carried out.

The invention will now be described for illustrative and not limitative purpose, according to a preferred embodiment and with reference to the attached figure 1, which shows the device according to the invention.

With reference to Fig. 1, with (A) is indicated a device, according to the invention, able to pick up, for example: the frequencies concerning the colours red and blue and to use the residual frequencies to produce heat. Said device (A) includes:

- a first reflector (3), hit by the solar radiation, whose surface is painted in red and blue, so that it reflects only the wavelengths relevant to these two colours, said first reflector (3) being fitted to heat up due to the effect of the not reflected radiation;
- a second reflector (6), fastened on a rod (6a), which it is fastened itself on a support (7), said second reflector (6), capturing the light, red and blue, reflected by said first reflector (3);
- a receiver (5) fitted to receive the red and blue light reflected by said second reflector (6), said receiver (5) being connected with an optical fiber (5a) fitted to transmit towards a user device (not shown) said red and blue light;
- means (8, 9), placed in a heat exchange relationship with said first reflector (3) and fitted to pick up the heat produced by said first reflector (3) due to the effect of the absorbed radiation.

According to a preferred embodiment, said means fitted to pick up the heat produced by said first reflector (3), include a coil having an end (8) and (9) through which a thermal fluid flows.

The described device (A) uses a Cassegrain dynamic, that provides for the use of said second reflector (6) positioned in correspondence with the focus of said first reflector (3), which has the shape of a paraboloid. According to said Cassegrain dynamic, the second reflector (6) focuses the reflected rays on said receiver (5) located in correspondence with the vertex of the paraboloid which constitutes the first reflector (3). Alternatively, the reflector (5) can be positioned in correspondence of the focus of the paraboloid.

According to a preferred embodiment, shown in Fig. 1, there are provided means fitted to pick up the environmental energy and to transfer it to said coil (8, 9). Said environmental energy can be, for example, the heat content of the air or of another medium such as, for example, of water taken from a source or of steam waste taken from a plant.

Said means fitted to pick up the environmental energy act by driving the laminar flows of fluids (gaseous or liquid) to lap the coil (8, 9). According to a preferred embodiment, said means include suitably oriented blades, for example, of stretched sheets (1, 2), fitted to create specific convective motions.

Said means (1), (3), (8, 9) allow a significant energy exchange in their basic configuration, that will be increased when, slaved to heat pumps, being able to take advantage of larger gradients and therefore of greater energy volumes. Particular attitudes of the blades in stretched nets, in the state of energy taking from the environment (conveying towards the inside), involve the progressive cooling of the contiguous materials, that for a greater density will generate descendants convective laminar motions, favouring the inflow towards the means (1), (3) and (8, 9) designed to pick up the thermal energy. The fins of the stretchched sheet will have to assume a symmetrically reverse configuration in the event of the transfer of energy to the adjacent materials.

Said coil (8, 9) may be advantageously shaped so as to ensure a uniform exchange (roundtrip, according to a square, circular, elliptical or other spiral).

According to a further embodiment, the first reflector (3) and the coil (8, 9) comprise a single element of the type called roll bond, which is shaped according to the surface of a paraboloid, whose concave side act as the reflector (3).

Said means (1), (3), (8, 9), replaced by panels "roll-bond" make the device more economical, the novelty is in their coupling with the function of the first reflector (3) and subsequent means to capture and to convey one or more frequencies of a electromagnetic spectrum towards the user device. The "roll bond" are composed by a sandwich of two sheets of aluminum (metals or equivalent alloys) between which it derives a pipe run by heat transfer fluids (gas or liquids such as refrigerating gas or aqueous liquids).

The invention finds applications in various sectors:

- algal crops, in which serves both the radiative spectrum and the thermal energy;
- (b) vegetable cultivations in greenhouse, to punctually convey specific radiative spectrum and thermal energy in other points more functional to the developments of the foliar and radical apparatuses;
- to convey only some frequencies useful to the effects of specific processes (e.g. photovoltaic ones) and in regimes concentrated with simultaneous recovery of residual frequencies to thermal purposes (together with the thermal energy from the environmental condition);
- vegetable crops in pits or cellars in schemes for hydroponic and aeroponic cultivation in urban structures;
- (e) to allow the vegetation of meadows in natural grass sports centers or in general in tensile pressostatic structures.

The invention has been described for illustrative and not limitative purpose, according to some preferred embodiments. The person skilled in the art could find many other embodiments, all included within the scope of protection of the enclosed claims.

CLAIMS

1. Method to selectively pick up one or more frequencies of an electromagnetic radiation, characterized in that it includes the following steps:
    - to pick up said electromagnetic radiation;
    - to induce the reflection of said one or more frequencies using a reflector coloured by colours corresponding to said one or more frequencies;
    - to receive said one or more frequencies reflected by said coloured reflector;
    - to convey said one or more received frequencies towards a user device.
2. Method to selectively pick up one or more frequencies of an electromagnetic radiation, according to claim 1, characterized in that it further includes:
    - the use of the not reflected part of said electromagnetic radiation to increase the temperature of said coloured reflector;
    - the pick up of the thermal energy produced by said coloured reflector.
3. Device (A) fitted to selectively pick up one or more frequencies of an electromagnetic radiation, characterized in that it includes:
    - the first means (3), fitted to reflect said one or more frequencies and to absorb said residual frequencies, so as to produce heat energy, said first means (3) being coloured with one or more colours corresponding to said frequencies to be reflected;
    - second means (5), fitted to receive said one or more frequencies reflected by said first means (3) and to transmit them to a user device.
4. Device (A), according to claim 3, characterized in that said first means (3), fitted to reflect said one or more frequencies, include a surface shake in such a way fitted to focus the reflected rays of said one or more frequencies in a circular zone.
5. Device (A), according to claims 3 and 4, characterized in that said second means (5), fitted to receive said one or more frequencies reflected by said

first means (3) and to transmit them to a user device, are positioned in correspondence of said circular or linear shaped area.

6. Device (A), according to claims 3 and 4, characterised in that it includes third means (6), fitted to receive said one or more frequencies reflected by said first means (3) and to reflect them on said second means (5), fitted to receive said one or more frequencies reflected by said first means (3) and to transmit them to said user.

7. Device (A), according to claim 6, characterized in that said first means (3), third means (6) and second means (5) are arranged according to a dynamic of Cassegrain.

8. Device (A), according to at least one of the claims from 3 to 7, characterized in that said second means (5), fitted to receive said one or more frequencies reflected by said first means (3) and to transmit them to said user, include an optic fitted to concentrate in an optical fiber (5a) the reflected rays of said one or more frequencies.

9. Device (A), according to at least one of the claims from 3 to 7, characterized in that said first means (3), fitted to reflect said one or more frequencies and to absorb said residual frequencies, so as to produce thermal energy, are in heat exchange relationship with a coil (8, 9) inside which a heat transfer fluid flows.

10. Device (A), according to at least one of the claims from 3 to 8, characterized in that it includes fourth means fitted to pick up the environmental energy and to transfer it to said coil (8, 9).

11. Device (A), according to claim 10, characterized in that said fourth means, fitted to pick up the environmental energy and to transfer it to said coil (8, 9), are fitted to direct the laminar flows of the concerned fluids (gaseous or liquid) so as to lap the said coil (8, 9).

12. Device (A), according to claim 11, characterized in that said fourth means, fitted to direct the laminar flows of the concerned fluids (gaseous or liquid) so as to lap the said coil (8, 9), include some blades oriented in such a way as to create specific convective motions.

13. Device (A), according to claim 12, characterized in that said fourth means, fitted to direct the laminar flows of the concerned fluids (gaseous or liquid) so as to lap the said coil (8, 9) include said blades that are oriented in such a way as to create specific convective motions, include some stretched sheets (1, 2).

14. Device (A), according to at least one of the claims from 3 to 13, characterized in that said first reflector (3) and said coil (8, 9) are integrated in a single element of the type called "roll-bond", said element roll-bond being shaped according to the surface of a paraboloid, whose concave side assumes the role of the said reflector (3).

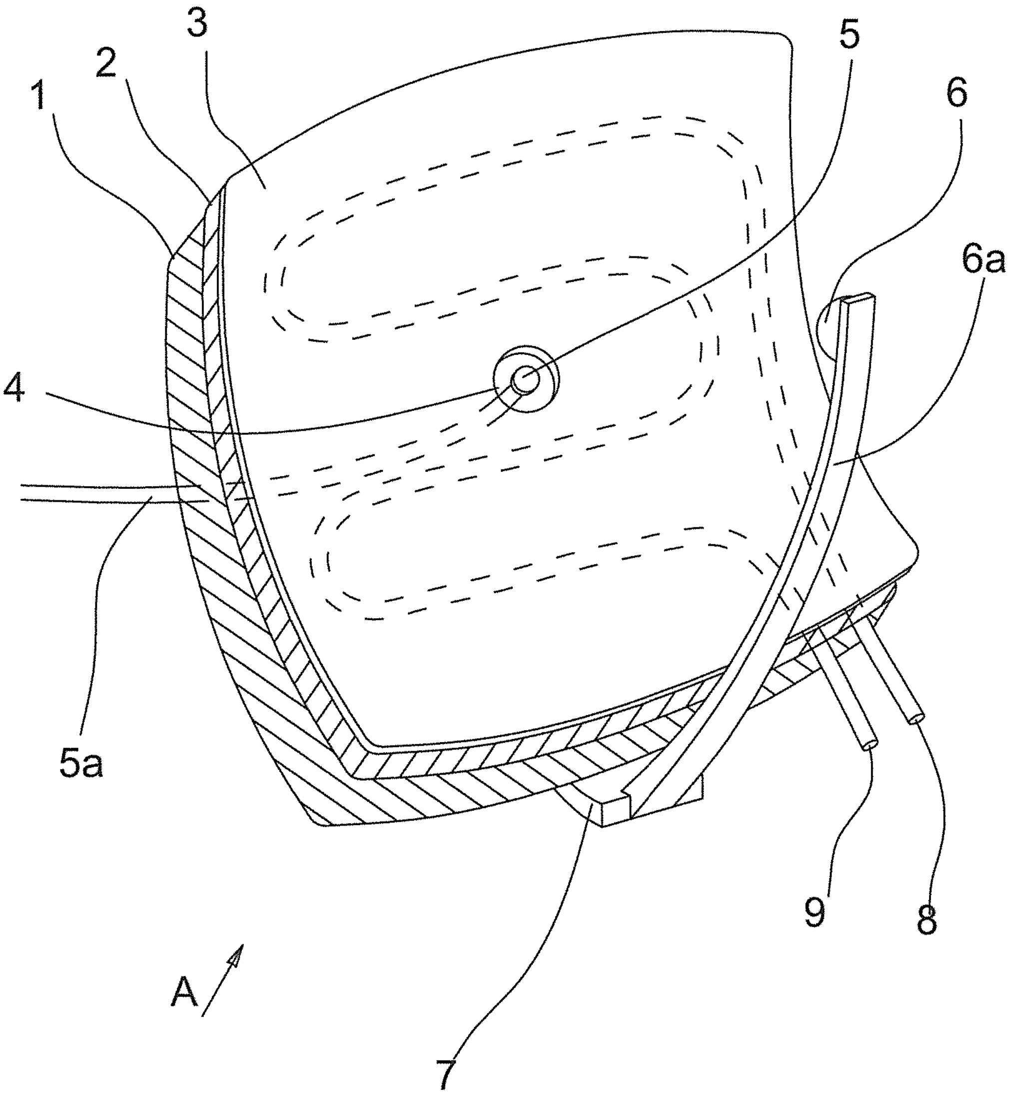

Fig. 1

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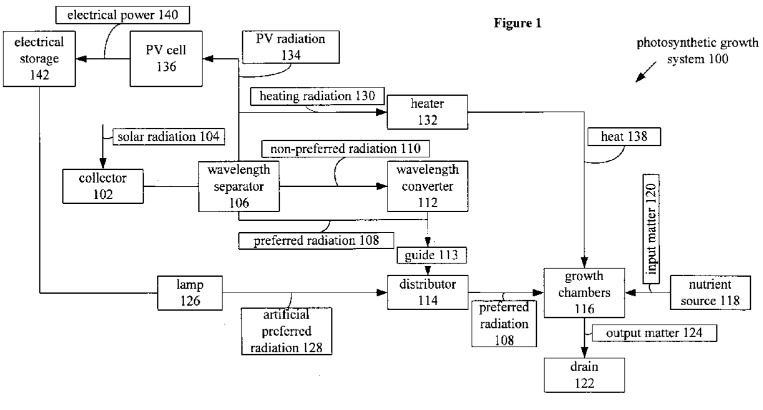

Figure 1

(57) Abstract: A photosynthetic growth apparatus including: photosynthetic material defining a preferred photosynthesis absorption band of optical wavelengths for performing photosynthesis; and a wavelength converter for emitting growth light in the preferred photosynthesis absorption band, for absorption by the photosynthetic material, by absorbing solar radiation in a converter absorption band different to the preferred photosynthesis absorption band, based on Stokes fluorescence.

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APPARATUS, SYSTEM AND METHOD FOR PHOTOSYNTHESIS

FIELD

The present invention relates to apparatuses, systems and methods for providing photosynthesis, for example for growing algae with a photobioreactor (PBR).

BACKGROUND

The climate of planet Earth is changing as increasing volumes of carbon dioxide (CO2) accumulate in the environment, in particular the atmosphere, lakes and oceans. Much of the CO2 released into the environment is generated by technologies and industries that have become important to national economies and people's way of life. For example, coal-fired electricity generation plants provide cheap electricity that is essential for modern society, but are increasingly under pressure to reduce the amount of CO2 they emit into the atmosphere. Governments and companies are in desperate need to reduce the amount of CO2 being released into the environment, and to reduce the amount of CO2 already released, using so-called "carbon capture" techniques. For example, photosynthetic growth captures CO2 to build structures of plants, such as its biological cells. However, there is insufficient growing photosynthetic matter (*e.g.*, plants on land and in the ocean) on Earth, or at least insufficient photosynthetic matter that is conveniently located, to capture enough CO2 to reverse its accumulation in the environment at current rates of emission.

There is a need for an increase in the Earth's capacity to capture CO2, including a need for more photosynthetic material performing photosynthesis, and more efficient use of available solar radiation in photosynthesis, in particular using solar radiation directly, in more efficient facilities. There is a need to provide high-efficiency photosynthesis concentrated in particular locations, *e.g.*, near CO2-emitting facilities. There is a need for containing photosynthetic materials in non-contaminating facilities, *e.g.*, through ingress or egress of materials / pollutants. There is a need for more robust and simpler apparatuses for supporting photosynthesis.

It is desired to address or ameliorate one or more of the problems, disadvantages and limitations associated with the prior art, or to at least provide a useful alternative.

SUMMARY

In accordance with the present invention, there is provided a photosynthetic growth apparatus including:

at least one solar collector configured to collect solar radiation;

at least one growth area configured for photosynthetic material to perform photosynthesis using radiation having at least one selected wavelength;

a wavelength converter configured to convert at least a portion of the collected solar radiation having at least one wavelength different from the at least one selected wavelength to radiation with the at least one selected wavelength for the photosynthetic material; and

a light modulator configured to control irradiation of the photosynthetic material by the radiation with the at least one selected wavelength to at least substantially reduce photoinhibition of the photosynthesis.

In some embodiments, the irradiation of the photosynthetic material uses light arising from the solar radiation.

In some embodiments, the light modulator modulates the amplitude of the irradiation of the photosynthetic material. In some embodiments, the light modulator modulates the amplitude of the irradiation between zero and a maximum.

In some embodiments, the light modulator includes a distributor configured to distribute the collected radiation and the converted radiation between a plurality of different portions of the photosynthetic material in the at least one growth area. In some embodiments, the distributor includes a moving distributor configured to selectively and sequentially direct the collected radiation and the converted radiation to the plurality of different portions of the photosynthetic material. In some embodiments, the moving distributor is a rotating distributor including a rotating reflector. In some embodiments, the moving distributor is a switching distributor including a plurality of switching reflectors. In some embodiments, the plurality of different portions of the photosynthetic material are in respective different growth areas of the at least one growth area.

In some embodiments, the light modulator is controlled by a modulation controller to control the intensity at a selectable maximum intensity, minimum intensity, modulation frequency, and/or modulation duty cycle. In some embodiments, the modulation frequency is about 1 Hz to 20 kHz, or about 25 Hz to 250 Hz. In some embodiments, the duty cycle is between about 10% and about 50%.

In some embodiments, the light modulator is controlled by a modulation controller to control the intensity to at least substantially reduce self-shadowing of the photosynthetic material due to excessive growth of the photosynthetic material.

In some embodiments, the at least one solar collector includes at least one reflective surface for concentrating the solar radiation. In some embodiments, the at least one reflective surface is moveable to track movement of the sun. In some embodiments, the at least one reflective surface is fixed relative to movement of the sun, and the at least one solar collector includes at least one respective tilting arm receiver moveable to track movement of the concentrated solar radiation caused by movement of the sun. In some embodiments, the at least one solar collector forms a fixed roofing structure, and the at least one reflective surface concentrates the solar radiation to a radiation capture device substantially protected from environmental and mechanical damage. In some embodiments, the at least one reflective surface includes two surfaces, and the first surface is shaped to concentrate the solar radiation to the receiver behind the second surface. In some embodiments, the first surface has a compound parabolic concentrator shape.

In some embodiments, the at least one selected wavelength includes one or more wavelengths respectively corresponding to one or more of the lowest photosynthetic absorption states of the photosynthetic material. In some embodiments, the at least one selected wavelength includes one or more wavelengths corresponding to red light. In some embodiments, the red light includes wavelengths from about 620 nm to about 780 nm. In some embodiments, the red light includes wavelengths from about 660 nm to about 750 nm.

In some embodiments, the photosynthetic growth apparatus includes an artificial light source configured to generate artificial radiation having at least one selected wavelength for irradiating the photosynthetic material to perform photosynthesis when the solar radiation is not available, to at least substantially reduce respiration by the photosynthetic material. In some embodiments, the artificial light source includes light-emitting diodes (LEDs) emitting red light. In some embodiments, the artificial light source is powered by electricity generated photovoltaicly from portions of the solar radiation not including the at least one selected wavelength.

In some embodiments, the photosynthetic growth apparatus includes a light guide configured to receive and guide the collected radiation and the converted radiation from the solar collector to the photosynthetic material. In some embodiments, the light guide includes a plurality of reflector elements for receiving the collected radiation from a first direction and for directing the received radiation in a second direction generally perpendicular to the first direction. In some embodiments, each reflector element includes two curved reflective faces with an open end for receiving the collected radiation, and wherein a first curved reflective face is shaped to direct radiation behind a second curved reflective face at a narrow end of the reflector element. In some embodiments, the light guide includes a plurality of wavelength convertor elements of the wavelength convertor for converting the portion of the solar radiation as the collected radiation is guided by the light guide. In some embodiments, the light guide is configured to separate the wavelength convertor and/or the at least one solar collector from the photosynthetic material to at least substantially reduce any effect of heat from the wavelength convertor and/or the at least one solar collector on the photosynthetic material. In some embodiments, the light guide includes a plurality of light panels to spatially distribute light across the at least one growth area.

In some embodiments, the at least one growth area includes at least one growth chamber configured to transmit the collected radiation and the converted radiation from the light guide to the photosynthetic material. In some embodiments, the at least one growth chamber includes a plurality of transparent side walls. In some embodiments, the at least one growth chamber is configured to allow fluid flow to and from the photosynthetic material. In some embodiments, the at least one growth chamber is in the form of a replaceable container. In some embodiments, sparging features are integrally formed in the replaceable container. In some embodiments, the sparging features include perforations between separate compartments of the at least one growth chamber.

In some embodiments, the photosynthetic growth apparatus includes at least one wavelength separator configured to separate portions of the solar radiation that do not have the at least one selected wavelength for use in heat generation and/or photovoltaic electricity generation. In some embodiments, the photosynthetic growth apparatus includes at least one wavelength separator having at least one wavelength-selective surface configured to separate portions of solar radiation having the at least one selected wavelength from portions not having the at least one selected wavelength. In some embodiments, the at least one wavelength-selective surface includes a dichroic reflective coating.

In some embodiments, the wavelength converter uses Stokes fluorescence to convert the solar radiation. In some embodiments, the photoluminescence is provided by a semiconductor material, and the semiconductor material includes a plurality of semiconductor quantum dots (QDs). In some embodiments, the converted radiation has a wavelength based on a morphology and/or dielectric environment of the QDs.

In some embodiments, the photosynthetic material includes microalgae.

The present invention also provides a photosynthetic growth system including:

the photosynthetic growth apparatus; and

a fluidic processing system for supplying the photosynthetic material with input matter for the photosynthesis.

The present invention also provides a photosynthetic growth facility for capturing carbon dioxide using photosynthesis including:

a plurality of the photosynthetic growth systems; and

a control system for controlling the photosynthetic growth apparatuses and the fluidic processing systems.

In some embodiments, the at least one solar collector includes an array of solar collectors forming a roof. In some embodiments, the roof is substantially sealed to fluid and/or temperature.

The present invention also provides a method of performing photosynthesis including the steps of:

collecting solar radiation;

converting at least a portion of the collected solar radiation having one or more wavelengths different from at least one selected wavelength to radiation with the at least one selected wavelength;

performing photosynthesis using photosynthetic material and the radiation having the at least one selected wavelength; and

controlling irradiation of the photosynthetic material by the radiation having the at least one selected wavelength to at least substantially reduce photoinhibition of the photosynthesis.

The present invention also provides a method of performing photosynthesis including the steps of:

collecting solar radiation;

converting a portion of the solar radiation that does not have at least one preferred wavelength for photosynthesis by a photosynthetic material into light having at least one preferred wavelength;

controlling the intensity of the collected radiation and the converted radiation to at least substantially reduce photoinhibition of the photosynthesis; and

performing the photosynthesis using the collected radiation and the converted radiation.

The present invention also provides a photosynthetic growth apparatus including:

at least one solar collector configured to collect solar radiation;

a wavelength converter configured to convert a portion of the solar radiation that does not have at least one preferred wavelength for photosynthesis by a photosynthetic material into radiation having at least one preferred wavelength for photosynthesis by the photosynthetic material;

a light modulator configured to control the intensity of the collected radiation and the converted radiation to at least substantially reduce photoinhibition of the photosynthesis; and

photosynthetic material for performing the photosynthesis using the collected radiation and the converted radiation.

The present invention also provides a solar collector including:

at least one reflector, fixed relative to movement of the sun, configured to concentrate solar radiation to a moving region; and

at least one moving receiver configured to move to receive the concentrated solar radiation in the region.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention are hereinafter further described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a photosynthetic growth system;

Figure 2 is a diagram of a perspective view of a photosynthetic growth apparatus of the photosynthetic growth system;

Figure 3A is a schematic diagram of a perspective view of an optical system of the photosynthetic growth apparatus;

Figure 3B is a diagram of a perspective view of the optical system;

Figure 3C is a schematic diagram of a cross-sectional view of a tracking collector of the optical system;

Figure 4 is a diagram of a perspective view of a distributor and a light guide of the optical system;

Figure 5 is a schematic diagram of a perspective view of a reflector and a lamp in the optical system;

Figure 6 is a schematic diagram of a cross-sectional view of a switching device of the distributor;

Figure 7A is a diagram of a plurality of light panels of the optical system;

Figure 7B is a schematic diagram of a switching distributor of the optical system;

Figure 8 is a diagram of a perspective view of a photosynthetic growth chamber of the photosynthetic growth apparatus;

Figure 9 is a diagram of a perspective view of an array of a plurality of the photosynthetic growth chambers;

Figure 10 is a diagram of a perspective view of a frame of the photosynthetic growth apparatus;

Figure 11 is a diagram of a perspective view of a photosynthetic growth facility including a plurality of the photosynthetic growth systems;

Figure 12 is a schematic diagram of a fluidic system of the photosynthetic growth system;

Figure 13 is a schematic diagram of a profile of a guide element of a waveguide assembly of the optical system;

Figure 14 is a schematic diagram of a side view of the waveguide assembly;

Figure 15 is a diagram of a perspective view of a tilting-arm collector of the optical system;

Figure 16 is a diagram of a perspective view of an array of tilting-arm collectors;

Figures 17A to 17E are schematic diagrams of side views of the tilting-arm collector in different positions;

Figure 17F is a chart of collection efficiency as a function of the angle of incident solar radiation;

Figure 18 is a schematic diagram of a profile of a concentrating collector of the optical system;

Figures 19A to 19C are diagrams of perspective views of arrays of the concentrating collectors; and

Figure 19D is a diagram of a perspective view of a facility including an array of the concentrating collectors.

DETAILED DESCRIPTION

Overview

As shown in Figure 1, a photosynthetic growth system 100 includes at least one solar collector 102 configured to collect solar radiation 104, a wavelength separator 106 for separating the solar radiation 104 into components (or "ports") based on their wavelengths and including preferred radiation 108 (including selected preferred wavelengths for photosynthesis) and non-preferred radiation 100 (including non-preferred wavelengths, and not including the selected wavelengths). The at least one solar collector 102 includes at least one reflective surface for concentrating the solar radiation.

The photosynthetic growth system 100 includes at least one growth area, including one or more growth chambers 116, configured for photosynthetic material to perform photosynthesis using the preferred radiation 108 (*i.e.*, radiation having at least one of selected preferred wavelength).

The photosynthetic growth system 100 includes a wavelength converter 112 configured to convert at least a portion of collected solar radiation having at least one wavelength different from the at least one selected preferred wavelength (also referred to as the non-preferred radiation 110) into radiation with the at least one selected wavelength for the photosynthetic material (also referred to as additional preferred radiation 108). The photosynthetic growth system 100 includes a light modulator configured to control irradiation of the photosynthetic material by the radiation with the at least one selected wavelength (the preferred radiation 108) to at least substantially reduce photoinhibition of the photosynthesis. Modulating the irradiation includes modulating the amplitude of the irradiation of the photosynthetic material, *e.g.*, zero and a maximum amplitude, and can be referred to as "flashing" the irradiation (or growth light), or photomodulating the light.

The photosynthetic growth system 100 includes a light guide 113 for guiding light to the modulator. The light guide 113 is configured to receive and guide the collected radiation and the converted radiation from the solar collector 102 to the photosynthetic material. The light guide 113 is configured to separate the wavelength convertor 112 and/or the at least one solar collector 102 from the photosynthetic material in the growth area(s) to at least substantially reduce any effect of heat from the wavelength convertor 112 and/or the at least one solar collector 102 on the photosynthetic material: the temperature of the photosynthetic material may need to be controlled at a level insulated from extremes of temperature in the wavelength convertor 112 and/or the solar collector 102 due to heat generated in the conversion process, or heat due to absorption of the collected solar radiation, respectively.

The light modulator can include a distributor 114, as shown in Figure 1, configured to distribute the collected radiation and the converted radiation between a plurality of different portions of the photosynthetic material in the at least one growth area. The distributor 114 directs the preferred radiation 108 (including the collected radiation and the converted radiation) to a plurality of different growth areas comprising the plurality of growth chambers 116 for growing photosynthetic material.

The solar radiation may be referred to as sunlight, solar irradiance, etc. The photosynthetic material, also referred to as "phototrophs" or "photoautotrophs", performs processes of biosequestration and photosynthesis. The photosynthetic material absorbs CO2 when growing based on the solar radiation and generates biomass. The photosynthetic growth system and or the photosynthetic growth apparatus may be referred to as including a "photobioreactor" (PBR). In some embodiments, the photosynthetic growth system 100 is used for growth of particular photosynthetic material that generate pharmaceutically useful by-products, such as generally modified algal species, *e.g.*, micro-algae (or "microalgae).

The apparatus can improve the economics of microalgae growth by reducing the cost of photon delivery to the algae.

Photosynthetic Material

The photosynthetic material can include photosynthetic species having chlorophyll (*e.g.*, green plants), plant species having phycobilins (*e.g.*, red algae), photosynthetic bacteria (Cyanobacteria, also known as blue-green algae, blue-green bacteria or Cyanophyta) and microalgae. The microalgae include: Archaeplastida, Chlorophyta (Green algae), Rhodophyta (Red algae), Glaucophyta, Rhizaria, Excavata, Chlorarachniophytes, Euglenids, Chromista, Alveolata, Heterokonts, Cryptophyta, Dinoflagellates, and Haptophyta. The Heterokonts include Bacillariophyceae (Diatoms), Axodine, Bolidomonas, Eustigmatophyceae, Phaeophyceae (Brown algae), Chrysophyceae (Golden algae), Raphidophyceae, Synurophyceae, and Xanthophyceae (Yellow-green algae).

Preferred Radiation

Each type of photosynthetic material has a preferred photosynthesis absorption band of optical wavelengths for performing photosynthesis for which the process of photosynthesis is more performed more efficiently, *i.e.*, less optical power is wasted as heat energy. The preferred photosynthesis absorption band is defined by specific species or characteristics of the photosynthetic material. Thus the at least one selected wavelength is selected to include one or more wavelengths respectively corresponding to one or more of the lowest photosynthetic absorption states of the photosynthetic material, thus providing a high photon efficiency for the photosynthesis.

The preferred radiation 108 is preferred as it includes wavelengths that are substantially utilised in photosynthesis by growing photosynthetic material, and therefore substantially (or wholly) stimulates photosynthesis and carbon dioxide capture, while also corresponding to the lower (or lowest) excited state(s) of the "photosystem" (*e.g.*, chlorophyll and/or accessory pigments). The colours (*i.e.*, wavelengths) of the incident light on the photosynthetic material preferably match the absorption band which corresponds to the lowest excited state of the photosystem of the photosynthetic material. In the case of chlorophyll, absorption bands are present in the blue as well as in the red spectral regions. In terms of energy economy, the less energetic red photons which, on a per-quantum base, serve photosynthesis equally well as the energy richer blue photons, are preferred. Red light substantially corresponds to the photon energy needed to reach the first excited state of chlorophylls a and b, which are the pigments present in the light-harvesting-antenna complexes (LHC) of green algae. An electron present in the chlorophyll's first excited state contains enough potential energy to impart a transmembrane charge separation at the photochemical reaction centre. From this intermediate status it may subsequently enter into the photosynthetic electron transfer chain. Blue light (blue photons contain about 40% more energy than red photons) can be absorbed by chlorophyll as well. With blue photons, electrons are elevated toward the second excited state of chlorophyll. However, this second excited state is just as effective for charge separation as the first excited one; in fact, the second excited state needs to relax to the first excited state before charge separation can occur. The excess energy present in the blue photons is wasted as heat. For example, microalgae can photosynthesise at their maximum rate when receiving only red light, which represents about 10% of the solar spectrum, rather than blue light which corresponds to a higher excited state.

The preferred radiation 108 represents portions of the spectrum of the solar radiation 104 selected to sustain the photosynthesis of the photosynthetic material, for.

In the described embodiment, the preferred radiation 108 includes a narrow band of the red spectrum of sunlight, representing about 10% of the incident solar power, that can sustain photosynthesis of plants such as microalgae. For example, the selected wavelengths can be in red light, from about 620 nm to about 780 nm, or from about 640 nm to about 750 nm, from about 660 nm to about 750 nm, for green algae.

In other embodiments, a low dose of blue light can be used to increase the rate of photosynthesis in certain algal species: the low dose of blue light (with wavelengths from about 455 nm to about 492 nm; or about 470 nm) can be from about 1% to about 20% of the total intensity. Blue light can play an essential role in regulation of cell growth and metabolism for certain photosynthetic materials, *e.g.*, to promote growth and/or partition of nutrients within algae of certain species.

Heating and Power

As shown in Figure 1, the wavelength separator 106 separates from the solar radiation 104 two further components of radiation, namely heating radiation 130, which is directed to a heater 132 of the photosynthetic growth system 100, and photovoltaic (PV) radiation 134, which is directed to a photovoltaic (PV) cell 136. The heater 132 generates heat 138 based on the heating radiation 130, and the heat 138 can be directed to the plurality of growth chambers 116 to maintain a selected temperature of the photosynthetic material in the plurality of growth chambers 116, under control of a system controller to control the rate of photosynthesis and growth.

The PV cell 136 generates electrical power 140 from the PV radiation 134, and the electrical power 140 is stored in electrical storage 142, *e.g.*, a battery or capacitive storage. The electrical power 140 in the electrical storage 142 is used by the lamp 126 to generate the artificial preferred radiation 128. As the electrical power 140 is stored in the electrical storage 142, the lamp 126 can generate the artificial preferred radiation 128 at some time after the PV cell 136 has received the PV radiation 134, for example, the lamp 126 may provide the artificial preferred radiation 128 during the night after the PV cell 136 has generated the electrical power 140 during a preceding day.

Wavelength Converter

The wavelength converter 112 generates additional photons in the preferred wavelength of the preferred radiation 108 based on photons in the non-preferred radiation 110 in a process referred to as "wavelength shifting". The wavelength converter emits growth light in the preferred photosynthesis absorption band based on photoluminescence, for absorption by the photosynthetic material, by absorbing solar radiation in a converter absorption band at least partially different from the preferred photosynthesis absorption band, *e.g.*, using Stokes fluorescence.

The non-preferred radiation 110 includes a converter absorption band of wavelengths corresponding to a respective plurality of semiconductor quantum dots with absorption bands across this spectrum and emission spectrum between 640 nm and 750 nm (*e.g.*, CdTe quantum dots), for the converter 112; and the heating radiation 130 and the PV radiation 134 includes a band of wavelengths, *e.g.*, from about 750 nm to about 1000 nm for PV cells 136 and heater 132 configured to absorb over this band.

The wavelength shifting in the wavelength converter 112 can be based on photoluminescent semiconductor quantum dots which absorb for example about 30% of the incident solar radiation 104 as the non-preferred radiation 110, and generate the preferred radiation 108 with an efficiency of for example about 30%, thereby providing an additional source of the preferred radiation 108. The quantum dots in the wavelength converter 112 are in optical communication via their tunnel barriers with light pipes, which provide photon channelling towards the distributor 114. In the plurality of quantum dots, different sized quantum dots are selected to emit different preferred wavelengths (also referred to as differently "coloured" light) based on the energy spectra of the quantum dots. The energy spectra of the quantum dots are selected by controlling the geometrical size, shape, and the strength of the confinement potential. For example, the larger the dot, the more red (lower energy) its luminescence spectrum, which allows the quantum dot to absorb photons containing less energy, *i.e.*, those closer to the red end of the spectrum, because electron-hole pairs in larger dots live longer causing larger dots to show a longer lifetime. Thus, the emitted growth light has an emission wavelength based on a morphology and dielectric environment of the QDs.

The quantum dots can be produced by chemical methods or by ion implantation, or using lithographic techniques with about 100 to 100,000 atoms within the quantum dot volume and diameters of 10 to 50 atoms. The quantum dots manufactured using a wet chemical process are fixed in a transparent material in the wavelength converter 112. The quantum dots may include CdSe. Alternatively, the quantum dots may be free of heavy metals with bright emissions in the visible far-red region of the spectrum with similar optical properties to CdSe quantum dots, for example, based on Indium phosphide (InP), an InGaP core coated with a ZnS lattice, copper, indium, gallium, selenium, Mn^{2+}-doped ZnSe, and the organic semiconductor tetrabenzoporphyrin.

The quantum dots can be preferable to luminescent organic dyes in the wavelength converter 112 due to their improved brightness (owing to the high quantum yield) and stability (allowing much less photo destruction). Quantum dots can have broader absorption bandwidths to convert a broader range of non-preferred wavelengths to preferred wavelengths. An advantage of using a semiconductor-based wavelength converter, and in particular of using a converter including QDs, can be that the absorption wavelengths and emission wavelengths of the converter can be substantially controlled by selection of QD parameters such as morphology and surrounding environment. Furthermore, QDs can be more stable and less reactive than other wavelength converters, such as fluorescent dyes.

In some embodiments, alternative or additional photoluminescent materials are included in the wavelength converter 112, such as fluorescent monomers, fluorescent polymers, metal complex dopants and dyes, light-emitting dopants, and fluorescent dyes (from Sigma-Aldrich Co., 3050 Spruce St. St. Louis, MO 63103, USA), or phosphor materials.

The photoluminescent materials can include materials that convert non-visible parts of solar radiation, *e.g.*, ultraviolet (UV) radiation (such as UVC with wavelengths from about 100 nm to 280 nm, UVB with wavelengths from about 280 nm to 315 nm, and UVA with wavelengths from about 315 nm to 400 nm) to radiation having the preferred wavelength(s).

Modulator

The modulator provides for intermittent exposure of a plurality of areas of the photosynthetic material to the preferred radiation 108 in a process referred to as "light flashing". The light flashing effect of the irradiation is applied to both the solar preferred radiation 108 and the artificial preferred radiation 128.

The light flashing can increase the growth rates of the photosynthetic material by reducing the incidence of photoinhibition. The term "photoinhibition" as used herein refers to any reduction in the quantum yield of photosynthesis, including saturation in the photosynthetic material causing a reduction in the photosynthesis in the photosynthetic material, and potentially damaging the photosynthetic material. Photoinhibition is reduced or avoided by only exposing the photosynthetic material to a limited number of photons, by limiting the time of exposure by the light flashing: by flashing the preferred radiation

108, each area of the photosynthetic material is exposed to the preferred radiation 108 for only a selected time for each flashing period. The flashing occurs at regular intervals, having a flashing frequency and a flashing duty cycle. The flashing frequency and flashing duty cycle are selected to provide sufficient light for photosynthetic growth while avoiding photoinhibition, and thus to stimulate a maximum level of photosynthesis. The kinetic resolution of time ranges at play in light trapping in the photosynthetic material are in the subpicosecond region, and charge separation proceeds in the subnanosecond domain. Even if light becomes trapped, its usage in charge separation can only occur if a reaction centre to which such an exciton is delivered is open (*i.e.*, the primary electron acceptor involved in charge separation Q_A, is oxidized). The state of oxidation of Q_A is largely determined by the balance of the rates at which the photosynthetic electron flow from PS II reduces Q_A and the efflux toward PS I which oxidizes Q_A.. PS I1 and PS I are functionally linked in series according to the Z-scheme of photosynthesis, which describes the electron transport chain used in photosynthesis. Electron flow via PS I also requires photons. In normal photosynthesis conditions, the PS I acceptor side does not restrain photosynthesis. If a PS I1 reaction centre is closed for charge separation, the excited state of chlorophyll is relaxed via nonproductive heat release or fluorescence. Time-modulated photon delivery at a selected frequency (*e.g.*, the flashing of the modulator) matches (or synchronised with) the light/dark rhythm in which most PS I1 reaction centres would be open (oxidized) at the time of photon delivery. The photon flux density is selected to be no more than enough to saturate the maximum rate of growth. Trapped surplus light due to a photon flux density above saturation is preferably avoided to avoid unwanted heat, fluorescence and possible damage to the photosynthetic apparatus (also referred as "photoinhibition" or saturation).

The light modulator is controlled by a modulation controller to control the intensity at a selectable maximum intensity, minimum intensity, modulation frequency, and/or modulation duty cycle. For microalgae, the flashing frequency is selected to be between about 1 Hertz (Hz) to about 20 kilohertz (kHz), and the duty cycle is selected to have the preferred radiation 108 incident on the photosynthetic material for between about 8% or 10% to about 30% or 50% of each flashing period, or a ratio between about 1:10 and about 1:2 for on:off. For alternative photosynthetic material, the modulation frequency is between about 25 Hz to about 250 Hz. The flashing of an approximately constant photon flux across areas of the photosynthetic material, or across the plurality of growth chambers 116, may allow the photosynthetic material to grow at a rate matching, or better than, a rate of growth for the photosynthetic material exposed to the constant photon flux without flashing areas of the photosynthetic material. The number of photons required for photosynthesis can be reduced by the duty cycle relative to constant illumination without overall loss of growth, thus increasing the overall efficiency or rate of CO2 capture by photosynthesis.

Distributor

The modulator can be in the form of the distributor 114 for selectively distributing the solar radiation, the emitted growth light, and/or artificial light to a plurality of the one or more growth areas. The distributing provides a flash of solar radiation to each growth area, timed to substantially avoid, or at least reduce, photoinhibition, and/or sustained periods of dark that cause a substantial reduction of CO2 biosequestration, *e.g.*, due to respiration of the photosynthetic material. In some embodiments, the distributor operates with a duty cycle of about 1:10 (on:off) at a frequency of about 1 Hz to 20 kHz. The duty cycle can be selected to be between about 1:2 and about 1:10 for microalgal species. The distributing action avoids waste of solar radiation through the use of multiple algae areas, in the chambers 116, that are exposed to the flashes of sunlight.

Artificial Radiation

As shown in Figure 1, the photosynthetic growth system 100 includes an artificial light source, in the form of a lamp 126. The artificial preferred radiation 128 is used to provide photo-stimulation to maintain photosynthesis in the photosynthetic material when the solar radiation 104 is insufficient to stimulate photosynthesis, *e.g.*, at night. The lamp 126 is configured to generate artificial radiation having the at least one selected wavelength for irradiating the photosynthetic material to perform photosynthesis when the solar radiation is not available, to at least substantially reduce respiration by the photosynthetic material.

The lamp 126 generates at least sufficient artificial preferred radiation 128 to substantially limit the onset of photorespiration by the photosynthetic material. "Photorespiration" (or "respiration") refers to the reverse of photosynthesis, where algae mass is lost and CO2 released. The lamp 126 can generate sufficient artificial preferred radiation 128 to stimulate photosynthesis at a level up to the substantial onset of photoinhibition. For microalgae, a constant low level illumination, with a photon flux in the range of about 9 to about 13 micro-mol per m^2 per second, can be sufficient to avoid photorespiration. When flashing artificial radiation, there is the potential to reduce the total energy required to avoid photorespiration by flashing the light at the above-mentioned intensity. The duty cycle can range from about 1.5:1 to about 10:1 depending on the microalgae species.

The artificial preferred radiation 128 is directed to the distributor 114. The artificial preferred radiation 128 includes the same preferred wavelengths as in the preferred radiation 108. The lamp 126 can include one or more light-emitting diodes (LEDs) generating the preferred wavelengths, *e.g.*, in red light.

Manufacture

In a manufacturing process of the system 100, firstly the species or type of photosynthetic matter is selected, based on availability, photosynthetic rate, longevity, *etc.* The type of photosynthetic matter defines values of parameters in the optical system of the system 100, such as: the absorption band of wavelengths, and thus the materials and morphology of the quantum dots and the dielectric coatings required; the photoinhibition threshold, and *e.g.*, the flashing frequency and duty cycle; and the photorespiration threshold, and thus the required flux of artificial light (which in turn determines electrical power requirements). The type of photosynthetic material and the optical system values determine the growth rate of the photosynthetic material, and thus values of parameters in the fluidic system of the system 100, including: gas (CO2) flow rate, nutrient (water) flow rate, and a growth rate of the photosynthetic material (including generating "biomass"), *etc.*

Growth Areas

As shown in Figure 1, the growth system 100 includes a nutrient source 118 for supplying input matter 120 to the one or more growth areas, in the plurality of growth chambers 116, to support the photosynthesis, and a drain 122 for draining output matter 124 from the plurality of growth chambers 116, for example grown plants and waste matter. The input matter 120 includes water, carbon dioxide and associated trace minerals including $NaNO_3$, K_2HPO_4, $CaCl_2$, $C_6H_8O_7$, $C_6H_{5+4y}Fe_xN_yO_7$, EDTA, ,Na_2CO_3, H_3BO_3,$MnSO_4$, $ZnSO_4$, $CuSO_4$,$(NH_4)_6Mo_7O_{24}$ to support the photosynthesis. In alternative embodiments, the input matter 120 includes brine. The output matter 124 includes oxygen gas and grown algae, (natural or genetically modified strains,) in the form of algae biomass, and may include hydrogen gas which is generated by some algae species in certain culturing conditions. The photosynthetic material is contained in a substantially sealed and closed processing system that avoids cross-contamination between the external environment and the photosynthetic material itself (*e.g.*, due to environmental pollution leaking in, or biological material leaking out).

Each chamber 116 is substantially sealed to fluids, apart from the input and output ports. Each chamber 116 can be formed by a supported recyclable plastic container or bag. The recyclable container can be formed on-site under sterile conditions. The container can be single use, which eliminates the need for cleaning of the growth chamber 116, or can be multi-use, with the container being cleaned using toxic cleaning agents (*e.g.*, a hydroxide) and agitation. The container can be made of a transparent (at least for the preferred radiation 108), cleanable and recyclable plastic material, such as polypropylene, polyethylene, or polycarbonate.

Each chamber 116 defines a light-penetration depth selected based on absorption of the light into the photosynthetic material (*e.g.*, a transmission distance of about 75 mm or 100 mm) to avoid the self-shadowing (also referred to as "shading"), due to growth of the photosynthetic material (*e.g.* algal growth can limit the penetration of light into the algal material to a depth of about 75 mm to 100 mm). The chambers 116 may be arranged in an array, as described hereinafter.

In some embodiments, the intensity, the period and the duty cycle of the modulation are also selected to substantially avoid self-shadowing of the photosynthetic material.

Tracking Collector and Guide System

As shown in Figure 2, a photosynthetic growth apparatus 200 of the photosynthetic growth system 100 includes the collector 102, in the form of a tracking collector 201, connected by a light guide, including delivery waveguide 202, to the distributor 114 which distributes the preferred radiation 108 to a plurality of light panels 204, which in turn spatially distribute the preferred radiation 108 to and across the plurality of growth chambers 116 respectively. In the tracking collector 201, the at least one reflective surface of the collector 102 is moveable to track movement of the sun.

The apparatus 200 includes a frame 206 for holding the tracking collector 201, the delivery waveguide 202, the distributor 114, the light panels 204 and the chambers 116 in their relative configuration. The frame 206 allows movement of the tracking collector 201 to follow the sun while supporting the chambers 116 when filled with fluid. The delivery waveguide 202 provides for substantial spatial separation of the tracking collector 201 and the growth chambers 116 to allow for the growing photosynthetic material to be generally separated from the solar radiation 104, to thereby allowing management of the environment of the photosynthetic material separate from external conditions. For example, the photosynthetic material is isolated in the growth chambers 116 from excessive heating by direct impingement of the solar radiation 104 and excess cooling due to radiation loss during the night or during cold weather.

The configuration of the photosynthetic growth apparatus 200 allows for the apparatus 200 to positioned with the tracking collector 201 on top of a roof, *e.g.*, of a building or vehicle, and the growth chambers 116 positioned underneath the roof and therefore protected from the external environment. Furthermore, any heat generation associated with the wavelength converter 112 is generally separated from the growth chambers 116, allowing for better temperature control of the photosynthetic material.

As shown in Figures 3A and 3B, in some embodiments the apparatus 200 includes an optical system 300 including the tracking collector 201, the delivery waveguide 202, the distributor 114 and the light panels 204. The tracking collector 201 includes a reflector 302 for reflecting the solar radiation 104 onto the light guide 113 in the form of waveguide beam 316 that directs light through the delivery waveguide 202 and the distributor 114 to a plurality of chamber waveguides 404 which guide the distributed light to the corresponding plurality of light panels 204.

The light panels 204 are shaped and oriented to fit on both sides of each chamber 116, substantially along the two extended faces of each chamber 116, for providing light into both sides of each chamber 116 substantially over the surface area of each chamber 116. The chambers 116 slidingly fit between the light panels 204 and the chambers 116 are substantially in contact with corresponding light panels 204 to provide substantial light conduction from each light panel 204 into its one or more corresponding chambers 116. A refractive-index matching material, such as a gel or thin film may lie between each light panel 204 and its corresponding chamber(s) 116 to improve light conduction from the light panels 204 to the chambers 116. The light panels 204 and chambers 116 are held in generally static contact by the frame 206.

As shown in Figure 3C, the tracking collector 201 includes the reflector 302 for receiving the solar radiation 104 and directing it to a first wavelength separator 304.

The reflector 302 is curved to act as a concentrator for focusing the solar radiation 104 into a small area of the first wavelength separator 304. The tracking collector 201 is mounted on a mechanical tracking system for tracking the reflector 302 to collect solar radiation 104 incident directly from the sun. Should the captured solar energy be so intense that photo inhibition of the algae is likely to occur, the tracking system is altered by a process management control system to reduce its photon capture efficiency, *e.g.*, by turning the reflector 302 at least partially away from the sun.

Waveguide Beam

The first wavelength separator 304 separates components of the solar radiation 104 into two groups: a first group, including the preferred radiation 108 and the non-preferred radiation 110, is directed into a first wave guide 306 of the tracking collector 201; a second group of components is directed to a heat and photovoltaic collector 308 of the tracking collector 201 which receives a heating radiation 130 and/or the PV radiation 134. The PV/heat collector 308 includes at least components of the heater 132 and the PV cell 136. As shown in Figure 3B, the PV/heat collector 308 includes a black-coloured pipe designed to absorb heat into fluid passing through the pipe, and being directed to a hot water storage system for example. The PV cell 136 includes a strip of photovoltaic devices for capturing the focussed, residual PV radiation 134. The photovoltaic devices are cooled by the fluid passing through the supporting structure of the PV/heat collector 308. The fluid may be a supply stream to the growth chamber 116 being partially diverted according to the particular photosynthetic material's temperature control requirements.

The first waveguide 306 directs the preferred radiation 108 and the non-preferred radiation 110 to a second waveguide separator 310 in the form of a dichroic coating on a surface of the first waveguide 306 that separates the preferred radiation 108 from the non-preferred radiation 110 by substantially reflecting the preferred radiation 108 back into the first waveguide 306 while transmitting the non-preferred radiation 110 into the wavelength converter 112. The wavelength converter 112 includes a material doped with semiconductor quantum dots that operate as photoluminescent compounds to transform at least a portion of the non-preferred radiation 110 into the preferred radiation 108. The non-preferred radiation 110 and any generated preferred radiation 108 propagates through the wavelength converter 112 to a second waveguide 312 and through the second waveguide 312 to a third wavelength separator 314 which reflects at least the preferred radiation 108 back to the first waveguide 306. The third wavelength separator 314 is a dichroic layer on the surface of the second waveguide 312. The generated preferred radiation 108 is reflected back through the second waveguide 312, back through the wavelength converter 112 and back through the second wavelength separator 310 to the first waveguide 306.

The first waveguide 306 guides the preferred radiation 108 to the delivery waveguide 202 for use in photosynthesis. The first waveguide 306 includes secondary coatings and angled optical features to direct light along the first waveguide 306 in a direction transverse to the direction of the solar radiation 104. The non-preferred radiation 110 in the second waveguide 312 is either reflected by the third wavelength separator 314 back into the wavelength converter 112 for further conversion to further preferred radiation 108; alternatively, at least some wavelengths of the non-preferred radiation 110 are transmitted through the third wavelength separator 314 and out of the tracking collector 201. The dichroic coatings are specific to the wavelengths of the preferred photosynthesis absorption band, *e.g.*, 640 nm to 750 nm for green algae.

The reflector 302 includes a curved metal sheet with a reflective coating on the inner curved surface. The reflector 302 may be of an elongate parabolic shape with an elongate focal line along the length of the tracking collector 201. The PV/heat collector 308, as shown in Figure 3C, has an approximately circular cross-section, and also extends the length of the tracking collector 201, as shown in Figures 3A and 3B. The first wavelength separator 304 has a curved and elongated surface for receiving the solar radiation 104 and for focusing the heating radiation 130 and/or the PV radiation 134 onto the PV/heat collector 308.

As shown in Figure 3C, the wavelength converter 112 may be in the waveguide beam 316, which also includes the first waveguide 306, the second waveguide 312 and the three wavelength separators 304, 310, 314. The waveguide beam 316 is an assembly of lateral waveguide components with coatings to manage light transmission through the surfaces. The coatings are thin films applied by vacuum sputtering onto polymer or glass substrates. The components are bonded together with optical adhesives such as used for camera lens manufacture. The waveguide beam 316 and the PV/heat collector 308 are supported along the length of the tracking collector 201 by support struts 303 connected to the reflector 302, as shown in Figures 3A and 3B.

In some embodiments, the waveguide beam 316 is replaced by an alternative guide system 113 in the form of a waveguide assembly 1400, described hereinafter with reference to Figures 13 and 14.

Rotating Distributor

As shown in Figure 4, the distributor 114 receives light of the preferred radiation 108 from the collector 102 through the delivery waveguide 202. The delivery waveguide 202 is coupled to the collector 102 by a collector coupling 402 which is in optical communication with at least the first waveguide 306 and carries light from the collector 102 into the distributor 114.

The delivery waveguide 202 can be composed of a waveguide with an approximately circular cross-section, as shown in Figure 4, and may include a light pipe as manufactured by "3M" Corporation. The preferred radiation 108 is directed from the distributor 114 via a plurality of chamber waveguides 404 which guide the distributed preferred radiation 108 to the corresponding plurality of growth chambers 116. The chamber waveguides 404 have emitting faces 406 for emitting the distributed preferred radiation 108 to the plurality of growth chambers 116. The chamber waveguides 404 include polymer waveguides with an approximately rectangular cross-section and varying lengths selected to guide light to the corresponding plurality of light panels 204 and respective growth chambers 116, which are arranged to be generally mutually parallel, as shown in Figure 2.

As shown in Figure 5, the distributor 114 can be a moving distributor configured to selectively and sequentially direct the collected radiation and the converted radiation to the plurality of different portions of the photosynthetic material. The moving distributor is a rotating distributor including a rotating reflector. The rotating distributor includes a rotating switch mechanism for distributing the preferred radiation 108 to the chamber waveguides 404 including a rotating mirror mounted in alignment with the path of the preferred radiation 108. The switching device includes a switch 502 for switching the light using an angled mirror in the form of a solar reflector 504 that receives light from the delivery waveguide 202 and directs it into receiving faces 506 of the corresponding chamber waveguides 404. The receiving faces 506 of the chamber waveguides 404 are formed directly adjacent each other so as to form a substantially complete circle around the switch 502 to allow the incident preferred radiation 108 falling on the reflector 504 to be conducted into at least one of the chamber waveguides 404 at any rotational angle of the switch 502 (and thus any rotational angle of the solar reflector 504). The solar reflector 504 is supported at an angle on the switch 502 by a mechanical support 508. The switch 502 is rotationally mounted on a collar 510 which provides for the generally constant axial alignment of the solar reflector 504 at its various rotation angles, allowing for light to be directed from the delivery waveguide 202 into at least one of the chamber waveguides 404.

The switch 502 also directs light from the lamp 126 into the plurality of chamber waveguides 404 in a manner equivalent to the distribution of the solar preferred radiation 108 by having a further reflector on the underside of the solar reflector 504 (referred to as the lamp reflector 602, as shown in Figure 6) and oriented to direct the artificial preferred radiation 128 from the lamp 126 sequentially into at least one of the chamber waveguides 404 as the switch 502 rotates. The lamp 126 is housed in a lamp housing 512. The switch 502 is driven by an electric motor to rotate at a frequency selected to correspond to the flashing frequency described above. In some embodiments, the solar reflector 504 and the lamp reflector 602 in the switch 502 are replaced by surfaces that provide reflection through dielectric contrast, such as one or more prisms.

As shown in Figure 6, the solar reflector 504 directs the solar preferred radiation 108, following a solar light path 604 from the delivery waveguide 202 to the chamber waveguides 404 while using the same switch 502, the lamp reflector 602 reflects light from the lamp 126 along an artificial light path 606 from the lamp 126 to the plurality of chamber waveguides 404. The switch 502 can simultaneously supply solar preferred radiation 108 along the solar light path 604 and artificial preferred radiation 128 along the artificial light path 606 to different chamber waveguides 404, thereby allowing for a combination of artificial preferred radiation 128 and solar preferred radiation 108 to be combined by the distributor 114 at the flashing frequency. This may allow for artificial preferred radiation 128 generated at a low power to provide a photon flux to contribute to the solar preferred radiation 108 when the solar preferred radiation 108 is insufficient for the desired level of photosynthesis but the solar radiation 104 is still available, *e.g.*, at dawn and dusk.

As shown in Figure 7A, the optical system 300 substantially conducts the preferred radiation 108 from the distributor 114 to the photosynthetic matter by guiding light from the emitting faces 406 of the chamber waveguides 404 into receiving faces 708 of the plurality of light panels 204, and along the light panels 204 on a corresponding plurality of input radiation paths 710. The receiving faces 708 are configured to fit closely with the emitting faces 406 of the chamber waveguides 404 to allow for a substantial fraction of the light in the chamber waveguides 404 to be conducted into the growth chambers 116. The light panels 204 also include scattering mechanisms, such as angled reflectors, to scatter the input light in towards the areas between the light panels 204 where the chambers 116 are received. The light panels 204 are manufactured of a polymer material that is substantially transparent at least to the preferred absorption wavelengths. The reflecting surfaces in the transparent walls 706 are embossed into the surface of the transparent walls 706.

Switching Distributor

In the described embodiment, a rotating switching device is used in the distributor 114 to direct the preferred radiation 108 to the plurality of growth chambers 116. In some alternative embodiments, the moving distributor can be a switching distributor including a plurality of switching reflectors. The distributor 114 can include an alternative switching device including a plurality of switching reflectors. In some embodiments, the switching reflectors rely on total internal reflection effects and liquid crystal switching, as described in a journal paper by A. Zhang, K. T. Chan, M. S. Demokan, V. W. C. Chan, P. C. H. Chan, H. S. Kwok and A. H. P. Chan, entitled "Integrated liquid crystal optical switch based on total internal reflection" (published in *Applied Physics Letters*, 86, 211108, 1-3, 2005). In other alternative embodiments, the switching reflectors may be based on switching techniques associated with the optical communications industry such as modular micro-electromechanical system (MEMS) switches, as described in a journal paper by A.

Fernandez, B. P. Staker, W. E. Owens, P. Lawrence, L. P. Muray, P. James, J. P. Spallas and W. C. Banyai, entitled "Modular MEMS Design and Fabrication for an 80 x 80 Transparent Optical Cross-Connect Switch" (published in *Optomechatronic Micro/Nano Components, Devices, and Systems*, Ed. Yoshitada Katagiri, Proc. SPIE, Vol. 5604, 208-217, 2004).

As shown in Figure 7B, in some embodiments, the distributor 114 includes switching reflectors including MEMS switches in a MEMS distributor 720 which includes a plurality of MEMS mirrors 722A, 722B, 722C, *etc*. The distributor 114 includes a combiner 724 which combines the preferred radiation 108 from the wavelength separator 106 and the wavelength converter 112 and the artificial preferred radiation 128 from the lamp 126 and directs the combined light into the MEMS distributor 720 where it falls on a primary mirror 722E in the centre of the MEMS distributor 720. The primary mirror 722E is switched, by a control system, to direct the combined light to one of a plurality of further mirrors, in the first case being either the secondary mirror 722D or the secondary mirror 722F. Both secondary mirrors 722D and 722F are also active reflectors and these secondary mirrors 722D, 722F are controlled to direct the light to: either the receiving face 708 of corresponding light panels 204 optically coupled to the MEMS distributor 720, as shown in Figure 7B by a broken arrow; or one of a plurality of reflective surfaces 726 in the MEMS distributor 720, as shown in Figure 7B by a solid arrow. The reflective surfaces 726 in turn further direct the light to tertiary MEMS mirrors 722C or 722G. As with the secondary mirrors 722D, 722F, the tertiary mirrors 722C, 722G are controlled to direct light to either their corresponding light panels 224 (shown by the broken arrows) or to further mirrors 726 of the main distributor 720 (shown by the solid arrows), and to quaternary MEMS reflectors 722B, 722H, *etc*. Through electronic control of the MEMS mirrors 722A, 722B, 722C *etc*., the main distributor 720 sequentially switches the preferred radiation 108 into the plurality of light panels 204, via corresponding receiving faces 708, and thus into the respective growth chambers 116, in a similar manner to the switch 502 described above with reference to Figure 5.

Example Growth Chambers

Each growth chamber 116 is configured to allow fluid flow to and from the photosynthetic material to provide nutrients *etc.* to allow it to perform photosynthesis and grow. As shown in Figure 8, each chamber 116 is generally rectangular in cross-section and elongate in a mutually parallel direction to provide for a large volume while having closely spaced parallel walls. Each chamber 116 is configured to receive the preferred radiation 108 from the light panels 204 along two sides of each chamber 116 through substantially mutually parallel transparent side walls 706, thereby providing the photosynthetic material with the preferred radiation 108 from two directions. As each chamber 116 is generally flat and rectangular, having a width of about 75 mm to 150 mm between the side walls 706—and the preferred radiation 108 is generally incident from both sides of the width—the photosynthetic material in the chamber 116 is generally no more than half the width of the chamber 116 distant from an input of light to the chamber 116. By providing light from both sides of the chamber 116, the photosynthetic growth apparatus 200 allows for twice the thickness of the chamber 116 while substantially avoiding self-shadowing of the light, and a consequent reduction in photosynthesis, by growing of the photosynthetic material.

As shown in Figure 8, the chamber 116 includes an inlet pipe 802 along two edges of the chamber 116 for providing a flow of gas and/or fluid into the chamber 116 via a plurality of perforations 806 or holes (which act as sparging features) between the inlet pipe 802 and the body of the chamber 116, which is defined by the sidewalls 706. The perforations 806 allow sparging, which is the process of bubbling a gas (*e.g.*,CO2) through a liquid (*e.g.*, the grown medium of the photosynthetic material), between the inlet pipe 802 and the body, which form two separate compartments of the chamber 116. The chamber 116 includes an outlet 804 at a corner of the chamber 116 to provide an outlet for fluid, gas and/or the photosynthetic matter.

The chamber 116 can be a replaceable container, formed of a material such as polyethylene with a higher transmit ability for selected wavelengths (*e.g.*, red light for photosynthetic green microalgae). The chamber 116 is constructed by welding sheets of material and blowing to form the inlet pipe 802, the outlet 804 and the body between the sidewalls 706 to be substantially sealed except for the perforations 806 between the inlet pipe 802 and the body. The sparging features are formed integrally as part of each chamber 116. The integrated forming of the sparging features in each two-compartment chamber 116 can be advantageous in efficient manufacture and operation of each chamber 116.

Array

As shown in Figure 9, a growth array 900 includes a plurality of chambers 116 arranged to be mutually parallel, to allow the light panels 204 to fit between adjacent chambers 116 and to be supported in the frame 206 of the apparatus 200. The inlet pipes 802 of the chambers 116 are joined by a gas inlet manifold 902 which provides inlet gas to the inlet pipe 802 and by a fluid inlet manifold 904 which provides fluid inlet to the inlet pipe 802. The outlets 804 of each chamber 116 are connected by an outlet manifold 906 for receiving fluids, gases and material from the chambers 116. The array 900 is arranged and held in the frame 206 in an upright configuration with reference to Figure 9, such that the fluid level in the plurality of chambers 116 is controlled by overflow into the output manifold 906, which is referred to as a "weir configuration". The chambers 116 are substantially sealed apart from the inlet pipe 802 and the outlet 804, thereby providing for control of environmental contamination *e.g.*, from external photosynthetic matter, fluids and/or gases.

As shown in Figure 10, the frame 206 includes a base 1002 for supporting the light panels 204 and the chambers 116 in their mutual configuration, and stands 1004 for supporting the collector 102 to move for controlling the quantity of incident sunlight to the collector 102, while being fixed relative to the distributor 114, *e.g.*, by allowing rotation of a collector 102 in the stands 1004 while fixing the delivery waveguide 202 along the axis of rotation of the collector 102 (as shown in Figure 2). The frame 206 is configured to support the configuration of the chambers 116 and optical system 300 by resisting forces due to the weight of fluid in the chambers 116 and flow of fluid through the chambers 116.

Facility

As shown in Figure 11, a plurality of growth apparatuses 200 are combined to form a photosynthetic growth facility 1100, arranged in an array to collect incident radiation and to allow for fluidic control of the contents of the chambers 116 via the inlet and outlet manifolds 902, 904, 906.

The facility 1100 can include the array of solar collectors 102 forming a roof, which is substantially sealed to fluid and/or temperature. The facility 1100 can thus be substantially sealed to provide a contained or "functionally closed" environment to protect and contain the photoluminescent material, which may be genetically modified plants/algae that need to be kept in a closed system.

Fluidic System

As shown in Figure 12, a fluidic processing system 1200 provides a generally closed system. The growth chambers 116 are linked to a water supply 1202 and a sparge gas supply 1204 which supply the input matter 120. "Sparge gas" refers to gas for sparging in the photosynthetic growth system 100, such as CO2 and flue gas. The output matter 124, including the photosynthetic material, is diluted out of the growth chamber 116 via the outlet 804, and delivered with a fluid stream to a separator 1206 where the photosynthetic material is concentrated, and delivered to a biomass collection 1208, while clarified water is returned to a water recycle tank 1210 in a water recirculation circuit. The water supply 1202 includes a pump 1212 for controlling the pressure and flow rate of water into the inlet pipe 802 of each chamber 116. The sparge gas supply 1204 includes a blower 1214 for receiving flue gas, *e.g.*, from an industrial CO_2 generator, and for controlling the pressure and flow rate of the sparge gas into a gas inlet pipe 1216 of the inlet pipe 802. Sparge gas stripped of its CO2 in the bioreactor, and augmented with oxygen and/or hydrogen released by the photosynthetic process in the growth chambers 116, flows through the chamber 116 and out through the outlet 804 where it is collected by a vent 1218 and may be recirculated into the sparge gas supply 1204.

The water supply 1202, supplemented where necessary with trace minerals, and the sparge gas supply 1204 comprise the "nutrient source" 118. The vent 1218 and the separator 1206 comprise the "drain" 122.

In the described embodiment, the CO2 is directed with the sparge gas into the chamber 116 by the gas inlet pipe 1216. In alternative embodiments, the CO2 may be delivered to the chamber pre-absorbed into the fluid pumped by the water supply 1202 into the inlet pipe 802.

Water flow rates in the fluidic system 1200 are controlled to manage a concentration of photosynthetic material in the chamber 116 close to a maximum level limited by the self-shadowing effect. During periods of low light availability, such as in winter or at night, the photosynthetic material concentration may be reduced through control of the water supply 1202 to minimise the amount of artificial radiation 128 required to avoid respiration.

The fluids in the closed water recirculation circuit 1202 are monitored for pH and temperature, and compensation for pH and temperature change is introduced if required. For example, controlling the CO2 concentration is used for managing pH, particularly with brine water. A brine-based system allows CO2 to be directly delivered with the water supply 1202.

An electronic control system 1220 controls the rates of liquid and gas flow in the fluidic system 1200 by controlling the pump 1212, the blower 1214, *etc.* The control system 1220 uses electronic signals received from sensors, *e.g.*, representing gas partial pressures and biomass weights, together with preset operating parameters (*e.g.*, temperature *etc.*, associated with the growth system 100) to control the fluidic system 1200, and aspects of the growth system (*e.g.*, properties of light incident on the photosynthetic material).

Alternative Light Guide System

In some embodiments, the light guide 113 is in the form of the waveguide assembly 1400 including a plurality of guide elements 1300, as shown in Figures 13 and 14. The wave guide assembly 1400 operates to receive concentrated photons of light from the collector 102 and guide them to the distributor 114. The waveguide assembly 1400 includes elements of the wavelength converter 112 in the form of photoluminescent material in the waveguide assembly 1400, as described hereinafter.

The guide element 1300 includes a curved main reflective surface 1306 (or face), as shown in cross-section in Figure 13, which reflects light incident on the guide element 1300 from an input direction 1302 having an effective input cross-section 1304 as shown in Figure 13, and partially focuses or concentrates the light into a region having an output direction 1308 and effective output cross-section 1310. The main surface 1306 is formed such that the output direction 1308 for a substantial majority of input light rays that is generally perpendicular to the input direction 1302. Thus the guide element 1300 guides lights coming from the input direction 1302, or at least generally falling into the guide element 1300 through its input face 1312, through an output face 1316 of the guide element 1300 in the output direction 1308, which is generally perpendicular to the input direction 1302. The main surface can include a compound parabolic concentrator (CPC) shape, *e.g.*, as described in the document "Modelling of 3D-CPCs for Concentrating Photovoltaic Systems", by A. Parretta, P. Morvillo, C. Privato, G. Martinelli and R. Winston (from the "PV in Europe from PV Technology to Energy Solutions" Conference and Exhibition, at the Palazzo dei Congressi in Rome, Italy, from 7 to 11 October 2002). For some input directions 1302, the input rays may fall incident upon a secondary curved reflective surface 1314 (or face) of the guide element 1300, which lies opposed main surface 1306, and together with the main surface 1306 defines the input face 1312 and a narrow end of the reflector element 1300. The secondary surface 1314 is reflective as the main surface 1306, and directs input light to the main surface 1306, whence the light is directed to the output face 1316 in the output direction 1308 at the narrow end of the element 1300. The main surface 1306 thus directs the collected radiation behind the secondary surface 1314.

The guide element 1300 can accept light from a plurality of different input direction 1302 and direct light from each direction to the output face 1316 in at least generally the output direction 1308. The guide element 1300 can therefore concentrate solar radiation incident in the input direction 1302 as the sun moves relative to the guide element 1300 during the day and/or during the year. The inner surfaces of the main surface 1306 and the secondary surface 1314 are coated with broad-spectrum optically reflective materials.

The waveguide assembly 1400 includes a plurality of reflective guide elements 1404, each formed according to the guide element 1300, arranged on one side of the waveguide assembly 1400, as shown in Figure 14, to receive light falling on an input surface 1402 of the waveguide assembly 1400 and to direct it along the waveguide assembly 1400 into a main output direction 1408. The main output direction 1408 is longitudinally along the waveguide 1400. The plurality of reflective guide elements 1404 are aligned in an array along the input surface 1402, as shown in Figure 14, with their input faces aligned in the same direction and their output directions aligned in generally the same direction, towards the main output direction 1408. The reflective guide elements 1404 include transparent bodies 1406 (*e.g.*, glass) which allow transmission of the input radiation. Light is transmitted from the reflective guide elements 1404 into a main guide 1410 of the waveguide assembly 1400 which is transparent to conduct the light (*e.g.*, being air-filled).

The waveguide assembly 1400 includes a plurality of dichroic guide elements 1412 aligned in an array in the waveguide assembly 1400 on the opposed side of the main guide 1410 from the reflective guide elements 1404. The dichroic guide elements 1412 are shaped each with a dichroic surface similar to the main surface 1306 of the guide element 1300. The dichroic surface is coated (*e.g.*, by sputtering) with layers and/or structures to reflect light of the preferred radiation 108 and to transmit light of the non-preferred radiation 110, at least for light incident on the main surfaces of the dichroic guide elements 1412 in the main output direction 1408 (*i.e.* light coming from and guided by the reflective guide elements 1404). The dichroic guide elements 1412 are arranged to direct preferred radiation 108 along the main output direction 1408 and to receive non-preferred radiation 110 into the body, *i.e.*, the photoluminescent bodies 1414 as shown in Figure 14 of the dichroic guide elements 1412. The dichroic guide elements 1412 include photoluminescent material in the photoluminescent bodies 1414 which acts as the wavelength converter 1124 for converting a substantial portion of non-preferred radiation 110 to preferred radiation 108. Non-preferred radiation 110 entering the photoluminescent bodies 1414 is at least partially converted into the preferred radiation 108. The dichroic guide elements 1412 reflect converted radiation from the photoluminescent bodies 1414 into waveguide assembly 1400 in the main output direction 1408. The dichroic guide elements 1412 are arranged with output faces directed in the same direction as the output faces of the reflective guide elements 1404, thus guiding the preferred radiation 108 in the main output direction 1408. The dichroic guide elements 1412 include primary dichroic surfaces 1418 for receiving the non-preferred radiation 110 into the photoluminescent bodies 1414 and for reflecting the preferred radiation 108, as shown in Figure 14. The primary dichroic surfaces 1418 are shaped as the main surface 1306 of the guide element 1300. The dichroic guide elements 1412 include secondary dichroic surfaces 1420 which reflect preferred radiation 108 that is generated in the photoluminescent bodies 1414 back into the photoluminescent bodies 1414 and thus through the output faces of the dichroic guide elements 1412, and thus into the main guide 1410 in the main output direction 1408. The secondary dichroic surfaces 1420 allow transmission of the non-preferred radiation 110, which is not converted by the photoluminescent material in the photoluminescent bodies 1414, and thus is transmitted by the secondary dichroic surfaces 1420 through a non-preferred output interface 1416 of the waveguide assembly 1400. The non-preferred output interface 1416 is on an opposed side of the waveguide assembly 1400 to the input surface 1402: thus, solar radiation incident on the input surface 1402 is collected by the reflective guide elements 1404 and directed along the main output direction 1408. Preferred radiation 108 in the guided light in the main guide 1410 is reflected by the reflective guide elements 1404 and dichroic guide elements 1412 which form the sides of the main guide 1410. Non-preferred radiation 110 in the guided solar radiation is transmitted by the dichroic guide elements 1412 into the photoluminescent bodies 1414 which at least partially convert the non-preferred radiation 110 into preferred radiation 108, which is then reflected back into the main guide 1410 for transmission in the main output direction 1408. The main output direction 1408 is defined by the common alignment of the output faces of the reflective guide elements 1404 and the dichroic guide elements 1412.

Light guided by one of the reflective guide elements 1404 into the main guide 1410 can follow one of a plurality of paths in the waveguide assembly 1400, depending on its wavelength. For example, light can follow path "A", as shown in Figure 14, which passes through the uncoated external face of the input surface 1402 into one of the reflective guide elements 1404, and is reflected by the main surface of the reflective guide element

1404 into the main guide 1410 in the main output direction 1408. As the light on path A does not lie exactly in the main output direction 1408, it reaches the side of the main guide 1410 opposite the reflective guide elements 1404 and is reflected by the dichroic guide element 1412 since it is of the preferred wavelength. Light of the non-preferred wavelength can follow along a path "B", which is directed in the same way as the preferred wavelengths by the reflective guide elements 1404, but is transmitted into one of the photoluminescent bodies 1414 by a corresponding one of the dichroic guide elements 1412 which has a dichroic coating. The at least one photon on path B is converted into a photon of the preferred wavelength, and is reflected by internal dichroic coatings on the secondary dichroic surfaces 1420 into the main guide 1410, as shown in Figure 14. A solar light ray following path "C" of the non-preferred wavelength is transmitted by the primary dichroic surface 1418 of one of the dichroic guide elements 1412, and is not converted by the photoluminescent bodies 1414 and therefore remains at the non-preferred wavelength, and is therefore transmitted by the secondary dichroic surface 1412 out of the non-preferred output interface 1416 of the waveguide assembly 1400.

Light transmitted from the non-preferred output interface 1416 is used for generating heat and/or generating electricity from photovoltaic cells as described hereinbefore.

The waveguide assembly 1400 can be formed from a plurality of the transparent bodies 1406, formed in the geometry of the guide element 1300, coated in reflective materials on the main surface and a secondary surface, and arranged in an array having the same orientation, as shown in Figure 14. The photoluminescent bodies 1414 are formed of material that exhibits Stokes fluorescence, *e.g.*, a transparent material incorporating a Stokes fluorescent material, such as quantum dots in a transparent substrate. The photoluminescent bodies 1414 (also referred to as "Stokes fluorescent bodies" in some embodiments) are coated with dichroic surfaces, arranged to reflect the preferred radiation 108 and transmit the non-preferred radiation 110 into the photoluminescent bodies 1414 through the main surface 1306 and out of the photoluminescent bodies 1414 through the secondary dichroic surfaces 1420. The dichroic guide elements 1412 are arranged in an array having the same orientation along the non-preferred output interface 1416. The main guide 1410 can be formed as a cavity between the reflective guide elements 1404 and the dichroic guide elements 1412. The reflective guide elements 1404 and the dichroic guide elements 1412 can be polished cast glass components, coated using sputter coating, and assembled into the waveguide assembly and held in a generally fixed geometrical relationship by an external frame or holder. Other transparent materials and coatings can be used that can withstand the heat generated in the waveguide assembly 1400 during use.

Tilting-Arm Collector

In some embodiments, the collector 102 can be in the form of a tilting-arm collector 1500, which includes a fixed, or non-moving reflector 1502 and a moving light guide 1504 for receiving solar radiation from the sun via the reflector 1502, as shown in Figure 15. The at least one reflective surface of the tilting-arm collector 1500 is fixed relative to movement of the sun. The moving light guide 1504 is a form of tilting arm receiver (or radiation capture device) moveable (or configured to move) to track movement of the concentrated solar radiation caused by movement of the sun.

The reflector 1502 is generally fixed in relation to the Earth, and the light guide 1504 is moved by a motor and controller to track the approximate focus or concentration area of the reflector 1502 as the sun moves relative to the reflector 1502. The reflector 1502 is a longitudinal trough reflector, which gathers light to a linear area by reflecting above the surface of the reflector 1502. The light guide 1504 is held by a tilting arm 1508 and support arm 1510 above the reflector 1502 and is tilted by the control system to the position above the reflector 1502 where the solar light is being concentrated. The light guide 1504 receives solar radiation from the reflector 1502, and directs it, *e.g.*, using the waveguide assembly 1400, to a delivery waveguide 1506, which delivers the light to the distributor 114.

The light guide 1504 is positioned by the control system at a height and angle above the reflector 1502 to collect the majority of reflected rays, thus collecting a plurality of incident rays 1706 as collected rays 1704, as shown as for a plurality of positions of the sun and the light guide 1504 in Figures 17A to 17E. As shown in Figures 17A to 17E, a substantial portion of the incident rays 1706 are collected by the light guide 1504, for a substantial plurality of positions of the light guide 1504. As the light guide 1504 itself has a surface area much smaller than the surface area of the reflector 1502, it does not substantially obscure or block the incident rays 1706 from falling on the reflector 1502, or from falling on an adjacent reflector in an array of the reflectors 1502. Preliminary experimental results indicate that an array of tilting-arm collectors 1500 can have substantially the same efficiency of solar collection as an array of the tracking collectors 201, *e.g.*, an example tilting-arm collector efficiency 1708, for capturing solar radiation, is similar to a tracking mirror collector efficiency 1710 over a full 180-degree range of angles of the sun relative to the horizon, as shown in Figure 17F.

A tilting-arm collector array 1600, as shown in Figure 16, is formed of a plurality of tilting-arm collectors 1500, and the plurality of reflectors 1502 form a reflector array 1602. The collector array 1602 captures a substantial portion of all instant radiation on the tilting-arm collector array 1600, thus forming a high-efficiency solar collector array. The tilting-arm collector array 1600 can also form a roof, as the reflectors 1502 do not move.

An example non-moving reflector 1502 can have parabolic shape with a width of about 1200 mm and conform to the parabolic shape defined by $Y = 0.0004 X^2$. The tilting arm 1508 can be about 650 mm long with a pivot point about 100 mm below the bottom of the parabolic surface. The width of the light guide 1504 can be about 200 mm, which is sufficiently wide to gather a substantial amount of the reflected solar radiation, while being sufficiently narrow to avoid substantial shadowing of the reflector 1502 and/or an adjacent reflector 1502.

Having the reflector array 1602 form a roof can be advantageous as the roof can be substantially sealed against environmental influences, such as external temperature fluctuations, wind, dust *etc.*, and against contamination of the external environment by materials in a growth chamber array 1604 beneath the reflector array 1602, such as genetically modified algae forms. Genetically formed algae may be a preferable photosynthetic material, but may need containment in a facility for environmental safety reasons, *etc*. The reflector array 1602 may also be manufactured and installed relatively simply and cheaply.

Concentrating Collector

The collector 102 may be in the form of an concentrating collector 1800 with at two reflective surfaces: a primary face 1802 forming a first surface, and a secondary face 1808 forming a second surface.

The primary face 1802 receives incident solar rays 1804 and gathering and reflecting them into collected rays 1806 in a narrowing part of the concentrating collector 1800, which has a wide input aperture for the incident rays 1804 defined by the primary face 1802 and the secondary face 1808, and a narrow region for the collected rays 1806 defined by the primary face 1802 and the secondary face 1808 drawing closer together. The collected rays 1806 pass through a gap between the narrow ends of the primary face 1802 and the secondary face 1808, and effectively enter behind the secondary face 1808. The secondary face 1808 is generally shorter than the primary face 1802. The primary face 1802 can have a compound parabolic concentrator (CPC) shape.

A concentrating collector array 1900 can be provided by a plurality of concentrating collectors 1800 formed as longitudinal troughs, which are mutually parallel as shown in Figures 19A, 19B and 19C. Each concentrating collector 1800 has a generally parabolic concentrator geometry and can be locked into an adjacent concentrating collector 1800 to form a fixed industrial roofing structure or decking. The concentrating collector array 1900 is assembled using a plurality of curved reflective sheets forming the primary face 1802 or the secondary face 1808 of the concentrating collectors 1800, each sheet being supported by a plurality of support struts 1902 which conform to the geometry of the concentrating collector 1800, the support struts 1902 being supported on a plurality of support beams 1904 which form the roof and run perpendicular to the troughs of the concentrating collector array 1900, as shown in Figure 19B. The support beams 1904 can be commercially available steel support structures, and the support struts 1902 can be formed of steel or aluminium for connection to the support beams 1904. The reflective material for the faces of the concentrating collector 1800 can be formed of coated shaped plastic or metal sheets for gathering the solar radiation. The troughs 1908 in the narrow bend of the primary face 1802, as shown in Figure 19C, are configured for receiving water run-off such as rain incident on the concentrating collector array 1900.

The concentrating collector array 1900 includes a plurality of light guides 1906, such as guides 113 as described hereinbefore, for receiving the collected rays 1806 of each concentrating collector 1800. The at least one reflective surface of each primary face 1802 concentrates the solar radiation to each light guide 1906, which forms a the receiver (or radiation capture device) substantially protected from environmental and mechanical damage. The light guide 1906 is protected from physical or environmental damage, *e.g.*, due to rain or storms, by being protected under the secondary face 1808 of each concentrating collector.

In an example configuration, the concentrating collector array 1900 has the concentrating collectors 1800 forming troughs oriented in an east-west direction. The concentrating collector array 1900 can be suspended as a roof over a plurality of growth chambers 116 as shown in Figure 19D to form a concentrating collector facility 1912. The facility 1912 includes a plurality of distributors 114 with light guided from the concentrating collectors 1800 through a plurality of light guides 1906. The light from the light guides 1906 may be combined in a plurality of combiners 1910 in the guide 113 for guiding light to the plurality of distributors 114. The growth chambers 116 are supported in the facility 1912 as described hereinbefore.

Interpretation

Many modifications will be apparent to those skilled in the art without departing from the scope of the present invention as hereinbefore described with reference to the accompanying drawings.

The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that that prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

CROSS REFERENCE TO RELATED APPLICATIONS

The disclosure of US Provisional Application No. 61/180240, filed 21 May 2009, is hereby incorporated by cross reference.

REFERENCE SIGNS LIST

Ref. Sign	Associated Phrase
100	photosynthetic growth system
102	collector
104	solar radiation
106	wavelength separator
108	preferred radiation
110	non-preferred radiation
112	wavelength converter
113	light guide
114	distributor
116	growth chambers
118	nutrient source
120	input matter
122	drain
124	output matter
126	lamp
128	artificial preferred radiation
130	heating radiation
132	heater
134	photovoltaic (PV) radiation
136	photovoltaic (PV) cell
138	heat
140	electrical power
142	electrical storage
200	photosynthetic growth apparatus
201	tracking collector
202	delivery waveguide
204	light panels
206	frame
300	optical system
302	reflector
303	support struts
304	first wavelength separator
306	first waveguide
308	heat and photovoltaic (PV) collector
310	second waveguide separator
312	second waveguide
314	third wavelength separator
316	waveguide beam
402	collector coupling
404	chamber waveguides
406	emitting faces
502	switch
504	solar reflector
506	receiving faces
508	mechanical support
510	collar
512	lamp housing
514	switch base
602	lamp reflector
604	solar light path
606	artificial light path
706	transparent walls
708	receiving faces
710	input radiation paths
720	distributor
724	combiner
726	reflective surfaces
802	inlet pipe
804	outlet
900	growth array
902	gas inlet manifold
904	fluid inlet manifold
906	outlet manifold
1002	base
1004	stands
1100	photosynthetic growth facility
1124	wavelength converter
1200	fluidic processing system
1202	water supply
1204	sparge gas supply
1206	separator
1208	biomass collection
1210	water recycle tank
1212	pump
1214	blower
1216	gas inlet pipe
1218	vent
1220	electronic control system
1300	guide elements
1302	input direction
1304	effective input cross-section
1306	main surface
1308	output direction

1310	effective output cross-section
1312	input face
1314	secondary surface
1316	output face
1400	waveguide assembly
1402	input surface
1404	reflective guide elements
1406	transparent bodies
1408	main output direction
1410	main guide
1412	dichroic guide elements
1414	photoluminescent bodies
1416	non-preferred output interface
1418	primary dichroic surfaces
1420	secondary dichroic surfaces
1500	tilting-arm collector
1502	non-moving reflector
1504	moving light guide
1506	delivery waveguide
1508	tilting arm
1510	support arm
1600	tilting-arm collector array
1602	reflector array
1604	growth chamber array
1704	collected rays
1706	incident rays
1800	concentrating collector
1802	primary face
1804	incident solar rays
1806	collected rays
1808	secondary face
1900	concentrating collector array
1902	support struts
1904	support beams
1906	light guides
1908	troughs
1910	combiners
1912	concentrating collector facility

CLAIMS:

1. A photosynthetic growth apparatus including:

   at least one solar collector configured to collect solar radiation;

   at least one growth area configured for photosynthetic material to perform photosynthesis using radiation having at least one selected wavelength;

   a wavelength converter configured to convert at least a portion of the collected solar radiation having at least one wavelength different from the at least one selected wavelength to radiation with the at least one selected wavelength for the photosynthetic material; and

   a light modulator configured to control irradiation of the photosynthetic material by the radiation with the at least one selected wavelength to at least substantially reduce photoinhibition of the photosynthesis.

2. The photosynthetic growth apparatus of claim 1, wherein the irradiation of the photosynthetic material uses light arising from the solar radiation.

3. The photosynthetic growth apparatus of any one of claims 1–2, wherein the light modulator modulates the amplitude of the irradiation of the photosynthetic material.

4. The photosynthetic growth apparatus of claim 3, wherein the light modulator modulates the amplitude of the irradiation between zero and a maximum.

5. The photosynthetic growth apparatus of any one of claims 1–4, wherein the light modulator includes a distributor configured to distribute the collected radiation and the converted radiation between a plurality of different portions of the photosynthetic material in the at least one growth area.

6. The photosynthetic growth apparatus of claim 5, wherein the distributor includes a moving distributor configured to selectively and sequentially direct the collected radiation and the converted radiation to the plurality of different portions of the photosynthetic material.

7. The photosynthetic growth apparatus of claim 6, wherein the moving distributor is a rotating distributor including a rotating reflector.

8. The photosynthetic growth apparatus of claim 6, wherein the moving distributor is a switching distributor including a plurality of switching reflectors.

9. The photosynthetic growth apparatus of any one of claims 5–8, wherein the plurality of different portions of the photosynthetic material are in respective different growth areas of the at least one growth area.

10. The photosynthetic growth apparatus of any one of claims 1–9, wherein the light modulator is controlled by a modulation controller to control the intensity at a selectable maximum intensity, minimum intensity, modulation frequency, and/or modulation duty cycle.

11. The photosynthetic growth apparatus of claim 10, wherein the modulation frequency is about 1 Hz to 20 kHz, or about 25 Hz to 250 Hz.

12. The photosynthetic growth apparatus of any one of claims 10 and 11, wherein the duty cycle is between about 10% and about 50%.

13. The photosynthetic growth apparatus of any one of claims 1–12, wherein the light modulator is controlled by a modulation controller to control the intensity to at least substantially reduce self-shadowing of the photosynthetic material.

14. The photosynthetic growth apparatus of any one of claims 1–13, wherein the at least one solar collector includes at least one reflective surface for concentrating the solar radiation.

15. The photosynthetic growth apparatus of claim 14, wherein the at least one reflective surface is moveable to track movement of the sun.

16. The photosynthetic growth apparatus of claim 14, wherein the at least one reflective surface is fixed relative to movement of the sun, and the at least one solar collector

includes at least one respective tilting arm receiver moveable to track movement of the concentrated solar radiation caused by movement of the sun.

17. The photosynthetic growth apparatus of claim 14, wherein the at least one solar collector forms a fixed roofing structure, and wherein the at least one reflective surface concentrates the solar radiation to a receiver substantially protected from environmental and mechanical damage.

18. The photosynthetic growth apparatus of claim 17, wherein the at least one reflective surface includes two surfaces, and the first surface is shaped to concentrate the solar radiation to the receiver behind the second surface.

19. The photosynthetic growth apparatus of claim 18, wherein the first surface has a compound parabolic concentrator shape.

20. The photosynthetic growth apparatus of any one of claims 1–19, wherein the at least one selected wavelength includes one or more wavelengths respectively corresponding to one or more of the lowest photosynthetic absorption states of the photosynthetic material.

21. The photosynthetic growth apparatus of claim 20, wherein the at least one selected wavelength includes one or more wavelengths corresponding to red light.

22. The photosynthetic growth apparatus of claim 21, wherein the red light includes wavelengths from about 620 nm to about 780 nm.

23. The photosynthetic growth apparatus of claim 22, wherein the red light includes wavelengths from about 660 nm to about 750 nm.

24. The photosynthetic growth apparatus of any one of claims 1–23, including an artificial light source configured to generate artificial radiation having at least one selected wavelength for irradiating the photosynthetic material to perform photosynthesis when the solar radiation is not available, to at least substantially reduce respiration by the photosynthetic material.

25. The photosynthetic growth apparatus of claim 24, wherein the artificial light source includes light-emitting diodes (LEDs) emitting red light.

26. The photosynthetic growth apparatus of any one of claims 24 and 25, wherein the artificial light source is powered by electricity generated photovoltaicly from portions of the solar radiation not including the at least one selected wavelength.

27. The photosynthetic growth apparatus of any one of claims 1–26, including a light guide configured to receive and guide the collected radiation and the converted radiation from the solar collector to the photosynthetic material.

28. The photosynthetic growth apparatus of claim 27, wherein the light guide includes a plurality of reflector elements for receiving the collected radiation from a first direction and for directing the received radiation in a second direction generally perpendicular to the first direction.

29. The photosynthetic growth apparatus of claim 28, wherein each reflector element includes two curved reflective faces with an open end for receiving the collected radiation, wherein a first curved reflective face is shaped to direct radiation behind a second curved reflective face at a narrow end of the reflector element.

30. The photosynthetic growth apparatus of any one of claims 27–29, wherein the light guide includes a plurality of wavelength convertor elements of the wavelength convertor for converting the portion of the solar radiation as the collected radiation is guided by the light guide.

31. The photosynthetic growth apparatus of any one of claims 27–30, wherein the light guide is configured to separate the wavelength convertor and/or the at least one solar collector from the photosynthetic material to at least substantially reduce any effect of heat from the wavelength convertor and/or the at least one solar collector on the photosynthetic material.

32. The photosynthetic growth apparatus of any one of claims 27–31, wherein the light guide includes a plurality of light panels to spatially distribute light across the at least one growth area.

33. The photosynthetic growth apparatus of any one of claims 1–32, wherein the at least one growth area includes at least one growth chamber configured to transmit the collected radiation and the converted radiation from the light guide to the photosynthetic material.

34. The photosynthetic growth apparatus of claim 33, wherein the at least one growth chamber includes a plurality of side walls transparent to radiation of the at least one selected wavelength.

35. The photosynthetic growth apparatus of any one of claims 33 and 34, wherein the at least one growth chamber is configured to allow fluid flow to and from the photosynthetic material.

36. The photosynthetic growth apparatus of any one of claims 33–35, wherein the at least one growth chamber is in the form of a replaceable container.

37. The photosynthetic growth apparatus of claim 36, wherein sparging features are integrally formed in the replaceable container.

38. The photosynthetic growth apparatus of claim 37, wherein the sparging features include perforations between separate compartments of the at least one growth chamber.

39. The photosynthetic growth apparatus of any one of claims 1–38, including at least one wavelength separator configured to separate portions of the solar radiation that do not have the at least one selected wavelength for use in heat generation and/or photovoltaic electricity generation.

40. The photosynthetic growth apparatus of any one of claims 1–39, including at least one wavelength separator having at least one wavelength-selective surface configured to

separate portions of solar radiation having the at least one selected wavelength from portions not having the at least one selected wavelength.

41. The photosynthetic growth apparatus of claim 40, wherein the at least one wavelength-selective surface includes a dichroic reflective coating.

42. The photosynthetic growth apparatus of any one of claims 1–41, wherein the wavelength converter uses Stokes fluorescence to convert the solar radiation.

43. The photosynthetic growth apparatus of claim 42, wherein the Stokes fluorescence is provided by a semiconductor material, and the semiconductor material includes a plurality of semiconductor quantum dots (QDs).

44. The photosynthetic growth apparatus of claim 43, wherein the converted radiation has a wavelength based on a morphology and/or dielectric environment of the QDs.

45. The photosynthetic growth apparatus of any one of claims 1–44, wherein the photosynthetic material includes microalgae.

46. A photosynthetic growth system including:

    the photosynthetic growth apparatus of any one of the preceding claims; and

    a fluidic processing system for supplying the photosynthetic material with input matter for the photosynthesis.

47. A photosynthetic growth facility for capturing carbon dioxide using photosynthesis including:

    a plurality of the photosynthetic growth systems of claim 46; and

    a control system for controlling the photosynthetic growth apparatuses and the fluidic processing systems.

48. The photosynthetic growth facility of claim 47, wherein the at least one solar collector includes an array of solar collectors forming a roof.

49. The photosynthetic growth facility of claim 48, wherein the roof is substantially sealed to fluid and/or temperature.

50. A method of performing photosynthesis including the steps of:

    collecting solar radiation;

    converting at least a portion of the collected solar radiation having one or more wavelengths different from at least one selected wavelength to radiation with the at least one selected wavelength;

    performing photosynthesis using photosynthetic material and the radiation having the at least one selected wavelength; and

    controlling irradiation of the photosynthetic material by the radiation having the at least one selected wavelength to at least substantially reduce photoinhibition of the photosynthesis.

51. A method of performing photosynthesis including the steps of:

    collecting solar radiation;

    converting a portion of the solar radiation that does not have at least one preferred wavelength for photosynthesis by a photosynthetic material into light having at least one preferred wavelength;

    controlling the intensity of the collected radiation and the converted radiation to at least substantially reduce photoinhibition of the photosynthesis; and

    performing the photosynthesis using the collected radiation and the converted radiation.

52. A photosynthetic growth apparatus including:

    at least one solar collector configured to collect solar radiation;

    a wavelength converter configured to convert a portion of the solar radiation that does not have at least one preferred wavelength for photosynthesis by a photosynthetic material into radiation having at least one preferred wavelength for photosynthesis by the photosynthetic material;

    a light modulator configured to control the intensity of the collected radiation and the converted radiation to at least substantially reduce photoinhibition of the photosynthesis; and

photosynthetic material for performing the photosynthesis using the collected radiation and the converted radiation.

53. A solar collector including:

at least one reflector, fixed relative to movement of the sun, configured to concentrate solar radiation to a moving region; and

at least one moving receiver configured to move to receive the concentrated solar radiation in the region.

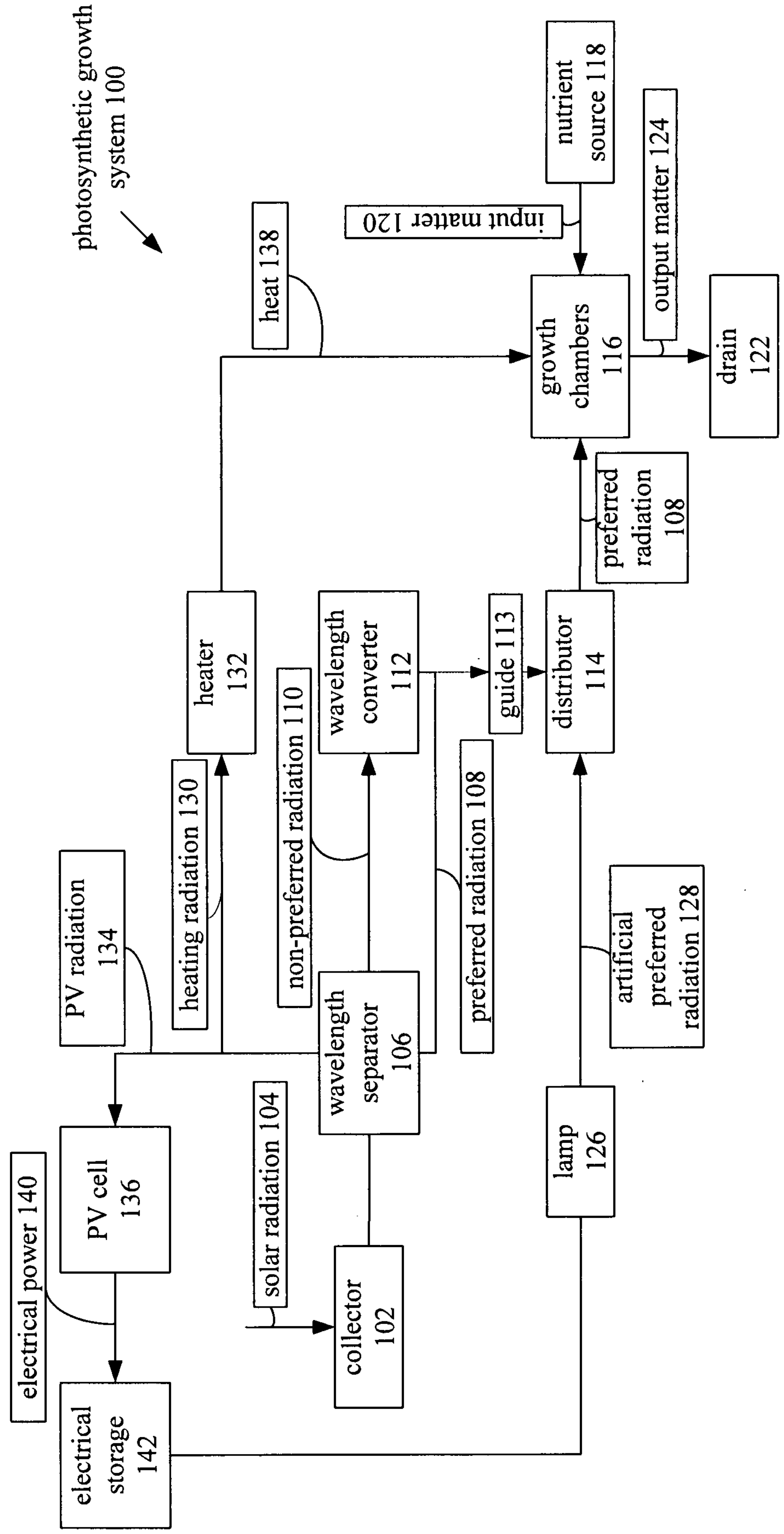
photosynthetic growth system 100
heat 138
input matter 120
nutrient source 118
output matter 124
growth chambers 116
drain 122
preferred radiation 108
heater 132
wavelength converter 112
guide 113
distributor 114
non-preferred radiation 110
heating radiation 130
preferred radiation 108
PV radiation 134
wavelength separator 106
artificial preferred radiation 128
solar radiation 104
PV cell 136
lamp 126
electrical power 140
collector 102
electrical storage 142

Figure 1

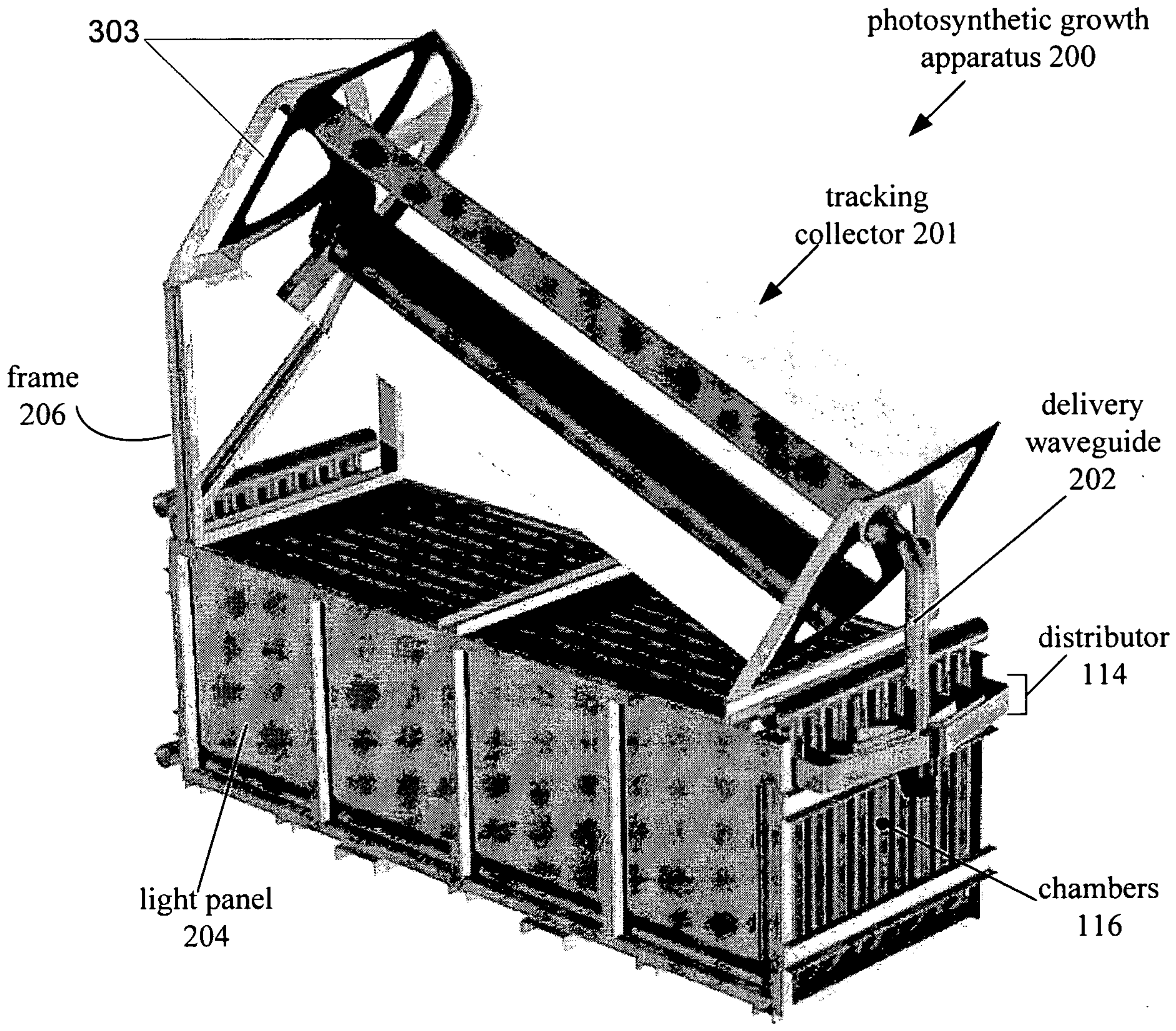
303
photosynthetic growth apparatus 200
tracking collector 201
frame 206
delivery waveguide 202
distributor 114
chambers 116
light panel 204

Figure 2

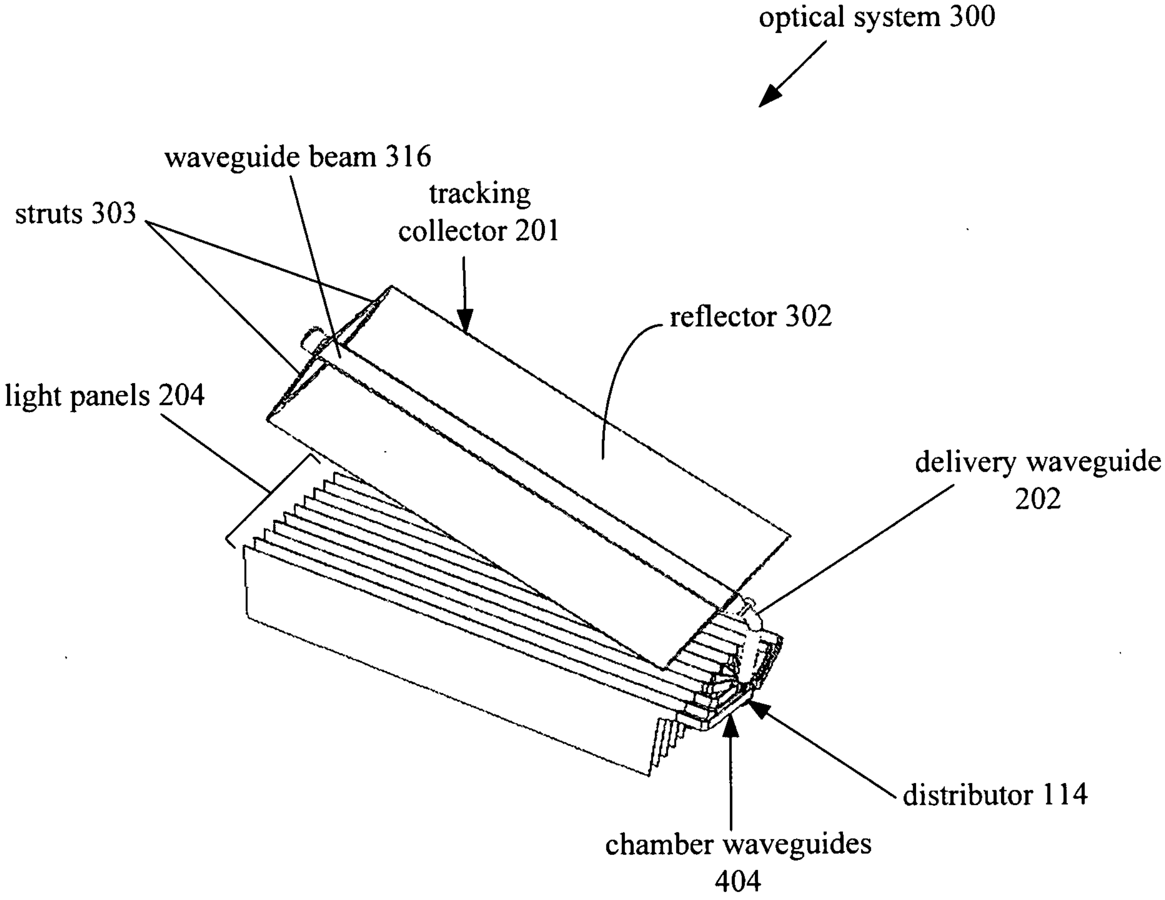
optical system 300
waveguide beam 316
tracking collector 201
struts 303
reflector 302
light panels 204
delivery waveguide 202
distributor 114
chamber waveguides 404

Figure 3A

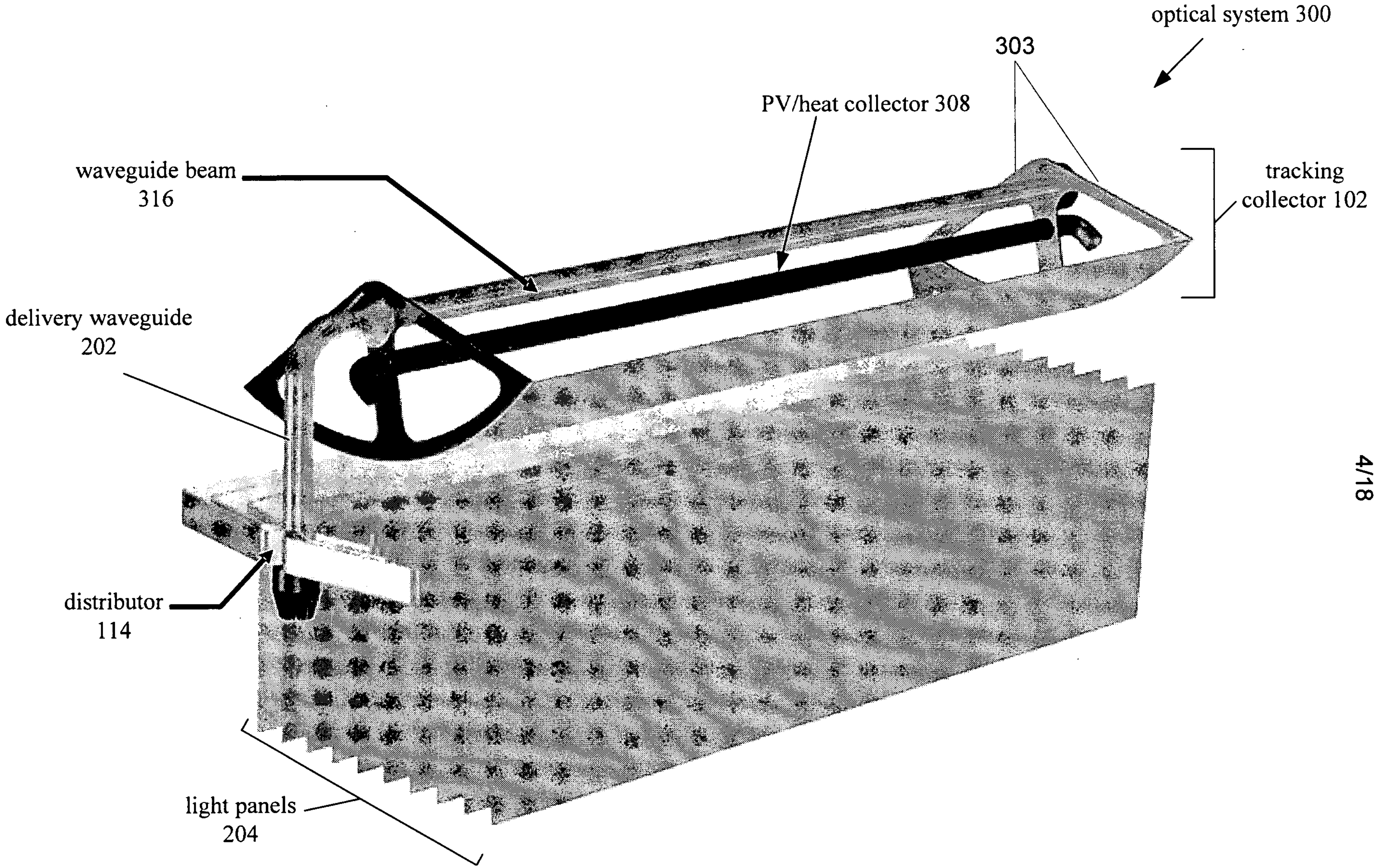
optical system 300
303
PV/heat collector 308
tracking
collector 102
waveguide beam
316
delivery waveguide
202
distributor
114
light panels
204

Figure 3B

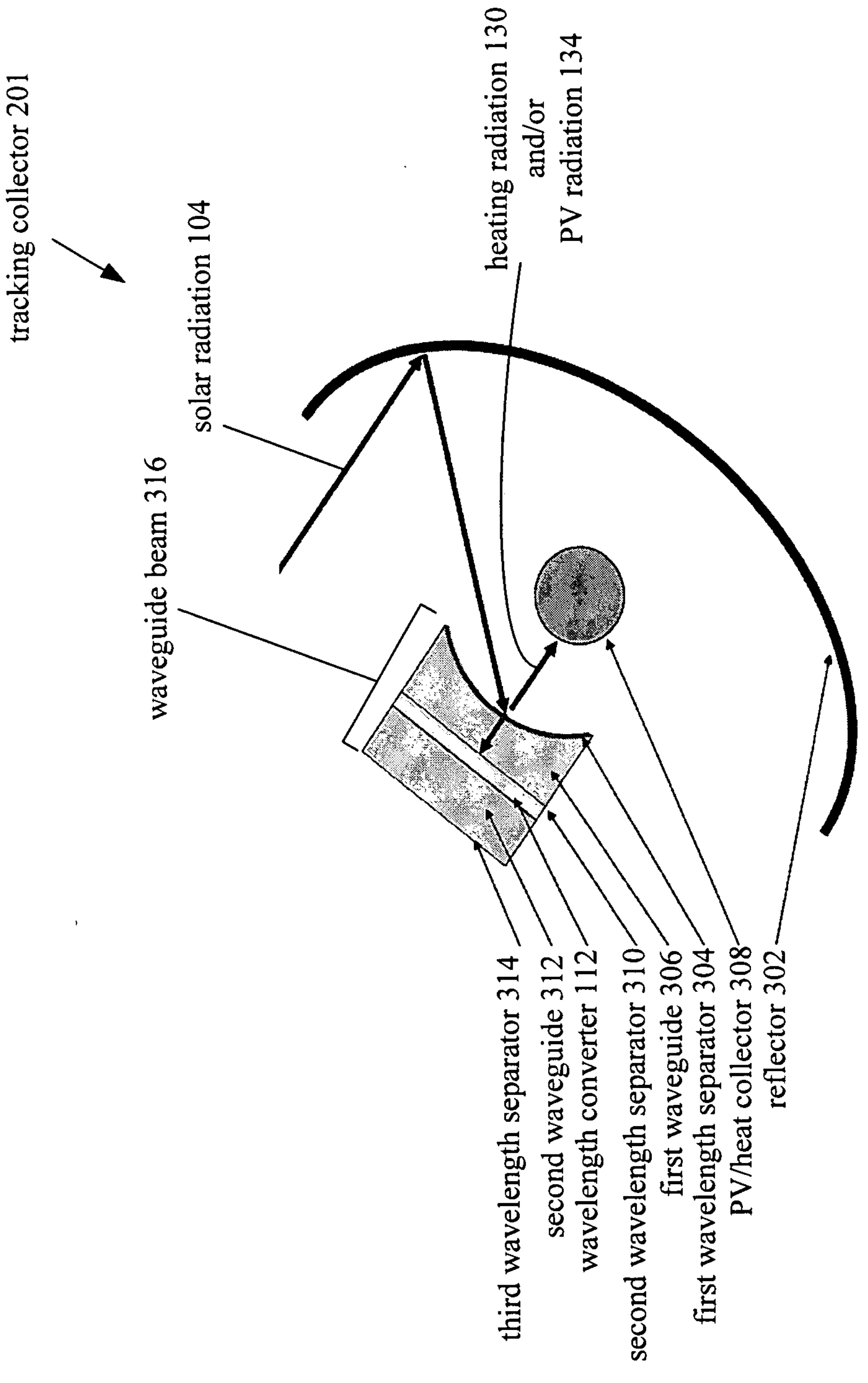
tracking collector 201
solar radiation 104
waveguide beam 316
heating radiation 130
and/or
PV radiation 134
third wavelength separator 314
second waveguide 312
wavelength converter 112
second wavelength separator 310
first waveguide 306
first wavelength separator 304
PV/heat collector 308
reflector 302

Figure 3C

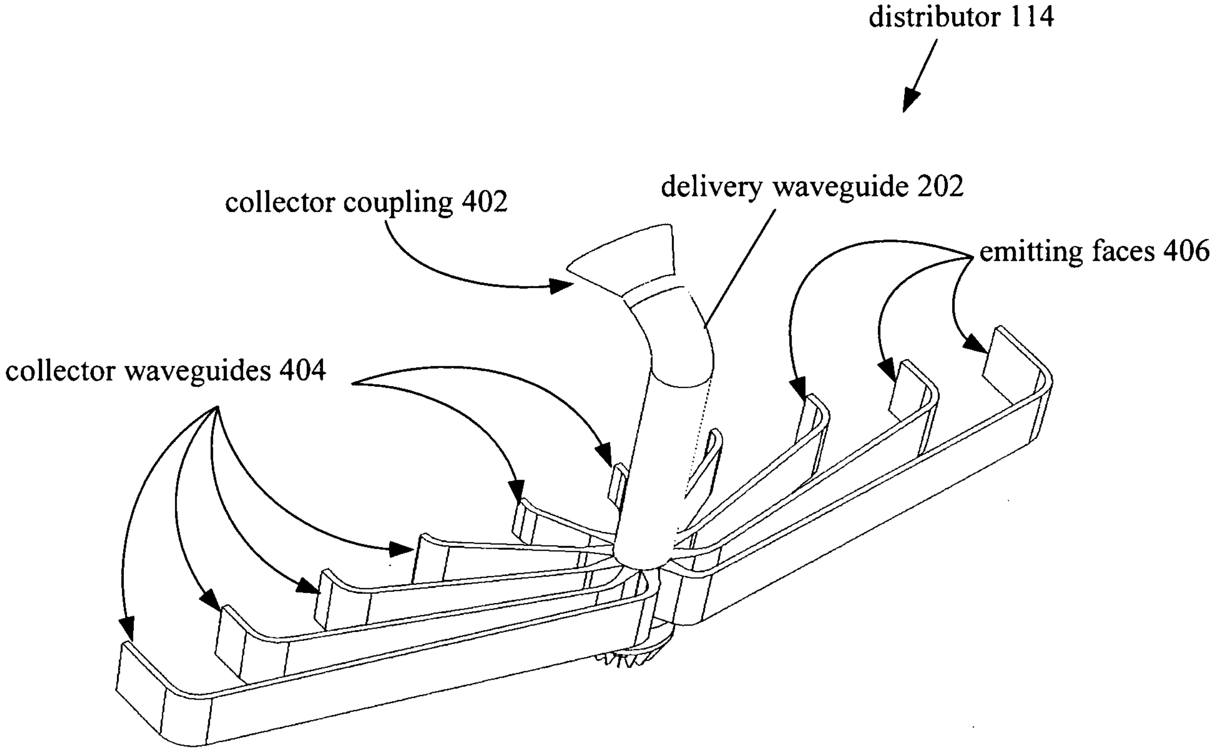

Figure 4

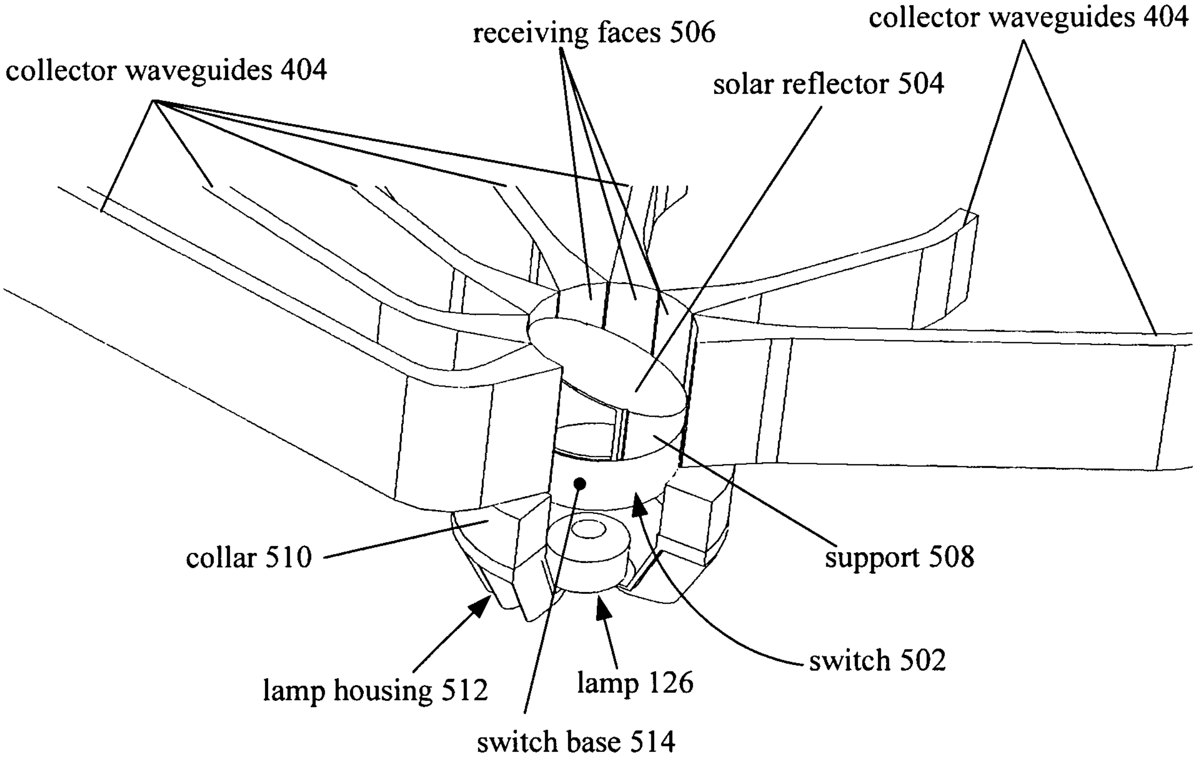

Figure 5

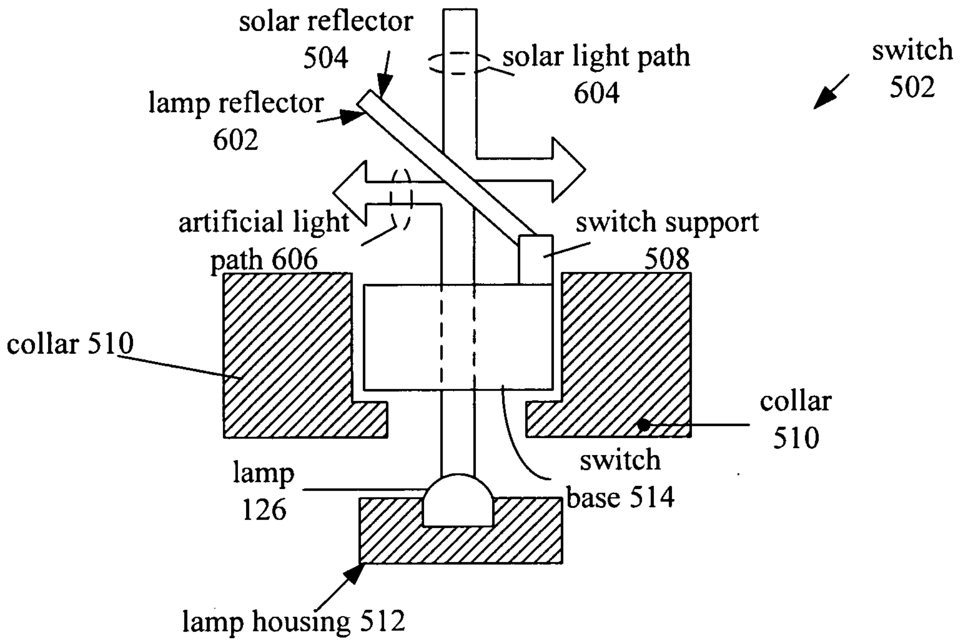

Figure 6

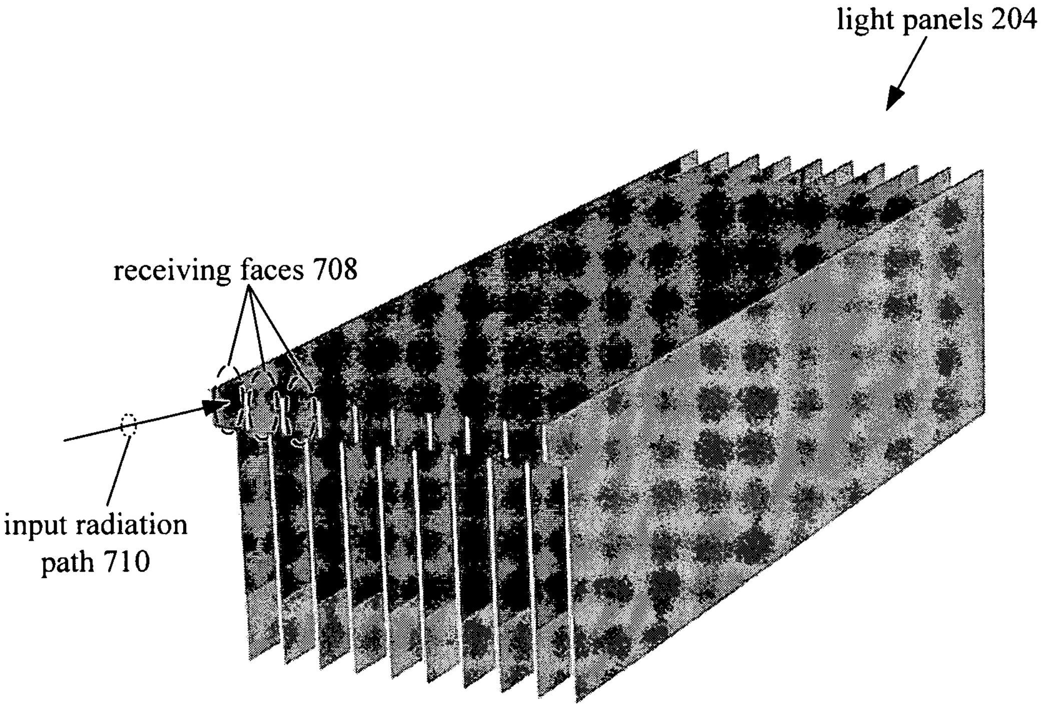

Figure 7A

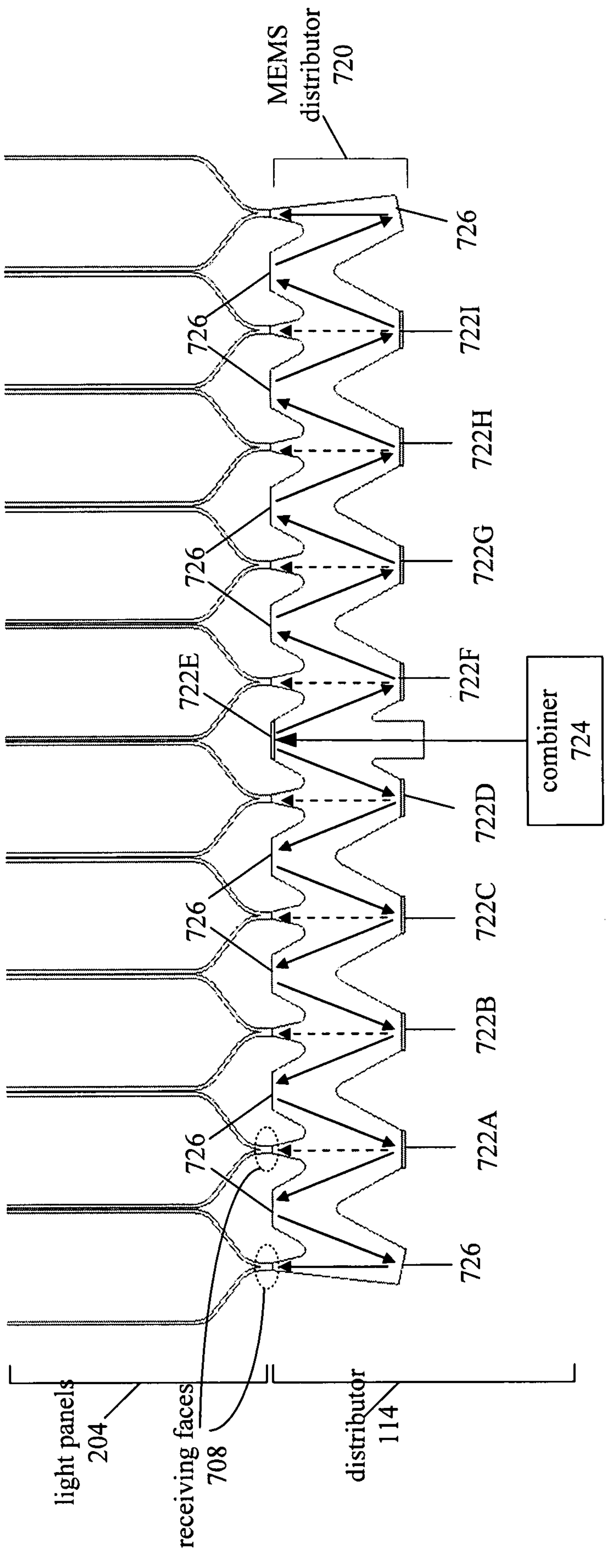
MEMS distributor 720
726
722I
726
722H
726
722G
726
722F
722E
combiner 724
722D
726
722C
726
722B
726
722A
726
726
light panels 204
receiving faces 708
distributor 114

Figure 7B

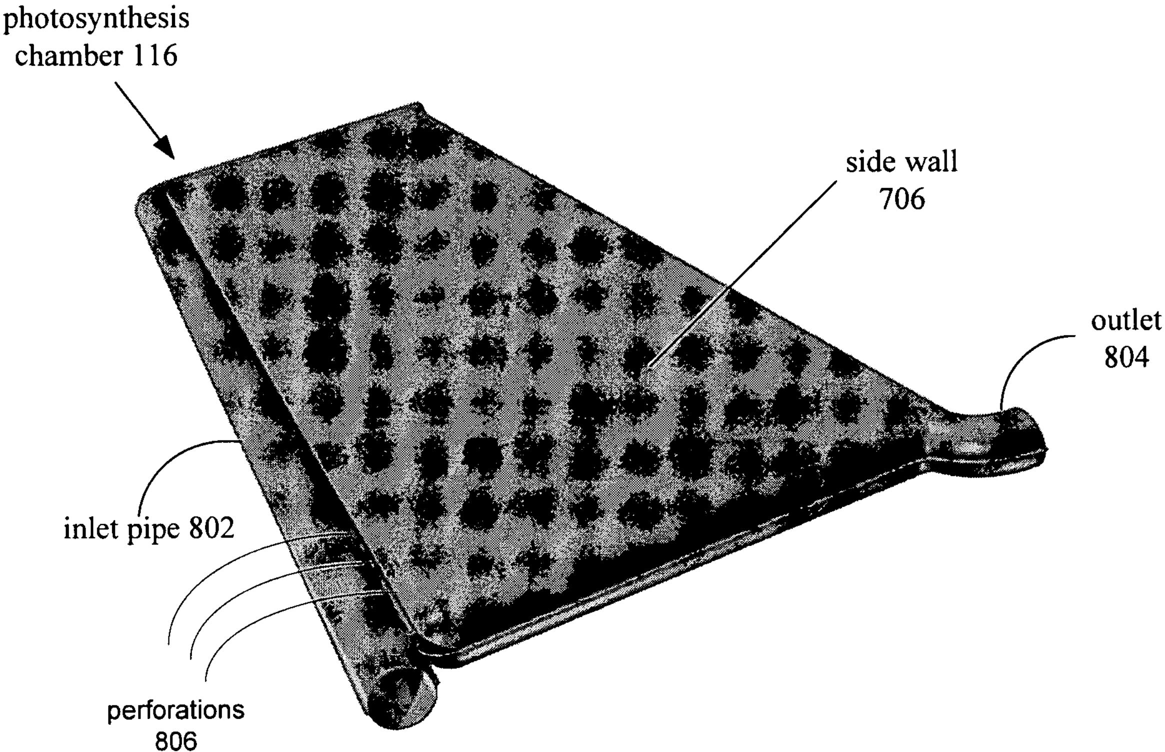

Figure 8

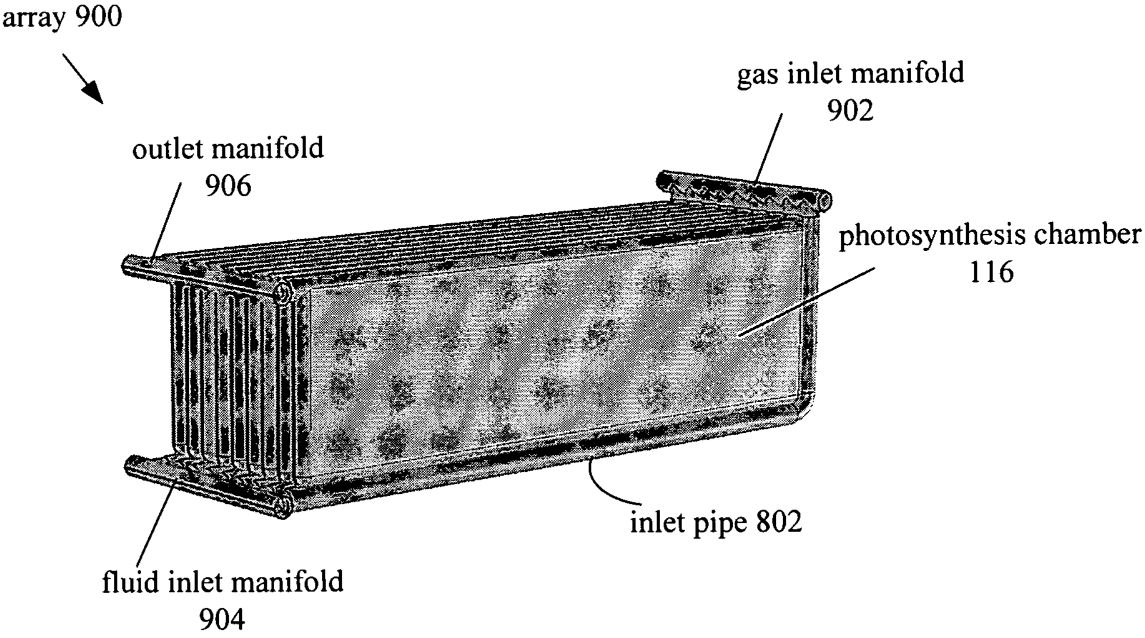

Figure 9

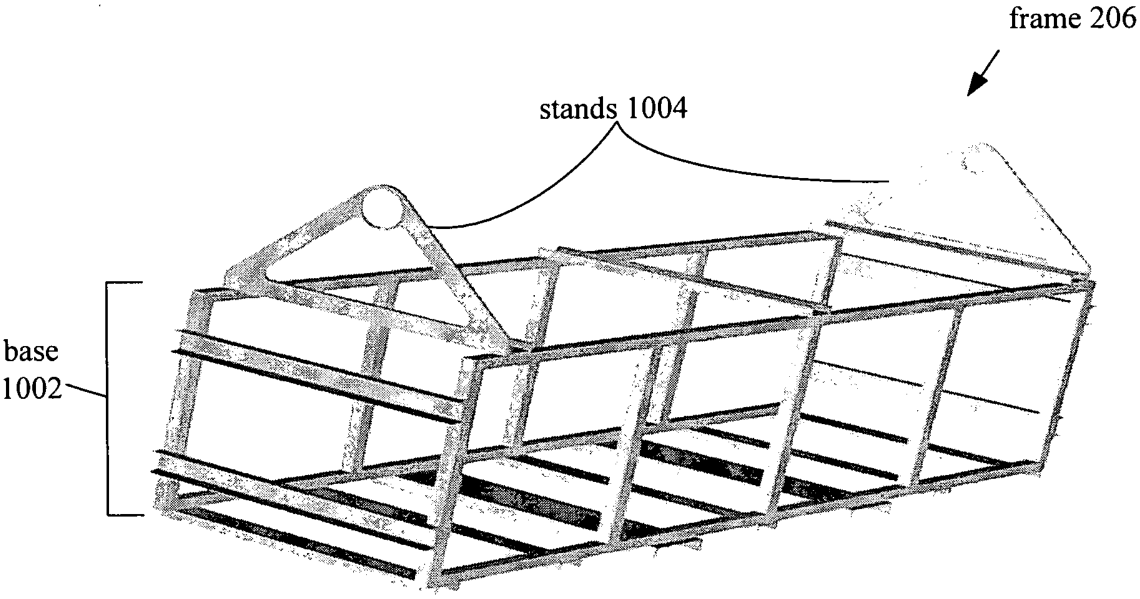

Figure 10

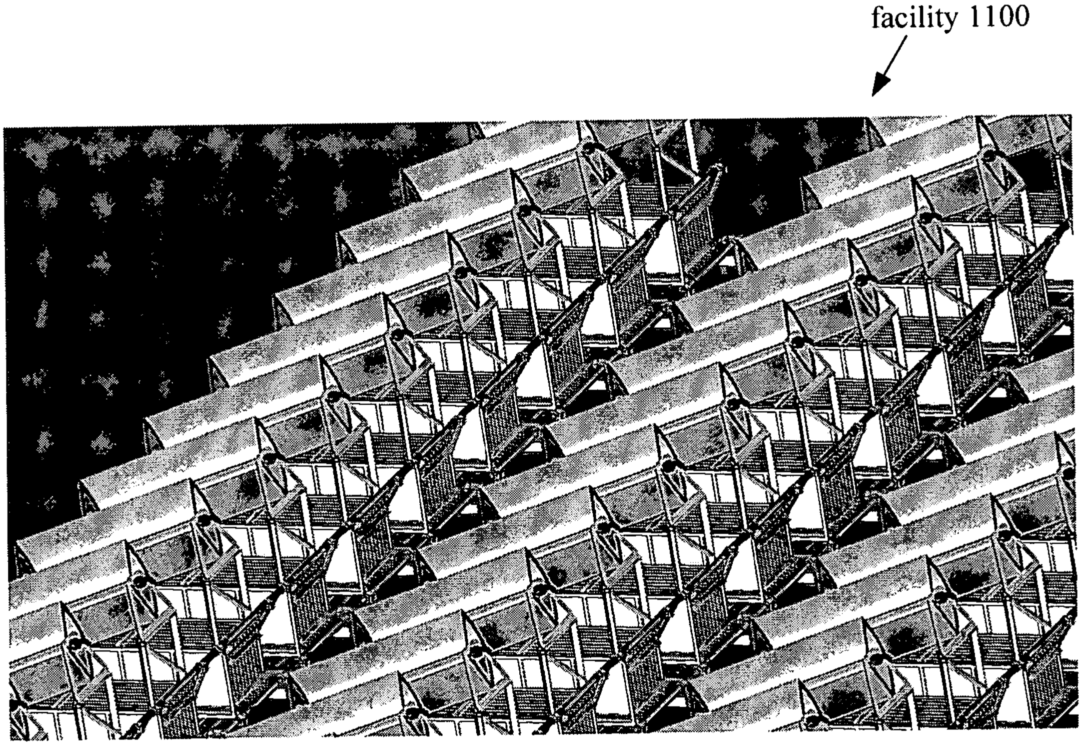

Figure 11

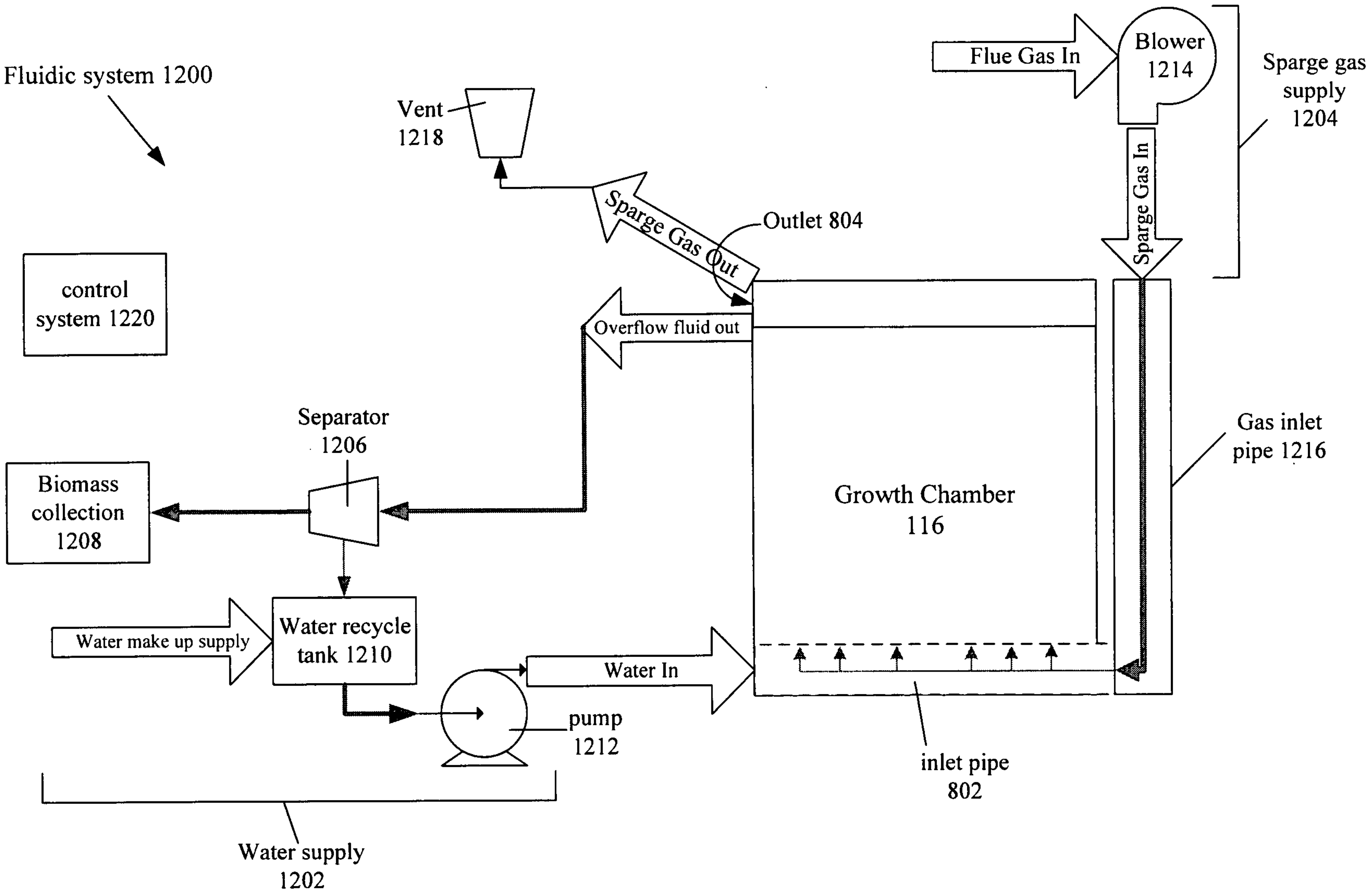
Fluidic system 1200
Vent 1218
Flue Gas In
Blower 1214
Sparge gas supply 1204
Sparge Gas In
Sparge Gas Out
Outlet 804
control system 1220
Overflow fluid out
Separator 1206
Biomass collection 1208
Gas inlet pipe 1216
Growth Chamber 116
Water make up supply
Water recycle tank 1210
Water In
pump 1212
inlet pipe 802
Water supply 1202

Figure 12

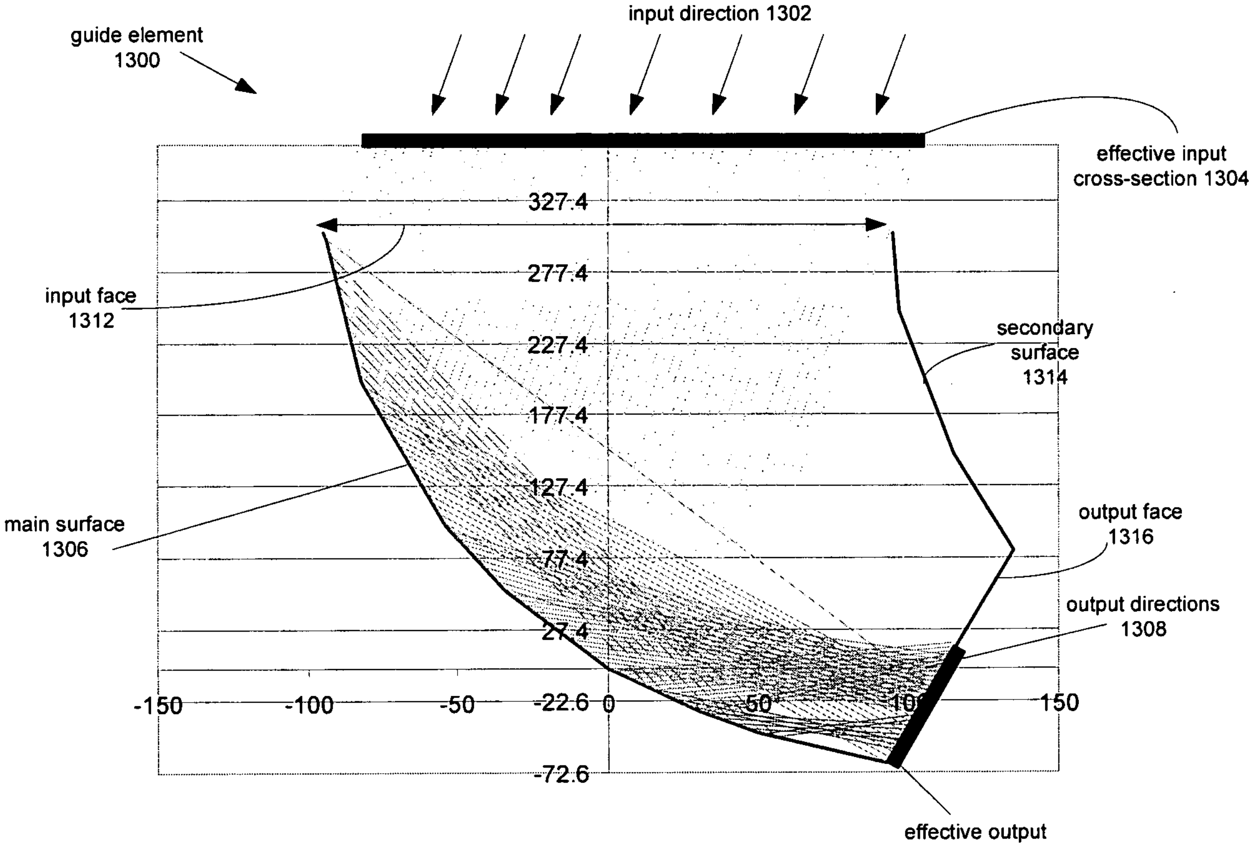

Figure 13

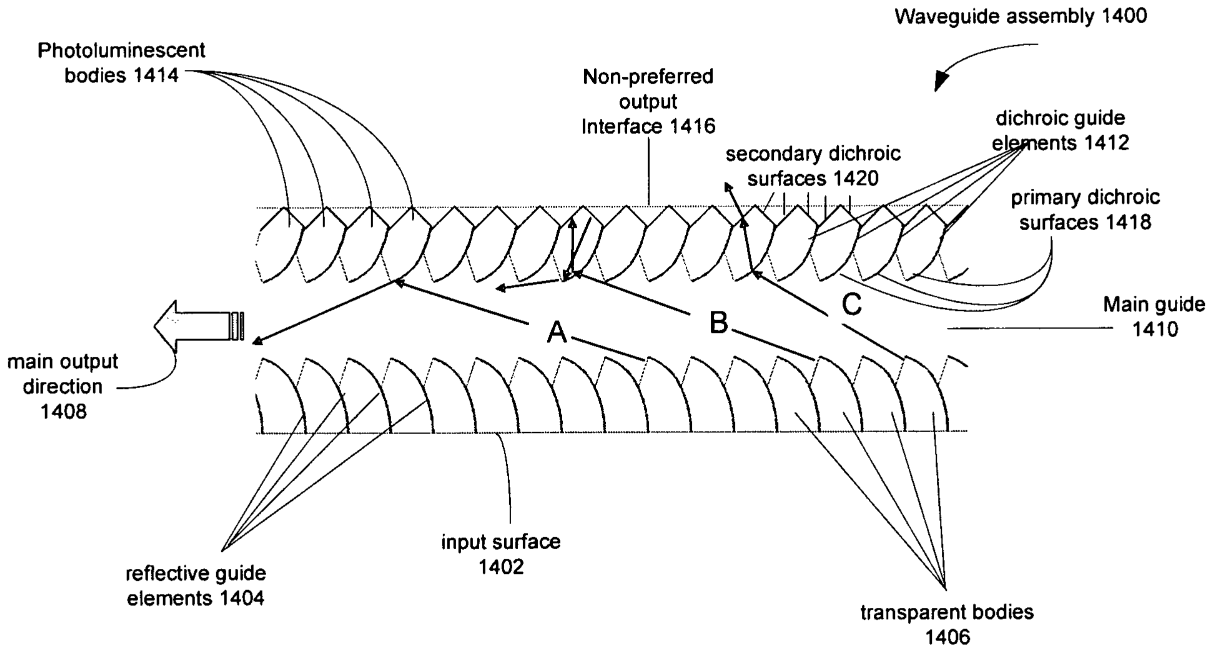

Figure 14

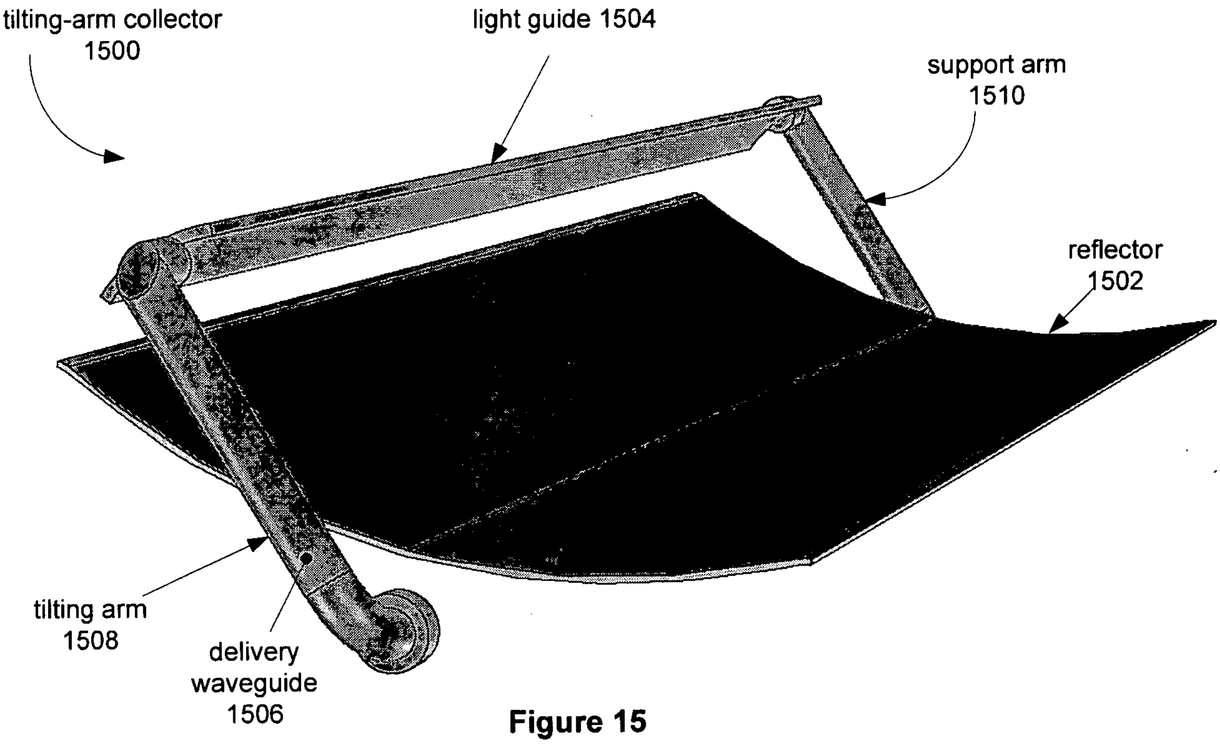

Figure 15

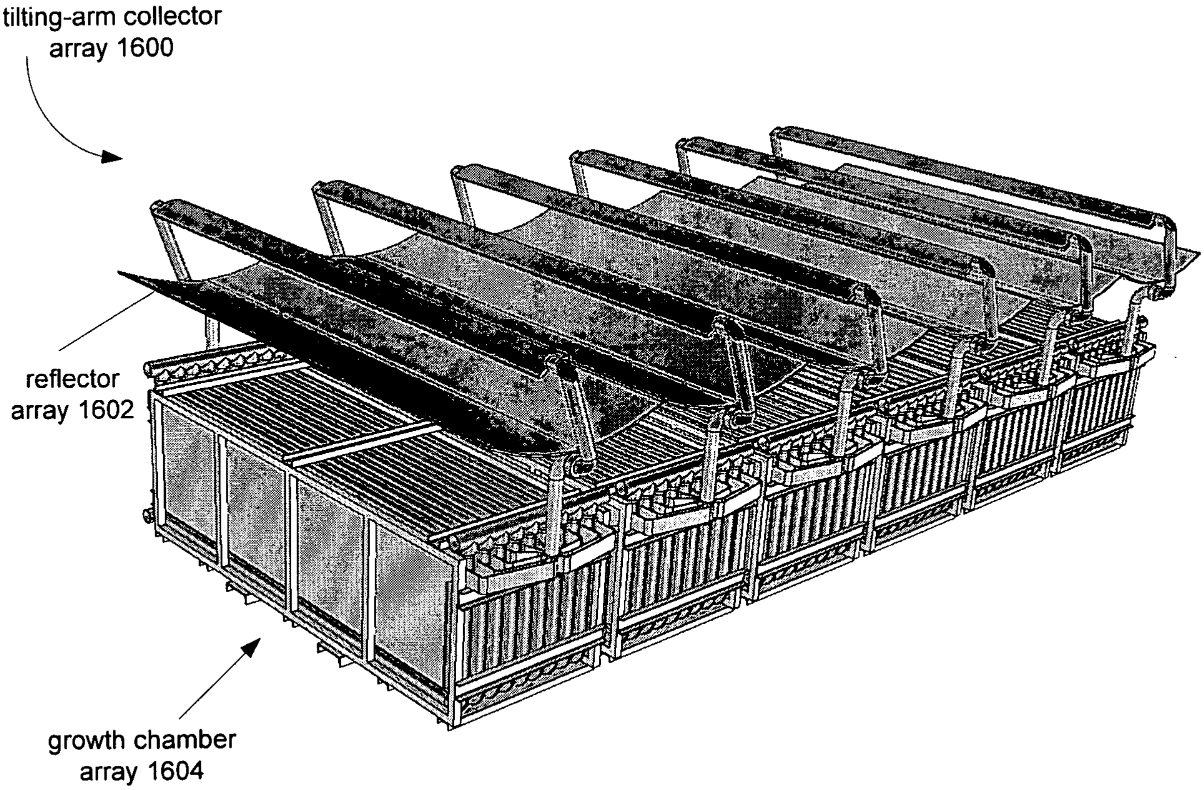

Figure 16

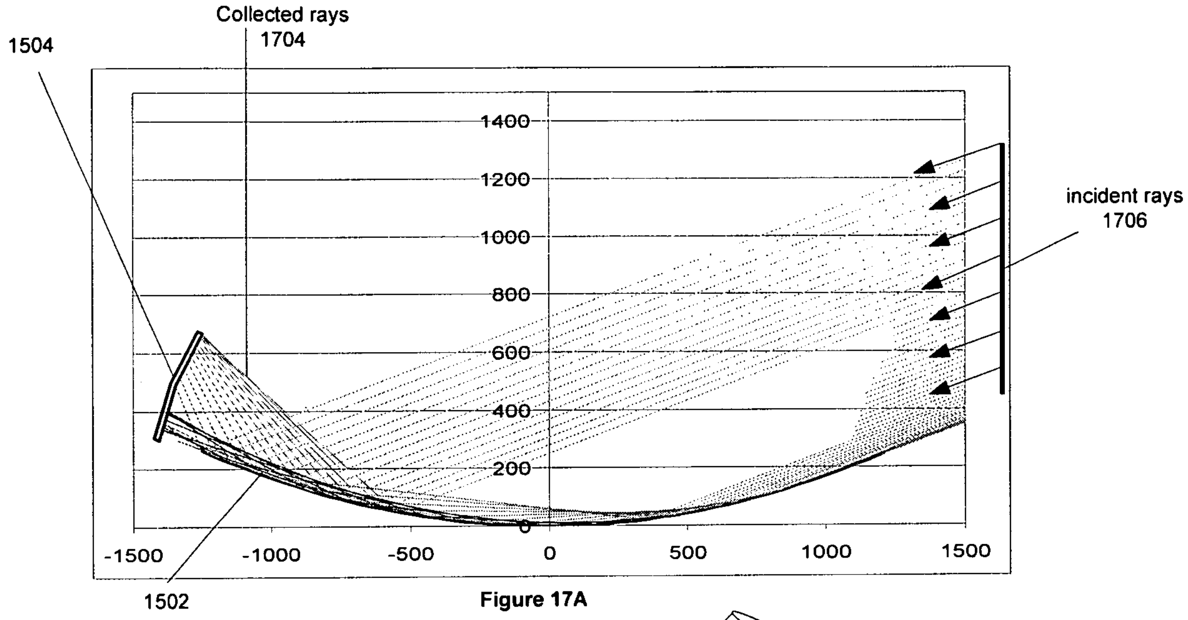

Figure 17A

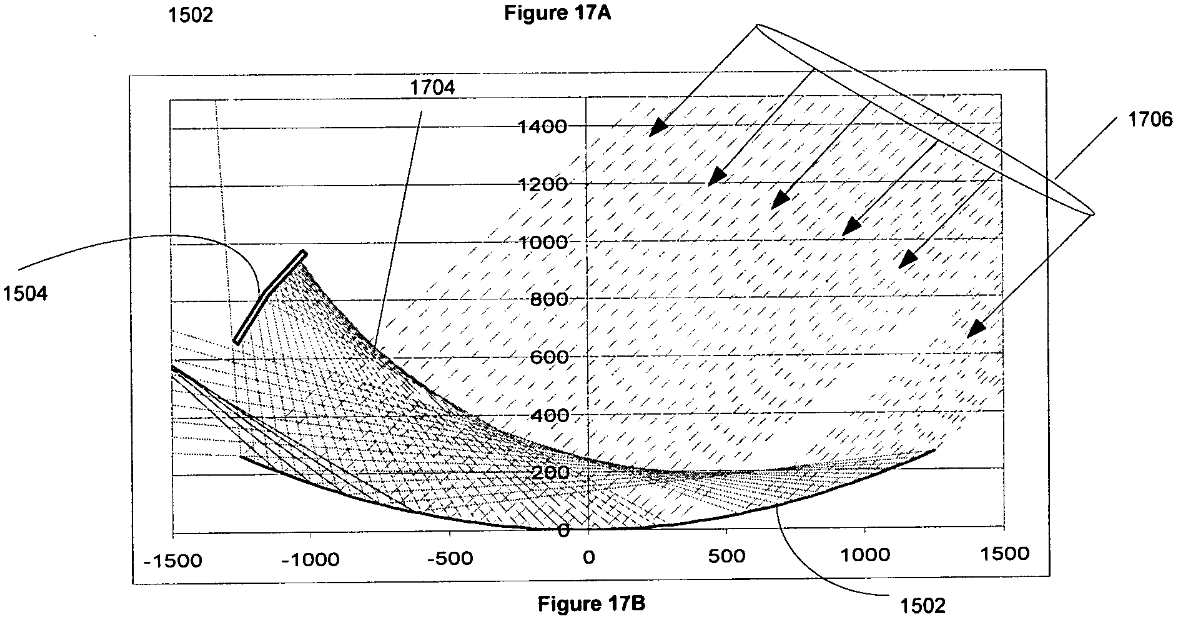

Figure 17B

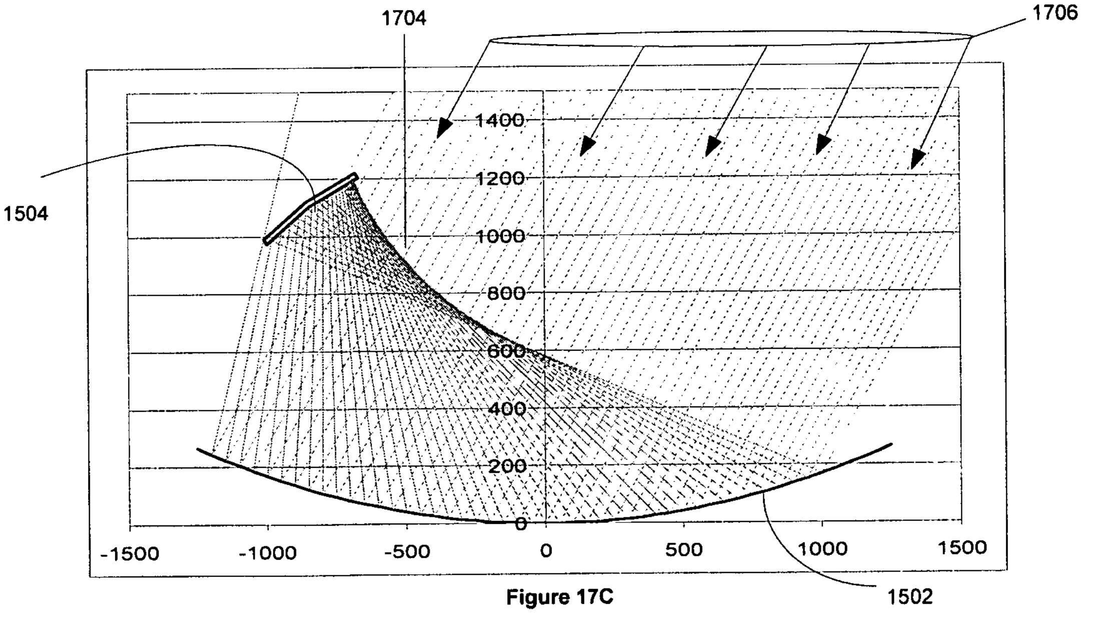

Figure 17C

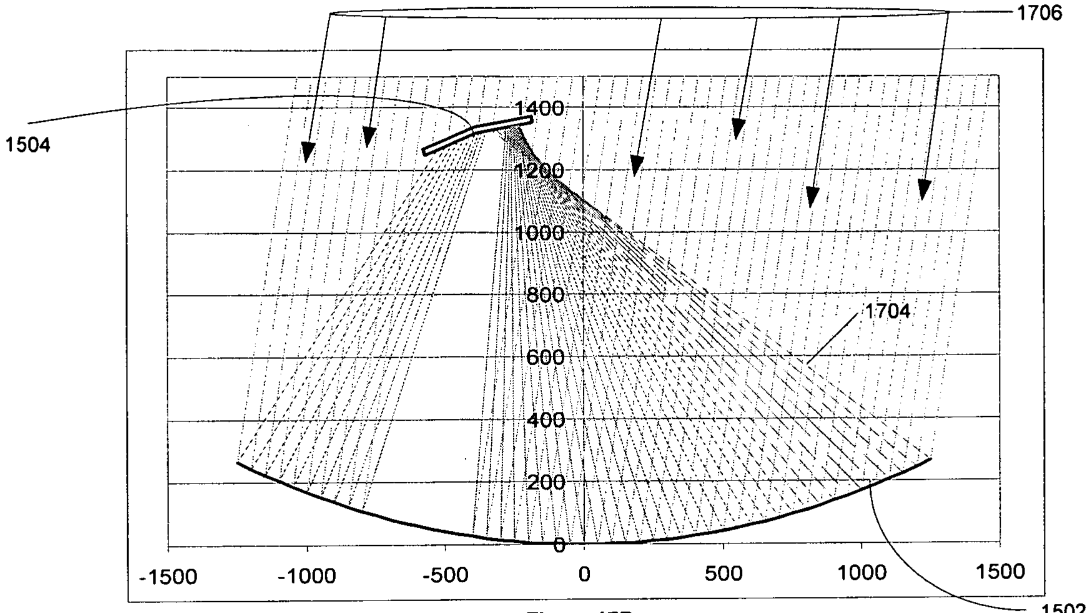

Figure 17D

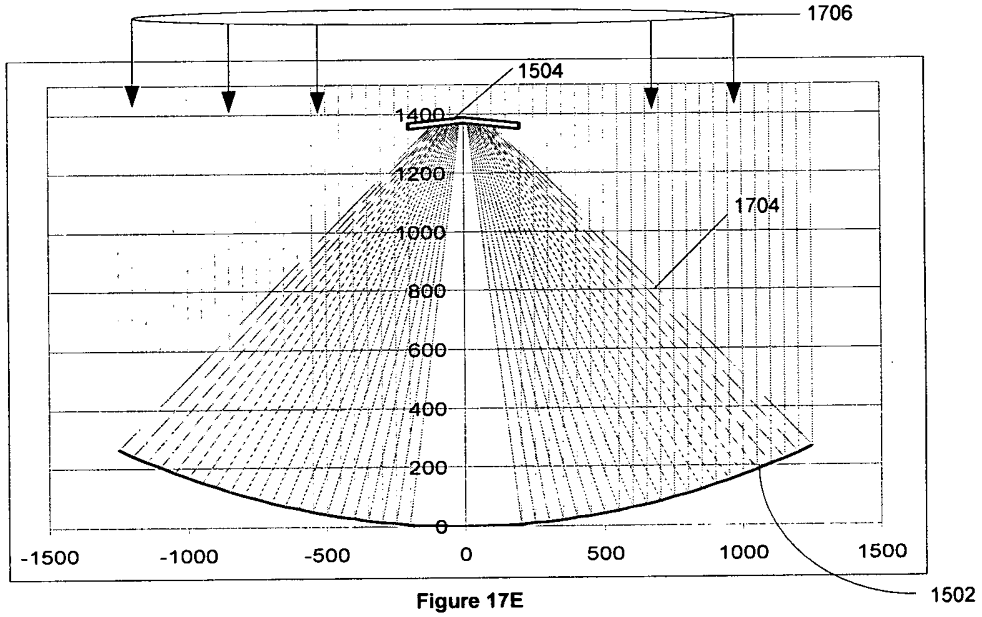

Figure 17E

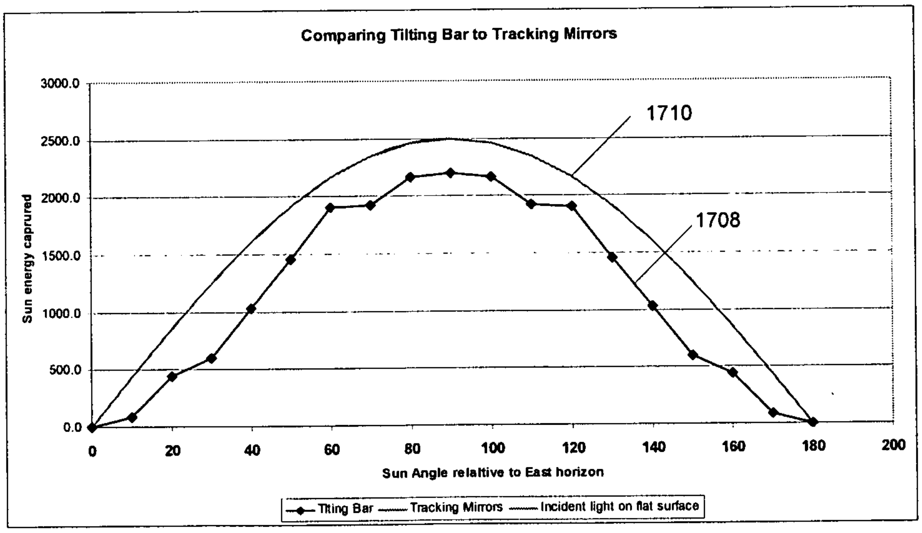

Figure 17F

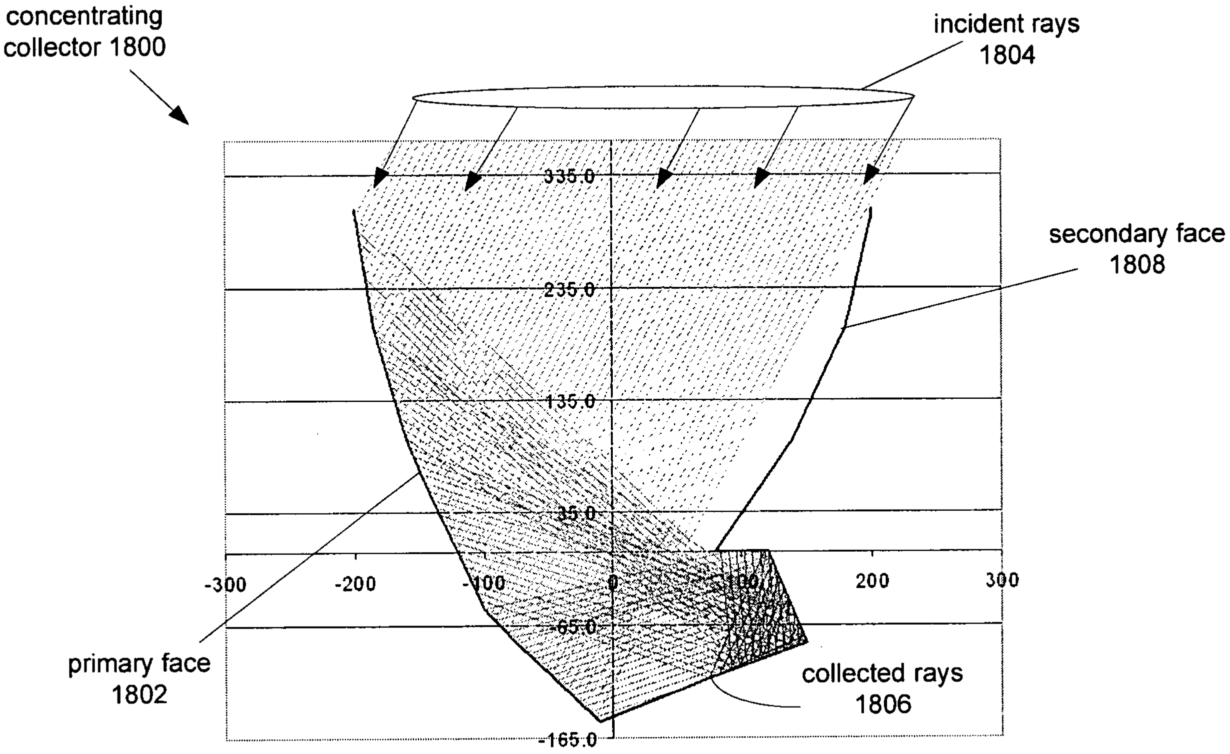

Figure 18

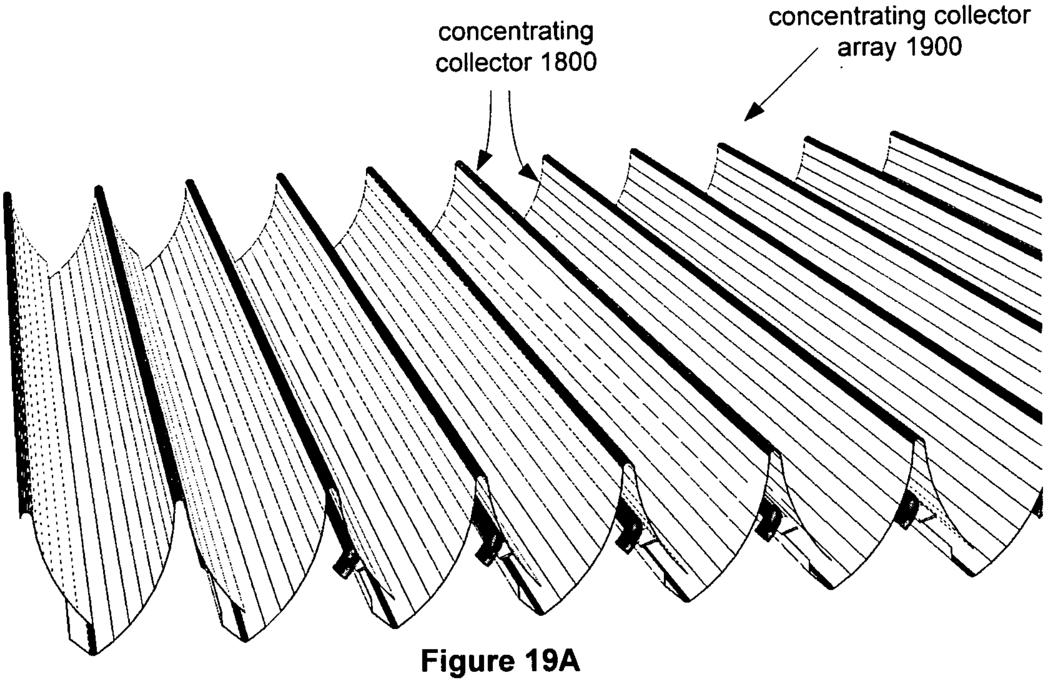

Figure 19A

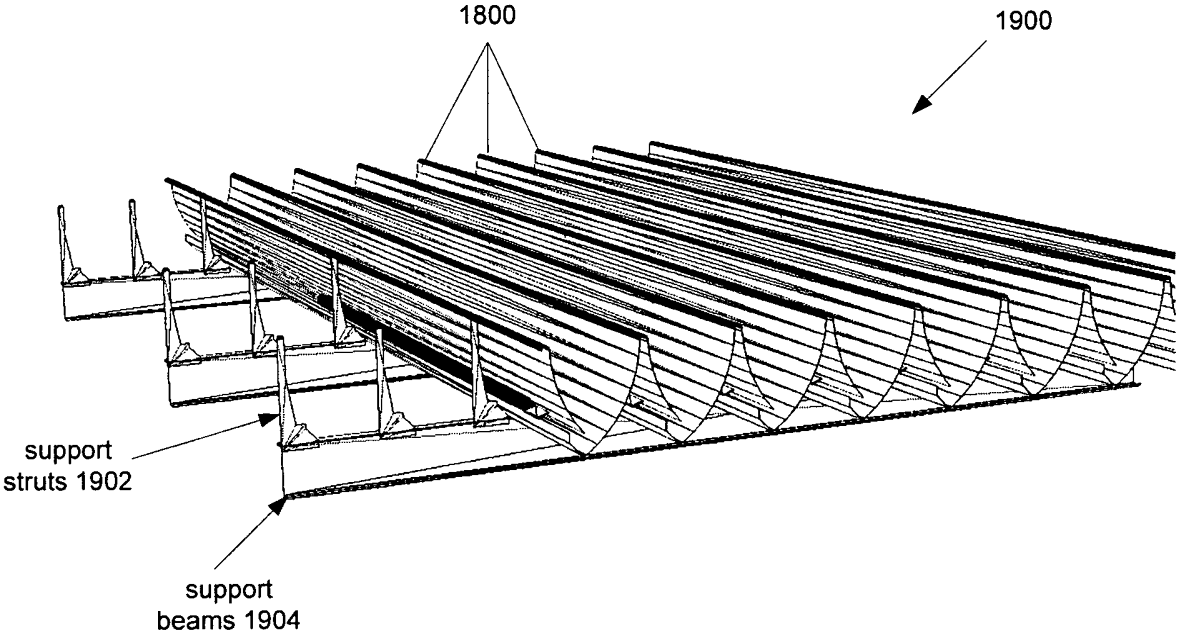

Figure 19B

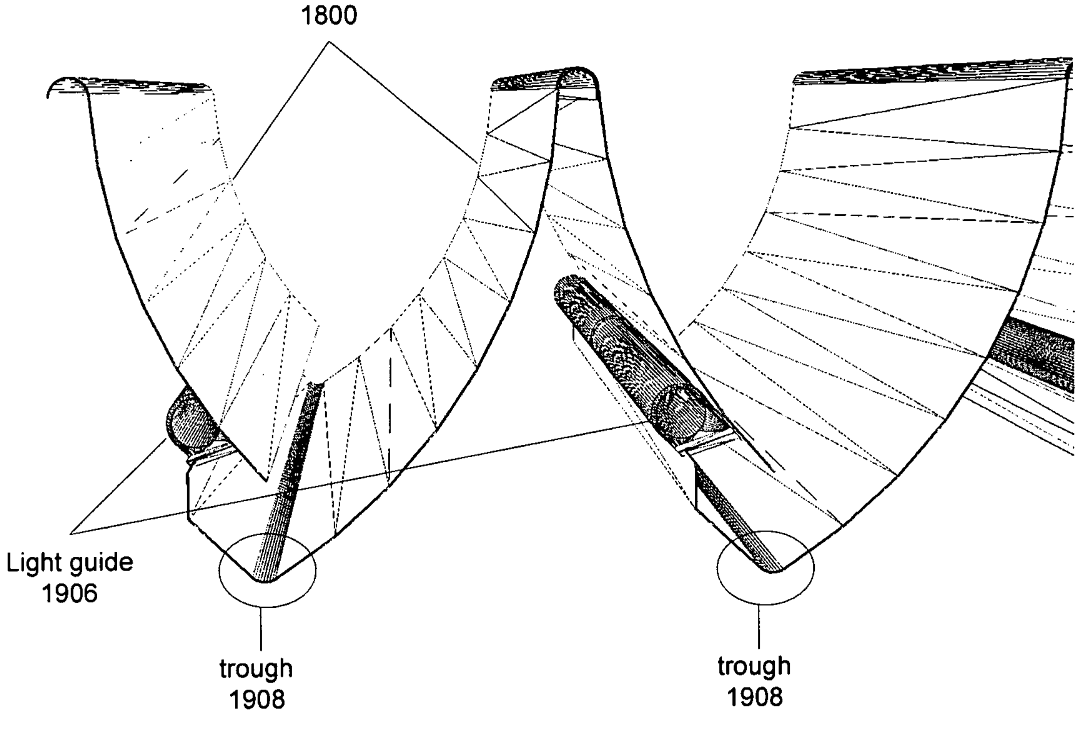

Figure 19C

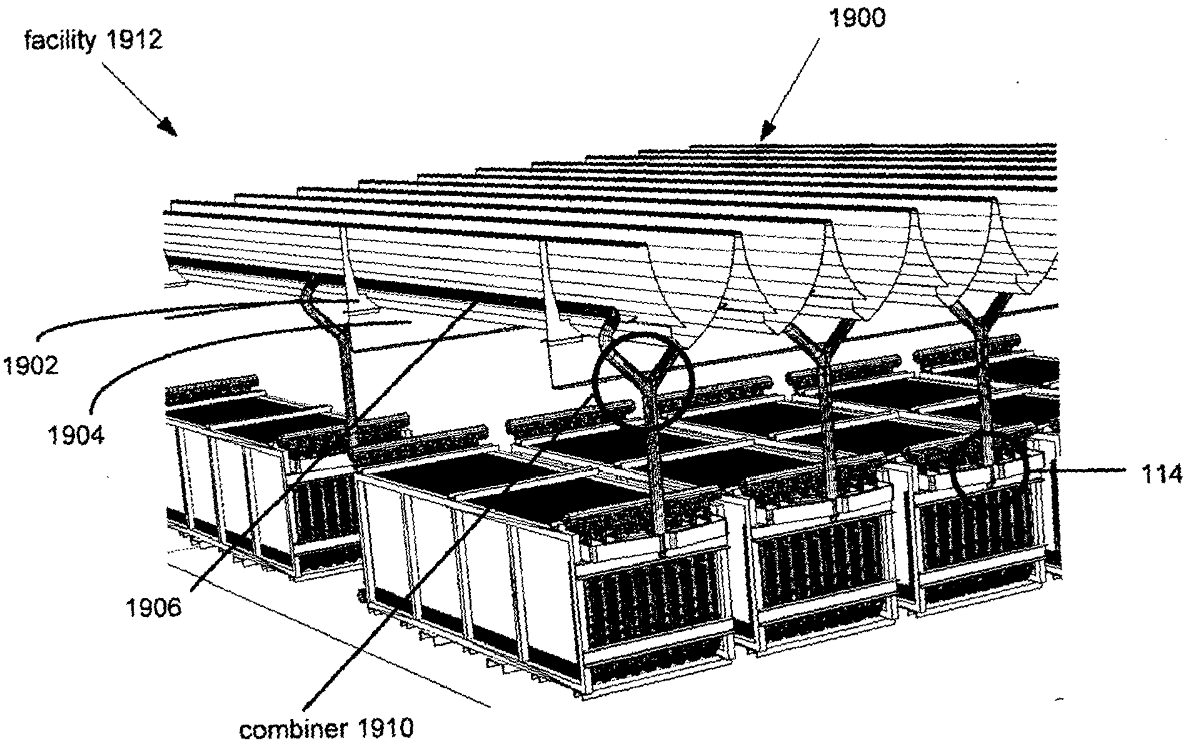

Figure 19D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2010/000617

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

C12M 1/00 (2006.01) *A01H 13/00* (2006.01) *H01L 31/052* (2006.01)
A01G 7/00 (2006.01) *C12N 1/12* (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPODOC and WPI with IPC C12M, C12N and keywords such as photobioreactor, photosynthesis, bioreactor, solar, radiation, collector, sun, growth, wavelength change, modifier, shifter, converter, light modulator, irradiation and the like..

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/101525 A2 (GREENFUEL TECHNOLOGIES CORPORATION) 27 October 2005 Abstract, Figures 1A, 1B, 2A, 3B elements (100), (102), (102`), (200) pages 3-4, 9-10 and 19-29.	1, 2, 14, 16-18, 20-24, 26, 33-36, 46, 50-52
X	WO 2009/002772 A2 (ALGAE-DYNE CORPORATION) 31 December 2008 Abstract, para[0011][0013][0019]; para[00129] – [00131]; para[00199]-[00206]; para[00168]-[00174].	50, 51
-- Y	[0008], [00170];[00291], [00129] – [00131];[00263]-[00270]; Figures 11-14, Figures 27-52.	1-5, 10-12, 14, 15, 20-27, 33-38, 42-47, 52

☒ Further documents are listed in the continuation of Box C ☒ See patent family annex

*	Special categories of cited documents:		
"A"	document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 21 July 2010	Date of mailing of the international search report 30 JUL 2010
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. +61 2 6283 7999	Authorized officer **VIARA VAN RAAD** AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No : +61 2 6222 3643

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6509188 B1 (TRÖSCH ET AL.) 21 January 2003 Abstract, Figure 2; col. 3, ln. 53- col. 5, ln. 64; col. 4, ln. 27-col. 5, ln 64.	1-5, 10-12, 14-17, 20-29, 32-38, 40, 42-47, 52
Y	US 6603069 B1 (MUHS ET AL.) 05 August 2003 Abstract, Figures 1-6, 11, 15-18 and related text; col. 3, ln. 7-46; col. 4, ln. 21-col. 5, ln. 6; col. 3, ln. 7-46; col. 4, ln. 21-col. 5, ln. 6;	1, 2, 14-17, 27-29, 32-35, 40, 42-45, 52
X	US 7192146 B2 (GROSS ET AL.) 20 March 2007 Abstract, Figures 1-6 and related text.	53
A	US 2005/0260553 A1 (BERZIN) 24 November 2005 Entire document	
	NOTE: for the Y types of documents: WO 2009/002772 is combined with the disclosure of US 6509188; US 6603069 is also combined with US 6509188.	

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See the additional sheet in Supplemental Box (1)

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Supplemental Box (1)
(To be used when the space in any of Boxes I to IV is not sufficient)

Continuation of Box No: III

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

In assessing whether there is more than one invention claimed, I have given consideration to those features which can be considered to potentially distinguish the claimed combination of features from the prior art. Where different claims have different distinguishing features they define different inventions.

This International Searching Authority has found that there are different inventions as follows:

- Claims 1-52 directed to a photosynthesis growth apparatus and method of aiding in the process of photosynthesis with a solar collector, light modulator and wavelength converter and a growth area for photosynthetic material for performing photosynthesis. It is considered that the said method and apparatus for photosynthesis using solar radiation, wavelength converting of the solar irradiation and light modulation comprises a first distinguishing feature.
- Claim 53 directed to a solar collector with at least one reflector fixed to movement of the sun configured to concentrate solar radiation to a moving region and at least one moving receiver to receive the concentrated solar radiation in the region. It is considered that the said solar collector comprises a second distinguishing feature.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

Each of the abovementioned groups of claims has a different distinguishing feature and they do not share any feature which could satisfy the requirement for being a special technical feature. Because there is no common special technical feature it follows that there is no technical relationship between the identified inventions. Therefore the claims do not satisfy the requirement of unity of invention *a priori*.

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	2005101525	NONE					
WO	2009002772	AU	2008268669	CA	2690384	EP	2171037
US	6509188	AU	45447/00	BR	0009764	CA	2364561
		CN	1345369	DE	19916597	EP	1169428
		IS	6065	MX	PA01010279	NO	20014150
		PL	350946	WO	0061719		
US	6603069	US	2004118447	US	7231128	US	2004187908
		WO	03038348				
US	7192146	US	2005034752				
US	2005260553	AU	2003234604	AU	2005274791	CA	2488443
		CN	1668185	EA	200702294	EP	1509076
		US	2005064577	US	2005239182	US	2009011492
		WO	03094598	WO	2006020177		

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

— *the filing date of the international application is within two months from the date of expiration of the priority period (Rule 26bis.3)*

[Continued on next page]

(54) Title: SOLAR HEAT COLLECTOR AND HEAT FOCUSER TO MELT SAND/METAL/SALT OR TO PRODUCE METHANOL AND TO GENERATE SIMULTANEOUSLY ELECTRICITY BY THE COOLING METHODS ANERGY CIRCUITS

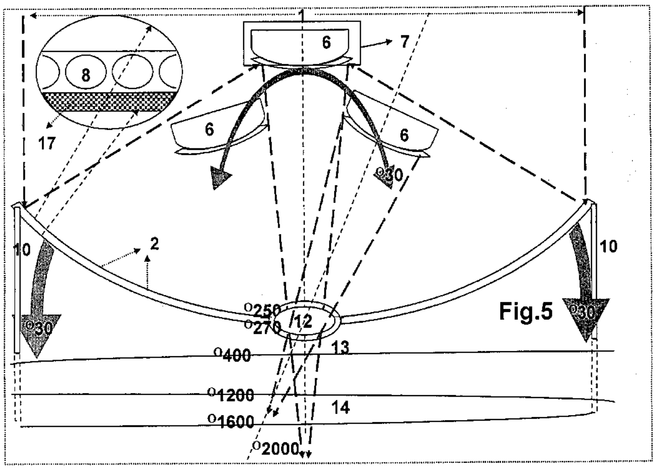

Fig.5

(57) Abstract: Solar mirror, or two connected mirrors adding up to a parabolic curve, to receive a round or rectangle focus on top, which will be reflected downwards by a smaller mirror with the same but a bit straitened parabolic curve, to develop below and behind the mirrors in the second focus high temperatures between 250°C and 1600°C, to melt metals -in factories- or to melt sand —producing desert roads, trenches, water channels walls- or salt -to produce building stones- and/or to receive Hydrogen -from water- and Carbon Monoxide -from Carbon Dioxide- to produce renewable Solar Methanol as a substitute for Fuel. The said collector produces by the way additional thermal energy from the mirror surface through water pipes -or rubber tubes-, integrated in the mirrors or placed behind them to strengthen them and thermal energy from cooling the 1st focus mirror by being welded to water pipes behind it -which is thermally isolated from the air by a vacuumed glass tube and sealed off with rubber pressure sealing rings-, which absorbs its heat not allowing the heat to exceed 99°C to be able to transport the water by rubber/plastic pipes, to store the hot water in a tank/pool/pond/lake as an heat source specially for the night, to be able to produce electricity with different Anergy circuits of the cooling method even

[Continued on next page]

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at night throughout the day and year, saving the Anergy circuits cooling power in additional cold water tanks/ponds/lakes to cool down the first focus at day time, closing the water circuit. - The hot water tank/pool/pond/lakes has to be covered to prevent the hot water from evaporation and is thermally isolated by a tent which is used additionally as solar heat collector. The shadowed spaces bellow the tents can be used in different application or the tents can be placed at a foot of a south-directed mountain. - Solar heat Methanol is preferably placed and produced in secured melted sand trenches covered with rubber tubes/hoses carpets covered with aluminum foil to be used as collecting mirror.

Solar heat collector and heat focuser to melt Sand/metal/salt or to produce Methanol and to generate simultaneously electricity by the Cooling Methods Anergy circuits

1.- Technical Field of the Invention

This invention relates to a Solar heat collector with two focuses like “Casse Grain” telescopes or satellite dishes, to melt with the second focus sand/metal/salt or to produce Methanol and the said Solar collector generates simultaneously electricity –even at night– by different “Cooling Methods” circuits using the in water stored and absorbed –not exceeding 99°C– heat, gained from cooling the first focus with water, as 99°C allows the use of plastic or rubber connecting water tubs and the use of rubber sealing rings between the surrounding thermal isolating glass tubes and the first focus instead of expensive material.

2- Prior Background Art

- World wide there are nearly uncountable solar heat collectors, collecting solar heat resp. thermal energy and if they produce electricity they add up –to my knowledge– to heating water up to 375-600°C, to drive with steam (from water) a turbine, driving a generator and to achieve this in the night they store high temperatures in expensive oils, or by melting salt, or just by storing the heat in cement blocks.
- Electricity is also produce from solar rays by Photovoltaic or Triple Junction cells, but generally heat lowers their efficiency. That is way triple junction cells have to be cooled down, which still until now consumes energy, instead like in this invention producing by the cooling Methods circuit additional electricity from the absorbed thermal energy.
- “Casse Grain” is known from telescopes or satellite dishes, but not used as heat collector.
- How to produce Methanol –as alternative fuel– with heat and pressure from Hydrogen and Carbon Monoxide (gained from heating up Carbon Dioxide) is known, but producing it as a side product along with generating electricity from solar heat is not a known Method.
- Reaching high heat in one upper solar focus is known, but how to transfer the solar rays heat downwards where it is needed in a factory or to melt dessert sand along with generating electricity is not known. That is why nobody uses solar energy directly neither to melt sand to excavate and straighten up dessert sand streets (nor metals) nor salt, which are the cheapest common materials and energy on earth to produce building walls, stones etc.

3.- Disclosure of the Invention and Method

3.1 Introduction of physical laws and facts used by the method of this invention

- The complete and detailed description of the invention could only be realized after understanding the drawings description and the introduction of physical laws/facts used.
- To over come my language defaults/mistakes, I will illustrate and stick my explanations in this introduction to international known Physical Laws/Facts and practical realistic example, used in the cooling methods circuits to produce electricity, that helps to gain a physical understanding of gas and liquid behavior to generate from thermal energy electricity, to make it easier for every body and to make shure this invention and Method is understood.

I.A – Bernoulli's corrected and added total pressure law driving a flow engine

P_f = 1/2 x D x v^2 ; (D) = Density (v) = speed	(**P_f**) Flow/dynamic Pressure
P_{st} = D x g x h ;(h) = Height; (g) = Earth gravity	(**P_{st}**) Static fluid weight Pressure
$P_D = P_{D1} - P_{D2}$; (P1) = high pressure; (P2) = low	(**P_D**) Static Pressure Difference
$P_T = P_f + P_{st} + P_D$ = Total Pressure	(**P_T**) Corrected Pressure law

- As we have a max. height difference of 1 meter in the Anergy circuits, we will ignore the weight pressure **P_{st}** make it easier. **Total Pressure** law adds up only to = **$P_T = P_f + P_D$**

I.B – Bernoulli's Law : stating the relation between force(**F**) and velocity/speed(**v**) of liquid in two connected pipes with different diameter resp. sizes: **A1/A2 = v2/v1 ; F1/F2 = A1/A2.** Defining, after the condenser with a broader diameter, the liquid gas speed in both pipes.

II. - Fact of converting fluid flow [P_f= 1/2 x D x v^2] into a mechanical drive to produce electricity { compared to an Expansion engine, **Flow engines** do miracles }.A **flow engine** such as a **Water** (Pelton, Francis, Kaplan, Curtis) **Turbine**, rotary engine or gear engine, convert the flow energy of liquid gas/fluid/water movement into a mechanical kinetic drive (a circular movement) by an efficiency up to 94% in a Pelton Turbine { more than an expansion engine could theoretically (max. 66%) ever reach }. A flow engine in the "reverse" energy consumption is a pump with an efficiency up to 93% till now (Expansion engines in "reverse" energy consumption are compressors, both have bad efficiencies, due to their enormous heat loses) to understand this an example from Germany.

- In Germany (Goldisthal), they save overproduced accessed electrical power (as the case in batteries, but on a larger scale) from the general electricity network, through pumping water up a lake located on top of a mountain. During peak electrical demand, electricity is generated by turbines, which use the water flow downwards (pressure difference). This process involves energy loss of 15%-20%. This means that out of 10 MW, about 8-8.5 MW is recovered. Let's assume the amount of electricity recovered is 8.19 MW (= 90% x 91%) - This means that the efficiency of the pump is about 90% (converting electricity into flow pressure to pump the water up the mountain) and the efficiency of converting the water flow into electricity is about 91% (generating electricity from the water flow down-wards). Rotary flow engines and pumps with one/two tied closing moving blades are preferred. Converting water flow with a static pressure into a mechanical drive to generate electricity, is similar to = converting flow of fluid/liquid gas (carbon dioxide/refrigerant/liquid) with pressure differences into a movement in the Anergy circuits, bearing in mind the difference in density between water and the used Refrigerant or liquid Carbon Dioxide or fluid. Converting electricity into flow by pumping water resembles pumping refrigerant/fluid/liquid carbon dioxide. The Anergy circuits differ only with the additional step of discharging coldness (= heat exchange) at the cold-water tank, to provide them with additional renewable thermal energy. Coldness resulting from the expansion of liquids to gas/vapor, produces a pressure reduction behind the flow engine and razes the pressure difference driving the flow engine with more force, to produce more kinetic energy (electricity) than consumed by the pump.

III. - Facts of the different stages of gas

A.- Always below critical temperature and higher than their boiling temperature:

1.- The **Normal spread gas stage in a pressure around 1.013 bar** or **higher, as f. ex. Air,** than on Earth compressed with a higher pressure than 1,013 bar till

2.- "Partial Liquefied Gas" on Earth (resp. a part above is gas and a part below is liquefied, due to earth gravitation which liquefies the gas bellow) than additionally compressed with under critical pressure and cooled/kept bellow critical temperature till

3.- "Completely Liquid Gas" bellow critical temperature

B.- Above the critical Temperature and/or above the critical Pressure : there is only One stage of "Over Critical Gas" available, with higher or lower density. At this stage the liquefying of gas is not possible (only in some exemptions with special conditions)

IV. –Only in the total gaseous stage (III.A.1&B), those approximate laws are applied:

A.- $V_2/T_2=V_1/T_1$, $P_2/T_2=P_1/T_1$ (P) Pressure, (T) Temperature in Kelvin, (V) Volume/size This fact delivers the compression heat from Air/Exhaust gas compression

B.- Constant × T × n = P × V. Explains the relation of gas density(n) to the Pressure (P), to Temperature(T) and to the Volume/size(V).

V. - Pressure fact for (partial and/or) **liquefied gases below "Critical" temperatures,** stating that there is a potential increase in the pressure of partial and/or liquid gas when temperature is slightly increased, till the temperature reaches the critical point. (Table)

- Example of the potential increase of pressure with "completely liquid R134 Gas"

Temperatur C°	Press./bar	Temp C°	in bar	Temp C° Celsius	Pressure/ bars
-35	0,66 Liquid	10	4,13	60	16,72
-30	0,84	15	4,90	65	18,79
-26Boiling point	1,013	20	5,70	70	21,05
-25	1,06	25	6,63	75	23,52
-20	1,32	30	7,70	80	26,21
-15	1,63	35	8,83	85	29,14
-10	2	40	10,10	90	32,34
-5	2,43	45	11,54	95	36,3
0	2,92	50	13,11	Critical T. 100,6	Critical Pr. 41,56
5	3,49	55	14,83	No liquid) over critical Gas only(	

Example with completely liquid Carbon dioxide (CO_2 = R744) gas as aiding circuit

Temperatur C°	Press./bar	Temp. C	in bar	Temp C° Celsius	Pressure bar
-78 Melting Point	< 1	0	ca.33	30	ca.72
-56 Boiling Point	1,013	10	ca.43	Critical T. 31	Critical Pr. 73,7
-10	ca.26	20	ca.56	No liquid) over critical Gas only(	

- This property is applicable to all gases in a temperature higher than their boiling points and beneath their critical point. This property is used in the Anergy circuits to increase the liquid gas pressure potentially, though in water stored solar heat before reaching the flow engine and this property it is used also by the expansion-/divergence-coldness of gas, to lower inverse potentially through cooling the gas pressure after the flow engine.

VI. - The Anergy circuits, the A/C's and the heat pumps Energy equation:

Gas compression circuits producing cooling power and heat (=thermal energy).

 # Compression/pumping Energy/Electricity **+ exchange of gas expansion coldness with surrounding temperature** (= Anergy = thermal energy) **= Total Energy in the circuit = Usable heat/drive + energy losses** (by efficiencies and/or heat losses)

- This states that a heat pump or an air condition circuit produces higher –amplified by a factor– heat energy, in relation to the energy consumed by its pumps/compressors, due to the difference between the cooling power produced and discharged, which absorbs the surrounding temperature = **Anergy.** **Anergy** differs from traditional thermal energy, as producing colder temperatures is a precondition, to be able to use the normal surrounding water temperature as a thermal heat source in **Anergy circuits**. The Cooling Methods circuits in the water tank absorb any surrounding temperature or added thermal energy from the solar heat collector, to deliver kinetic energy.

- **Example from traditional air conditioners** (or heat pumps) **circuits available around global markets**, which use as Refrigerant gas R410 or R407 (or R134 etc.):

1 KW (pumping or compressing electricity) for the compressor + 3 KW discharged coldness (cooling the room resp. Anergy or heat exchange) = **4KW** in the circuit = **3.2 KW** released heat (outside the room) + **0.8 KW** energy loss (this includes converting electricity into compression and/or flow losses, the compressors/pump and other heat losses, etc.)

- All heat losing and efficiency losing (which appears also as heat) parts of the used Anergy circuits of the Cooling Method are placed in the water tank to be recovered there.

- **Theoretically**, the kinetic energy used to compress/pump the gas can be amplified to higher thermal/heat energy by a factor up to **8.1** times, by discharging the cooling power of the circuit, which is more than the **3.2** relation factor mentioned in the above m. example.

- **Notice:** In all cases of pumping/compressing gas (refrigerants, or carbon dioxide, or air etc.) in a circuit, heat energy and coldness is produced. The thermal energy gained is always higher than the energy used and consumed by compressing/pumping the gas.

- **Also to be noticed:** that there are variances between different Anergy circuits used and also between different gases used, in terms of the amplified heat factor and the cooling power produced, as a result of compressing different gases and/or pumping liquid gases.

VII.- Heat absorption Factor:

Indicates the different heat absorption abilities of gases/liquids/fluids in its stages

- For example, R410A in its liquid state absorbs heat by a factor around 1600. { In its gaseous state and according to its density it absorbs heat by around 800 or less. } A bit lower values are obtained by other refrigerant gases as R407, R134 etc...

- Carbon dioxide R744 in its liquid state absorbs heat by a factor around 2200. In its gaseous state and according to its density it absorbs heat by about 1100 or less.

Example for the heat absorption factor: Water absorbs heat by a factor around 4200. To heat up 1000L of water in a thermally isolated tank by 6 degrees Kelvin, f. ex. from 3°C to 9°C, within an hour (3600 sec.) 1000l x (9°C - 3°C) x (4200 / 3600 sec.) = we need about **7KW/h** electricity. **That means conversely** : in 1000L of water heated up to 99°C we have stored about 100KW of thermal energy {= 1000l x (99°C - 9°C) x (4170 / 3600) }, which can be used 32 by the Anergy circuits to deliver electricity and cooling power31.

Example for the thermal Energy stored in water, to be able to imagine the size of it.

- In 10 cubic meter of water, heated up to 99°C, there is 1000KW =1 MW stored to be used
- In a small pond32 (10 m wide, 10 length, 10 deep) with 1000 cubic meters of heated up water to 99°C, there is 100 MW (Mega Watt) of thermal energy stored.
- In a pool (20 x50x10) with 10.000 cubic meters of heated up water to 99°C, 1000 MW= 1GW of thermal energy is stored (nuclear power plant out put is 1GW/h), wherein the pool 32 has to be covered by a light thermally isolating swimming cover, to prevent the water from evaporation, which has a strong cooling effect on the stored waters temperature.
- A small lake32 (50 x200x12) with 120.000 cubic meters of heated up water to 99°C, has stored 12GW thermal energy, to produce 1GW/h electricity by Anergy circuits at night.

IX. – The solar thermal energy for example in Egypt (or north African countries, or Sudan till Senegal, Arabian peninsula, Iran, Pakistan, southern USA, Mexico, etc.)

In summer one1 square meter of dessert (or a house roof) can deliver during daylight up to 8 KWh/m^2 heat and **in winter** it starts at 2.5 KWh/m^2 in the North (at the Mediterranean sea side) and up to 5 KWh/m^2 in the mid till south of the Sahara dessert during daylight.

X. - Energy law for circuits filled with fluids in static pressure less than 0.8 bar

 # Compressing or pumping energy + Anergy (= thermal energy = heat exchange between expansion coldness and the surrounding temperature) **= Total energy in the circuit = kinetic energy** (produced by flow engine to deliver electricity) **+ energy losses.**

XI. - "Natural rotation" fact of fluids and gases; is used permanently in the water tank. Warmer fluids (including water) and gases (in closed circuits) rise naturally and colder fluids and gases descend naturally. Only **Water bellow 4°C** differs in behavior.

3.2 Description of the Method and invention

Solar mirrors heat collector and heat focuser with two focuses an upper bigger one and **a high heat smaller focus** behind and/or bellow the collector, similar to "Casse Grain" dish /telescope but not equal, wherein the **second focus** is used to melt Sand/Metals/Salt/etc, or to produce Methanol or just to heat up additional water with/without integrated triple junction cells **and** wherein the **first focus** temperature does not exceed 99°C to be able: **A.-** to use rubber hoses and plastic connecting tubes **B.-** to store heat in water tanks/pools /ponds/lakes to generate Solar-electricity by Anergy circuits in the night **C.-** to use simple elastic rubber pressure sealing rings, as the first focus is surrounded –as thermal isolation– by an air vacuumed glass tube/pot/cylinder and cooled by cold water from Anergy circuits of the cooling Method –which generate simultaneously electricity– **D.-** to use triple junction cells **and** wherein **the collectors big mirror(s)** warmness is also absorbed by water tubes/pipes/hoses in or placed at the back of the bigger collecting mirrors.
- Used also as single round solar thermal heat –lower temperatures than 99°C– collector, which stores his absorbed and gained heat in an isolated water tank for the electricity generating process at night, through one of the different Anergy circuits of the Cooling Method and saving vise versa their cooling power in a different water tank for the day time electricity production, to cool both focuses down to 99°C. This way –if applied– we can add now electricity producing triple junction cells in the (first or) second strongly cooled focus.
- Used also in long collector ditches/trenches, dug directly by bulldozers as parabolic curve into the deserts sand and covered with hoses/tubes carpets/mats with a layer of reflecting aluminum-foil on top of them, to reflect solar rays into the first focus, which reflects the rays back into a small lower ditch, where the Methanol producing pressure tube is placed.
- Used –only with one focus– as heat collector with solar ray reflecting tents, covering the water ponds/lakes and/or covering south directed foots/versants of mountains. And also as
- a cheap special solar collector for sunny developing countries and/or in flooding crises, used without a pump using an aspirator, driven only with solar-heat, water and a cloth filter, to boil/distill the floods water, changing it to clean cocking/dinking water and/or used with a flow engine and a dynamo/alternator in the under-pressure (< 0.8bar) Anergy circuit, to generate electricity and cooling power, which condenses humidity, moister and vapor to clean drinking water.

- The basic idea is to collect solar heat and to concentrate it **in the second focus,** to be able (not traditionally heating water above the its critical temperature but) to melt sand/salt/ metal bellow the collector, using the free solar energy and the most common free and/or cheapest materials on earth –sand, salt and water– to produce building stones with the **salt** With the **sand** to flatten desert streets / trenches directly on the spot without any materials, or to produce fast high walls for water dams and to protect fields from desertification. With **water** by producing Hydrogen either by overheating with a catalyst or by the electrolyzing process, to be added to carbon mon-/di-oxide to produce **methanol** (the fuel of the future).
- Through reflecting the solar rays from the first focus to the second focus bellow, a big problem appears, the heat will add up in the first focus and melt the small mirror away. So the first focus resp. the mirror bellow the focus must be cooled, which makes the use of the second focus uneconomically. By using **the cooling Methods Anergy circuits** to cool down the first focus reflector and producing through the cooling Method –just by the way– electricity from the absorbed heat, this invention turns to be extremely economical though producing on the side and by the way additional electricity. This leads to razing the **heat gathering efficiency** of this solar heat collector, **A.-** by surrounding the first focus with a vacuumed glass casing/pipe/pot, so gained heat is not lost **B.-** by gathering the heat of the big mirror(s), so as much solar heat as possible is gathered, **C.-** not allowing the heat to exceed 99°C, to be able to store it in water tanks/ponds/pools/lakes to generate electricity even at night through the Anergy circuits of the cooling Method.
- Which leads us to the **different electricity generating Anergy circuits** of the cooling Method and their explan-ations, which are explained in details in the following detailed description of figures. But basically the Cooling Methods Anergy circuits produce a kinetic drive to generate electricity, through a high pressure difference, before and after their flow engines. Through expansion/divergence of liquid gasses or liquids it creates a strong cooling power, which lowers the pressure additionally behind the flow engine.
- And in gaseous Anergy circuits through additional heating –up to 99°C– of the liquid gas the pressure is razed tremendously before the flow engine, driving the flow engine with a very high pressure difference and producing kinetic energy, which drives a dynamo/alternator/ generator, delivering from **waste-heat** –absorbed by cooling the focus– additional electricity.

4.- Description of Figures and Drawings

4-1 Description of all elements shown and used in the figures and drawings of the solar heat collector and focuser including all the components/elements used in all different Anergy circuits using the thermal energy to produce electricity

1 – Solar parallel rays

2 – The surface of the big round mirror, or of the big two rectangle curved mirrors

3 – The non-existing real focus above the parabolic curved mirror(s) (named also 1.focus) which reaches temperatures above 2000°C as a straight line or as a hotter round point.

4 – The reflecting focuser, resp. the smaller mirror placed before the real focus, to reflect it downwards to the second focus into the center behind the curved collectors big mirror(s).

5 – The place of the 2.nd focus after reflecting the 1.st focus backwards into the collector.

6 – The cooling water tube/pipe/pot placed behind the reflecting focuser or smaller mirror

7 – The vacuumed Glass tube/pipe/pot/cylinder surrounding the reflecting focuser used as thermal isolation against air/wind, which razes the gathering heat efficiency of the collector.

8 – Heat absorption water pipes/tubes in/behind the mirror, which is strengthening the form of the curve and gives the collector a self-carrying property, saving costly chasses. If the collector is used as fixed trench, they change to be rubber tube mats/carpets saving costs.

9 – The air vacuumed areas used as high thermal isolation and which are closed by elastic rubber pressure sealing rings, as any temperature in the collector does not exceed 99°C

10 – Hanging and moving covers –protecting from the cooler wind used as heat isolation– connected to the end of both big rectangled mirrors, only used if a melting process of sand/ metal/salt is ongoing, to keep the heat and to reach the high heat necessary for melting.

11 – The strong dark metal water pipe placed in the middle or in the weight/gravity center of the rectangled collector and which the collector turns around it. Only used, if the collector is used just as a purely water heater.

12 – Pressure tube/pipe placed at the bottom in the center of the collector or in a ditch bellow the trench, which is filled with carbon monoxide and hydrogen, to produce Methanol through heating up the gaseous mixture under pressure to a temperature about 250-270°C

13 – The Salt melting 2.nd focus place –between 260-400°C–, to produce building stones

14 – The Sand melting 2.nd focus place –between 1300-1600°C–, to melt and flatten roads, trenches directly or to produce building stones and ready made walls or big wall blocks.

15 – Weight or gravity center of the collector on which the rectangled mirrors turn.

16 – Carrying pipe of the upper 1.st focus resp. the water-cooled reflecting focuser.
17 – Material used as thermal isolation like the earth of the trench or flexible water cover.
18 – Holding and strengthening pipes or iron strings fixing both rectangled mirrors together, to keep them in their self carrying ideal parabolic curved form.
19 – Using elastic rubber pressure sealing rings –as temperature does not exceed 99C–, which prevent the air from entering the air vacuumed glass pipes/tubs/pots.
20 – Only one straight vertical/upright breadth mirror, placed opposite the sun and at the end –only in rectangled mirror collectors in a collector street or a trench– perpendicularly to the sun rays, and which reflects the opposite last focuser sun rays back into the 2.nd focus
21 – Flow engine of high efficiency (no expansion engine) preferably rotary with 1/2 blades.
22 – Electrical generator or an alternator or a dynamo etc.
23 – Thermally isolated tank/pipe, which lowers the pressure through expansion coldness.
24 – Serpentine-pipe in gaseous Anergy circuits, between pump/compressor and flow engine, to absorb the waters heat of 99°C in the liquid gas before driving the flow engine.
25 – An efficient Compressor/pump, preferably inverter or RPM regulated driven rotary type with one/two rotating moving blades.
26 – Cold-water tank, in which all Anergy circuits are placed in, to discharge all their cooling power and to use all their heat losses from compressors/pumps flow engines generator. After storing the cold water separately, it is used during daytime to cool down the focus(es).
27 – Descending gas condenser after the compressor/pump, ending in a narrower pipe, beginning with a one-way direction valve. All are placed in a thermally isolated water tank.
28 – Cooling coil as coldness discharger, absorbing the surrounding water temperature.
29 – Controllable Valve/faucet, to control the quantity of flow in the Anergy circuit.
30 – Thermally isolated separated water tank, in which the serpentine pipe of a condenser is placed, to discharge the gas-compression-heat and to pick up the upper heat from the water, with a climbing narrow pipe with a serpentine, to heat up the liquefied gas again.
31 – Tank/pool/pond/lake where the cooled water from the Anergy circuits are stored at night, to be used as cooling source at day light to cool the focus(es)
32 – Tank/pool/pond/lake, which is filled during daylight with hot water, heated up to 99°C, and the hot water is used as stored heat source at night, to drive the Anergy circuits.
33 – Heat resistant rubber tubes/hoses/pipes closing the 99°C hot water circuit
34 – Water pump, controlled by a 99°C thermostat, placed between both cold&warm tanks.

4-2 Detailed Description of Figures and Drawings

I.- All the different rectangled collectors used

- **Figure (1): The reflecting focuser 4,** respectively the smaller mirror is placed before the first focus3, to send the focused solar rays back to the second high heat focus.
- If the reflecting focusers mirror4 has the same parabolic curve as the big mirror(s), in a smaller size, the parallel solar rays are reflected in a parallel way backwards into the center of the collector and the second focus will have the same size of the first focus.
- If the reflecting focuser –placed right before the first focus– is a straight mirror4, the second focus5 will be a line/point bellow and very near to the focusers mirror4, or if the mirror4 is more distanced it will be bigger and will cover too much of the collector2.
- If the reflecting focusers mirror has the same parabolic curve as the big mirror(s), but it is a bit straightened, the second focus will be a line/point at the center of the collector or behind and bellow the collector and this is the reflecting focuser used in this invention.

- **Figure (2) To collect the main mirrors surface2 warmth or heat,** additional tubes/ hoses 8 are passed through the mirror(s) or are attached to the back of the mirror(s), to col- absorbing the mirrors heat into water, to prevent the mirror from strong shrinking/ expansion by keeping in the mirror a steady temperature (f.ex.60°C) during sun light.

- **Figure (3)** If the collector's mirror(s)2 are turned till 30° degrees, the second focus doesn't move that fare away, if the turning center/point/axe is near to or is the second focus. This encourages using the collector directly as a roof of a hanger or an industrial hall, to deliver directly and bellow the collector, the need necessary heat for the production.
- Additional to the main salt/metal/sand melting or the Methanol producing task, razing the efficiency of the collector and his heat collecting property is advisable through

1.-) surrounding the cooled focus by an **air-vacuumed9 glass pipe/pot**7, used as thermal isolation, not to loose any of the gathered heat/thermal energy.

2.-) not exceeding with the heat absorbed the temperature **of 99°C by** pumping more water
I- to avoid strong water evaporation resp. the boiling point which creates pressure and to
II- lower the temperature difference delta between the water and the surrounding temperature, as this will raze the heat lose factor and to

III- lower the cost of thermal isolation material and to be able to
IV- use simple rubber hoses and plastic/proplean pipes to transport the water and to
V- use rubber pressure sealing ring between the glass and focus and in turning parts and
VI- to be able to use water as a thermal storing medium in tanks/pools/ponds/lakes to be able to generate solar electricity with Anergy circuits at night and to be able
VII- to enter triple junction cells into the cooled focus, to produce electricity during sunlight additionally, to be able to release some Anergy circuits for maintenance. Absorbed heat is stored in water tanks as thermal source, to generate with Anergy circuits electricity at night.
3.-) The **big mirror2 warmth is** additionally **absorbed** by water pipes8, which lowers the parabolic curve deformation, through shrinking and expansion, razing its efficiency.

- Figure (4) One turn able unit, used only as solar heat collector for the house use, delivering in form of saved heat in a water tank hot water for washing, or to generate electricity with Anergy circuits, which deliver additional strong cooling power. The second focus will be than a strong dark metal water pipe placed in the weight/gravity center of the rectangled collector on which the collector turns. The solar heat collector is used just as a water-heater here, delivering hot water and storing its heat, to generate 24 hours electricity.
- No additional cold-water tank is used, as the cooling power of the Anergy circuit is used in summer inside the house and in winter, a ventilator discharges it externally. The cooling power simultaneously condenses moister from the air, which delivers additional clean condensed water for washing and other purposes, important for flooded and dessert areas.
- The metal pipes integrated into the big mirrors surfaces are creating a self carrying (body) curve, which is only supported with holding pipes 18 or iron strings between both rectangled mirrors, to strengthen them and to keep both big mirrors in their parabolic curved form, hanging on their own gravity/weight center11 and turning easily around it, to follow the sun by 180° degrees from sunrise to sunset.
- One straight vertical/upright mirror20 is placed always at the end of the collector opposite the sun, to reflect the last focusers angled sun rays back into the 2nd gravity centered focus

- Figure (5) Controlling the temperature by adjusting the distance to the second high heat focus reaching up to 2000°C, to be used in different applications as producing Methanol 250-270°C, or melting salt 260-400°C, or melting metals 300-1260°C, or melting

sand 1300-1600°C and also if the angle of the reflecting focuser is moved opposite to the sun, following the first focus the collector can be fixed, but it lowers the temperature a bit, due to the mathematical sinus-angle-effect on the size of the solar rays collecting surface.
- Hanging and moving covers10 are added, at the sides, as heat isolation against the colder surrounding air and wind, protecting the heat of the ongoing melting area.
The reflecting focuser mirror4 is a bit bigger now, to allow a lot more water to pass its tube/ pipe6, as it has to take in and reflect all the focused solar rays1, which can reach in the second focus more than 2000°C.
In melting factories or excavating desert water channels or flattening machines of dessert-roads by melting the desert sand directly, the collector is placed on top of the road machine or factory, to melt/heat up material just bellow it. And as it is the roof it can't be turned more than 30° degrees to the west or east. But other additional 30° degrees can be reached, by moving the reflecting focuser mirror4 according to the 1st focus3 movements. The last suns descending and rising 30° degrees are ignored in the melting or in methanol trenches.

- **Figure (6) Solar Methanol production in price worthy ditches/trenches,** which are dug directly by bulldozers as parabolic curve into the deserts sand and fixed as a parabolic curve by melting the sand a bit. This trench is covered with flexible heat absorbing carpets/ mats of hoses/tubes, which are covered with a layer of reflecting aluminum-foil on top of them, to reflect solar rays into the first focus, which reflects the focused solar rays back into a small lower centered ditch, where the Methanol producing tube is placed, which is filled with a gas mixture under a pressure between 40-45 bars and heated up to 250-270°C, to produce Methanol –the fuel of the future– from hydrogen and carbon monoxide (gained from carbon dioxide by heating it up) or carbon dioxide with a catalyst metal like iron.
Equations to liquefy Hydrogen to Methanol by adding carbon monoxide gas and heat Electrolyzing water $2H_2O = \mathbf{2H_2} + O_2$; Heating + Catalyst + $2CO_2 = \mathbf{2CO} + O_2$; Heating & compressing $\mathbf{2H_2 + CO = 3H\text{-}C\text{-}OH}$ = **Methanol** (The fuel of the future instead of oil)

II.- <u>The round parabolic collector</u> used, to melt metals or sand precisely or used with additional triple junction cells placed at the 2nd focus, which has to be than cooled down to lower than 99°C, to raze those cells and the heat collectors efficiency .

- **Figure (7)** Round Casse Grain (similar but not equal) electro-magnetic waves collectors are know from satellite receiving dishes and Casse Grain week light collectors are know from telescopes. As soon as it changes to observe the sun a lot of problems appear as the first focus is heating up tremendously (not mentioning the second), which is solved in telescopes, by selizium-carbide heat resisting mirrors, or by placing the mirror in a vacuum and /or stretching the focus as fare away as possible deep into the earth, or just through steady and costly cooling of the 1st focus by water, in which triple junction cells can than be placed
- As we have two focuses, one bellow the round collector to melt different Metals or sand, but –to be able to use the collector as focuser– we need to cool down the mirror in front of the first focus, through cooled water pipes6, which are holding/carrying simultaneously the focusers mirror including the cooling water cylinder/pot6 behind it, which is surrounded by a thermally isolating air vacuumed glass7 cylinder/pot.
- **Figure (8)** Shows the stabilizing heat absorbing pipes8 behind the collector's big round mirror, which will support the thin metal layer of the mirror2 as a self-carrying chasse.
- **Figure (9)** Shows the stabilizing heat absorbing pipes8 as a spiral behind the collector's mirror, which is the mirror2 and a self-carrying chasse.

- **Figure (10)** the round collector are turned by 180° degrees around the 2nd focus5 or are turned around a different center point between the collector 2 and the 2nd focus behind it, to be used as salt/metal/sand etc... melting focusing collector, during the whole day following the sun. The spiral pipe8 is integrated into the big collecting mirror2.

III.- Different tent solar collectors, including the heat storing water tank/pond/lake

- **Figure(11)** The water tank/pool/pond/lake32, have to be covered by a light thermally isolating swimming cover, to prevent the water from evaporation, as evaporation has a strong cooling effect on the stored waters temperature and additionally, which can be isolated against cooling winds, through tents covering the whole area of the pool/pond/lake.
Small natural bays can be also used as lakes and separated from the rest lake by melted –by this invention– sand walls, 5 meters thick, as water-dam.
- If we use tents to cover the tank/pool/pond/lake32, we can produce reflecting tents –cloth with an aluminum foil–, which reflects the solar rays into several different focuses, to use

those tents enormous big surfaces additionally as solar heat collectors, cooling (shade in the dessert) simultaneously the area bellow them. If the tank/pool/pond/lake is lowered into the earth and covered by melted 5 meters thick sand plates, the tents area can be used as factory/station/for housing/as agricultural land.

- Those simple additions are reached, with no big investment costs but: The aluminum foil 2 stuck on the tents cloth, Some hoses/pipes holding the tents cloth and absorbing its heat, some stands and cables to hold and move the focuses between them, according to and following the suns movements, some rubber hoses/pipes33 delivering cooled water from the cold water tank31 to the several focuses4 and transporting –up to 99°C– heated water away from the focuses to the heat storing tank32, with or without entering triple junction cells into those cooled 1st focuses3 of the tents. The electricity generating Anergy circuits, –by being heated up24 and discharging28 their cooling power in the water tank 26– are placed under those tents, between both cold31 and hot32 water tanks/pools/ponds/lakes.

- **Figure (12) illustrates a southern directed rocky dessert foot/**versant **of a mountain** covered also by solar heat collecting tents (similar to Fig.11 but not equal, as it is only half of tent in Fig.11), as this rocky space is not used for some thing else. Those tents are also used to condense the humidity/moister/fog from the air during the whole night, delivering additional drinking water. Both heat32 and cold31 water tanks are placed bellow the tents.

- The stands –which are holding the focuses and supplying them through hoses and pipes with cooling water– must be able to move forward-backward and left-right and up-down, to be able to adjust to the different focuses4 places changing by the suns angles from east till west and winter to summer and the focuses4 them self's are turned a bit additionally. Each tent slice is to be considered as a straight cut out sliced piece of a round collector. The tents slices are carried by cables/curved pipes placed between the slices and can be (as in the sand trenches) hose-carpets absorbing the solar and the internal tents heat loses.

IV.- The cooling methods different Anergy circuits, using the solar collectors stored thermal energy in the water tanks/pools/ponds/lakes, to generate electricity:

A.- Gaseous Anergy circuits of the cooling method use the stored heat directly

- **Figure (13)** illustrates **the gas compression Circuits, (Law. IV), which partially liquefies his circled gas by compression & cooling,** through a compressor/pump25, by compressing gas in a descending heat discharger27 or condenser/serpentine/pipe ($_G$), placed including the compressor/pump25 in a long thermally isolated water tank, to cool the compressed gas bellow its critical temperature, to be able to partially liquefy the gas (Law III.A.2). The liquefied gas is than passed by a check valve and directed upwards in a **climbing** narrower pipe($_L$), to be reheated in the upper coil24, through the upper water heat in the tank, using the 'Natural Rotation" of water (**Law.XI**) and using the property of liquid gas –the potential increase of pressure by raising its temperature (as in the table of **Fact.V**)– to receive/operate by a higher pressure difference the flow engine21, driving a generator22, which are both placed in the pressure reducing tube23. The circuit discharges the expansion coldness through the following heat exchanger28 in the cold-water tank 26, to absorb the waters temperature as thermal energy source, to produce electricity, producing –just on the side– the cold water used to cool down the collectors focus in sunlight.

- **Example per equations to understand**: Using Bernoulli's laws, which states the relation between forces(F) & liquids velocities(v) in different sized pipes.$\{\mathbf{F_G / F_L = A_G / A_L = v_L / v_G}\}$ (gas **G** & liquid **L**). $\mathbf{1/2 \times D_G \times v_G^2 = P_G = P_L = 1/2 \times D_L \times v_L^2}$ Knowing in one tube (**$A_{G/L}$**) the liquid or gas flow pressures in the condenser are equal. So if speed is halved(1/3), the density is four(9) times as thick (liquid), due to the potential velocity factor $(v_L)^2$.

Narrowing(**n**) the following climbing pipe(**A_{Ln}**) to a quarter($^1/_9$) size of the gas pipe(**$A_{G/L}$**) size resp. to half($^1/_3$) its diameter, we will have than the same velocity $\mathbf{v_G = v_{Ln}}$; from $\mathbf{A_L / A_{Ln} = v_{Ln} / v_L}$; with different densities **(D_L) >> (D_G)** and with different forces **(F_{Ln}) < (F_G)** resp. from the equation the force, in the narrow(A_{Ln}) pipe, is by a quarter($^1/_9$) weaker.

- Considering that we have instead of gas now static liquid gas (highest density) and by adding its own gas compression suspended **(**due to different "Heat Absorption Factors" from gas to water in the tank than to liquid gas**)** heat (+) back to the now liquid gas, the static pressure (from **Fact V** & table), will rise potentially and is converted to added flow pressure (**Law.III**) driving –as the check valve (a triangle) blocks a return– the flow engine. Knowing that a constant amount of gas/liquid is circulating in the closed circuit as flow (F) than $\mathbf{P_{FLn+} = 1/2 \times (D_L) \times (v_{FLn+})^2}$ as **(v_{FLn+}) >> (v_G)** and **(D_L)** is now liquid.

Passing the strong liquid flow **P_{FLn+}**, through the heated up water to 99°C, via the coil24, the flow pressure **P_{FLn+}** rises tremendously to $\mathbf{P_{FLn+99} = P_{D1}}$ before the flow engine21.

- Considering that the "thermally isolated pressure lowering tube23" drops the static pressure $\mathbf{P_{D2}}$ behind the flow engine (placed inside the tube23) through cooling –as the liquid gas expands to gas– and suction, the flow engine will be driven with a tremendous pressure difference **(P_{FLn+99} – P_{D2})**, much higher than the compressor/pump had initiated. Kinetic energy from flow engines21 generates electricity by generator22, covers the compressors25 electricity needs and delivers a lot of excess electricity and cooling power28.

- **Figure (14)** illustrates the **liquid gas pumping circuit, filled completely with liquid gas An example: "Completely Liquid R134 Gas" in a surrounding temperature of 30°C** (See table above from **Fact V** and the **Total pressure Law III**):
If the lower water temperature of the tank26 is 30°C degrees the liquid gas pressure is 7.7bars. Inserting a pump25, which develops 2 bars flow pressure and a –2 bars suction pressure, the temperature of the liquid gas before the flow engine (similar to the capillaries resistance in A/C"s) will raze up to 38°C degrees Celsius. After the flow engine21 the pressure will fall, through the pumps25 suction and the liquid gas divergence and the liquid gas temperature in the isolated tube23 and will reach a temperature of about 20°C(5.7bars), which lowers the pressure additionally in the "**thermally isolated pressure lowering tube23"**, used as pressure difference driving the flow engine21, generating electricity22.
- Discharging the cooling power lower than 20°C after the tube23 through the serpentine-pipe28 in the water tank26 and absorbing24 at the top while rising additional solar heat 95°C, we receive before the flow engines21 a pressure of about 36 bars and a driving pressure difference of about 30bars (= 36 – 6), from the "pressure lowering tube23", which has reduced the pressure to 5.7bars behind the flow engine, through saved coldness 20°C. The coldness is discharged at the warmer water and during the nights the sinking cold water through "Natural rotation", is saved in the cold water tank31, to separate it from the hot water. The Anergy circuit is recharged24 during the nights from the water tank32 with thermal energy up to 95°C < Anergy circuit pressure, which is used to generate electricity
- Any thermal energy losses from the Anergy circuit, which appears as heat, is absorbed immediately through the water tank 26 –with his lower temperature than 20°C– as heat will rise and add to the pressure difference through the "Natural Rotation" of the water.

- **Figure (15)** illustrates the **liquid gas pumping circuit, filled partially with liquid gas,** It is the same circuit as in **Figure (14)** but stronger and only partially filled with liquid gas. This partial filling with liquid gas in liquid gas pumping circuits, is only used to secure the partial natural continuous liquidation in the circuit, so the pump is pumping only liquid gas.

- This circuit produces a lot of cooling power, specially when the liquid gas is minimized in the "thermally isolated pressure lowering tube23" and the size of the tube23 is maximized, to maximize the expansion coldness, to reduce the pressure and to raze the pressure difference, which drives the flow engine21 even stronger. Tube23 works here as natural evaporator and in the same time as liquidizer, to secure the liquid pumping property

The flow engine21 and the generator22 are placed inside the tube23 in the upper gas area.

- Example for the minimum liquid gas filling of CO_2, to receive partial liquid gas
(From **Fact IV.2.**) Gas starts to liquefy partially at a specific minimum gas liquefying **pressure/quantity**. The pressure differs between the different gases/refrigerants and relates to the surrounding temperature too. With CO_2 f. ex. at steady and cooled 20^0C surrounding temperature, the CO_2 gas will not liquefy under less pressure than 5 bars. Knowing that tubes filled completely with liquid CO_2 gas at 20^0C, create about 57bars pressure, we can estimate that the minimum partially filling with liquid CO_2 gas is higher than the relation of > 5/57, to reach a durable continuous natural partial liquidation of CO_2 gas in the tube23 as evaporator during pumping. But to guaranty that the pump25 will find always liquid gas at the bottom of the tube23 and to be able to discharger the expansion coldness through liquid CO_2 in the serpentine-pipe28 at the water tank26, we have to raze the liquid gas filling according to the circuit pipes size to about 1/8 of the circuit, securing a minimum of liquid gas at the bottom of tube23, to be circulated by the pump25.

- This example gives us an Idea about how strong the liquid gas can expand (1 to 11) and the cooling power generated by this circuit. And how much solar heat (thermal energy) from the collectors focus it can absorb (Anergy) and transform into rotation/kinetic energy by using the tremendous pressure difference before and after the flow engine21, resulting from the cooling power (in tube23) by expansion, added to the pumps25 flow pressure added to an "over critical" pressure rise (up to 85bars) from about 95°C heat added, which produces a tremendous pressure difference as kinetic driving force to generate electricity.
- Opening and closing valves/faucets 29 control the amount of liquid gas flow resp. the electricity generated from this **partially with liquid gas filled liquid gas pumping circuit.**

B. **Backup aiding Anergy circuits used at the end of the night, to generate electricity from rest heat** (10 °C to 30°C), **if the stored 95°C solar heated water is consumed.**

1.- Gaseous circuits: back to

1.a - Figure (13) The gas compressing and liquefying Anergy circuit: Uses his own gas compression heat27 discharged in a small thermally isolated water tank30, to raze the flow pressure of his own liquefied gas with the heat from the same water tank30, through "Natural rotation" of the water. He needs only to get rid resp. discharge/exchange his liquid gas expansion coldness to gas resp. his cooling power28 with a rest temperature of 20°C to 30°C, to recharge his Anergy circuit with thermal energy, to be able to produce a pressure drive with his flow engine21 resp. kinetic energy to generate electricity22.

1.b - Figure (15) The liquid gas pumping circuit filled partially with liquid CO_2 gas Needs only to get rid resp. discharge/exchange his liquid gas expansion coldness to partial liquid gas in tube 23 resp. his cooling power28 with a rest temperature of 20°C to 30°C, to recharge his Anergy circuit with thermal energy, to generate a 50bar drive resp. electricity.

2.- Vacuumed circuits filled partially with non freezing fluids till –30°C, , as Methanol, or Ethanol, Propanol or other fluids. in static pressure less than 0.8 bar

2.a.- Figure (17) illustrates **the Liquid**(s) **pumping circuit**, with a static circuit pressure less than 0.8 bar, filled partially with Ethanol, Propanol, distilled cleaned water from all particles, or any other fluids, or fluid mixtures, or gas fluid mixtures, which all have a freezing point bellow –30°C degrees. This circuit doesn't produce any heat of importance and **generates strong coldness,** through the fluid or mixtures expansion to partial fluid.

- Important is that the pump25 is pumping only liquid fluid, sucked in from the bottom of the "thermally isolated pressure lowering tube23" via a serpentine pipe/heat exchanger28, pumped as liquid into the flow engine21, connected to the generator22. Pump25, flow engine21 and generator22 are placed in the upper vapor/steam inside the tube23, to raze their efficiency by cooling them, by dropping their pressure-sealing rings and by using their heat loses. The strong cooling power is discharged by pipe coil28 in the water tank26, which needs to have a temperature between 10°C to 30°C, to be able to take the coldness and to recharge the Anergy circuit with thermal energy to function as electricity generator properly. This Anergy circuit is capable to deal with just the surrounding night temperature and it will still gain thermal energy from it, by discharging its strong coldness.

2.b. - Figure (18) illustrates **the Steam/vapor compression and liquefying circuit, with a static circuit pressure less than 0.3 bar,** using also Ethanol, Propanol, distilled water (freed from any particles) or any other fluid with a freezing point bellow -30°C degrees and a boiling point higher than 60°C. Due to the static "under pressure" (<0.3 bar), when steam/vapor of those fluids are compressed, there is nearly no compression heat realized .
- This circuit produces electricity and extreme cooling power through cavity and expansion from liquid fluid to vapor/steam, which has to be discharged from the Anergy circuit.
- This circuit is composed in series of a compressor25, followed directly beneath it by a flow engine21 ending in the expansion tube23, which is connected from below via pipe with a climbing heat exchanger28 as coldness discharger28, which produces a secondary cooling power by cavity through the suction of the compressor25 from the top of the exchanger 28. Compressor25, flow engine21 and generator22 are placed in the expansion tube23, to raze their efficiency by cooling them, getting rid of all pressure sealing rings(as in traditional compressors, placed with its electrical motor in a pressure box) and using their heat loses.

V.- An Anergy circuit integrated in the simplest, price worthy solar heat collector, used as a special solar collector for sunny developing countries and/or in/at flooding crises.
Figure (16): Using just a shining reflecting funnel2 made from a round piece of a thin metal plate (directly stain less or aluminum, or a metal plate covered with aluminum foil), where a triangle slice is missing. Some circled connected or as spiral turned pipe is holding the funnels form together and absorbs the funnels heat additionally, before passing the warmed up water in the dark focus4 pipe placed in the center, to be heated up by the solar rays, till boiling temperatures 75-99°C. If possible the dark iron pipe is surrounded by a glass pipe7 and the dark pipe ends directly in the flow engine21 (connected to a dynamo/alternator), which ends in a water expansion coldness/heat exchanger28, ending in a water tank26 placed higher than the dark iron focus4 pipe24. The funnel must be directed towards the sun, to be able to use it as heat collector. This special designed Anergy circuit integrated in a simple solar collector, is driven only with solar-heat, water, a direction/check valve, some cloth as water filter, to boil/distill the mood water, changing it to filtered and solar cocked dinking water and/or used with an aspirator(no pump), flow engine and a dynamo/alternator in an under-pressure (< 0.8bar) Anergy circuit, to generate electricity and cooling power, which condenses humidity/moister/vapor form the surrounding air to clean drinking water.

5.- Claims of the Solar heat collector and heat focuser ......

1.- Solar heat collector and "Casse Grain" **heat focuser**, comprises having two focuses: **a 2.nd** smaller, high heat **focus**, placed in the center of, or bellow/behind the collector, used to melt sand/metals/salt, or to produce Solar-Methanol or just to warm up a lot of water and **a 1.st** bigger, upper, low heat –not exceeding 99°C–,hollowed mirror **focus**, cooled by cold water, gained from the cooling Methods electricity generating Anergy circuit(s) and which is connected by rubber/plastic hoses/pipes to the heat storing covered water lake by tent(s), **wherein** elastic rubber pressure sealing rings are used, between the mirrored water tube/ pot in the 1.st focus and the surrounding air vacuumed glass tube/pot/cylinder –as thermal isolation– and **wherein** the warmth of the collectors big mirror(s) is additionally absorbed by water tubes/pipes/hoses, integrated in, or placed at the big collecting mirrors back.

2.- Solar collector as heat focuser according to claim 1, comprises using moving/ fixed parabolic curved, one round or two rectangle big mirror(s), which reflects and focuses the solar rays/heat above it/them in the 1.st focus –as a point/line– and by placing a round/ rectangle moving/fixed **reflecting focuser** –a small hollowed water cooled mirror with the same, but a bit straightened/flattened, parabolic curve– before the 1.st focus, the **focuser** creates in/or bellow the center of the big collecting mirror(s) a **2.nd real focus** –as "Casse Grain" point/line –, which reaches up to 2000°C, used as high heat thermal energy source.

3.- Solar collector as heat focuser according to claim 1-2, comprises using the **2.nd** real focus high heat temperatures –up to 2000°C and more–, to melt **Sand/Metals/Salt /etc...,** or to produce **Solar-Methanol**, by **controlling the distance to the 2.nd real focus** –as line/point– to lower or to raze resp. to receive the right temperature needed for melting.

4.- Solar heat collector and heat focuser according to claim 1-2, comprises **collecting** simultaneously the **collectors big mirror**(s) and the **1.st focus/reflecting focuser** warmth/ heat as additional soft –not exceeding 99°C– heat source, heating up cold water and **storing this hot water**, to generate –from this lower than 99°C stored water heat– with the different Anergy circuits –of the cooling Method– solar electricity, even at night.

5.- Solar collector as heat focuser according to claim 1-2 and 4, comprises using an **air vacuumed glass pipe/tube/pot/cylinder surrounding the 1.st focus/reflecting focuser**, as thermal isolation, to raze the efficiency additionally of this focusing heat collector.

6.- Solar collector as heat focuser according to claim 1-2 and 4-5, comprises using simple **elastic rubber pressure sealing rings**, withstanding 110°C –as temperature is controlled by thermostat valve and water pump and doesn't exceed 99°C–, between the 1.st focus / focuser and the surrounding air vacuumed glass pipe/pot/etc..., **to seal of the vacuum.**

7.- Solar collector as heat focuser according to claim 1 and 4, comprises **using only water** stored in tanks/pools/ponds/lakes **as heat/thermal energy storing medium** –as the temperature gained doesn't exceed 99°C–, to generate solar-electricity, by the different Anergy circuits of the Cooling Method, which use the stored water heat, specially at night.

8.-.Hot water tanks/pools/ponds/lakes of the collector according to claim1,4,7-8 **comprises covering the hot waters surface** in tanks or in open pools/ponds/lakes –as the hot water is used and the water level descends in the storing facilities till morning–, **with a thermally isolating swimming foam or plastic cover** –preventing the water from evaporation which cools the water temperature strongly– and saving by that its heat till the early morning,.

9.- Solar heat collector according to claim 1-2 and 4, comprises collecting and **absorbing** additionally **the warmth/heat of the collectors big mirror(s) surface**, through water pipes/tubes/hoses, integrated in, or placed behind the big collecting mirror(s).

10.- Solar heat collectors water circuit according to claim 1,4,6 and 9 comprises **using** simple **rubber/plastic/proplean/etc.. pipes/tubes/hoses,** withstanding 110°C –as the temperature gained doesn't exceed 99°C–, to transport and close all water circuits between the big mirror(s) and the focus(s) and between the solar collectors focus(s), the hot water tank/lake, the Anergy circuits water bassain, the cold water pond and back to the collector.

11.- Solar heat collector according to claim 4 and 9-10, comprises using unbendable **strong water pipes** integrated **in or placed behind** the big round/rectangle **mirrors,**

creating a **self-carrying parabolic curved structure**, to skip all other chasse elements and only in rectangle mirrors, holding strings/cables/pipes are added between both mirrors.

12.- Solar heat collector according to claim 1-4 and 9-10, **comprises** –to produce Methanol by heating the gas mixture of hydrogen and carbon monoxide, gained from carbon dioxide– **using** –cause of security reasons– **fixed collectors placed in sand trenches** with a ditch for a pressure pipe and wherein only the focuser will follow the daily sunlight, in the dessert

13.- Solar collector as heat focuser according to claim 4, 9-10 and 12, comprises using **carpets/mats of rubber tubes/hoses**, covered by shining aluminum foil as big mirrors and placed **as a fixed collector in sand trenches** with a –by bulldozers excavated ready-made– parabolic curve, conserved, by melting the sand through solar focused heat.

14.- Solar heat collector and heat focuser according to claim 1-4, comprises **adjusting either the angle of the whole collector** each day to the suns differing positions **from winter till summer, or** fixing the angle of the collector to the worst dessert winter position and just during all other days of the year adjusting/lowering just **the focuser**, according to the descending 1st focus till summer, initiated by the suns angled position on the collector.

15.- Solar heat collector and heat focuser according to claim 1-4, comprises **following either with the** whole **collector** the **sun from sunrise till sunset**, **or** –in a fixed collector– **following the sun only by focuser** with a maximum angle of 60° degrees to the vertical, **or both** –if the collector is used as a roof of a hall or a factory for melting materials– the whole collector follows the sun only by an angle of 30° degrees to the vertical and the focuser follows the sun after or before that by additional 30° degrees –the lower solar thermal energy of the sun rise and sun set is ignored–.

16.- Solar heat focuser according to claim 1-4 and 15, comprises –when used to melt sand/metal/salt on external sights or as a roof of a hall – **hanging down,** movable, closing **covers at the end of each side of the** rectangled **mirrors** but the center, protecting the centered heat for melting –from air and wind– from cooling down,

17.- Solar heat collector according to claim 1,4,6, 9-11 comprises –if the rectangle collector is used only as water heater– **using** a **dark iron pipe** placed in the second focus and **in the weight/gravity center,** on which the whole collector is turned, to follow the daily sun.

18.- Solar heat focuser according to claim 1-4, comprises **turning preferably the round solar collector (dish)** –used for melting– **around an axe,** placed behind the collector, between the real 2nd focus and the center of the big mirrors back, to follow the daily sun.

19.- Solar heat collector and Anergy circuits according to claim 1,4,7 and10 comprises generally **generating electricity** from Anergy circuits, **by** –first– **thermally isolating the expansion** –divergence– **coldness** behind the flow engine, to lower the pressure and **to raze the pressure difference**, which drives the flow engine, than substituting/replacing/ exchanging the cooling power with collected and stored soft solar heat not exceeding 99°C.

20.- Anergy circuits cooling power for the heat focuser according to claim 1,4,7,10 and 19 comprises, **storing**/saving **the cooling power** produced by the Anergy circuits in a separateed cold-water tank/pool/pond/lake, specially during the night **and using** the cold water, **to cool down during daylight the focus(s)** resp. heat focuser of the solar heat collectors.

21.- Solar heat collector and Anergy circuits as generator according to claim 1,4,7,10,19-20 comprises, **heating up the liquid** –or by compression or naturally liquefied– **gas,** by hot water not exceeding 99°C, before the flow engine of only gaseous Anergy circuits, to raze potentially –using the liquid gas property– the pressure before the flow engine, creating a strong drive/kinetic energy, which turns generator/alternator/dynamo to generate electricity.

22.- The Cooling Method gaseous Anergy circuit according to claims 1,4,7,10 and 19-21 **comprises: the use of a liquid gas pumping** Anergy circuit, **filled completely with liquid gas**, which is composed in series of: a liquid gas pump, followed by a heat exchanger/ serpentine pipe, absorbing the hot waters temperature into the liquid gas –to increase the pressure potentially–, followed by a flow engine connected to a generator, followed by the thermally isolated pressure reducing tube, connected to a heat exchanger –discharging the cooling power from liquid gas divergence in the water bassain–, ending back at the pump.

23.- The Cooling Method gaseous Anergy circuit according to claims 1,4,7,10 and 19-21 **comprises: the use of** a **liquid gas pumping** Anergy circuit(s) vacuumed and **partially filled** with liquid gas, which is composed in series of: a liquid gas pump, followed by a heat exchanger/serpentine pipe, absorbing the hot waters temperature into the liquid gas –to increase the pressure potentially–, followed by a flow engine, connected to a generator, which are both, flow engine and generator, placed –to save the pressure sealing rings and razing their efficiency by cooling– at the top in the thermally isolated pressure reducing tube –which is partially filled with liquid gas–, connected from its lowest point –so the pump sucks only liquid gas– to a heat exchanger, discharging the cooling power –from liquid gas expansion to partial liquid gas– in the water bassain, ending back at the pump.

24.- The Cooling Method gaseous Anergy circuit according to claims 1,4,7,10 and 19-21 15-18 and 23 **comprises: the use of** a **gas compression Anergy** circuit(s), which compressesby pump/compressor refrigerant gas in a wider descending condenser –as heat discharger tube/serpentine, until the gas is partially liquefied bellow–, **placed incl. its compressor** in a thermally completely isolated water tank, to absorb all gas compression heat and the said condenser ends at his lowest point in a check valve connected to a climbing narrower pipe –hosting only liquid gas, to be reheated by the warmed up water of the water tank, using the natural rotation, to increase potentially the pressure of the liquid gas–, ending on-top outside the water tank –with or without additional absorption of heat from the hot water– in a flow engine connected to a generator, **which are both** –flow engine and generator– **placed** –to save the pressure sealing rings razing their efficiency by cooling– **in** the thermally isolated pressure reducing tube –through cooling, which is filled with gas only–, connected to a heat exchanger, discharging the cold temperature–from liquid gas expansion to gas– of the gas bellow in the water bassain, ending back at the compressor.

25.- The Cooling Method aiding Anergy circuit as generator according to claims 1,4,7,10, 19-20 and after one of the claims 23-25 **comprises: the use of** a **liquid fluid pumping Anergy circuit** –only at the end of the night if needed–, vacuumed and filled only partially –lower than 0.8bar– with a fluid, which has a lower freezing point than minus 30^{O}C and a higher boiling point than 60^{O}C, such as Methanol –Ethanol, distilled condensed water freed from all particles, or other fluids– and **is composed in series of a pump** pumping only fluid, through a connecting pipe, **to the flow engine**, connected to a generator, which are both, flow engine and generator **placed** –to save the pressure sealing rings– **at the top** in the thermally isolated **pressure reducing tube**, –which is partially filled with liquid fluid and the rest is filled with vapor/steam–, connected from its **lowest point** –so the pump sucks only liquid fluid– **to a heat exchanger**, discharging the strong cooling power –from liquid fluid expansion to partial liquid fluid and vapor/steam– **in the water bassin**, **ending** back **at the pump,** consuming only rest warmness of the cold water tank/pond/lake at night.

26.- The Cooling Method aiding Anergy circuit as generator according to claims 1,4,7,10, 9-20 and after one of the claims 23-25 **comprises: the use of a steam/vapor compressing Anergy** circuit –only at the end of the night if needed–, vacuumed and filled only partially –lower than 0.3bar– with a fluid, which has a lower freezing point than -30°C and a higher boiling point than 60°C, such as Methanol –Ethanol, distilled condensed water freed from all particles, or other fluids– **and is composed in series of** compressor/pump connected directly to the flow engine bellow it, hocked to a generator and **which all** –flow engine, generator and compressor– **are placed** –to save the pressure sealing rings, razing their efficiency by cooling– **at the top** in the thermally isolated pressure reducing tube – which is minimally filled with liquid fluid and the rest filling is vapor/steam–, connected from its lowest point –so only liquid fluid is sucked out by the compressors suction– to a climbing heat exchanger, hosting vapor/steam and discharging the extreme cooling power –from liquid fluid expansion to partial liquid fluid, than expansion by cavity to only vapor/steam– in the water bassian , ending again at the top in the compressor/pump again, consuming only the rest warmness of the cold water tank/pool/pond/lake at the end of night.

27.- Hot water tank/pool/pond/lake of the solar heat collector according to claims 1,4,7-8,19, and 21, comprises **covering the hot water** tank/pool/pond/lake **with additionally a Tent(s)** protecting it from being cooled down by wind and air and **recovering the rising heat loses** through the tents rubber tube/hose carpets, which are used instead of the tents cloth and creates the rectangled sliced, nearly parabolic dish curved tents surfaces.

28.- Tents of the hot water tank/pool/pond/lake according to claims 1,4,7 & 27, comprises **covering the tents** rubber hose **carpets** with solar rays reflecting **aluminum foil, creating**

a **focus** to each of the tents sliced surfaces directed S/W/East,– supplied by water rubber hoses, to cool and absorb the focuses heat, held by wires attached to moving stands–, **using the** –hot water lake– **isolating tents surfaces additionally as solar heat collector.**

29.- Solar collector Tents according to claims 1,4,7,10, 27-28, comprises **covering both** hot and cold water ponds/lakes **by** 5 meters thick **plates** of melted sand, **placing** both of **them** including the whole water cycle and Anergy circuit(s), **bellow the tent**, using the free **shady area** bellow the solar collector tent as housing space, as a factory hall, or as station, or as **agricultural land** etc., or placing all incl. tent on a south directed **foot of a mountain**

30.- Solar collector as heat focuser according to claims 1-4 ,,7,10,20 and 27, comprises melting the sand or the salt to building **stones** or to complete thin ready-made building walls and only the sand is melted to 1to10 meters thick big **plates/walls**, used as water dam/channel/pond, to cover a water channel/lake, or to protect from desertification, etc....

31.- Solar collector as heat focuser according to claims 1-4 and 30, comprises **melting the sand in the dessert directly, to** straightened and flattened **dessert streets**, or as house fundament **or** –excavated by bulldozer and directly– **melted to water**, agricultural draining and/or **suewitch channels** –covered by thick melted sand plates, to seal of air/solar heat– **or** melted to **fixed solar** heat collecting **trenches,** or solar methanol trenches with ditches.

32.- Solar collector as heat focuser according to claims 1-4, comprises **replacing the roof** of a factory hall **with a** 30^{o} degree on the vertical **moving solar collector** with a moving focuser, **to melt metals/salt/sand** by solar heat during daytime **in an industrial process.**

33.- Solar heat collecting focuser according to claims 4,7,9-11comprises using a funnel melted into an under pressure Anergy circuit, without a pump –to condensate humidity and generate electricity–, consisting of a reflecting funnel, surrounded by heat absorbing spiral hose –holding the funnels form–, connected to the dark water pipe –covered by a glass pipe–, placed in the center of the funnels, ending at the top in two pipes, a **thinner pipe** to the **aspirator**, which ends in the hose and a wider **pipe** to the **flow engine**, which ends in an upper evaporator/heat exchanger, ending in a lower water tank, ending in the **aspirator.**

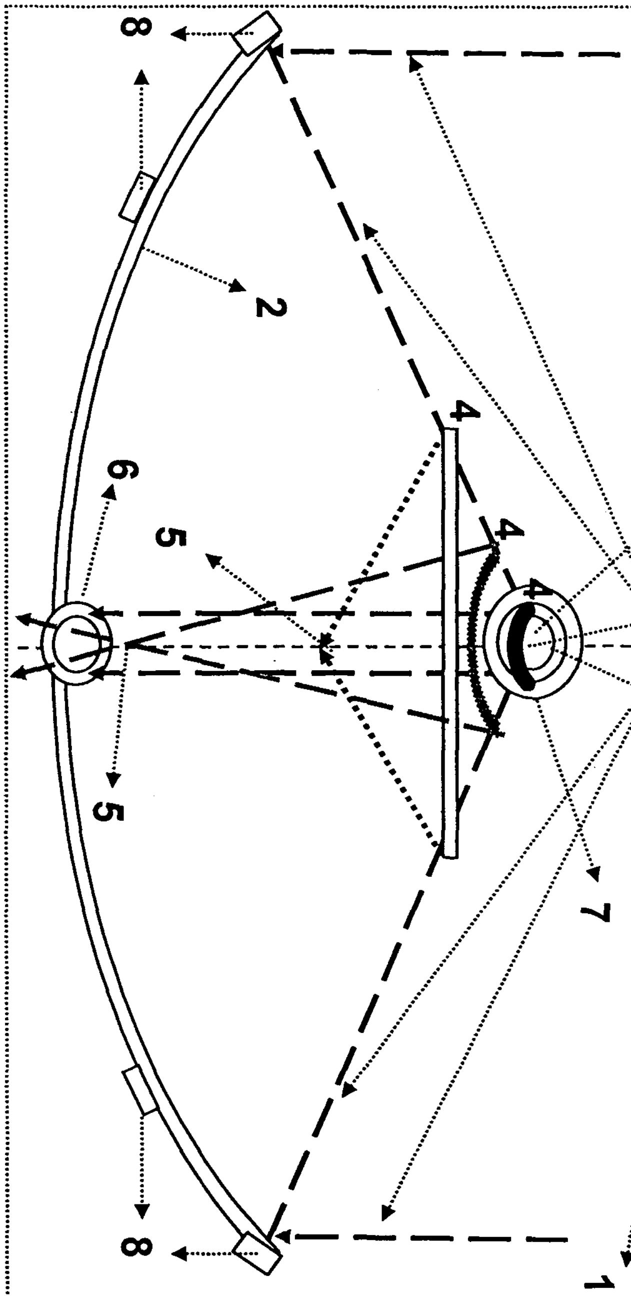


Fig.1

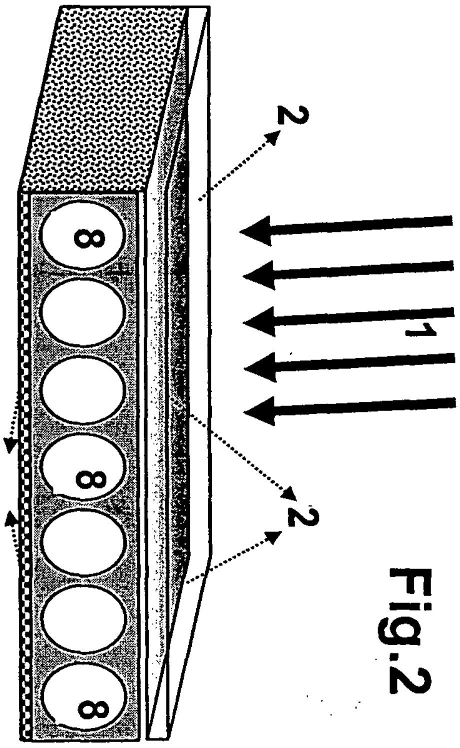


Fig.2

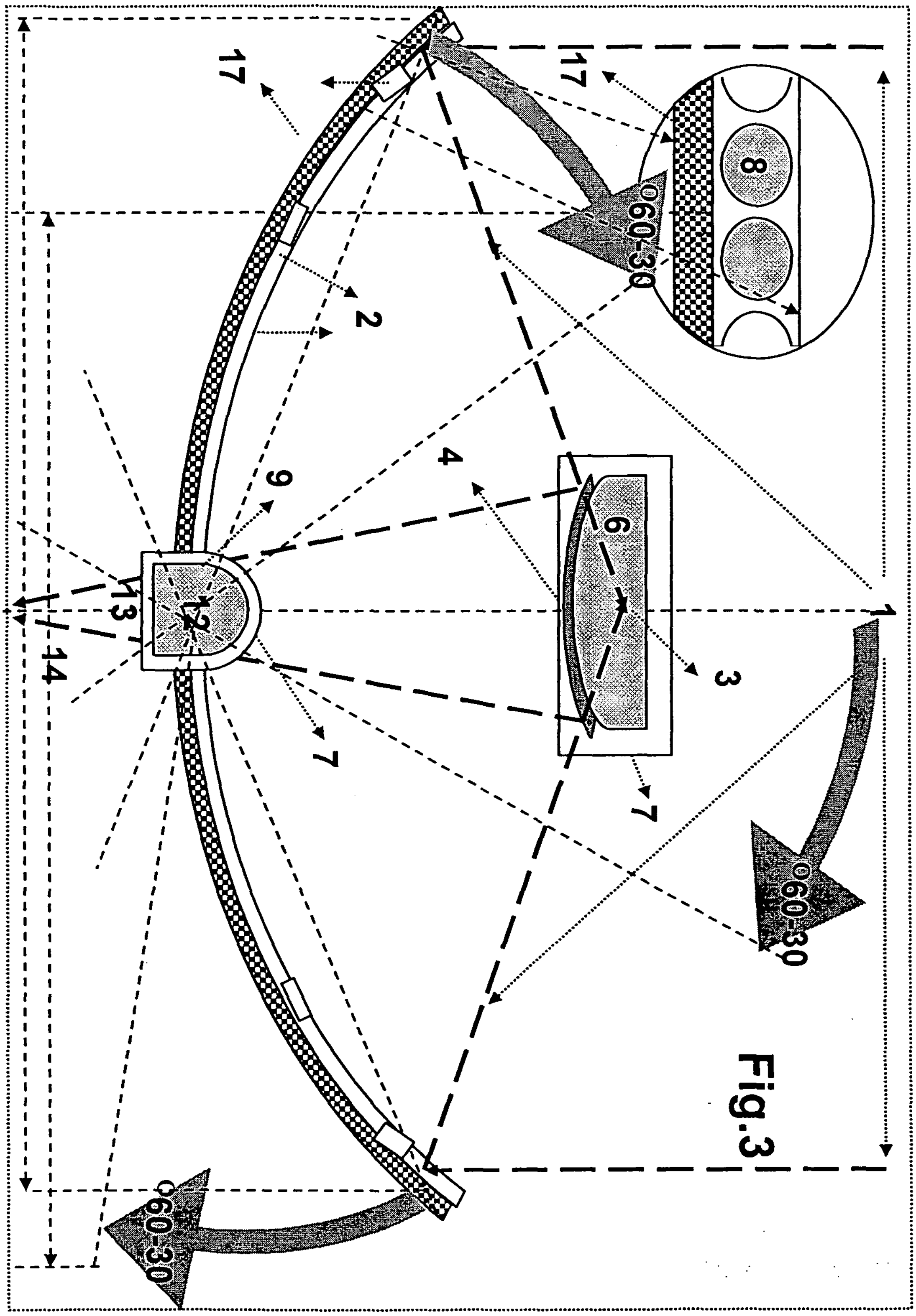


Fig.3

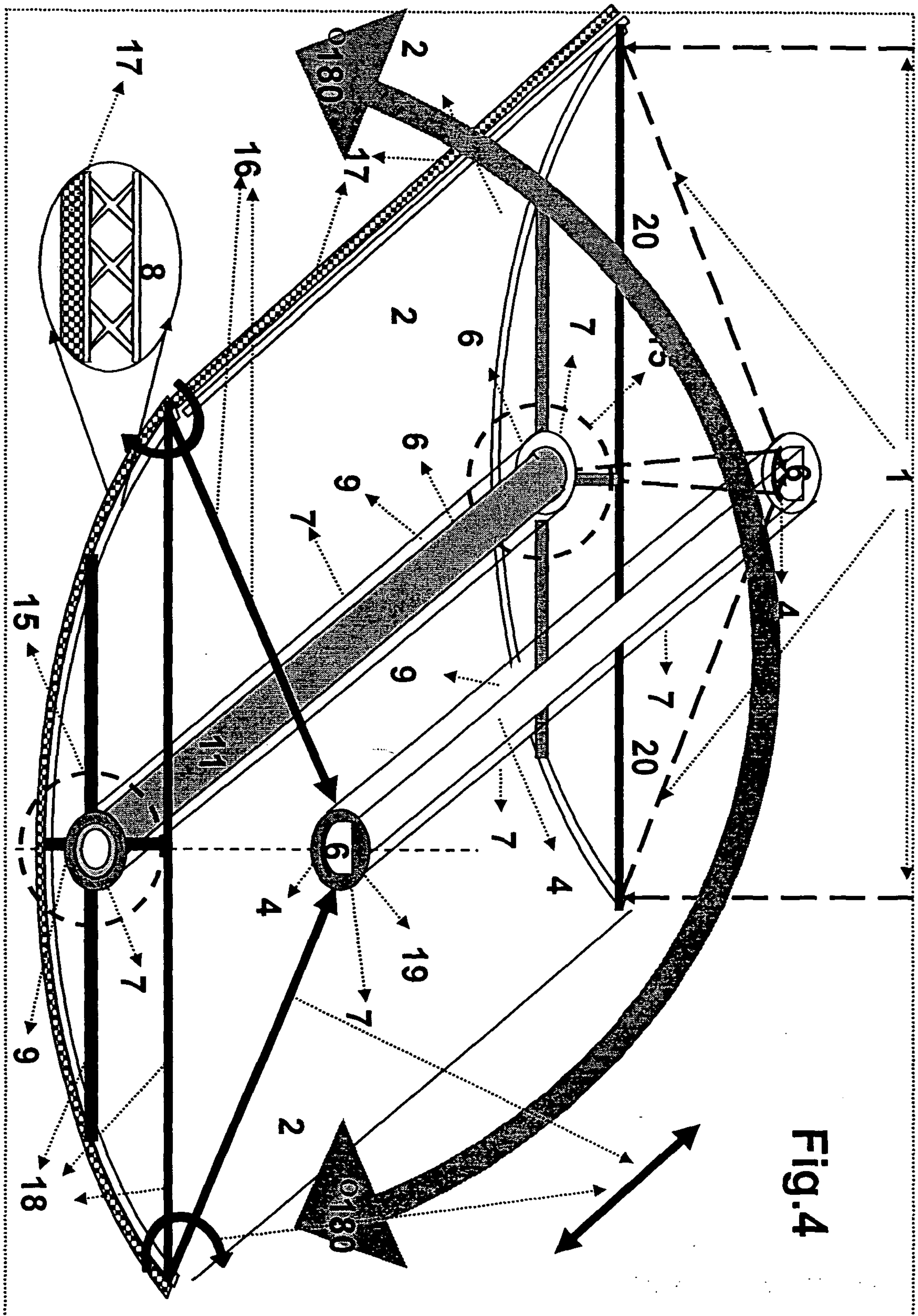


Fig.4

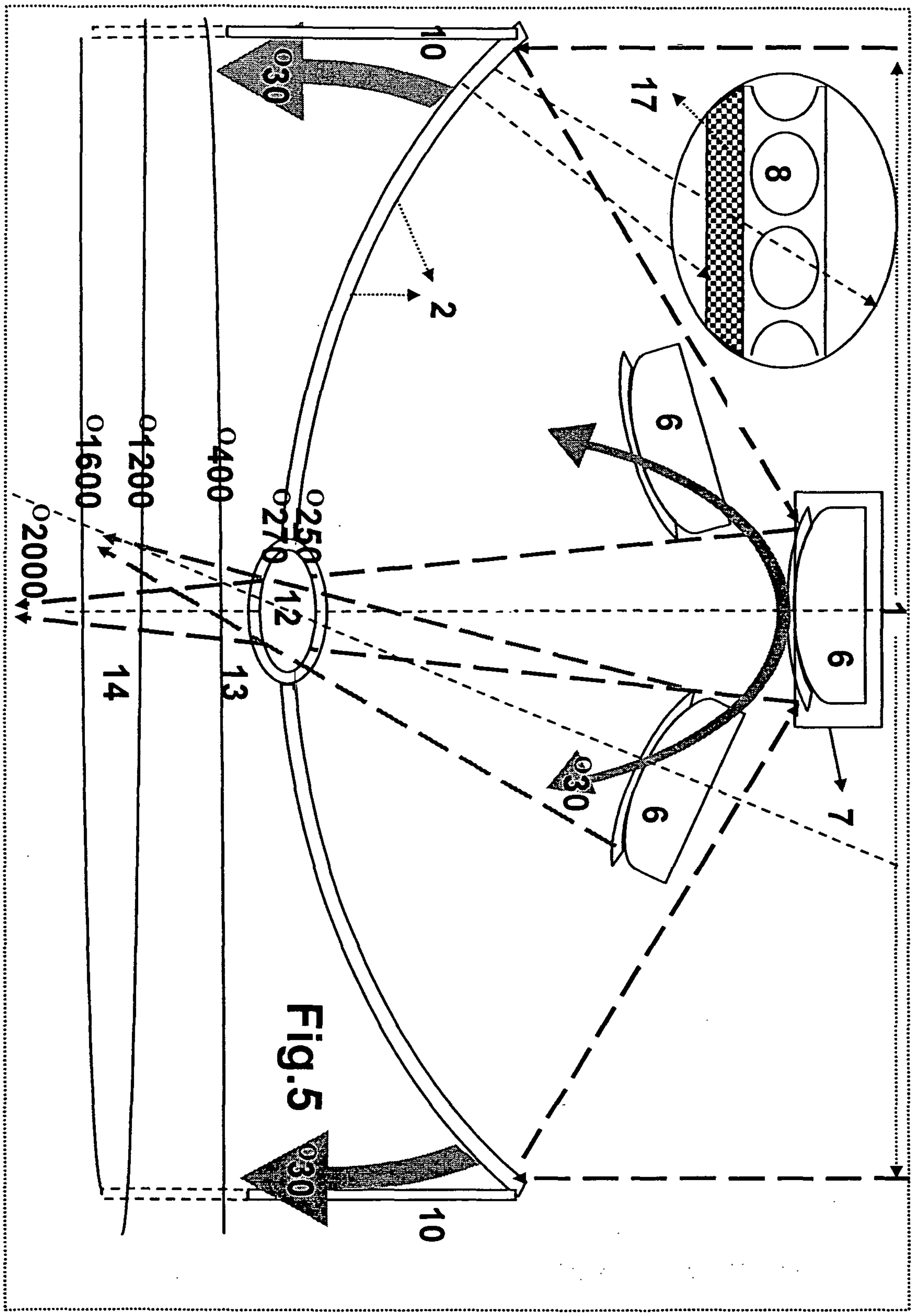


Fig.5

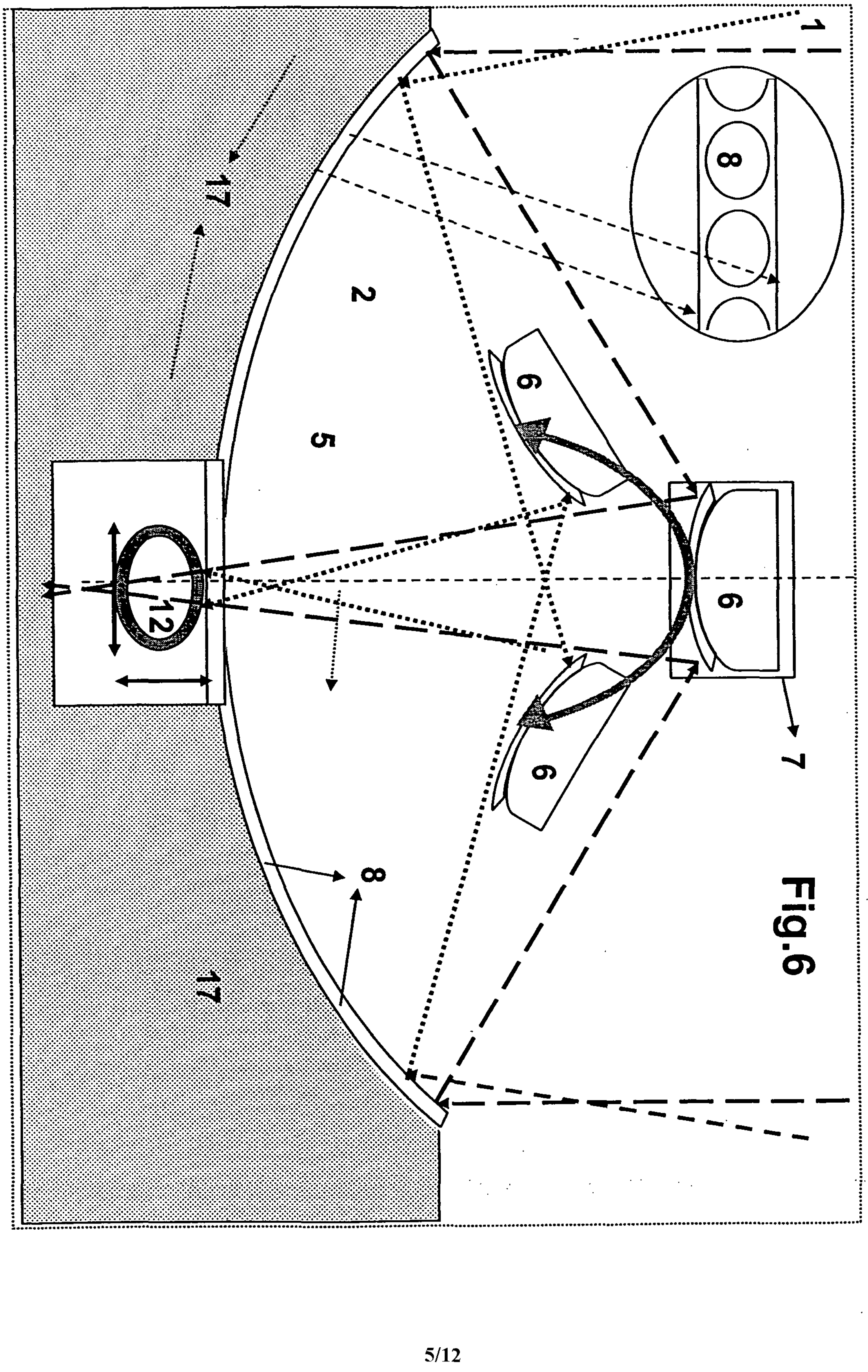


Fig.6

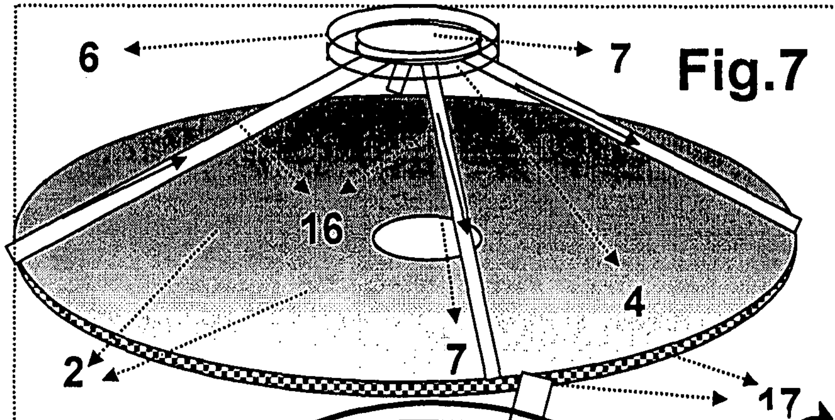


Fig.7

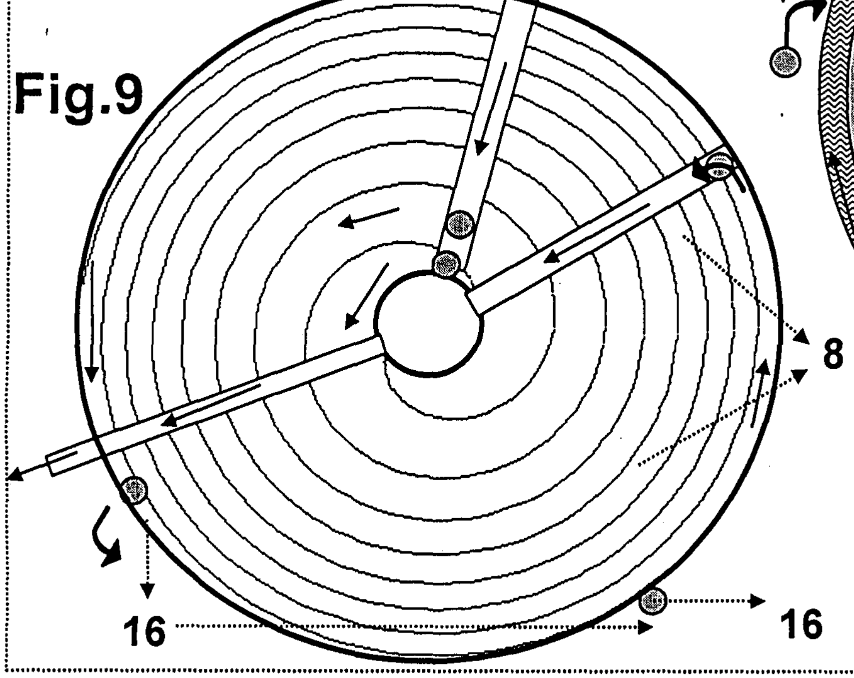


Fig.9

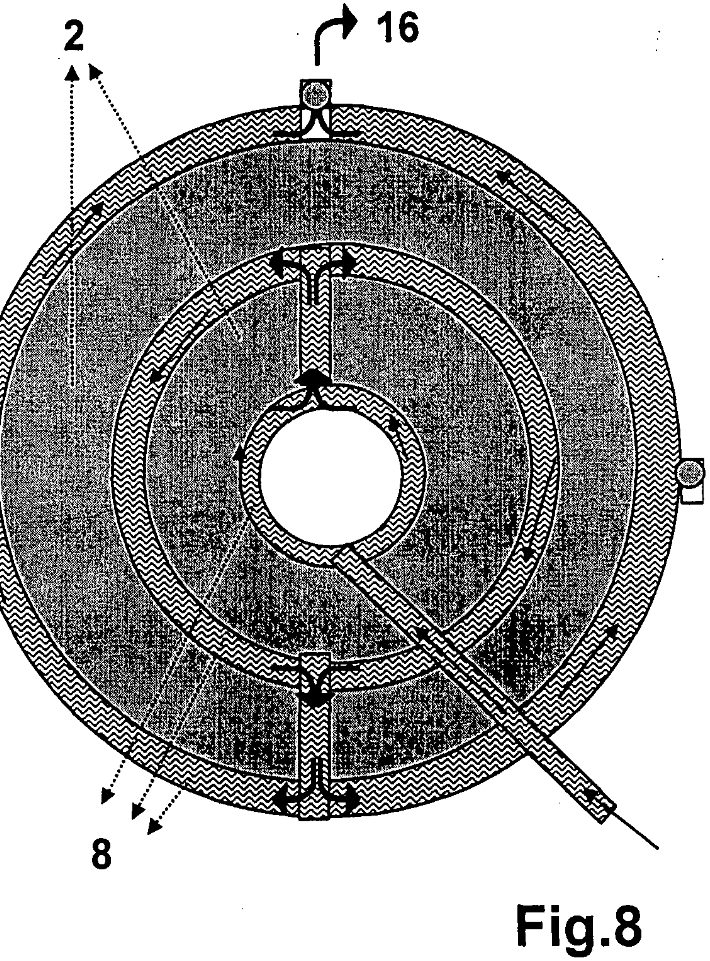


Fig.8

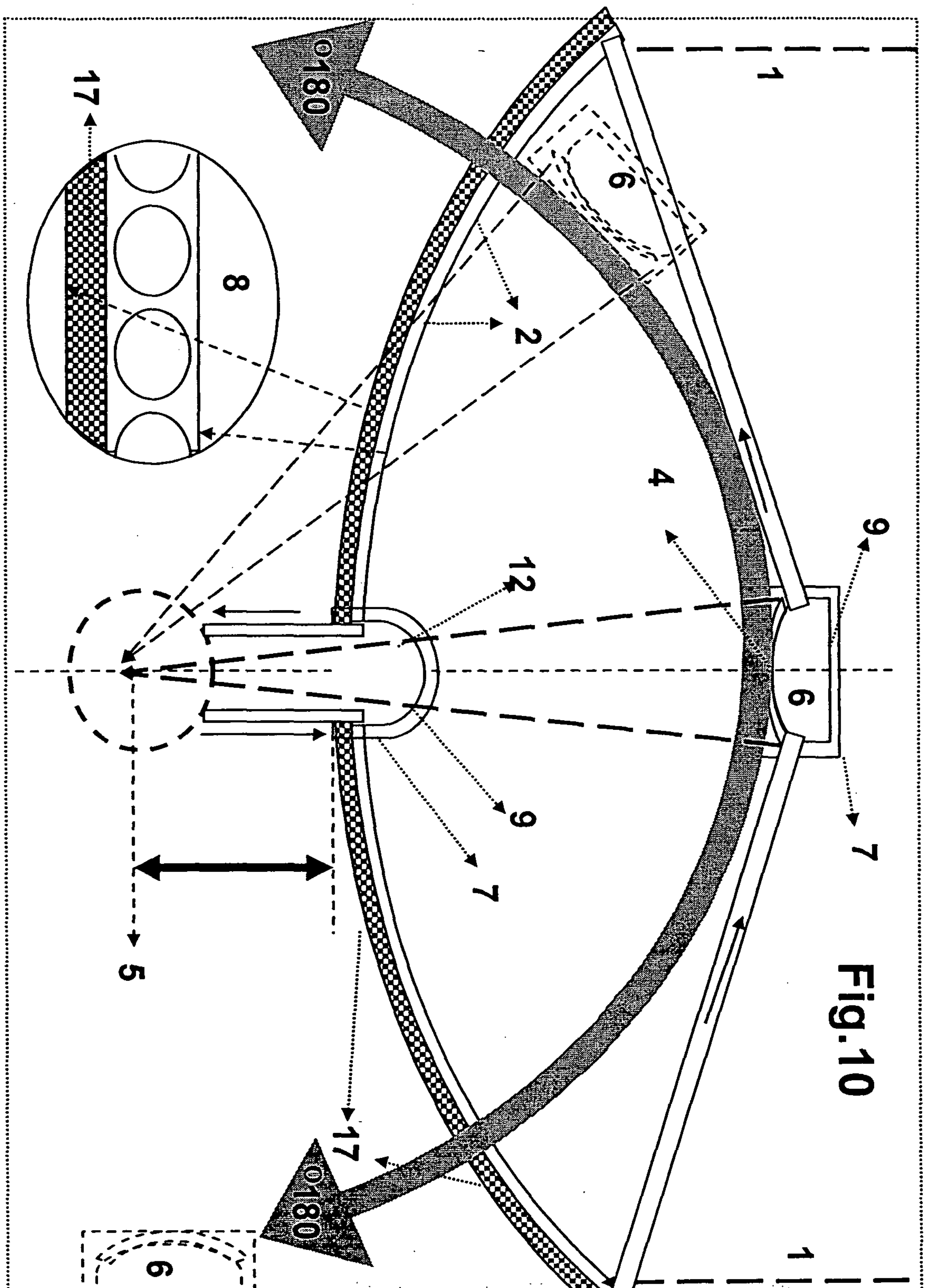


Fig.10

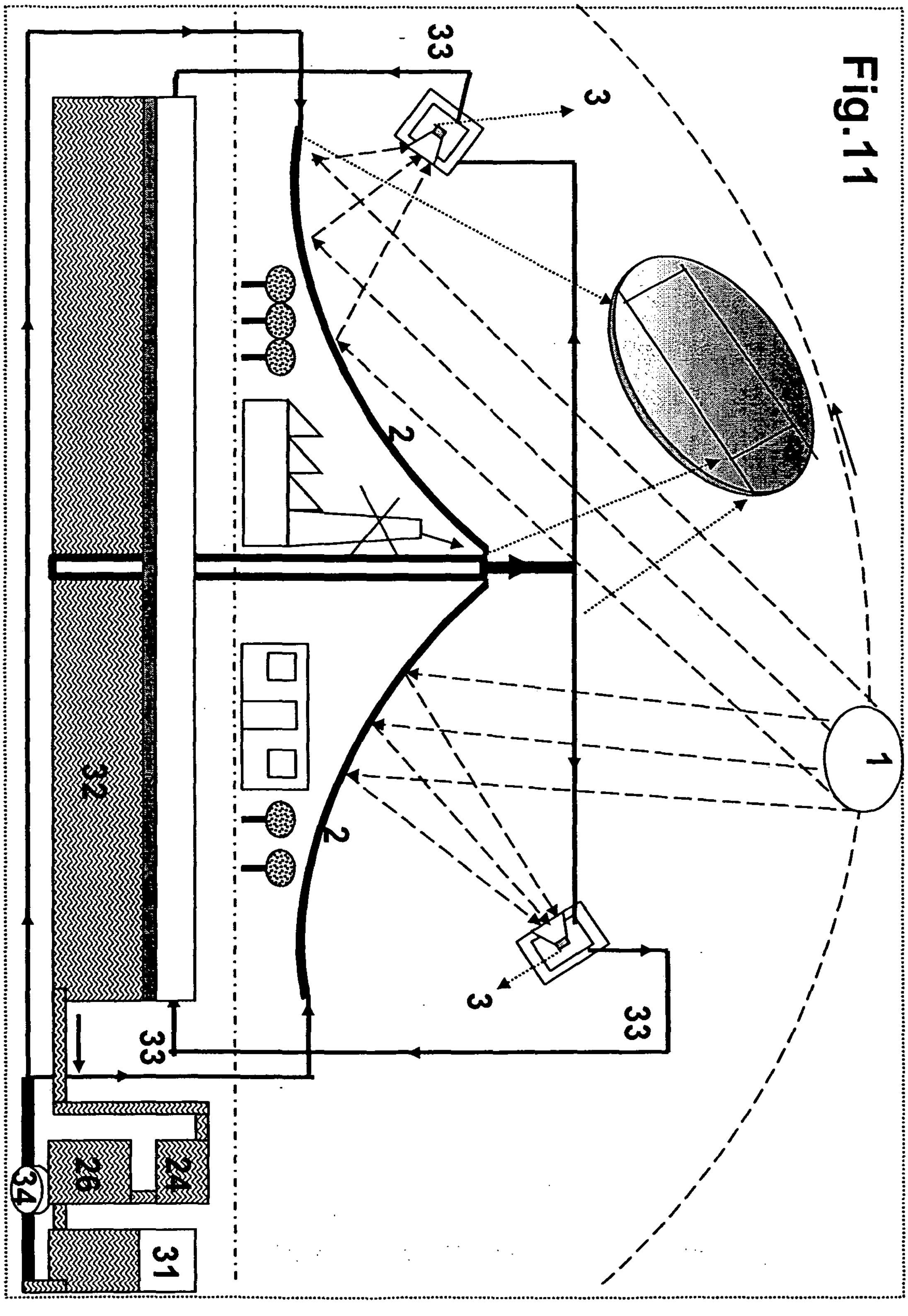
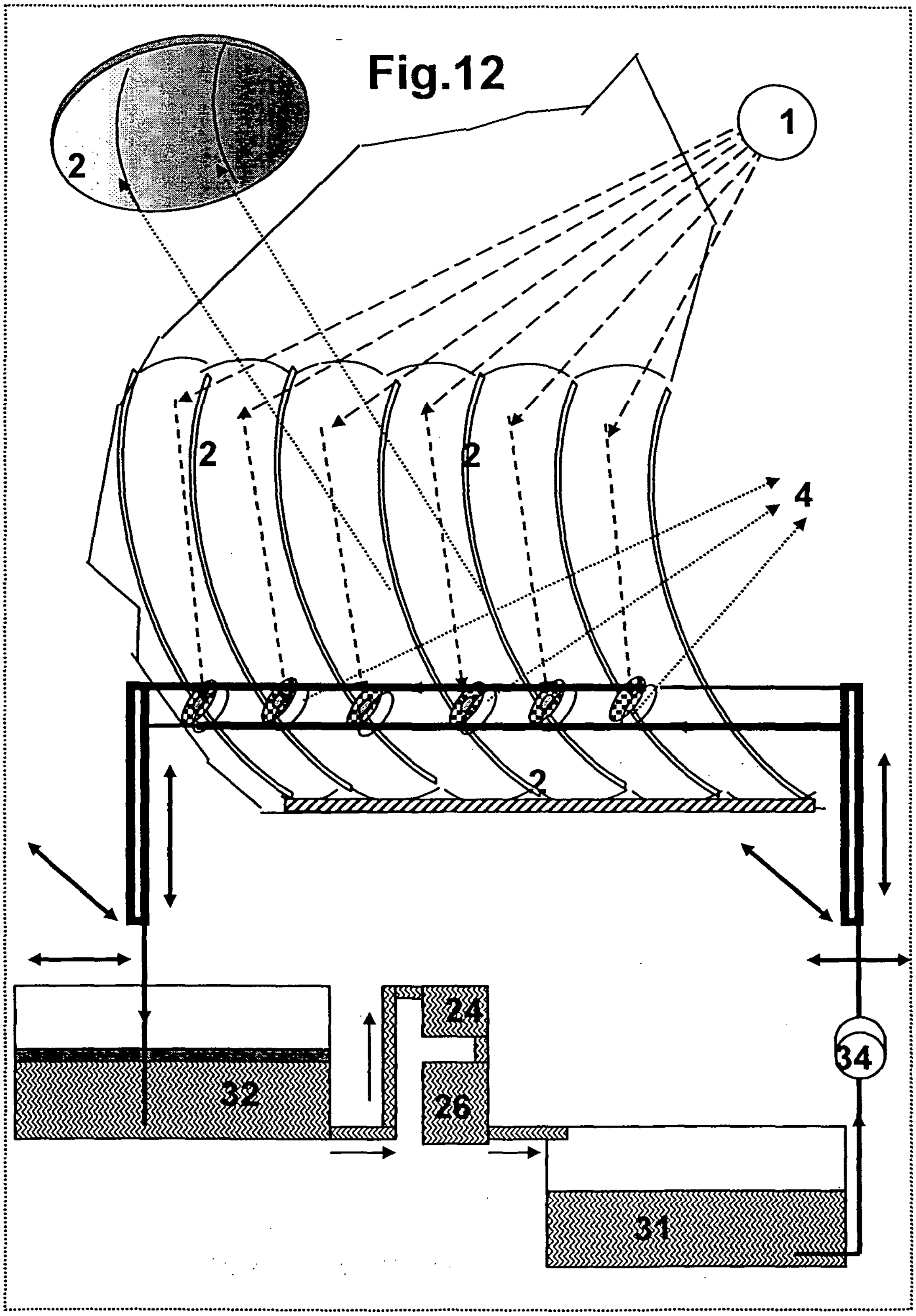


Fig.11

Fig.12



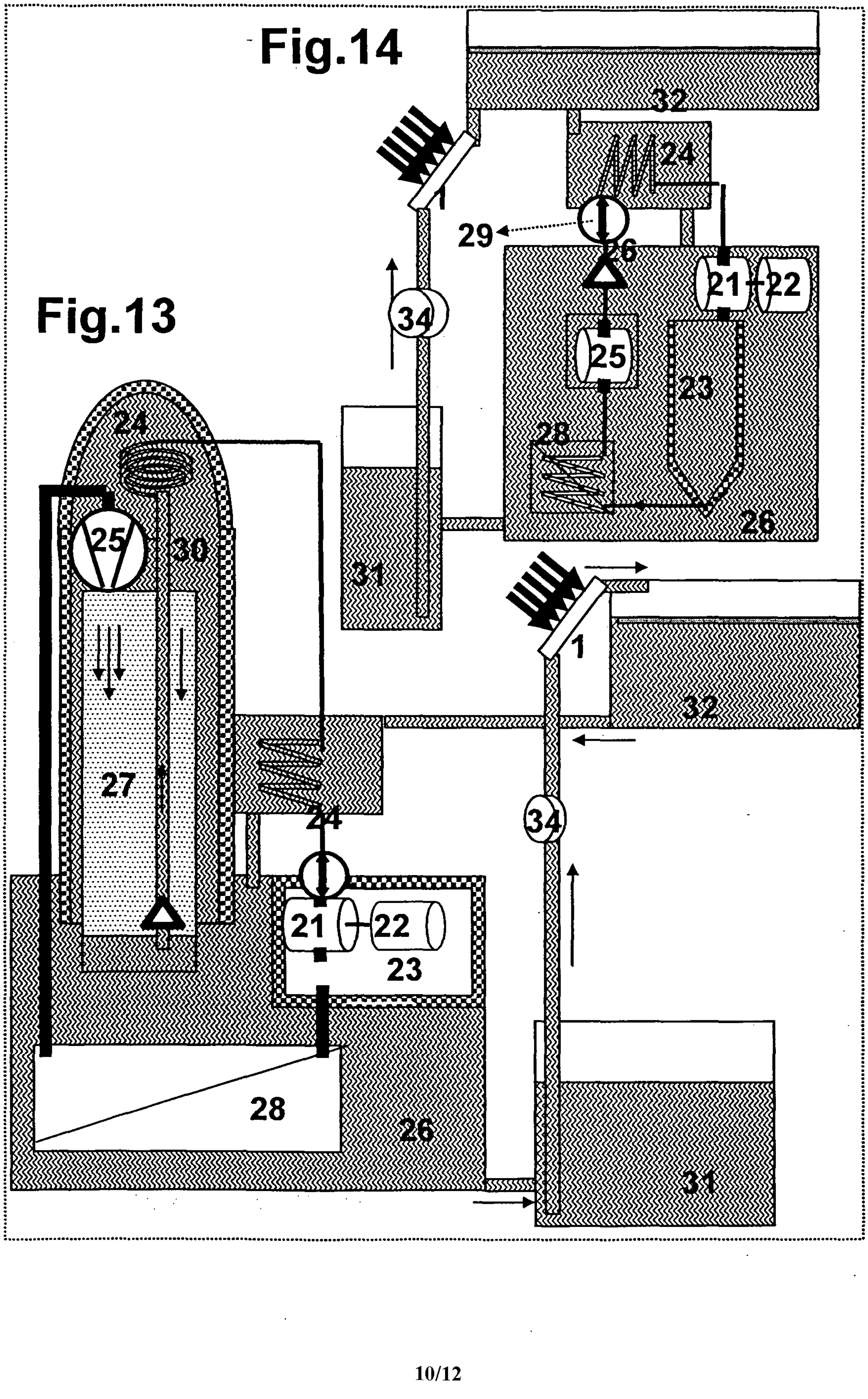


Fig.14

Fig.13

32
24
1
29
26
21
22
34
25
23
28
26
31
24
25
30
27
1
32
24
34
21
22
23
28
26
31

Fig.15

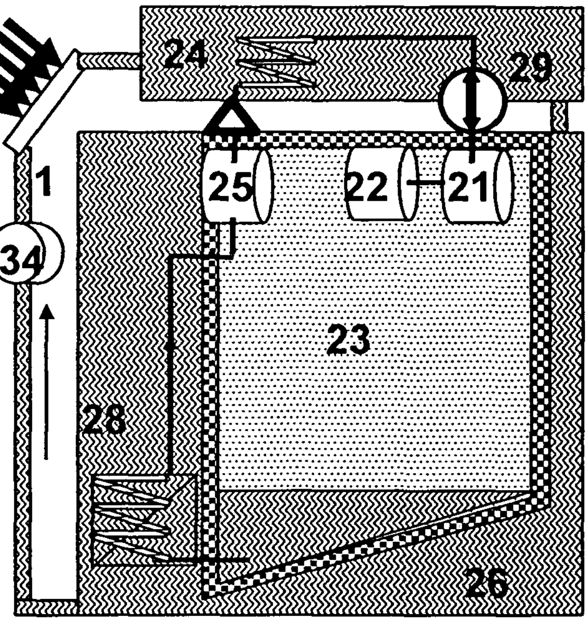
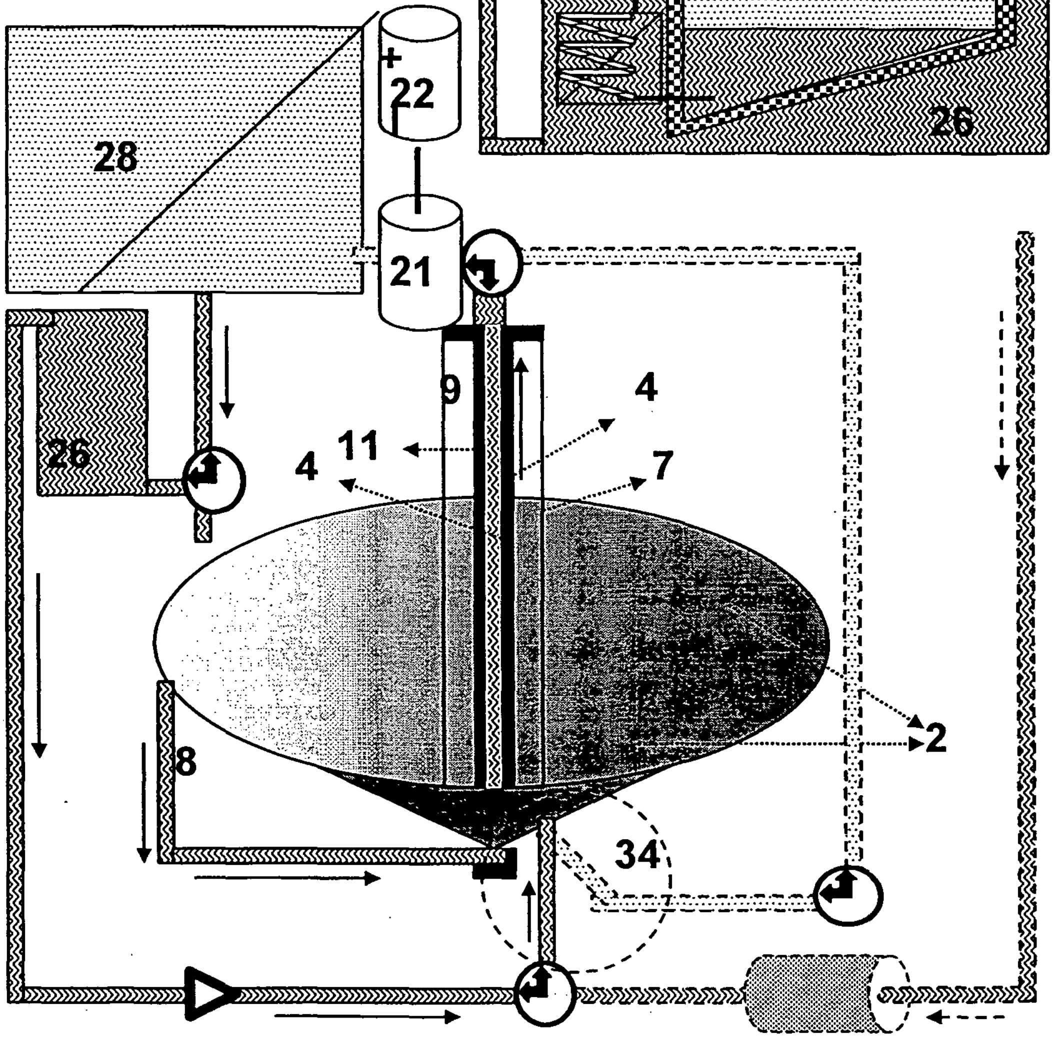


Fig.16



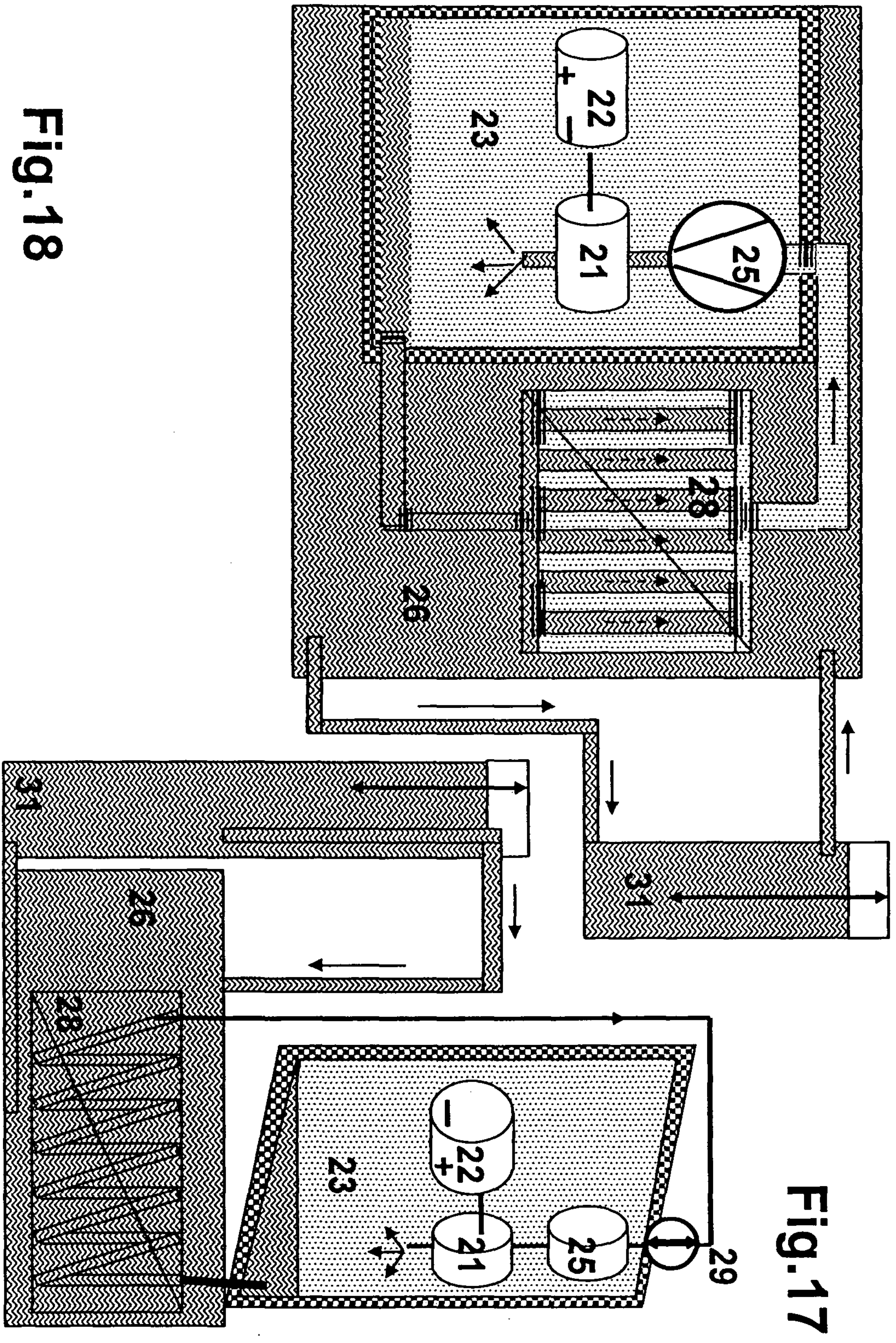


Fig.17

Fig.18

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(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2011/0240009 A1**

Haskins et al. (43) **Pub. Date: Oct. 6, 2011**

(54) MIRROR HAVING REFLECTIVE COATINGS ON A FIRST SURFACE AND AN OPPOSITE SECOND SURFACE

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(73) Assignee: **PPG INDUSTRIES OHIO, INV.**, Cleveland, OH (US)

(21) Appl. No.: **13/073,332**

(22) Filed: **Mar. 28, 2011**

Related U.S. Application Data

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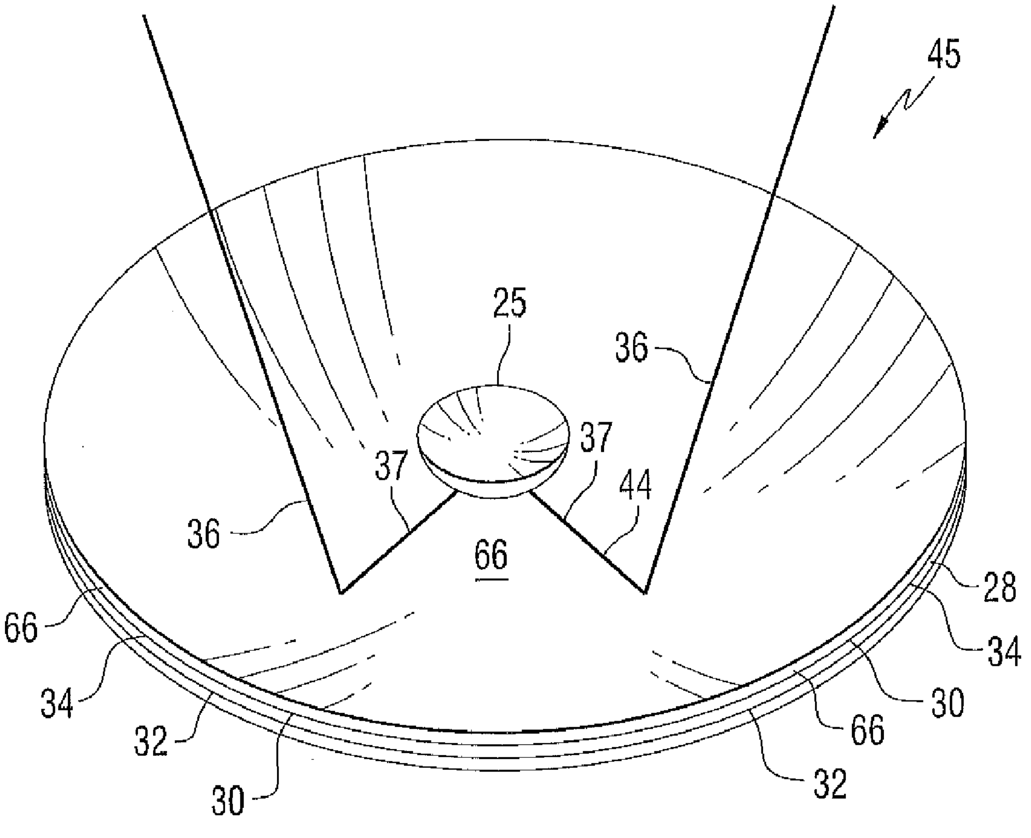
Publication Classification

(51) **Int. Cl.**
F24J 2/10 (2006.01)

(52) **U.S. Cl.** **126/684**

(57) **ABSTRACT**

A solar mirror includes an opaque reflective coating on a surface of a transparent substrate facing away from the sun and a transparent reflective coating on the opposite surface of the substrate. The transparent reflective coating increases the percent reflection of wavelengths in selected ranges, e.g. wavelengths in the infrared range to increase the total solar energy reflected by the solar mirror to increase the solar energy directed to a receiver that converts solar energy to electric and/or thermal energy.



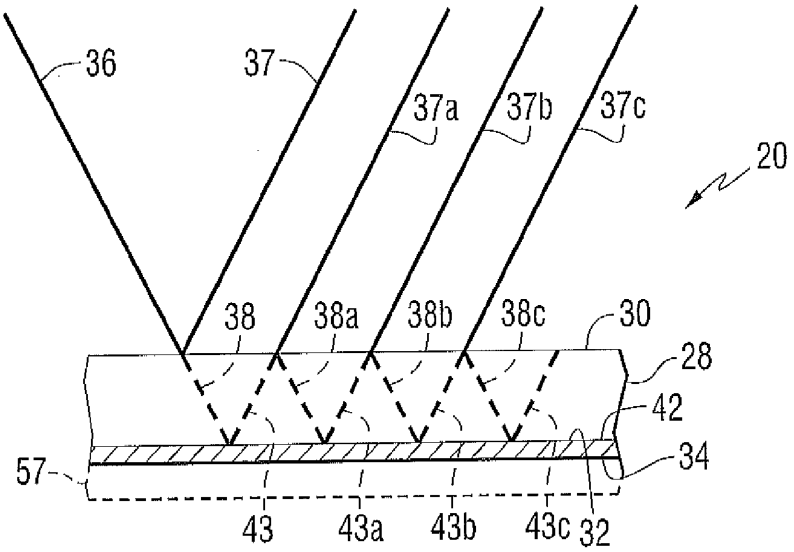


FIG. 1
PRIOR ART

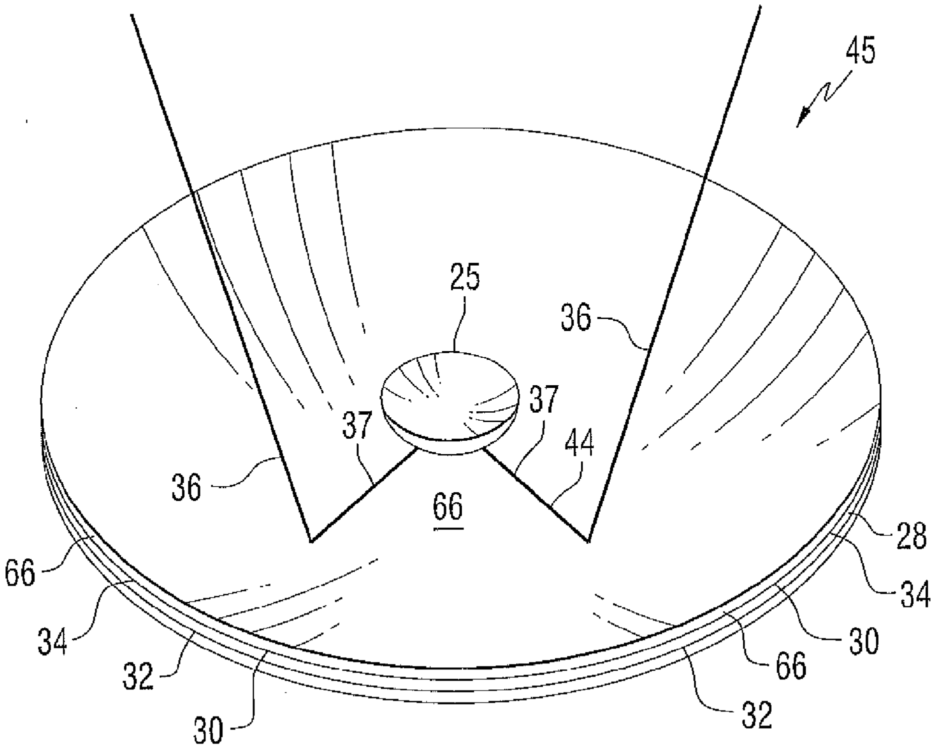


FIG. 2

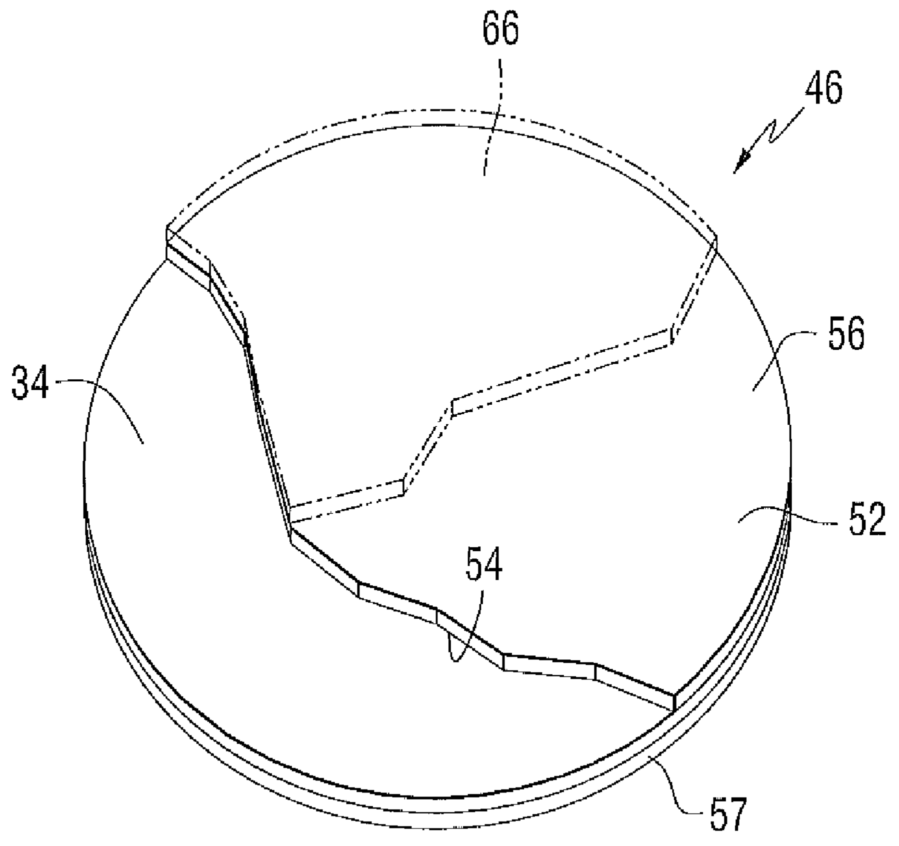


FIG. 3

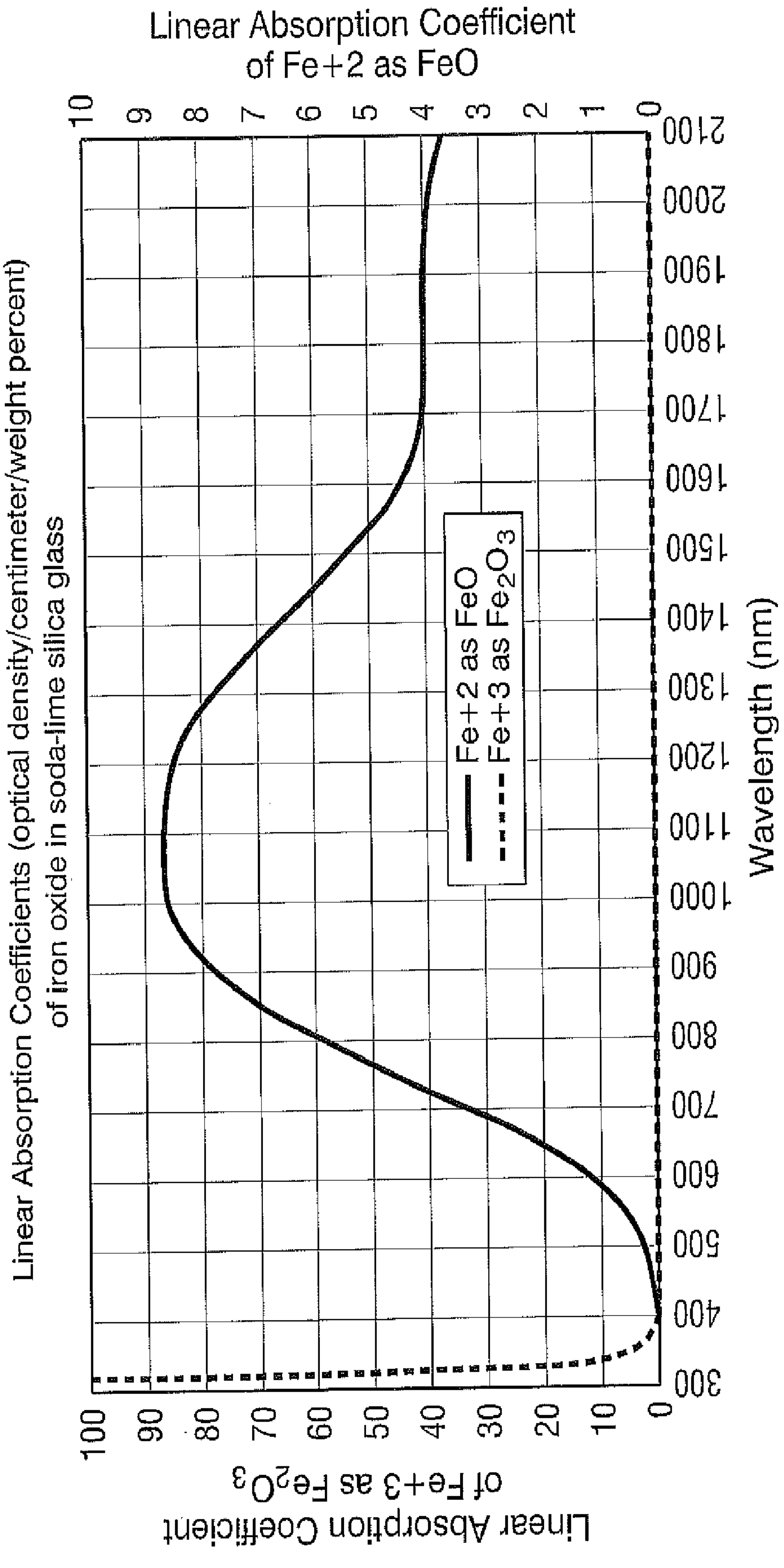

Linear Absorption Coefficient of Fe+2 as FeO
0
1
2
3
4
5
6
7
8
9
10
Linear Absorption Coefficients (optical density/centimeter/weight percent) of iron oxide in soda-lime silica glass
Fe+2 as FeO
Fe+3 as Fe_2O_3
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
Linear Absorption Coefficient of Fe+3 as Fe_2O_3

FIG. 4

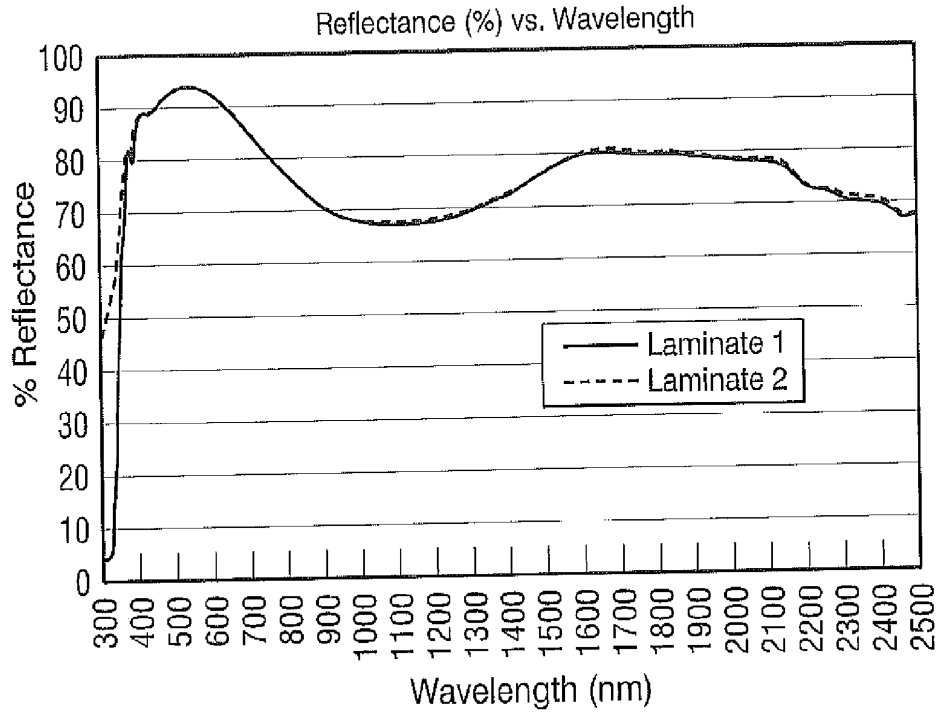

Reflectance (%) vs. Wavelength
% Reflectance
100
90
80
70
60
50
40
30
20
10
0
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
Wavelength (nm)
Laminate 1
Laminate 2

FIG. 5

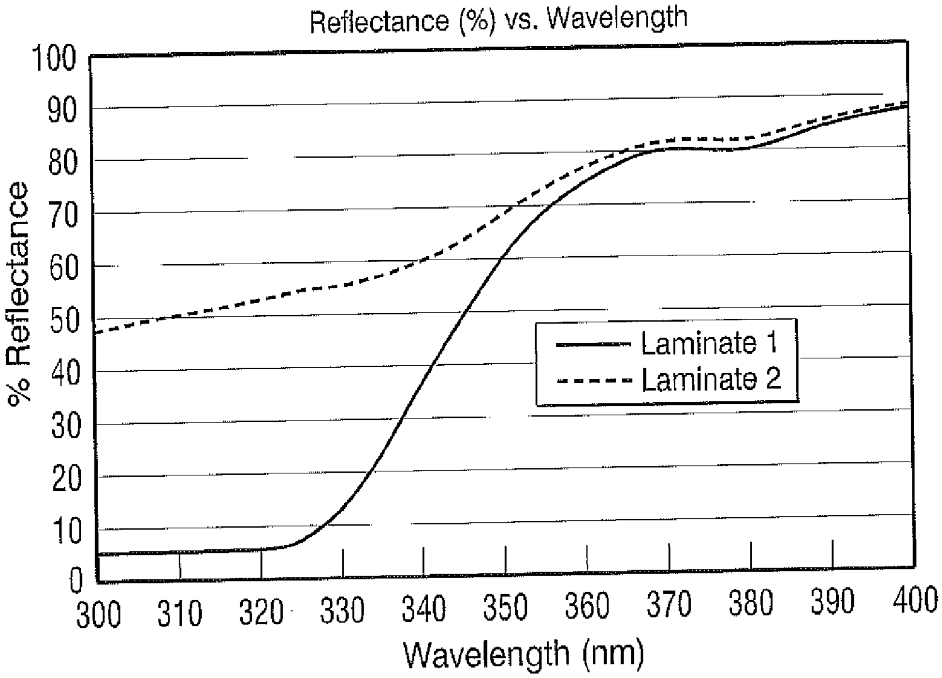

Reflectance (%) vs. Wavelength
% Reflectance
100
90
80
70
60
50
40
30
20
10
0
300
310
320
330
340
350
360
370
380
390
400
Wavelength (nm)
Laminate 1
Laminate 2

FIG. 6

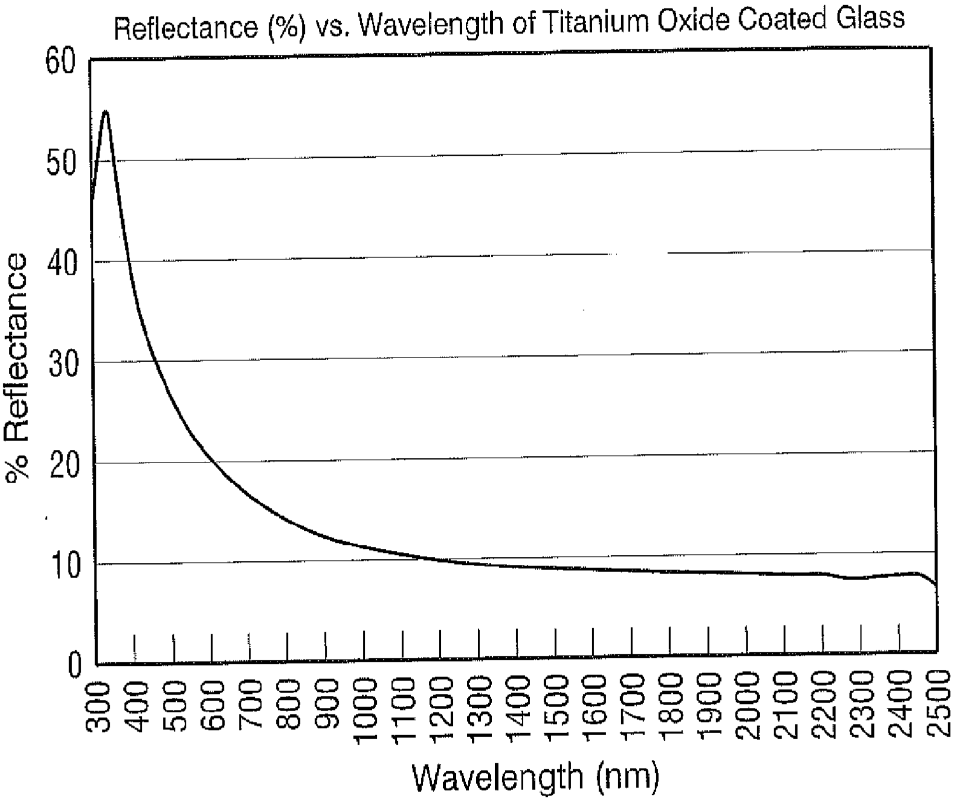

Reflectance (%) vs. Wavelength of Titanium Oxide Coated Glass
% Reflectance
60
50
40
30
20
10
0
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
Wavelength (nm)

FIG. 7

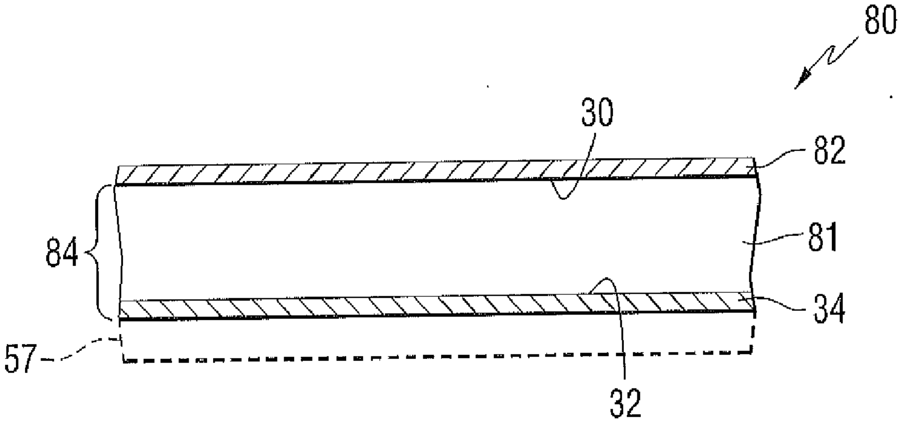


FIG. 8

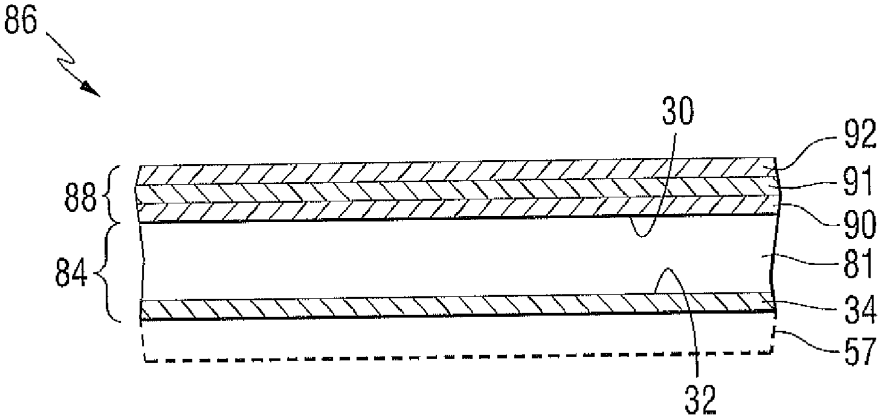


FIG. 11

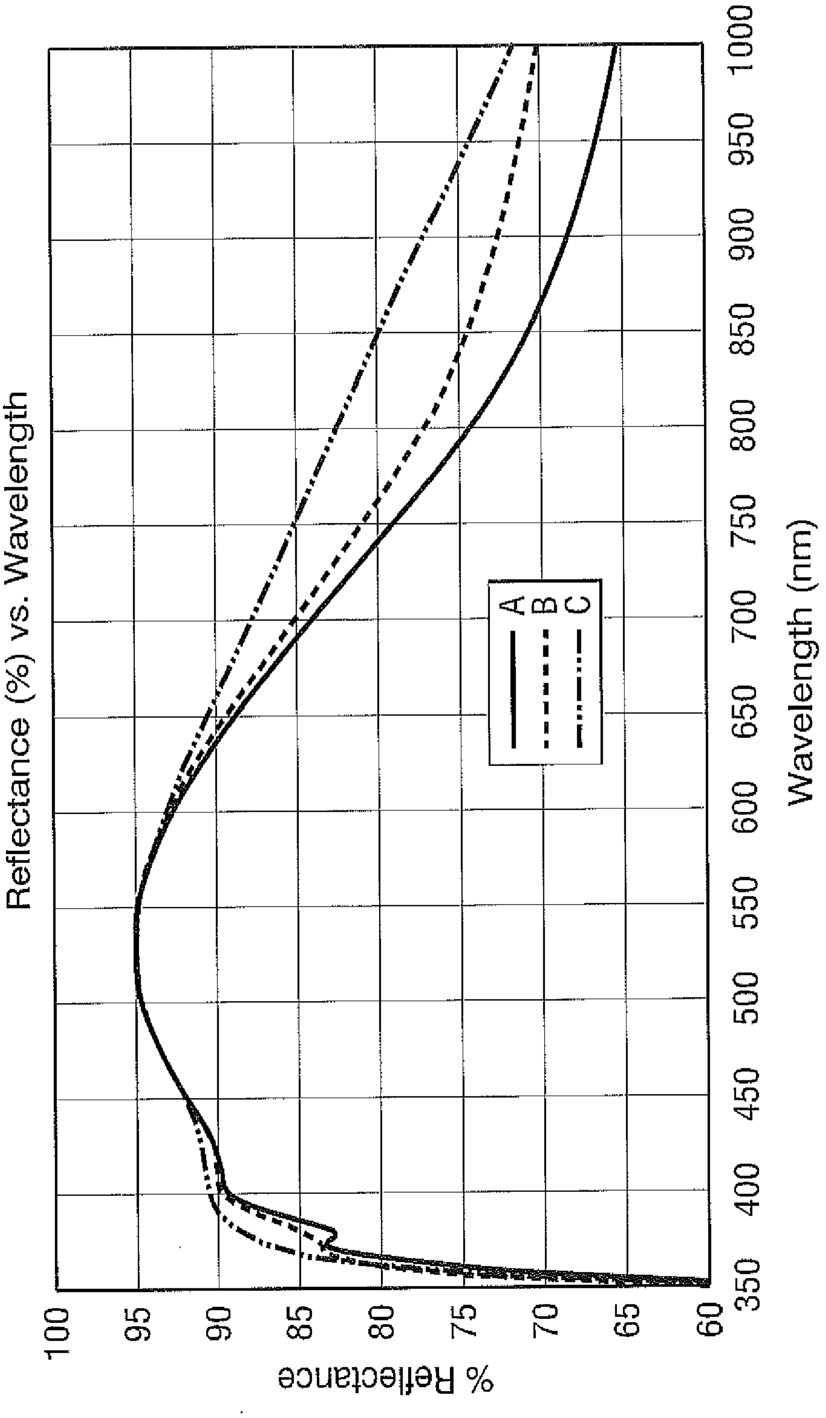

Reflectance (%) vs. Wavelength
% Reflectance
100
95
90
85
80
75
70
65
60
Wavelength (nm)
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
A
B
C

FIG. 9

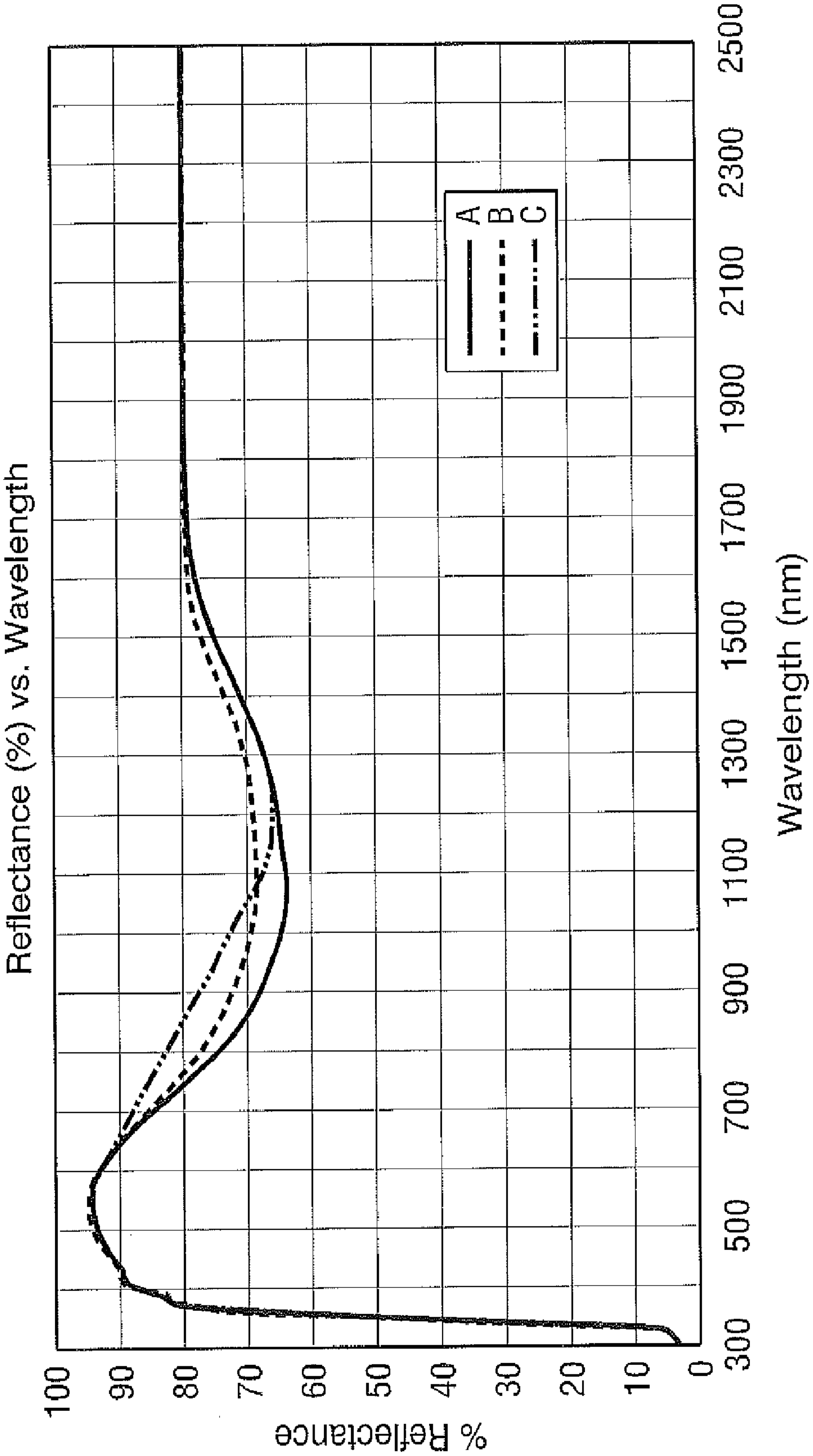

Reflectance (%) vs. Wavelength
% Reflectance
100
90
80
70
60
50
40
30
20
10
0
300
500
700
900
1100
1300
1500
1700
1900
2100
2300
2500
Wavelength (nm)
A
B
C

FIG. 10

MIRROR HAVING REFLECTIVE COATINGS ON A FIRST SURFACE AND AN OPPOSITE SECOND SURFACE

[0001] This application claims the benefit of the filing date of Patent Application Ser. No. 61/319,601 filed Mar. 31, 2010, in the names of David R. Haskins and Mehran Arbab, and titled SOLAR MIRROR HAVING REFLECTIVE COATINGS ON A FIRST SURFACE AND AN OPPOSITE SECOND SURFACE, and the application in its entirety is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates to a mirror having reflective coatings on a first surface and an opposite second surface, and more particularly, to a solar mirror having an opaque reflecting coating on a second surface of a transparent substrate to reflect light passing through the substrate and a transparent reflecting coating on the opposite first surface of the transparent substrate to reflect wavelengths in selected ranges of the electromagnetic spectrum that are absorbable by the substrate.

[0004] 2. Discussion of the Technical Challenge

[0005] At the present time, there is interest to increase the efficiency of solar collectors, e.g. and not limiting to the discussion, improve the efficiency of solar mirrors, e.g. flat solar reflecting mirrors and shaped solar reflecting mirrors, used to reflect the sun's rays to a converting device. The converting device is usually of the type known in the art to convert the sun's energy to another form of energy, e.g. electric energy and/or thermal energy. In general and not limiting to the discussion, the solar mirror can be a primary mirror or a secondary mirror. The term "primary mirror" as used herein is a mirror on which solar rays are first reflected, and the term "secondary mirror" as used herein is a mirror on which reflected solar rays are re-reflected, e.g. to another solar mirror, or to a receiving element or receiver. The reflected solar rays incident on the secondary mirror can be reflected from a primary mirror or from another secondary mirror. The receiving element, or receiver, can include, but is not limited to, photovoltaic devices or a tube containing a fluid.

[0006] In general but not limiting to the discussion, the primary mirror is a shaped mirror, e.g. a parabolic, or cylindrical, shaped mirror having an opaque solar reflective coating, e.g. a silver coating on the convex surface or second surface of a shaped transparent substrate. The secondary mirror can be a shaped mirror or a flat mirror having the opaque solar reflective coating on a surface of a shaped or flat transparent substrate. Usually, the secondary mirror is a flat mirror having the reflective coating on the back surface or the second surface of a flat or lens shaped transparent substrate. In practice, the solar rays are incident on the first surface or concave surface of the primary mirror. A portion of the sun's rays are reflected from the first surface of the shaped mirror toward the receiver, or a secondary mirror, and a portion of the sun's rays pass through the substrate and are reflected by the opaque reflective coating back through the transparent substrate toward the receiver or the secondary mirror. In the instance when the sun's rays are reflected toward a secondary mirror, the reflected sun's rays from the primary mirror are incident on the secondary mirror and reflected by the secondary mirror to the receiver, or toward another secondary mirror. A more detailed discussion of primary and secondary solar reflecting mirrors is presented in U.S. patent application Ser. No. 12/709,045 filed on Feb. 19, 2010 and titled SOLAR REFLECTING MIRROR HAVING A PROTECTIVE COATING AND METHOD OF MAKING SAME, which document in its entirety is hereby incorporated by reference.

[0007] The transparent substrate of the primary and the secondary mirrors is usually made of soda-lime-silica glass because of the high yield in shaping a flat piece of soda-lime-silica glass into a parabolic shaped substrate; the low cost of making soda-lime-silica glass, and the high yield and low cost of applying a solar reflective coating on a surface of a flat piece or shaped piece of soda-lime-silica glass. Although soda-lime-silica glass is an acceptable material for the substrates for the solar mirrors, there are limitations. More particularly, a commercial grade soda-lime-silica glass is made of batch materials that include ingredients that absorb selected wavelengths of the electromagnetic spectrum. For example and not limiting to the discussion, a commercial grade of batch materials to make soda-lime-silica glass usually has at least 0.04 weight percent of iron oxides, namely ferric oxide (Fe_2O_3) and ferrous oxide (FeO). The ferric oxide has its absorption in the wavelength range of 300 to 400 nanometers ("nm") of the electromagnetic spectrum, and the ferrous oxide has its absorption in the wavelength range of 780-1550 nm of the electromagnetic spectrum and its peak absorption in the wavelength range 1000-1200 nm of the electromagnetic spectrum. The absorption by the ferric oxide in the 300-400 nm range, and by the ferrous oxide in the 780-1550 nm range, of the electromagnetic spectrum reduces the amount of solar energy incident on the converting device.

[0008] As is appreciated by those skilled in the art, a purer grade of soda-lime-silica glass batch materials having reduced weight percents of iron oxides are available. For example, soda-lime-silica glasses having less than 0.04 weight percent of iron oxides are disclosed in U.S. patent application Ser. No. 12/275,264 filed Nov. 21, 2008 and U.S. Pat. No. 5,030,594, which documents in their entirety are incorporated herein by reference. PPG Industries, Inc. sells such glasses under the trademarks STARPHIRE and SOLARPHIRE PV.

[0009] Unfortunately, the cost of batch materials for making soda-lime-silica glasses having less than 0.04 weight percent of iron oxides is two to three times more expensive than the cost of the batch materials for making soda-lime-silica glasses having more than 0.04 weight percent of iron oxides. As can now be appreciated, it would be advantageous to provide a solar reflecting mirror having a soda-lime-silica glass substrate having greater than 0.04 weight percent of iron oxides and having reduced absorption of wavelengths in selected ranges of the electromagnetic spectrum, e.g. in the wavelength ranges of 300-400 nm, and 780-1550 nm, of the electromagnetic spectrum.

SUMMARY OF THE INVENTION

[0010] This invention relates to an improved solar reflecting mirror of the type having a transparent substrate having a first surface designated to face a source of solar energy and a second surface opposite to the first surface, the second surface designated to face away from the source of solar energy. The glass substrate has a composition including, among other things, an ingredient that absorbs one or more wavelengths of the electromagnetic spectrum defined as absorbable wavelengths, and an opaque solar reflecting coating on the second surface of the glass substrate. The improvement of the invention includes, among other things, a transparent reflecting coating over the first surface of the substrate to increase the percent reflection of one or more of the absorbable wavelengths of the electromagnetic spectrum in a direction away from the first and the second surface of the transparent substrate.

[0011] This invention further relates to a solar reflecting mirror having, among other things, a substrate, especially a glass substrate, having a second surface designated to face away from the source of solar energy and a first surface opposite to the second surface, i.e. the first surface facing the sun, wherein the glass substrate has a composition including, but not limited to, an ingredient that absorbs one or more wavelengths of the electromagnetic spectrum defined as an absorbable wavelengths; an opaque solar reflecting coating applied to the second surface of the glass substrate, and a transparent reflecting film applied to the first surface of the glass substrate to reflect one or more of the absorbable wavelengths of the electromagnetic spectrum.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is a cross sectional view of a prior art solar mirror showing the reflection and re-reflection of a sun's ray incident on the surface, e.g. the first surface, of the solar mirror. The cross hatching of the reflective coating is shown, and the cross hatching of the transparent substrate is not shown, for purposes of clarity.

[0013] FIG. **2** is an elevated plan view of a shaped solar mirror of the invention.

[0014] FIG. **3** is an isometric view of a flat secondary mirror of the invention having portions of the transparent reflective coating of the invention removed for purposes of clarity.

[0015] FIG. **4** is a graph showing the linear absorption coefficients (optical density/centimeter/weight percent) of iron oxide in soda-lime-silica glass. The linear absorption coefficients for ferric oxide (Fe_2O_3) are shown on the left side of the graph and are in the range of 0-100, and the linear absorption coefficients for ferrous oxide (FeO) are shown on the right side of the graph and are in the range of 0-10.

[0016] FIG. **5** is a graph showing reflectance of laminate 1 and laminate 2 in the wavelength range of 300-2500 nanometers of the electromagnetic spectrum. Laminate 2 is a non-limiting embodiment of the invention.

[0017] FIG. **6** is a graph similar to the graph of FIG. **6** showing reflectance of laminate 1 and laminate 2 in the wavelength range of 300-400 nanometers of the electromagnetic spectrum.

[0018] FIG. **7** is a graph showing reflectance of a titanium oxide coated glass in the wavelength range of 300-2500 nanometers of the electromagnetic spectrum.

[0019] FIG. **8** is a view similar to the view of FIG. **1** showing the cross-section of a non-limiting embodiment of a solar mirror of the invention.

[0020] FIG. **9** is a graph showing reflectance vs. wavelength of an uncoated glass and coated glasses of the invention in the wavelength range of 350-1000 nanometers.

[0021] FIG. **10** is a graph showing reflectance vs. wavelength of the uncoated glass and coated glasses of the invention FIG. **9** in the wavelength range of 300-2500 nanometers.

[0022] FIG. **11** is a view similar to the view of FIG. **8** showing the cross-section of another non-limiting embodiment of a solar mirror of the invention.

DETAILED DISCUSSION OF THE INVENTION

[0023] In the following discussion, spatial or directional terms, such as "inner", "outer", "left", "right", "up", "down", "horizontal", "vertical", and the like, relate to the invention as it is shown in the drawing figures. However, it is to be understood that the invention can assume various alternative orientations and, accordingly, such terms are not to be considered as limiting. Further, all numbers expressing dimensions, physical characteristics, and so forth, used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical values set forth in the following specification and claims can vary depending upon the desired properties sought to be obtained by the present invention. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Moreover, all ranges disclosed herein are to be understood to encompass any and all sub-ranges subsumed therein. For example, a stated range of "1 to 10" should be considered to include any and all sub-ranges between (and inclusive of) the minimum value of 1 and the maximum value of 10; that is, all sub-ranges beginning with a minimum value of 1 or more and ending with a maximum value of 10 or less, e.g., 1 to 6.7, or 3.2 to 8.1, or 5.5 to 10. Also, as used herein, the terms "applied over", or "provided over" mean applied, or provided on but not necessarily in surface contact with. For example, a material "applied over" a substrate or a substrate surface does not preclude the presence of one or more other materials of the same or different composition located between the deposited material and the substrate or substrate surface.

[0024] Before discussing non-limiting embodiments of the invention, it is understood that the invention is not limited in its application to the details of the particular non-limiting embodiments shown and discussed herein since the invention is capable of other embodiments. More particularly, in the following discussion, the invention is practiced on solar mirrors, the invention, however, is not limited thereto, and can be practiced on any type of mirror. Further, the terminology used herein to discuss the invention is for the purpose of description and is not of limitation. Still further, unless indicated otherwise, in the following discussion like numbers refer to like elements.

[0025] In the following discussion, the solar rays initially impinge on, and are reflected from a shaped, e.g. a cylindrical, spherical or parabolic shaped, reflecting mirror, however, the invention is not limited thereto, and the invention, unless indicated other wise can be practiced with any mirror having a curved reflective surface and a focal point or focal area, or with a flat surfaced mirror. A "focal point" and "focal area" is defined as a position where more than 80% of the solar rays reflected from the shaped mirror converge. The size of the "focal area" is less than one fifth of the reflective area of the mirror.

[0026] With reference to FIG. **1** there is shown a cross sectional view of a solar mirror **20** having a transparent substrate **28**, e.g. but not limiting to the invention a soda-lime-silica glass having a first surface **30** facing the sun (not shown), and an opposite surface or second surface **32**. In the instance when the solar mirror **20** is a shaped mirror, e.g. but not limiting to the discussion, a parabolic shaped solar mirror (see FIG. **2**), the first surface **30** (FIG. **1**) is the concave surface, and the second surface **32** is the convex surface, and in the instance when the solar mirror is a flat mirror (see FIG. **3**) the surfaces **30** and **32** (FIG. **1**) are usually parallel to one another and both of the surfaces **30** and **32** are flat. A reflective coating, layer or film **34** is applied to the second surface **32** of the substrate **28** to reflect the sun's rays in the manner discussed below. The opaque solar reflective film **34** can be metal, e.g. but not limited to silver, aluminum, nickel, stainless steel or gold. Usually the reflective film **34** is silver.

[0027] As can be appreciated, the invention is not limited to the material of the transparent substrate **28**, and the substrate **28** can be any type of transparent material, e.g. but not limited to glass and plastic.

[0028] In the following discussion reference is made to a shaped solar mirror (FIG. **2**), and the discussion, unless indicated otherwise, is applicable to a flat solar mirror (FIG. **3**). With continued reference to FIG. **1**, the parallel solar energy rays represented by ray **36** in FIG. **1** is incident on the first or concave surface **30** of the shaped glass substrate **28**. The solar energy rays are shown in FIG. **1** as one ray **36** for purpose of clarity and simplicity instead of the infinite number of parallel solar energy rays incident on the concave surface **30**. A portion **37** of the ray **36** is reflected from the concave surface **30** of the mirror **20** to a receiver (receiver **25** only shown in FIG. **2**) or to a secondary mirror (flat mirror **46** shown in FIG. **3**). With continued reference to FIG. **1**, a portion **38** of the ray **36** passes through the surface **30** of the substrate **28**, through the transparent substrate **28**, and is reflected from surface **42** of the reflective film **34** as reflected ray **43** back through the glass substrate **28**. A portion of the reflected ray **43** passes through the surface **30** of the substrate **28** as ray **37***a* toward the receiver **25**, and a portion **38***a* of the ray **43** is reflected from the first surface **30** through the glass substrate **28** to the second surface **32**. The ray **38***a* is reflected from the surface **42** of the reflective film **34** as reflective ray **43***a*. A portion of the ray **43***a* passes through the first surface **30** as ray **37***b* toward the secondary mirror **25**, and a portion **38***b* of the ray **43***a* is reflected from the first surface **30** through the glass substrate **28** to the second surface **32**. The ray **38***b* is reflected from the surface **42** of the reflective film **34** as reflective ray **43***b*. A portion of the ray **43***b* passes through the first surface **30** as ray **37***c* toward the receiver **25**, and a portion **38***c* of the ray **43***b* is reflected from the first surface **30** through the transparent substrate **28** to the second surface **32**. The ray **38***c* is reflected from the surface **42** of the reflective film **34** as reflective ray **43***c* to repeat the reflection of the rays as discussed above. As is appreciated by those skilled in the art, a portion of the rays **38**, **38***a*, **38***b* and **38***c* at the convex surface **32** is reflected back through the transparent substrate **28**, and a portion of the rays **38**, **38***a*, **38***b* and **38***c* passes through the second surface **32** (these multiple reflected rays are not shown in FIG. **1** for purposes of clarity).

[0029] In the embodiment of the invention shown in FIG. **2**, the rays **37**, **37***a*, **37***b* and **37***c* shown in FIG. **1** are collective shown in FIG. **2** as ray **37**. With reference to FIG. **2**, the reflected rays **37** are incident on the receiver **25** positioned at the focal point or focal area of the shaped solar mirror **45**. The invention, however, is not limited thereto, and the invention contemplates directing the rays **37** to a secondary mirror, e.g. the secondary mirror **46** shown in FIG. **3**, positioned at the focal point or focal area of the shaped mirror **45**. In this instance, the rays **37** are incident on the secondary mirror **46** and are reflected from the secondary mirror **46** to a receiver, e.g. as disclosed in U.S. patent application Ser. No. 12/709,045 filed on Feb. 19, 2010.

[0030] As can be appreciated, the invention is not limited to the receiver **25**, and the receiver **25** can be any of the types used in the art to receive solar energy and convert the solar energy to electric energy or thermal energy. In one non-limiting embodiment of the invention the solar mirrors reflect solar energy in concentrated solar power (CSP) or concentrated photovoltaic (CPV) applications.

[0031] With reference to FIG. **3**, in a non-limiting embodiment of the invention, the secondary mirror **46** includes a flat transparent substrate **52**, e.g. a sheet of soda-lime-silicate glass or a sheet of transparent plastic having the opaque solar reflective coating **34** applied over major surface **54** of the transparent substrate **52**. The reflected solar rays **37** (see FIG. **2**) from the primary mirror **45** impinge on major surface **56** of the transparent substrate **52**, pass through the substrate **52** and are reflected by the opaque solar reflective coating **34** back through the transparent substrate **52** as the secondary rays **44** directed toward the receiver **25** as disclosed in U.S. patent application Ser. No. 12/709,045 filed on Feb. 19, 2010.

[0032] The discussion above regarding internally reflected solar rays **38** and **43** as the ray **36** is incident on, and passes, through the shaped transparent substrate **28** is applicable to the solar ray **37** incident on and passing through the major surface **56** of the transparent substrate **52** of the secondary mirror **46**.

[0033] Optionally, a protective plastic coating or film **57** can be provided over the reflective coating **34**. As is known in the art, the protective coating **57** protects the reflective coating **34** against damage from the environment, e.g. against scratches and chemical attack.

[0034] It can now be appreciated that the sun's rays **36** absorbed by the glass substrate **28** of the primary mirror **45** (FIG. **2**) and the glass substrate **52** of the secondary mirror **46** (FIG. **3**) reduces the solar energy incident on the receiver **25**. In the practice of the invention, the loss of solar energy by absorption is reduced at selected wavelengths by 20-35%, preferably 35-40% and more preferably by 40-45% by increasing the reflection of selected ones of absorbable wavelengths of the electromagnetic spectrum away from the glass substrates **28** and **52**. In this manner, the percent absorption of the selected ones of the absorbable wavelengths of the electromagnetic spectrum passing into the glass substrates **28** and **52** is reduced.

[0035] One non-limiting embodiment of the invention is practiced to reduce the percent absorption of the solar energy by the iron oxides, namely ferric oxide (Fe_2O_3) and ferrous oxide (FeO), in soda-lime-silica glass. The ferric oxide has its peak absorption in the wavelength range of 300 to 400 nm, and the ferrous oxide has its peak absorption in the wavelength range of 780-1550 nm, of the electromagnetic spectrum (see FIG. **4**), The graph of FIG. **4**, clearly shows that the peak absorption of ferric oxide in the wavelength range of 300-400 nm is much greater than the peak absorption of ferrous oxide in the wavelength range of 780-1550 nm. For purposes of clarity in the discussion of the invention, the ultraviolet wavelength range of the electromagnetic spectrum is greater than 0 to 380 nanometers ("nm"), the visible light wavelength range of the electromagnetic spectrum is greater than 380 to 780 nm, and the infrared energy wavelength range of the electromagnetic spectrum is greater than 780 nm.

[0036] As can be appreciated, as the weight percent of the ferric oxide and the ferrous oxide increases, the percent absorption increases. The invention, however, is not limited to weight percent of ferric oxide and ferrous oxide present in the glass substrate, and the benefits of the invention are realized with the presence of ferric oxide and of ferrous oxide in weight percents greater than zero.

[0037] The following experiment was conducted to measure the improvement in reflected solar energy by the practice of the invention. A piece of glass of the type sold by PPG Industries Inc. under the trademark SOLARPHIRE PV had an opaque silver reflecting coating on a first major surface. The glass having the silver coating is hereinafter referred to as "Sample 1". The glass of Sample 1 had a weight percent of ferric oxide (Fe_2O_3) of 0.0047, and a weight percent of ferrous oxide (FeO) of 0.0033. A piece of soda-lime-silica glass (hereinafter referred to as "Sample 2") having a thickness of 0.125 inch (0.32 centimeter), and a weight percent of ferric oxide (Fe_2O_3) of 0.058, and a weight percent of ferrous oxide (FeO) of 0.027 was positioned on the second major surface of Sample 1; the second major surface of Sample 1 was opposite to the silver coated first major surface of Sample 1. A liquid film of index matching oil having an index of refraction of 1.52 was provided between and in contact with the second major surface of Sample 1 and the surface of the Sample 2 to eliminate index of refraction changes as the rays of solar energy pass between the adjacent surfaces of Sample 1 and Sample 2. The reflected solar energy of laminated Sample 1 and Sample 2 (hereinafter also referred to as "Laminate 1") in the wavelength of 300 to 2500 nm of the electromagnetic spectrum was measured using a PerkinElmer Lambda 950 spectrophotometer. The reflected solar energy for Laminate 1 for the wavelength range of 300 to 2500 nanometers of the electromagnetic spectrum is shown in the graph of FIG. **5**, and the reflected solar energy for Laminate 1 for the wavelength range of 300 to 400 nanometers of the electromagnetic spectrum is shown in the graph of FIG. **6**.

[0038] Sample 1 and Sample 2 were separated. A piece of glass having a titanium oxide coating on a first major surface and an uncoated opposite second surface (hereinafter referred to as "Sample 3") was provided. The composition of the glass and the thickness of Sample 3 was the same as the composition of the glass and thickness of the glass of Sample 2. The titanium oxide coating of Sample 3 had a thickness of 25 to 30 nm, and the titanium oxide was applied by the chemical vapor deposition coating method and was of the type disclosed in U.S. Pat. No. 7,049,022, which patent in its entirety is incorporated herein by reference. The coated glass described above was selected as the transparent reflective coating for Sample 3 because it has a high reflectance in the wavelength range of 300-400 nanometers of the electromagnetic spectrum. More particularly, the graph of FIG. **7** shows Sample 3 having a reflectance peak of 55% at a wavelength of 350 nm of the electromagnetic spectrum, which is within the peak absorption range for the ferric oxide (see FIG. **4**), and a reflectance in the range of 9.5-15% in the wavelength range of 780-1550 nm, which is the peak absorption range for the ferric oxide (see FIG. **4**).

[0039] The uncoated second surface of Sample 3 was positioned on the uncoated second major surface of Sample 1. The film of index matching oil was provided between and in contact with the uncoated second surface of Sample 3 and uncoated second major surface of Sample 1. The reflected solar energy in the wavelength of 300 to 2500 nanometers of laminated Sample 1 and Sample 3 (hereinafter also referred to as "Laminate 2") was measured using the Perkin Elmer Lambda 950 spectrophotometer. The reflected solar energy for Laminate 2 is shown in the graphs of FIGS. **5** and **6**.

[0040] Graphs of FIGS. **5** and **6** show the reflectance vs. wavelength to be about the same in the wavelength range of 400 to 2500 nanometers, and a significant difference in the range of 300 to 400 nanometers. More particularly, Laminate 1 has a reflection of about 5% in the wavelength range of 300-325, and the Laminate 2 has a reflection in the range of 46-55% in the wavelength range of 300-325 nanometers. Table 1 below shows the percent reflectance for Laminate 1 and Laminate 2. The reflected solar energy was measured using the Perkin Elmer Lambda 950 spectrophotometer. The values are based on ISO 9050, 2003 methodology with wavelength ranges of 300 to 380 nm for the ultraviolet range ("UV"), greater than 380 to 780 nm for the visible range ("VIS"), greater than 780 to 2500 nm for the infrared range ("IR"), and 300 to 2500 nm for the total solar energy range ("TS") range of the electromagnetic spectrum.

TABLE 1

	Reflectance in %			
	UV	VIS	IR	TS
Laminate 1	55.95	92.98	72.3	80.93
Laminate 2	70.23	92.97	72.3	81.44

The change in reflectivity in the VIS and IR ranges were minor; however this is acceptable because the peak absorption of FeO is low in the VIS and IR ranges, e.g. a linear absorption coefficient of less than 9 in the wavelength range of greater than 380-1550 nm, and the titanium oxide at a thickness of 25-30 nm has a reflectance of less than 12% in the wavelength of 780-1550 nm. As can be appreciated from the data of the Table 1, the practice of the invention increased the TS reflectance by 0.6% and increased the UV reflectance by 25.5%.

[0041] With reference to FIG. **8**, there is shown a cross section of a solar mirror **80** incorporating features of the invention. The solar mirror **80** includes glass substrate **81** having the opaque reflective film **34** on the second surface **32** of the glass substrate **81** and reflective coating **82** of the invention on the first surface **30** of the glass substrate **81**. The reflective coating **82** in this non-limiting embodiment of the invention is a titanium oxide coating **82** having a thickness of 90 nm. For purposes of discussion and not limiting to the invention, the glass substrate **81** having the opaque reflective coating **34** is referred to as subassembly **84**.

[0042] With reference to FIGS. **9** and **10**, the reflectance of the subassembly **84** (the glass substrate **82** without the coating **82** and with the opaque reflective film **34**) is shown by Curve A, and the reflectance of the subassembly **84** having the coating **82** is shown by Curve B. The reflectance of Curve A and of Curve B over the wavelength range of 300-1610 nm was obtained using a proprietary software program developed by PPG Industries, Inc. using historical data from glass substrates and titanium oxide films deposited on glass substrates. The upper wavelength range limit of 1610 nm was selected as a cutoff because the peak absorption for the ferric iron is in the wavelength range of 300-400 nm; the peak absorption for the ferrous iron is in the wavelength range of 780-1550 nm, and the historical values beyond wavelengths of 1610 nm were considered too random. The reflectance for the wavelengths in the range of 1610-2500 shown in FIG. **10** is a linear extension of the reflectance at the wavelength of 1610 where the calculated reflectivity values for the Curve A and for Curve B converge.

[0043] Table 2 below shows the percent reflectance for the subassembly **84** and the subassembly **84** having the titanium oxide coating **82**. The values are based on ISO 9050 (2003) methodology with wavelength ranges of 300 to 380 nm for the ultraviolet range ("UV") greater than 380 to 780 nm for the visible range ("VIS"), greater than 780 to 2500 nm for the infrared range ("IR"), and 300 to 2500 nm for the total solar energy range ("TS"). The reflected UV, VIS, IR and TS were calculated using ISO 9050 (2003) methodology.

TABLE 2

	Reflectance in %			
	UV	VIS	IR	TS
Subassembly 84	59.26	93.84	70.51	80.60
Subassembly 84 with coating 82	60.78	93.92	73.82	82.31

With reference to Table 2, the reflectance change in the UV is an increase of 2.5%; in the VIS is an increase of less than 0.01%; in the IR is an increase of 4.6%, and in the TS is an increase of 2.1%. With reference to Tables 1 and 2, increasing the thickness of the titanium oxide film reduced the percent increase in reflectance in the UV and increased the percent reflectance in the TS.

[0044] As can be appreciated, the invention is not limited to the thickness of the titanium oxide coatings **66** and **82**, and the thickness of the titanium oxide coating should be selected to maximize the total solar energy reflected by the solar mirror. Although not limiting to the invention, the invention contemplates having the titanium oxide coating in the thickness range 25-125 nm, preferably in the thickness range of 30-100 nm and most preferably in the thickness range of 35-95 nm.

[0045] In another non-limiting embodiment of the invention, a solar collector **86** coated in accordance to the teachings of the invention is shown in cross section in FIG. **11**. The solar collector **86** includes the glass substrate **81** having the opaque reflective coating **34** (subassembly **84**) on the second surface **32** of the glass substrate **81** and a transparent reflective coating **88** on the first surface **30** to increase the reflectance of wavelengths in the wavelength range of greater than 780-1550 nm, which is the peak absorption wavelength range of the ferrous oxide (see FIG. **4**). The coating **88** is a stack of three dielectric films **90-92**, which includes a 90 nm thick titanium oxide film **90** provided on or over the first surface **30** of the glass substrate **81**, a 90 nm thick silicon oxide film **91** provided on or over the titanium oxide film **90**, and a second 90 nm thick titanium oxide film **92** provided on or over the silicon oxide film **91**.

[0046] With reference to FIGS. **9** and **10** as needed, the percent reflectance of the subassembly **84** (Curve A) and of the subassembly **84** having the coating **88** (Curve C) over the wavelength range of 300-1610 nm was obtained using the proprietary software program developed by PPG Industries, Inc. discussed above. The reflectance for the wavelengths in the range of 1610-2500 shown in FIG. **10** is a linear extension of the reflectance at the wavelength 1610 nm where the calculated reflectance values for the subassembly **84** (Curve A), the coated subassembly **80** (Curve B) discussed above, and the coated subassembly **86** (Curve C) converge.

[0047] Table 3 below shows the percent reflectance for the subassembly **84** of the solar mirror **86** and the subassembly **84** having the coating **88** of the solar mirror **86**. The values are based on ISO 9050 (2003) methodology with wavelength ranges of 300 to 380 nm for the ultraviolet range ("UV") greater than 380 to 780 nm for the visible range ("VIS"), greater than 780 to 2500 nm for the infrared range ("IR"), and 300 to 2500 nm for the total solar energy range ("TS") range of the electromagnetic spectrum. The reflected UV, VIS, IR and TS were calculated using ISO 9050 (2003) methodology.

TABLE 3

	Reflectance in %			
	UV	VIS	IR	TS
Subassembly 84	59.26	93.84	70.51	80.60
Subassembly 84 with coating 88	55.64	94.02	74.85	83.15

With reference to Table 3, the percent reflectance change between the subassembly **84** and the subassembly **84** having the coating **88** is a decrease of 6% in the UV; is an increase of 1% in the VIS; is an increase of 6% in the IR, and is an increase of 3% in the TS. The subassembly **84** having the coating **88** (FIG. **11**) has a greater percent reflectance increase in the TS than the subassembly **84** having the coating **82** (FIG. **8**) because of the percent increase of reflectance in the VIS and the IR ranges.

[0048] The embodiments of the coatings of the invention are not limited to the non-limiting embodiments of the invention discussed above to increase the total solar energy reflected by a solar mirror by increasing the percent reflectance of the wavelengths in the wavelength ranges of ferric and ferrous iron. As is appreciated, ferric and ferrous irons are colorants which impart optical properties to the glass, e.g. as disclosed in, but not limited to U.S. Patent Publication No. 2007-0243993. The invention, however, is not limited to increasing the reflectance of the wavelengths for ferric and ferrous irons, and can be used to increase the reflectance of other colorants, e.g. but not limited to cobalt oxide (CoO), selenium (Se), chromium oxide (Cr_2O_3), neodymium oxide (Nd_2O_3), titanium oxide (TiO_2), erbium oxide (Er_2O_3) and nickel oxide (NiO). Further, the invention in is not limited to the reflective coatings discussed herein, and other coating stacks of dielectric layers, e.g. as disclosed in Australian Patent No. 758267 can be used in the practice of the invention. The Australian patent in its entirety is hereby incorporated by reference.

[0049] Further the invention contemplates applying one coating to increase the reflectance of the absorbable wavelength of one colorant, e.g. the ferric iron, and a second coating to increase the reflectance of the absorbable wavelength of another colorant, e.g. ferric iron. Increasing the number of coating to increase the reflectance of solar energy can decrease the transmission of solar energy through the glass substrate to be reflected from the opaque reflective coating **34**. In selecting the transparent reflective coating, the reflection and transmission of the solar energy in the different wavelength ranges for the UV, VIS and IR have to be balanced to optimize the total solar energy reflected by the solar mirror. In other words, the transparent reflective coating on the first surface of the solar mirror should increase the reflectance of the absorbable wavelengths and increase the total solar energy reflected by the solar mirror toward the converting device **25** (see FIG. **2**).

[0050] As can be appreciated, the invention is not limited to the manner in which the transparent reflective coating **66** (FIG. **2**, **82** (FIG. **8**) and **88** (FIG. **11**) is applied to the glass substrate. In the preferred practice of the invention the coating is applied to a glass ribbon as it passes through a flat glass forming chamber as discussed in U.S. Pat. No. 5,356,718, or applied to the glass ribbon as it passes from the float glass forming chamber to an annealing lehr as discussed in U.S. Pat. Nos. 4,111,150 and 4,719,126. Further, the transparent reflective coating of the invention can also be applied to the glass by the magnetron sputtering vacuum deposition coating process (also known as "MSVD"), e.g. as disclosed in U.S. Pat. No. 7,323,249. The titanium coating used in the practice of the invention is of the type disclosed in U.S. Pat. No. 7,049,022, and the dielectric coating **88** is of the type disclosed in Australian Patent. No. 758267. U.S. Pat. Nos. 4,111,150; 4,719,126; 5,356,718; 7,049,022, and 7,323,249 in their entirety are incorporated herein by reference.

[0051] In another non-limiting embodiment of the invention, the transparent reflective coating of the invention, e.g. the titanium oxide coatings **66** and **82** are sodium ion barriers that prevent, or limit, sodium ions from leeching out of the soda-lime-silica glass. The sodium ions leeching out of the glass react with moisture in the atmosphere, which moisture converts sodium ions to sodium compounds, e.g. sodium hydroxide and sodium carbonate. The sodium compounds can etch the surface of the glass sheet and can deposit as a precipitate on the surface of the glass substrate. The sodium compound precipitates on the glass surface decrease the transmission of solar energy through the glass substrate, decreases the transmission of the solar energy reflected from the reflective coating **34** and changes the specular concave surface **30** of the shaped substrate **28** (see FIG. **2**) and the specular surface **56** of the flat glass substrate **52** (see FIG. **3**) to a non-specular or diffusing surface. The term "specular surface" as used herein means a light reflective surface where a light ray incident on the reflective surface has an angle of incident equal to the angle of reflection. The term "non-specular or diffusing surface" as used herein means a reflective surface where a light ray incident on the reflective surface has an angle of incident different from the angle of reflection. Titanium films having a thickness of 50 nm (500 angstroms) provide a barrier to prevent or limit sodium ions reacting with the atmosphere.

[0052] Attention is directed to U.S. patent application Ser. No. 12/709,045 filed on Feb. 19, 2010 for a more detailed discussion of sodium ions leeching out of the soda-lime-silica glass and techniques for applying, sodium ion barrier coating to prevent buckling and fracturing of the barrier coating during a glass shaping process to shape a coated flat piece of glass to a parabolic shaped piece of glass. U.S. patent application Ser. No. 12/709,045 in its entirety is hereby incorporated by reference.

[0053] As can now be appreciated, the invention is not limited to the percent reflectance of the transparent reflective coating in the wavelength range desired to be reflected. More particularly, the reflectance can be equal to or more than 10%, preferably equal to or greater than 35%, most preferably equal to or greater than 50%.

[0054] As can now be appreciated, the invention can be used with other articles to reduce the absorption of wavelengths, e.g. windows. Further, in another non-limiting embodiment of the invention, the transparent first surface mirror can also selectively reflect wavelengths of light, for example ultraviolet light, that can be harmful to the substrate, for example transparent polymeric substrates, or the layers of material deposited on the second surface of the mirror.

[0055] As can be appreciated, the invention is not limited to the embodiments of the invention discussed herein, and the scope of the invention is only limited by the scope of the following claims.

What is claimed is:

1. In a solar reflecting mirror of the type having a transparent substrate having a first surface designated to face a source of solar energy and a second surface opposite to the first surface, the second surface designated to face away from the source of solar energy, wherein the glass substrate has a composition comprising an ingredient that absorbs one or more wavelengths of the electromagnetic spectrum defined as absorbable wavelengths, and an opaque solar reflecting coating on the second surface of the glass substrate, the improvement comprising:

a transparent reflecting coating over the first surface of the substrate to increase the percent reflection of one or more of the absorbable wavelengths of the electromagnetic spectrum in a direction away from the first and the second surface of the transparent substrate.

2. The solar reflecting mirror according to claim **1**, wherein the substrate is a glass substrate.

3. The solar reflecting mirror according to claim **2**, wherein the absorbable wavelengths are in the wavelength range of 300-2500 nm.

4. The solar reflecting mirror according to claim **3**, wherein the absorbable wavelengths are in the range of 300-400 nanometers.

5. The solar reflecting mirror according to claim **4**, wherein the ingredient that absorbs one or more wavelengths of the electromagnetic spectrum is ferric iron.

6. The solar reflecting mirror according to claim **5**, wherein the coating is a titanium oxide film on the first surface of the glass substrate.

7. The solar reflecting mirror according to claim **6** wherein the titanium oxide film has a thickness in the range of 25-125 nanometers.

8. The solar reflecting mirror according to claim **7** wherein the titanium oxide film has a thickness of 25 nanometers.

9. The solar reflecting mirror according to claim **7** wherein the titanium oxide film has a thickness of 90 nanometers.

10. The solar reflecting mirror according to claim **2**, wherein the absorbable wavelengths are in the wavelength range of 780-1550 nanometers.

11. The improved solar mirror according to claim **10**, wherein the ingredient that absorbs one or more wavelengths of the electromagnetic spectrum is ferrous iron.

12. The solar reflecting mirror according to claim **11**, wherein the coating is a dielectric coating stack.

13. The solar reflecting mirror according to claim **12** wherein the dielectric coating stack comprises a first titanium oxide film on the first surface of the glass substrate, a silicon oxide film over the first titanium oxide film and a second titanium oxide film over the silicon oxide film.

14. The solar reflecting mirror according to claim **13** wherein the first and second titanium oxide films and the silicon oxide film have a thickness in the range of 80-100 nanometers.

15. The solar reflecting mirror according to claim **14** wherein the silicon oxide film is on the first titanium oxide film, the second titanium oxide film is on the silicon oxide film, and the first and the second titanium oxide film and the silicon oxide film have a thickness of 90 nanometers.

16. The solar reflecting mirror according to claim **3**, wherein the absorbable wavelengths are in the range of 300-400 nanometers and in the range of 780 to 1550 nanometers.

17. The solar reflecting mirror according to claim **16**, wherein the ingredient that absorbs one or more wavelengths of the electromagnetic spectrum in the wavelength range of 300-400 nanometers is ferric iron; the ingredient that absorbs one or more wavelengths of the electromagnetic spectrum in the wavelength range of 780-1550 nanometers is ferrous iron, and the coating is a dielectric coating stack.

18. The solar reflecting mirror according to claim **17** wherein the dielectric coating stack comprises a first titanium oxide film on the first surface of the glass substrate, a silicon oxide film over the first titanium oxide film and a second titanium oxide film over the silicon oxide film.

19. The solar reflecting mirror according to claim **2** wherein the ingredient that absorbs one or more wavelengths of the electromagnetic spectrum is a colorant that provides the glass substrate with optical properties.

20. A solar reflecting mirror, comprising:

a glass substrate having a second surface designated to face away from the source of solar energy and a first surface opposite to the second surface, wherein the glass substrate has a composition comprising an ingredient that absorbs one or more wavelengths of the electromagnetic spectrum defined as absorbable wavelengths;

an opaque solar reflecting coating applied to the second surface of the glass substrate, and

a transparent reflecting film to reflect one or more of the absorbable wavelengths of the electromagnetic spectrum.

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DEMANDE
DE BREVET D'INVENTION

㉑ **N° 79 29706**

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(54) **Réflecteur sur tour pour centrales solaires à concentration.**

(51) Classification internationale. **(Int. Cl 3) F 03 G 7/02; F 24 J 3/02.**

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La présente invention concerne un réflecteur sur tour pour centrales solaires à concentration en deux étages du rayonnement.

Les centrales solaires de ce type sont connues, comme l'indique par exemple la revue SPIE, volume 68 (1975) Solar Energy Utilization, pages 85 et suivantes. Elles représentent une transposition du concept des absorbeurs sur tour déjà réalisés, dont traite la revue Brennstoff-Wärme-Kraft 28 (1976) n° 12, pages 470 à 473.

Les figures 1 et 2 rendent compte schématiquement du niveau de la technique. Dans le type d'absorbeur sur tour de la figure 1, une batterie d'héliostats 11 en genre de miroir de Fresnel géant, d'un diamètre de plusieurs centaines de mètres, concentre la lumière solaire directe dans un absorbeur sur tour 12. La tour 16 a une hauteur imposante, que l'on a déjà envisagé de porter à 450 mètres. Un fluide caloporteur est refoulé par une pompe, à travers des conduites 13, vers l'absorbeur placé au sommet de la tour, dans lequel il se trouve chauffé et d'où il parvient à un générateur de vapeur 14 implanté au pied de la tour 16. La vapeur est ensuite utilisée de façon classique pour entraîner une turbine 15.

Les inconvénients des centrales à absorbeur sur tour sont évidents : la tour doit être construite de façon très stable afin de pouvoir porter l'asorbeur; les canalisations, éléments de robinetterie et pompes nécessaires abaissent le rendement; les travaux d'entretien et de mise en état aux alentours de l'absorbeur sont compliqués et prennent beaucoup de temps.

Ces inconvénients, et bien d'autres encore, ont conduit à la solution selon la figure 2 qui est à la base de l'invention. Au lieu de placer l'absorbeur 12 au sommet de la tour, on le pose sur le sol 17, ce qui simplifie déjà considérablement la construction de l'installation. Un réflecteur 20 fixé au sommet de la tour renvoie vers l'absorbeur 12, au sol, la lumière solaire 10 concentrée par la batterie d'héliostats 11. Conduites principales, pompes et autres accessoires sont ainsi supprimés. Le réflecteur 20 peut en outre être établi de manière à assurer une meilleure concentration de la lumière solaire et par conséquent un rendement plus élevé. Cela permet d'être moins exigeant quant à la précision des héliostats et de leur mouvement de poursuite du soleil. Enfin, l'absorbeur peut être intégré avec un accumulateur.

L'invention a pour objet un réflecteur sur tour efficace qui se construise aisément et garantisse par des moyens simples de longues durées de vie, notamment pour la métallisation.

Ce réflecteur sur tour est caractérisé par un mode de construction tel que la métallisation soit appliquée sur une structure profilée qui permet un refroidissement actif et à laquelle est fixable un élément-support.

Dans un mode de réalisation préféré de l'invention, la structure profilée galvanisable est constituée par un matériau de haute conductibilité thermique et la métallisation est électrodéposable, tandis qu'à la face arrière de ladite structure profilée se rattache un revêtement continu réalisé électrolytiquement qui forme des canaux de refroidissement et qui est suivi d'un blindage électrodéposé de haute portance pour la fixation de l'élément-support.

Suivant d'autres particularités possibles de l'invention : la structure profilée est réalisable de façon entièrement électrolytique aussi bien à l'égard de la forme donnée à la métallisation que des canaux de refroidissement; la métallisation est applicable sur une structure soudée en tubes profilés; un fluide caloporteur est transportable, pour le refroidissement actif, à travers les canaux appropriés et utilisable pour une production d'énergie.

La réalisation par voie électrolytique permet d'obtenir, et de maintenir par le refroidissement actif pendant l'utilisation, la précision de surface nécessaire du point de vue optique d'une façon particulièrement simple. La surface réfléchissante est maintenue constamment à une basse température, si bien que l'on évite des pertes de rayonnement. La structure légère et rigide autorise des tours de construction également légère et moins coûteuse . Le refroidissement actif permet, de plus, de recourir, par des conduites de relativement faible section, au fluide caloporteur pour couvrir les besoins électriques propres de la centrale.

Cette consommation propre pouvant très bien représenter 10% et plus de la puissance de la centrale, la chaleur à dériver est réglable par un choix judicieux du coefficient d'absorption de la métallisation. D'où l'avantage auxiliaire de pouvoir renoncer d'emblée à des revêtements coûteux, et sensibles aux intempéries, propres à abaisser le coefficient d'absorption.

L'invention sera mieux comprise à l'aide de la description détaillée d'un mode de réalisation pris comme exemple non limitatif et illustré schématiquement par le dessin annexé, sur lequel :

la figure 3 définit une structure d'ensemble du réflecteur sur tour ;

la figure 4 correspond à une réalisation électrolytique de la structure du réflecteur;

la figure 5 concerne une réalisation soudée;

la figure 6 représente une installation comportant des dispositifs propres à couvrir sa consommation propre.

Selon la figure 3, les composants essentiels du réflecteur sur tour 20 sont une structure refroidie 21 et un élément-support 22 réalisé, de façon connue, en construction légère;

La figure 4 représente de façon plus détaillée la structure de réflecteur 21 réalisée par voie électrolytique. Elle se compose d'une métallisation 23, par exemple d'argent, et d'une structure profilée 24 qui, d'une part, définit une courbure éventuelle du réflecteur et, d'autre part, accueille, sur sa face arrière, des canaux de refroidissement 25. Cette structure profilée 24 est réalisée, de façon connue, par pure électrolyse sur des corps de forme voulue.

Un revêtement 26 est également électrodéposé de manière à fermer les canaux de refroidissement 25. Ceux-ci parcourent en genre de méandres le corps profilé 24 de façon non représentée. On choisit pour ce corps profilé et son revêtement un matériau de haute conductibilité thermique, par exemple du cuivre ou un alliage de cuivre.

Pour conférer à l'ensemble une portance suffisante, on apporte sur lui, également par voie électrolytique, un blindage 9. On peut utiliser à cet effet, comme matériau de haute rigidité, du chrome ou du nickel par exemple. Le blindage 9 sert en outre à la fixation de la structure porteuse 22 par vissage ou autre moyen analogue.

Les canaux de refroidissement 25 de la structure profilée 24 peuvent bien entendu aussi être réalisés par fraisage, électro-érosion ou autres méthodes analogues connues.

La figure 5 représente un variante dans laquelle on utilise une structure soudée à partir de tubes profilés 27. La métallisation 23 est appliquée directement sur les tubes profilés 27 amenés auparavant à la courbure voulue.

La figure 6 donne le schéma d'une réalisation couvrant sa consommation propre. Des conduites 28 transportent un fluide caloporteur approprié vers le réflecteur et, de là, vers un générateur de vapeur 29 suivi de façon classique d'une turbine 20 qui produit le courant.

REVENDICATIONS

1. Réflecteur sur tour pour centrales solaires à concentration en deux étages caractérisé par le fait que ledit réflecteur (21) est construit en sorte que la métallisation (23) soit appliquée sur une structure profilée (24) permettant un refroidissement actif.

2. Réflecteur sur tour selon la revendication 1 caractérisé par le fait qu'un élément-support (22) est fixable sur la structure profilée (24).

3. Réflecteur sur tour selon la revendication 1 caractérisé par le fait que la structure profilée galvanisable (24) est composée d'un matériau de haute conductibilité thermique, que la métallisation (23) est électrodéposable et qu'à la face arrière de cette structure profilée (24) se rattache un revêtement continu (26) réalisé par voie électrolytique et formant des canaux de refroidissement (25) qui est suivi d'un blindage électrodéposé de haute portance pour la fixation de l'élément-support (22).

4. Réflecteur selon la revendication 2 caractérisé par le fait que la structure profilée (24) est réalisable par voie entièrement électrolytique, aussi bien à l'égard de la forme donnée à la métallisation que des canaux de refroidissement (25).

5. Réflecteur sur tour selon la revendication 1 caractérisé par le fait que la métallisation (23) est applicable sur une structure soudée en tubes profilés (27).

6. Réflecteur sur tour selon l'une quelconque des revendications 1 à 5 caractérisé par le fait qu'un fluide caloporteur est transportable, pour le refroidissement actif, à travers les canaux de refroidissement (25) et utilisable pour produire de l'énergie.

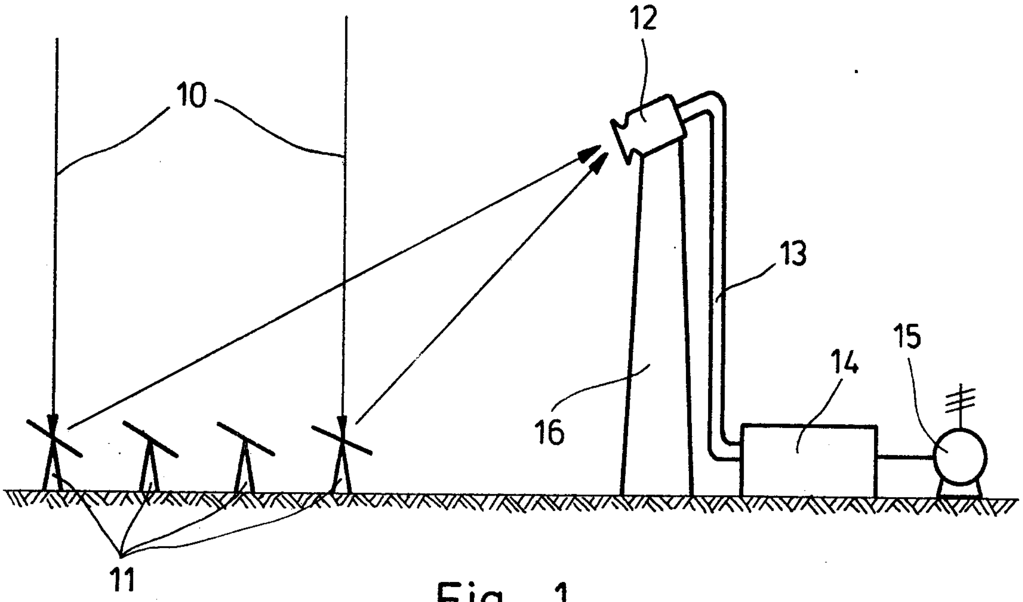

Fig. 1

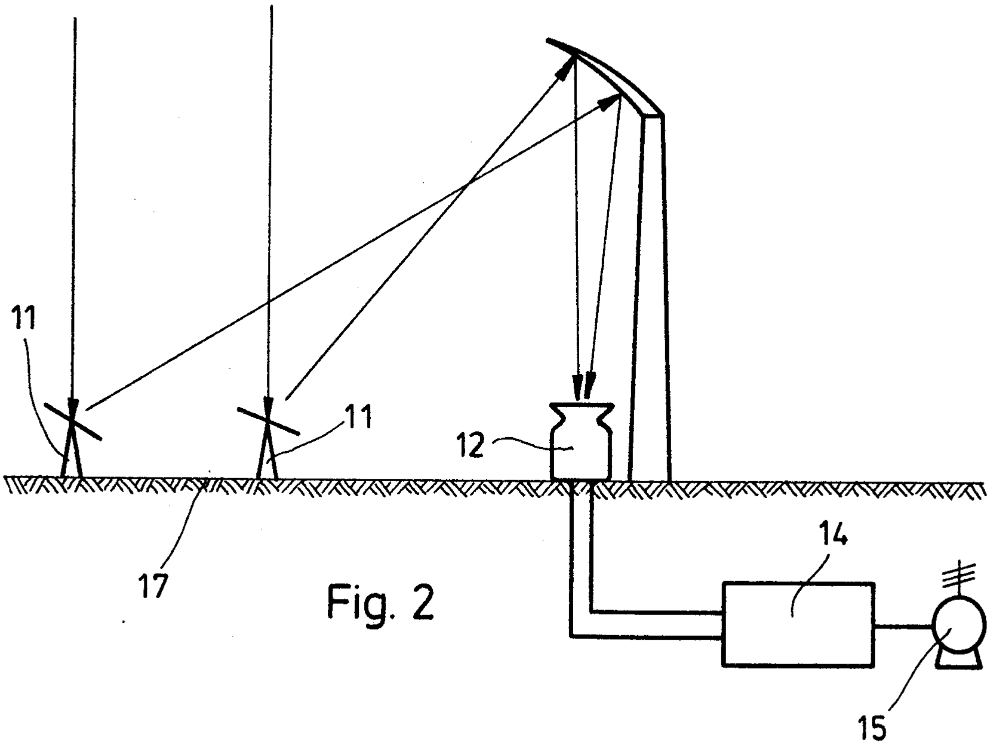

Fig. 2

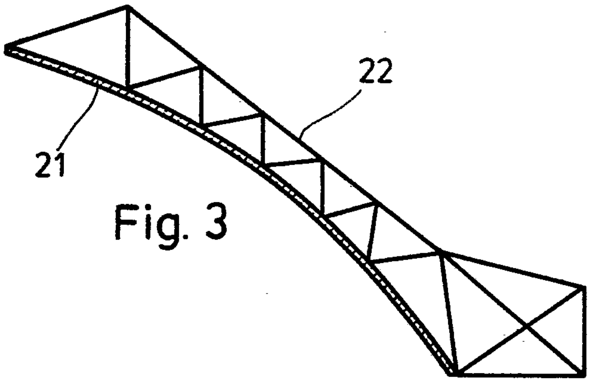

Fig. 3

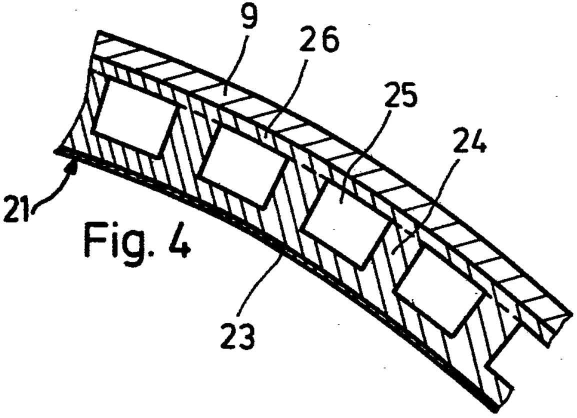

Fig. 4

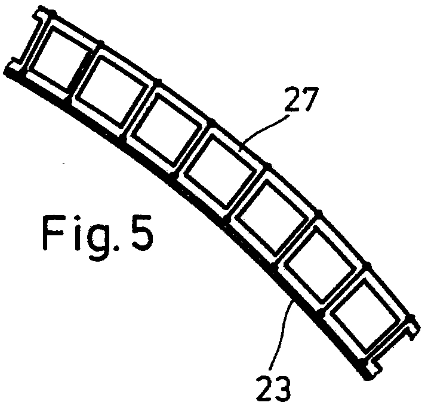

Fig. 5

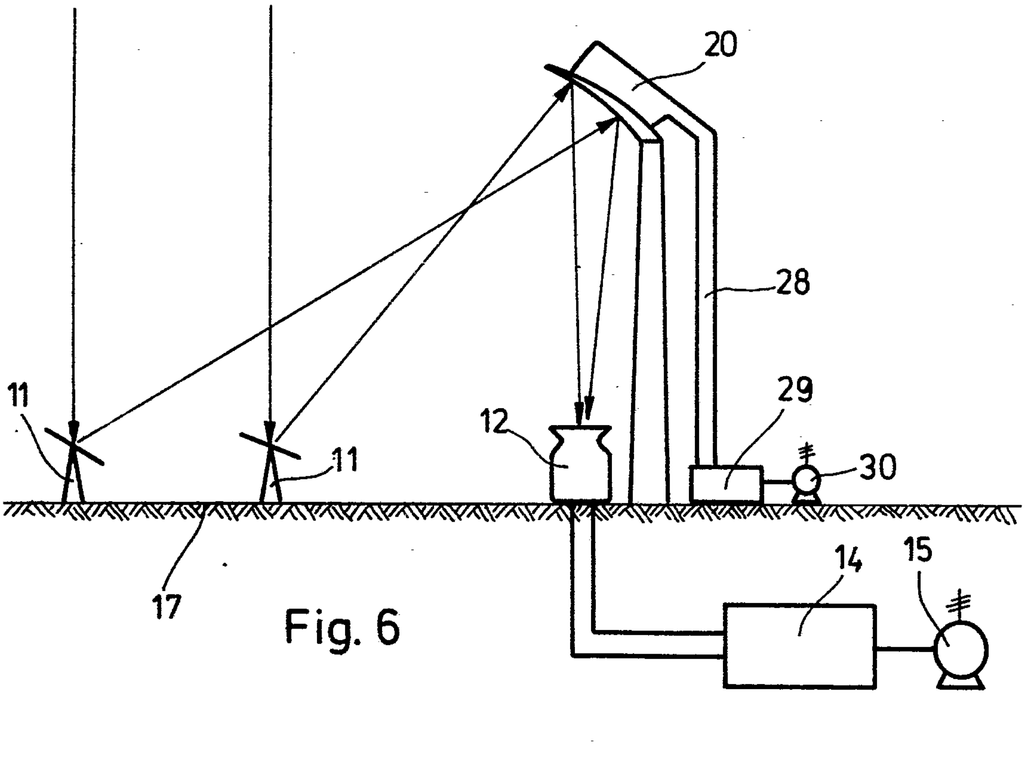

Fig. 6

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Declarations under Rule 4.17:

[Continued on next page]

(54) **Title**: SOLAR CONCENTRATOR AND ASSOCIATED ENERGY CONVERSION APPARATUS

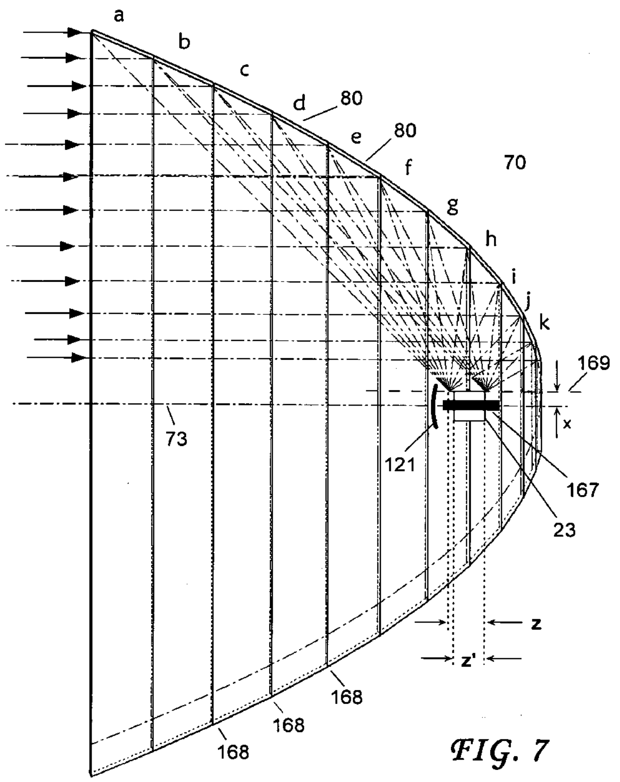

FIG. 7

(57) **Abstract**: The disclosed invention relates to apparatus utilized for concentrated solar power, and more particularly, high-concentration reflective concentrators that are constructed as a compound concentrator utilizing flexible high-reflectance layers that are produced by roll-to-roll manufacturing. In its first preferred embodiment, the disclosed solar concentrator is utilized in conjunction with a solar-energy conversion device located within the volume of the concentrator, and, in the first preferred embodiment, this device is solar-thermal receiver tube utilizing absorbing media wherein absorption occurs at a liquid-particle interface, whereby the limitations of Kirchhoffs Law are circumvented and emissive losses are minimized. In another embodiment, the disclosed concentrator is utilized to irradiate a modular assembly housing an array of multi-junction photovoltaic modules. Various other solar-energy conversion devices are disclosed for use in the disclosed apparatus.

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- *of inventorship (Rule 4.17(iv))*

Published:

- *with international search report (Art. 21(3))*
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SOLAR CONCENTRATOR AND ASSOCIATED ENERGY-CONVERSION APPARATUS

Technical Field

The present invention is related to and claims the benefit of U.S. provisional patent application 61/396.387 (Hilliard), filed May 26, 2010, U.S. provisional patent application 61/397,275 (Hilliard), filed June 08, 2010, U.S. provisional patent application 61/455,576 (Hilliard), filed October 23, 2010, U.S. nonprovisional patent application 12/803,213 filed June 21, 2010, and PCT application PCT/US2011/000050 filed January 11, 2011, all of which applications are, in their entirety, incorporated herein by reference. The present invention relates in general to concentrated solar power and associated solar energy conversion apparatus that benefit from irradiation by high-concentration solar concentrators. More particularly, the invention relates to solar-reflective concentrators, and associated reflective components, having a concentric dish structure wherein solar radiation reflected by the concentrator is directed to a receiver apparatus located centrally in the cavity formed by the concentrator.

Background Art

A primary obstacle in the commercialization of solar energy conversion devices, whether with regards to solar-thermal, solar photovoltaic's, concentrated solar systems, etc, comprises the need to simultaneously minimize manufacturing costs while maintaining physical tolerances and durability necessary to retain a desired efficiency and device lifetime. In segments of the solar energy industry utilizing a solar concentrator or condenser, the challenge to reduce manufacturing costs is most significant in the solar collector design, as the component generally requiring the greatest materials expense. A crowded array of art has been introduced to address this challenge, including, broadly speaking, such relatively large solar concentrators as linear trough systems and linear Fresnel systems, dish systems including parabolic and compound reflectors. Also, various, typically in conjunction with photovoltaics, concentrators have been utilized in solar panels that incorporate a periodic array of concentrators that couple to a receiver. Within these broad groups of concentrating means are utilized a vast assortment of optical designs that, while utilizing well-known refractive, diffractive, and reflective properties of well-known and understood optical components, are primarily advanced on the basis of a particularly advantageous manufacturing approach involving a proprietary geometric optics design, which in turn is expected to deliver a desirable cost per kilowatt delivered.

A problem with these various solar concentrators of the prior art is their reliance on proprietary system components that require widespread adoption of a narrowly applicable optical system as a precondition to a projected cost performance. In addition, these system components are typically plagued by materials development issues that are unique to the particular system in question and its operational characteristics. These system-specific materials challenges result in circumstances wherein expending resources on materials development will be compensated only if the specific solar application addressed is successfully commercialized, thus increasing investment risks.

There is therefore a need in the solar industry for a solar concentrator that provides , relatively to previous designs, much higher strength-to-weight ratio and rigidity-to-weight ratio, this with a commensurate savings in manufacturing cost, and while providing an inherently high-precision tooling and manufacturing platform; in addition, it is more preferable that this solution be in a concentrator format that enables utilization broadly across numerous segments of the concentrating solar industry, so that such a concentrator is readily adaptable to both a wide range of concentration ratios and solar energy-conversion processes .

Disclosure of Invention

In accordance with the first preferred embodiments, a compound conical concentrator comprising a solar concentrating reflector is disclosed. In a first embodiment, a high-reflectivity (>90% reflectivity in visible spectrum) conical frustum is disclosed, comprising a conical frustum structure comprising a double-layered structure wherein parallel outer layers are separated by an integral, lightweight, networked structure comprising the mesh structure of a hollow core, preferably comprising a honeycomb-type core. In a major sectional profile taken through a plane containing the frustum's central axis, the frustum has opposite parallel surfaces in the form of a parallelogram; the double-layer structure comprising opposing inner and outer surfaces of the conic frustum, the first surface and second surface roughly parallel the inner surface preferably having an optical reflectivity of at least 90%, preferably with a divergence of inner surface of less than 1% from the associated, theoretically ideal frustum surface.

The inner core of the embodied frustum preferably comprises a plurality of concentric and parallel ring-shaped surfaces extending between inner frustum surface and outer frustum surface, the ring-shaped surfaces at a substantially uniform acute angle adjoining inner and outer frustum surfaces, wherein separated rings of the honey comb material are preferably sandwiched within the spaces formed between these concentric rings and between the inner and outer surfaces of the embodied frustum. The core mesh material is preferably an expanded core material between first and second surfaces, the expanded core material having a regular pattern of structural walls forming a regular pattern of open spaces, the walls roughly orthogonal to the ring-shaped surfaces, and in the preferred mode comprising an aluminum honeycomb structure. In addition, the preferred sectional profile of a parallelogram is provided by, in addition to parallel inner and outer surfaces of the frustum, parallel top and bottom edge-surfaces of the embodied frustum, which are accordingly parallel to one another, and more preferably have an orthogonal relationship with surfaces of the inner core materials comprising mesh core material and ring-shaped surfaces. The parallel top and bottom edge-surfaces of the embodied frustum are accordingly, preferably, orthogonal to the optical axis of the conic frustum, or alternatively such edge-surfaces are parallel to the frustum's optical axis and accordingly comprise cylindrical surfaces; in either case, such top and bottom edge-surfaces provide the preferred orthogonal relationship to surfaces of the inner core materials, with the preferred sectional profile of a parallelogram. The top and bottom, and preferably parallel edge-surfaces of the embodied stackable conic frustums comprise alignment surfaces for aligning and stacking a series of adjacent frustums in a coaxial arrangement.

Further embodied is a stackable conic frustum comprising a single conical section constructed of a single self-standing integral structure having substantially parallel inner and outer surfaces, the frustum comprising a composite layer of approximately uniform thickness, the frustum having an inner surface and outer surface comprised of a flexible sheet metal, the frustum having an inner core comprising a first multitude of first supporting members comprising a thin sheet material, the inner core comprising a multitude of second supporting members comprising a thin sheet material, the first supporting members having a roughly perpendicular relation to the second supporting members as determined in a sectional plane containing the optical axis of the frustum, wherein both first members and second members adjoin the flexible sheet metal so that the inner surface, first members, and second members are coordinated in a triangular formation.

Wherein the frustum is a network of interlocking tetrahedral structures, the tetrahedral structures characterized by continuous lengths of structural material – whether inner frustum surface layer, outer frustum surface layer, concentric ring-shaped surfaces, or mesh core material – interlinking vertices of the tetrahedral structures.

Thus an objective of the present invention is to provide a conical frustum incorporating tetrahedral reinforcement structures within the interior of each frustum, providing rigidity-enhancing tetrahedral structures formed at interfaces between embodied frustum surface cladding and the interior core structure of the frustum. The embodied interlocking tetrahedral reinforcing structure of the inventive conic frustums is advantageous over conventional honeycomb panels, since the tetrahedral space-frame geometry of the embodied frustums offers the highest intrinsic strength and rigidity for given mass over either prior art honeycomb panels or a square-pyramid space-frame, thus lowering potential of interfacial shear stress at the interface between core materials and the inner and outer surface cladding – or "skin" – of the embodied hollow-core frustum structure.

An objective of the presently embodied solar concentrating reflector is accordingly to provide an assembly of conical frustums that each have a sectional profile, as taken through a sectioning plane that contains the frustum's optical axis, which comprises a parallelogram, and wherein external surface of such a frustum accordingly comprise parallel inner and outer frustum surfaces as well as two parallel edge-surfaces, wherein edge surfaces are surface adjoining the inner and outer surfaces of the frustum at its top and bottom.

In a further embodiment, there is disclosed in the present invention a stacked compound conical concentrator (CCC) comprising a compressively loaded stack of coaxial frustum structures, the frustum structures each comprising a double-walled, hollow-core reinforced structure with reflective inner surface layer and having interior-core support members at acute angles to the reflector layer, the stack of frustum structures preferably compressed along its central optical axis by means of a plurality of flexible straps fastened at opposite ends to top and bottom regions of the frustum-stack comprising the CCC. The flexible straps are preferably maintained in a stretched condition (i.e, under tensile loading that is substantially equivalent to the preferred compressive loading of the stack) by means of an intermediate spacing/tensioning ring located substantially concentric to the optical axis and intermediate to upper and lower fastening means located at accordingly the top and bottom of the embodied CCC.

A telescoping CCC is further embodied that is disposed for rapid deployment and stowage, wherein a series of interlocking frustums is stowed in a contracted form that is preferably extended to its operating state by pulling a base section along the optical axis, whereby interlocking surfaces of the adjacent frustums are brought into a interfacing orientation, the frustums preferably prevented from over-extension by stopping surfaces, and registered to desired position by a plurality of retractable interlocking mechanisms. Self-alignment of the CCC structure is accomplished in relatively expedient manner by subsequently compressing the telescoping structure in its extended and interlocked position by means of a plurality of the tensioned straps (including cords, wires, cables, ropes, etc) that are evenly spaced for uniformly compressing the CCC along its optical axis, so that preferably the uniform and axial compressive force can cause deformation of the CCC only in accordance with a uniform axially directed force.

It is accordingly preferred, in the telescoping embodiments, that the individual conical frustums of the present invention are constructed so that upper and lower edge-surfaces of the frustum structures are terminated as a cylindrical surfaces having central axis coincident with the optical axis, so the reflective, inwardly facing frustum surface and outer-facing frustum surface are interconnected and terminated at both upper edge-surface and lower edge-surface by these adjoining cylindrical surfaces.

A method for making a clad conical frustum, comprising the steps of:
forming a preform structure, the preform structure comprising a multilayer stack of repeating layers, the layers alternating between layers of a substantially continuous sheet metal and layers comprising and an expanded metal core material; machining the structure to form a first parted surface of the preform, the first parted surface conical; laminating a reflective material layer to the first parted surface of the preform, the reflective material layer having a first reflective-layer side and a second reflective-layer side, the first reflective-layer side terminated with a high-reflectivity coating, the second reflective-layer side laminated to the first parted surface of the preform to form a supported reflective surface; performing a parting operation wherein the preform is parted so as to separate a conical frustum structure from the preform, the conical frustum having an inner conical surface formed by the reflective material, the conical frustum having a second parted side formed by the parting operation; and, laminating an outer frustum layer to the outer parted surface of the parted frustum structure to form the clad conical frustum, the clad frustum having an outer conical surface formed by the outer frustum layer, so that the clad frustum comprises a self-standing structure of substantially uniform thickness.

Preferably, the reflective material is laminated to the first parted frustum surface (a discontinuous surface) while this surface is still integral to the preform and provided its desired figure by finishing means. Lamination of the reflector material to the first parted surface then provides added rigidity to the immediately underlying preform structure, so that subsequent cutting of the second parted surface of the instant frustum, whereby the frustum is separated from the preform, may be conducted without undesired strain of the frustum structure.

In its first preferred embodiment, the disclosed concentrator is utilized for providing high-concentration (e.g., 500X) for irradiation of high-temperature solar-thermal receiver tubes, particularly those disclosed in the listed earlier co-pending applications by same author. In a further embodiment, associated solar energy conversion apparatus are disclosed that are seen as uniquely advantageous when utilized in combination with the disclosed CCC. Particularly, in an alternative preferred embodiment, a photovoltaic (PV) module comprising multiple multijunction photovoltaic (MJPV) arrays arranged on a faceted cylinder comprising bus leads and conductive cooling means. The embodied MJPV module is incorporated into the embodied tubulated hot-finger for irradiation by the CCC for combined heat and electrical power generation (CHP), wherein efficient cooling of the MJPV is performed by incorporation of an internal coaxial cooling conduit for cooling the MJPV module by oil or alternatively water, or a mixture thereof.

In a further preferred embodiment, the return path for the heat transfer fluid (HTF) of the present MJPV-CHP embodiment, comprises a substantially transparent return passage that comprises an annular passage-way surrounding the MJPV module, so that an HTF that is substantially transparent to solar radiation passes in front of the MJPV arrays (e.g., Ge/GaInP/GaAs), the HTF thereby being additionally heated by the concentrated solar radiation of the CCC. This present alternative MJPV-CHP embodiment is particularly advantageous for providing an HTF at considerably higher temperatures than the preferred operating temperature of the MJPV module (<100C). The embodied HTF in the annular transparent passage is further advantageous in its ability to be tailored to a specific absorption spectrum, so that, for example, IR radiation that is in excess of that to required for current-balancing of the MJPV array is absorbed by the HTF, rather than being absorbed by the MJPV so as to result in undesirable heating of the MJPV array. In this manner, the present alternative MJPV-CHP embodiment utilizing HTF-shielding of the MJPV array in conjunction with the preferred CCC, can be readily deployed utilizing an over-powered CCC (e.g., 700x suns), wherein the HTF can be tailored to optimize the spectral characteristics of the light that is actually incident upon the MJPV array.

The HTF-shielded MJPV/CHP allows for band-gap engineering of the MJPV module to be optimized for manufacturability rather than to precisely accommodate a specific soar spectrum (e.g., ASM 1.5D). This is seen as a further great advantage, since much of the cost of optimum MJPV modules is incurred by the introduction of lattice-matching layers, buffer layers, and nucleation layers that enable utilization of semiconductor materials that are optimum for a segment of the solar spectrum, but are not particularly compatible in a heteroepitaxial arrangement. Not only do these according heteroepitaxial MJPV structures incur additional manufacturing expenses in fabrication, there is also great expense incurred in losses due to higher defect levels resulting from lattice mismatch, and the consequent binning process whereby the lifetime and power rating of the MJPV module is determined. In the present embodiments, utilizing HTF-shielding, MJPV designers are provided a degree of freedom in that MJPV arrays may be manufactured with spectral characteristics optimized for more ideal lattice matching and robust MJPV processing, rather than a specific solar spectrum, Instead the

MJPV can be designed and manufactured to optimize a particular spectrum resulting from filtration of the solar spectrum by both the earth's atmosphere and the optimized HTF's spectral absorption, wherein the HTF's spectral absorption is, in turn, optimized for cost-effective manufacturing of the MJPV; in particular, by providing greatest transmission in the vicinity of each semiconductor material's band-edge, as well as by allowing relatively high optical transmission for spectral requirements of the MJPV junction that is most limiting to overall current through the MJPV (with junctions connected in series). In addition, an HTF's spectral absorption, in the present alternative embodiment, can be altered in real time to adjust to daily and seasonal changes, so that an algorithm-driven circulation system may remove or introduce a particular absorber (e.g., water) into the HTF fluid (e.g., ethylene glycol) so as to optimize the MJPV performance in relation to the solar spectrum available, as a function of time-of-day and seasonal changes, at the particular site where such a MJPV-CHP system is deployed. With the cost-effective CCC embodiments of the present invention, and utilization of the heated HTF for use in various solar-thermal applications of the prior art, it is therefore not necessary to maximize utilization of every particular wavelength of the available solar spectrum for promoting electricity generation in the MJPV, since the MJPV may instead be irradiated to its optimum power rating by the HTF-filtered spectrum using an over-concentrating CCC (e.g., 700x suns), whereas almost all other available solar energy is converted to usable solar-thermal energy in the HTF.

In another embodiment, the embodied CCC is utilized in conjunction with hydrogen generation means particularly embodied for utilization with solid oxide fuel cell and associated hydrogen generating means. In particular, hydrogen-bearing gases are reformed by means of annular solid oxide-based apparatus operated in hydrogen generation mode, wherein an integral storage tank is also embodied for storage of an energy storage medium.

Another advantage of the present invention is realization of rigid freestanding conical frustums that may be stacked and loaded mechanically with compressive force in the direction of the optical axis of the stacked frustums.

A primary advantage of the concentrator design herein is in its ability to allow precision optical resolution and concentration factors equivalent to parabolic dish systems, without the expenses associated with making actual aspherical surfaces. The parabolic and other aspheric concentrators of the prior art that require quadratically derived surfaces, or surfaces that possess curvatures in more than one axis, typically require both proprietary molding/shaping processes for producing panels that possess these aspheric properties. Instead, the present embodiments realize the concentration capabilities of a tracking parabolic dish, but through use of flat reflector sheet utilized for less concentration trough systems. Rather than incorporating the relatively expensive forming of quadratic surfaces that is required in prior art trough systems and tracking parabolic dishes, the present embodiments provide high concentration by use of linear structural elements

Another important advantage of the present invention is its use of reflector materials that may be produced by roll-to-roll manufacturing; that is, sheet material that is manufactured in a substantially planar form that can be processed and stored using rolls of sheet material, and through use of such manufacturing processes as roller mills and web processing. In the preferred embodiments, the reflector material is fashioned into segments that are each provided a shape unique for the purpose of matching the surface area and shape of a conic frustum incorporated in the CCC structure.

Another advantage of the presently embodied solar concentrating reflector is in the realization of a telescoping compound conical concentrator which replaceable conic frustums.
Another advantage of the presently embodied solar concentrating reflector is in the realization of an expandable compound conical concentrator that can be deployed rapidly in remote locations or for distributed generation..

Another advantage of the presently embodied solar concentrating reflector is in the realization of an expandable compound conical concentrator that is transported in a contracted form within a container that is smaller in depth than the assemble CCC, and preferably less than twice the depth of the deepest frustum in the container.

Another advantage of the presently embodied solar concentrating reflector is in the realization of an expandable compound conical concentrator wherein component frustums for greater that 20, and preferably greater than 50 CCC's are shippable in a container of volume equal or less in height than twice the height of one of the same CCC in its assembled operational form.

Another advantage of the presently embodied solar concentrating reflector is in the realization of an expandable compound conical concentrator that is simultaneously adaptable for CHP utilizing multijunction PV, solar thermal for molten salts, or fuel cell hydrogen production. WEAK

Another advantage of the presently embodied solar concentrating reflector is in the realization of an expandable compound conical concentrator that is transported

Other objects, advantages and novel features of the invention will become apparent from the following description thereof.

A primary advantage of the concentrator design herein is in its ability to allow precision optical resolution and concentration factors equivalent to parabolic dish systems, without the expenses associated with making actual aspherical surfaces

Brief Description of Drawings

FIG. 1 is a diagram of a single-ended, tubulated solar receiver of the preferred embodiments, integrated with a compound conical concentrator of the preferred embodiments, comprising a N=6 concentrator.

FIG. 2 is a front sectional cut-out view of a solar tracking apparatus utilizing a compound conical concentrator and receiver tube in a preferred embodiment, wherein section is taken along the normal plane containing pivot axis **(62)**, and wherein the receiver tube is aligned to the pivot axis.

FIG. 3 is a top view of flat reflective sheet segments for a CCC of the preferred embodiments.

FIG. 4 (a) is a perspective view of a single-ended and tubulated receiver tube of the preferred embodiments comprising a dual-use solar thermal receiver and multi-junction PV collector. **FIG. 4(b)** is an aluminum honeycomb panel of the prior art.

FIG. 5(a-d) is preform providing parted frustum structures of the present invention, comprising **(a)** sectional side-view of a planar, honeycomb-reinforced, sheet having mid-plane **(151)**, **(b)**, a close-up caption **(150)** comprising a sectional top-view of the sheet taken along plane **(151)**, **(c)**, a sectional side-view of a toroidal preform of the preferred embodiments, with sectioning plane taken through central axis **(73)** and, **(d)** a sectional side-view of the annulus comprising the toroidal preform.

FIG. 6(a-c) is a self-supported frustum of the preferred embodiments comprising **(a)** a side-sectional view of the annular structure forming the frustum, **(b)** a side sectional view of an alternative preferred embodiment of the annular structure forming the frustum, and **(c)** a perspective view of the self-supported frustum in accordance with the preferred embodiments.

FIG. 7 is a side-sectional schematic view of a hot-finger/CCC assembly of the invention, comprising an, N = 11, CCC structure and alternative preferred embodiments of a hotfinger assembly of the invention with a cylindrical region of highest optical flux.

FIG. 8(a-d) are schematics of internal structure of a conical frustum in accordance with the preferred embodiments comprising, **(a)** relative orientation of consecutive expanded core material, **(b)** a tetrahedral coordination diagram, **(c)** a side-sectional schematic of a truss structure, and **(d)** a perspective cut-away of a conical frustum in accordance with the preferred embodiments, with cutaway section taken through plane, **a'** , the plane containing optical axis **(73)**.

FIG. 9 **(a-b)** is a side-section view of a preferred interlocking mechanism comprising **(a)** edge-surface regions of adjoining conical frustums in accordance with the preferred embodiments, and **(b)** a side section view of interlocking frustums of the preferred embodiments.

FIG. 10(a-b) are perspective views of an assembled CCC in accordance with the preferred embodiments.

FIG. 11 (a-b) is a side sectional view of an assembled CCC of the preferred embodiments comprising **(a)** a side sectional view of the embodied CCC in a contracted form, and, **(b)** a side sectional view of the embodied CCC in an extended and assembled form, with sectioning plane taken through central optical axis **(73)**.

FIG. 12(a-b) is a preform structure in accordance with an alternative preferred embodiment, comprising **(a)** side section view, and **(b)** a perspective, cut-away, sectional view with cut-away region **(140)** revealing interior honeycomb core layers.

FIG. 13(a-b) comprises **(a)** a side sectional view of a shipping container housing component frustums of a multitude of CCC's of the preferred embodiment, and, **(a)** spectral characteristic of a terrestrial solar irradiance with MJPV and HTF absorption characteristics in accordance with an alternative embodiment of a MJPV/CHP receiver tube.

FIG. 14(a-c) is an alternative preferred embodiment comprising **(a)** side-sectional view taken though a plane containing central axis **(9)** of a MJPV/CHP receiver tube, **(b)** is a sectional end-view orthogonal to central axis **(9)** of the MJPV/CHP receiver tube, and **(c)** is an inner transparent receiver tube with patterned absorber coating .

FIG. 15 is a multi-junction PV solar receiver of the preferred embodiments.

FIG. 16(a-b) is a **(a)** side-sectional and **(b)** front view of a single-ended, tubulated solar receiver of the preferred embodiments, wherein side-sectional view **6(a)** is taken through plane **(6)** in front-view of **7(b)**.

FIG. 17(a-b) is a tubulated solar receiver and integrated 2-axis rotating union in accordance with a preferred embodiment, comprising a **(a)** front-sectional and **(b)** front view, wherein section is taken through central axis **(9)** of receiver tube and normal to plane **(6)** in **FIG. 16.**

FIG. 18 is a foreshortened side sectional view of a CCC of the preferred embodiments in conjunction with a photo-catalytic hydrogen generation device and an annular SOFC.

Best Mode for Carrying Out the Invention

In accordance with the preferred embodiments, a solar concentrator system comprising multiple conical frustums, with associated energy-conversion apparatus, is disclosed in conjunction with **FIGS. 1-18** and in conjunction with the relied-upon co-pending applications of the present disclosure, which are included herein, in their entirety, by reference. While the embodied CCC structure may be realized in a wide variety of concentrators that embody its primary structural elements, it is found in the present invention that certain preferred features and manufacturing methods are preferred for low-cost manufacture and efficient energy conversion.

Accordingly, a CCC of the present invention comprises at least five conical reflector sections **(80)** comprising a conical frustum. In the preferred embodiments, it may thus be readily understood that each conical section, or frustum, will concentrate direct solar radiation into an identical volume comprising the embodied receiver tube. Accordingly, a region of upper foci **(81)** determined by optical rays propagating from an uppermost reflective region of each reflecting frustum is located near the top portion, preferably closed end, of the absorbing receiver tube. Conversely, a region of lower foci **(82)** resulting from optical rays propagating from bottom reflective region of each reflecting frustum, will reside in a bottom portion of the receiver tube. Herein, "bottom" of the conical sections refers to the smaller end of the conical frustum that is closest to the tilt axis.

The CCC height **H** is defined by the total height of reflective area of the main conical sections. The length **h** of the receiver tube assembly from its top to the tilt axis **(42)** is preferably provided such that the clearance distance between CCC base plane **(59)** and tilt axis **(42)** is greater than 20cm, and more preferably greater than 50cm. The distance between platform and tilt axis may be provided with any reasonable dimension providing the needed clearance between CCC structure and platform. Alternatively, clearance for the CCC structure at low altitude (morning and late afternoon) tilt settings be provided in part by placement of the platform on an elevated structure, such as a structure housing the intended work load.

The absorber length **h'** of the receiver tube comprises the embodied receiver tube's effective absorber length disposed so as to provide substantial heating of the HTF, and is preferably provided so as to efficiently absorb the reflected, preferably direct, solar rays propagating from each conical frustum of the embodied CCC, in FIGS. 9-10. Accordingly, the absorber length is preferably provided such that it is roughly equivalent or slightly longer than the envelope of parallel rays resulting from the paraxial rays reflected by each frustum, as depicted. In its first preferred embodiment, the absorber length **h'** of the receiver tube is preferably such that $0.01\mathbf{D} < \mathbf{h'} < 0.3\mathbf{D}$, and more preferably, $0.05\mathbf{D} < \mathbf{h'} < 0.18\mathbf{D}$. A non-transparent region **(69)** of the receiver can comprise the mounting nipple of the hot-finger assembly, but preferably, in the case of high-temperature operation, is a coating or cover over the glass receiver tube.

It is pointed out that the relative diameter of the single-ended receiver tube, relative to **h'** and **D**, in **FIGS. 1**, is depicted as larger in diameter than is typically preferred for purposes of clear representation. In the preferred embodiments, the diameter, **d**, of the hot-finger receiver tube **(11)**, which is the fused silica tube containing and contacting the HTF, is preferably such that $0.001\mathbf{D} < \mathbf{d} < 0.02\mathbf{D}$, and more preferably $0.004\mathbf{D} < \mathbf{d} < 0.015\mathbf{D}$, wherein **D** is the diameter (or diagonal dimension in square embodiments) of the CCC reflector, or, equivalently, the larger diameter of the largest conical frustum's reflecting surface.

An axis of normal incidence **(74)** resides in a plane containing the optical axis **(73)** and the propagating solar rays, and is perpendicular to the optical axis, thereby designating the axis of normal incidence with respect to the substantially linear portion (as opposed to hemispherical portion) of the embodied receiver tube's surface, for the propagating solar rays that enter the receiver tube in the plane. For example, in **FIG. 1**, an axis of normal incidence **(74)** is contained in the CCC base plane **(59)**. It is preferred that the conical frustums be constructed so that at least 90% of the solar radiation incident on the linear portion of the receiver tube is at an angle $\mathbf{\Theta}_i$ of propagation, relative to normal incidence, preferably such that $0^\circ \leq \mathbf{\Theta}_i \leq 60^\circ$. Preferably this is accomplished within the constraint that the radius of the CCC's central opening is such that this radius $\mathbf{r_c}$ is less than 1 meter and greater than **2d**, though this is not a required limitation.

In **FIG. 1**, the conical frustums represented by the profiles **A-F** each correspond to a separate, stackable conical section with the distinct slope of the respective profile. In the preferred embodiments, the separate sections are stacked to form the embodied compound conical concentrator (CCC). Accordingly, an embodied CCC structure having profiles A-F may have, for example, the bottom-most section, F, removed or not employed, so that concentrated solar is received instead from conical frustums corresponding to A-E. In the same manner, a CCC constructed for a specific receiver absorbing height, **h'**, may have additional frustums stacked and attached to the top frustum, A, so as to provide the CCC with an effectively greater receiving area, and hence, in the preferred embodiments, a higher effective concentration factor. It is preferred in the present embodiments, in **FIG. 1**, that at least the uppermost frustum be appropriately extended to additionally provide irradiation of the hemispherical top **(16)** of the embodied receiver tube assembly. In this embodiment it is accomplished that the

As concentration factors of the embodied CCC's are easily obtained in the region of several hundred suns, it is preferred that a protective cylindrical shroud or sleeve **(68)** be transferred over the receiver tube during start-up and cool-down procedures, so as to absorb and deflect solar radiation from entering the transparent receiver tube preferably until tracking position is obtained.

In the preferred embodiments, there is a minimum clearance between the central axis (9) of the hot-finger assembly and the CCC reflecting surface, so that a central clearance opening **(67)** in the CCC with internal radius $\mathbf{r_c}$ is provided. Additionally, it is preferred that this cavity is extended by an integral CCC-base cavity structure **(118)**, preferably provided concentric to and opening to the central cavity formed at the base of the CCC.

The clearance cavity of the cavity structure is preferably provided so as to allow adequate clearance for both the single-ended receiver tube assembly and a retractable absorbing sleeve **(68)** that is preferably moved over the single-ended receiver tube during power-up and aligning the tracking mechanisms. Such protective shield is preferably telescoping in the preferred embodiments, but may alternatively be retracted to a position above the hot-finger assembly and within the cavity formed by the CCC structure, so that the protective sleeve **(68)** is in any case retracted to a position substantially removed to a position that will not block desired irradiation of the hot-finger assembly. The protective sleeve will preferably also incorporate a multitude of temperature and/or optical sensors for determining operating conditions near the sleeve surface prior to and after retraction of the protective retractable sleeve **(68)**.

In addition, it is preferred that a top-hat heat shield **(121)** in the form of a circular concave IR mirror reside directly over the sealed end of the receiver tube, the heat shield reflecting emitted IR from the top - and preferably hottest portion - hemispherical end of the tube. The heat shield is preferably of a diameter slightly smaller than that which would result in occlusion of propagating rays from the upper most portion of the top frustum. In addition, a similar disk-shaped reflecting region comprising a metal reflecting film is deposited on a top disk-shaped portion of the hemispherical portion **(16)** of the tube, which is similarly limited in size to avoid occlusion of the uppermost locus of incoming rays.

In an alternative preferred embodiment, it may be desired that the irradiation of the receiver tube not be uniform, but that a particular gradient be realized in the solar flux and/or HTF temperature. Concentration of solar radiation by the concentrator onto the absorbing receiver tube may be readily implemented, by slight alteration of one or more conical section slopes, so that one end of the receiver tube is irradiated with greater solar flux relative to the opposite end. For example, it may be advantageous to realized hotter temperatures or higher heating of the top end of the receiver tube, so that emissive losses are minimized by requiring less heating distance at the hotter and higher-emitting end of the transparent receiver tube.

Unless noted otherwise, direct sunlight and incoming solar radiation of the present invention shall be that direct solar propagation that propagates, as paraxial rays, roughly parallel to the optical axis of the solar concentrator, typically with a divergence of less than 0.5 degrees.

In certain cases, it may be found desirable to implement a CCC that provides a higher solar power to one end of the embodied receiver tube, wherein for example, emissive losses may be reduced by increasing effective solar concentration at the end of the HTF heating path, which is the top of the receiver tube in the present embodiments. Such a gradient in the effective solar concentration, along the length of the receiver tube, may be readily achieved through slight modification of one or more conical frustums of the present invention. The implementation of this concentration gradient may be realized, for example, through an according adjustment in the slope angle of and shortening height of the uppermost conical frustum of the embodied CCC structure, so that the top of the embodied solar receiver tube is thereby preferentially heated.

Whereas any tracking mechanism may be utilized for maintaining the concentrator with its optical axis pointed toward the sun, it is preferred that the tracker be economical in its construction so as to provide a low cost of ownership. This is provided in the present invention through the utilization of a tracking base that does not require expense pedestals, large arc elements, or massive gear assemblies. It is preferred that the base be constructed with heavy use of steel cabling. In particular, the embodied CCC/hot-finger tracking assembly (120) provides tilt and pivot movement wherein tilt and pivot axes are located a preferred distance below the CCC base plane **(59)**, such plane defined by the bottom-edge of the reflective surface (110) that is provided by the lowest and smallest-diameter conical frustum, and orthogonal to the optical axis of the CCC, as described in previous disclosures by same author, and in **FIGS. 1-2**.

The single-ended receiver tube assembly and 2-axis rotating union of the previous embodiments are preferably utilized in conjunction with a concentric tracking concentrator disposed for allowing the high degree of solar concentration that is seen as most beneficial for the preferred high temperature molten salt HTF's and for high-through-put of lower-temperature HTF's such as oil or water.

A hot-finger/CCC assembly **(120)** of an earlier disclosed preferred embodiment, in **FIG. 2**, is depicted with aligned central axes **(9) (73) (62)** of the solar receiver tube, the CCC structure, and pivot rotation, respectively. The CCC/hot-finger tracking assembly **(120)**, in **FIG. 2**, incorporates preferred embodiments of the previously described conical frustums, comprising a segment of sheet reflector material **(78)** that is formed into the embodied conical frustum's desired shape, in part due to the support of a conical frame of the frustum comprising conical frustum support struts **(71)** and reflector structural rings **(72)**, which is preferably a round metal stock, that interlock into the support rings .

A primary concentrator support ring **(77)** provides main structural support of the assembled CCC structure, and is preferably composed of aluminum alloy, but is alternatively composed of steel, fiberglass, plastic, wood, or bamboo.

A 2-axis union enclosure box **(119)** provides mounting surface and housing for the 2-axis union, and is adjoined on either side and coaxial to the tilt axis **(42)** by respective steering nipples **(48)**, which steering nipples connect the 2-axis union rigidly to the surrounding tracker base assembly, so that pivot rotation of the tracker base assembly **(13)** in the lateral plane will thereby steer, or rotate, the 2-axis union about its pivot axis **(62)**, so as to rotate uniformly with the base and CCC in this axis of rotation. Since the single-ended receiver tube/union assembly is preferably attached to the CCC base in a semi-rigid manner, by way of the concentrator mount flange preferably interfacing the CCC base by linear bearings that allow only very slight relative motion of the receiver tube assembly with respect to the CCC structure in the direction parallel to the optical axis, it may be preferable in certain windy installations that the steering nipples provide some compliance in their linear direction, so that any strain in the structure does not incur a stress within the rotating union assembly. In addition, it is preferred that the

Mounted on steering nipples **(48)** opposite 'Y' struts preferably on the same rotating bearing/housing is a ballast weight **(56)** for providing a counterweight to the mass represented by CCC structure and attached single-ended receiver tube assembly that tilt about the tilt axis **(42)** opposite the ballast weight.

A pedestal **(57)** is provided in the tracker platform **(58)** that preferably provides the interconnection to the work-load, which preferably resides directly below the pedestal. In the case that the tracker base is disposed over a building that houses the work load, it is preferable that the pedestal is detachable from the base structure, so that the 2-axis joint assembly can be optionally lowered into the building for service. Connection between the pedestal/base and the HTF output connector **(115)** is preferably made via a high temperature alloy bellows **(114)** that allows for a non-rigid connection to the HTF connector. Rotating connection to the lower and rotatable insulated tube **(45)** is made within the lower-temperature HTF supplied into the annular supply passage **(22)**, and so can be made with similar non-hermetic seals as rotating connections between insulated tubes in the other regions of the embodied 2-axis union.

The tracker platform **(58)** is a suitably flat and hard platform providing sufficient area for a base pivot track **(64)** that comprises the circular path of the base rotation casters **(61)**, which are mounted at the four corners of the embodied square base structure. The mechanism for driving the pivot rotation of the base and attached CCC and single-ended receiver tube/union assembly is preferably incorporated in the caster modules, though driving the pivot rotation can be provided by any suitable drive mechanism of prior art trackers, including pivot drive means located in the central pedestal structure.

The primary CCC support ring (77) is supported on either side by "Y" struts **(63)** that rotate on bearing housings about the central steering nipple shaft comprising linear pipe sections of the steering nipples. the 'Y' struts are disposed to rigidly support a concentrator support ring **(77)** that in turn provides primary support for the CCC structure. It is therefore provided that the 'Y' struts, attached support ring, and CCC structure are allowed to tilt about the tilt axis **(42)**. The position of tilt is provided by cables **(55)** attached to the 'Y' struts, which cables **(55)** are opposingly tensioned and spooled in or out by spooling of the stepper motor/winch assembly **(60)** , determine the tilt position of the CCC structure and attached single-ended receiver tube assembly. The assembly of 'Y' struts and steering nipples is in turn supported on a square frame that houses the winch/stepper units, and rotates on the platform by virtue of driven caster wheels **(61)**.

In the preferred embodiment, each conical frustum is constructed utilizing the preferred reflective metallic strip material, preferably comprising a rolled metal strip of relatively thin gage, preferably less than 2.0 millimeters thick, and more preferably between 0.2 and 0.8 millimeters thick, though other thicknesses outside this range may be readily utilized. The reflective sheet segment is preferably composed of joined subsections that are preferably welded, or otherwise joined along linear seams **(79)** that allow for the entire reflective sheet segment to be constructed into a single monolithic sheet segment. In some alternative embodiments, the reflective sheet segments may be provided with fastening holes/features **(101)** that enable fastening the sheet segment to its respective conical frame. The fastening holes are further operational in providing registration of the sheet segment with the conical frame at a plurality of points, so that the reflective sheet segment **(78)** becomes a tensioning element in the resulting conical frustum, thereby enabling it to retain its desired shape while frustrating undesired flexure or distortion.

In the first preferred embodiments of the present invention, concentration factors of 200-1000 suns are preferred for allowing relatively loose tolerances in the construction and low cost in the materials utilized in the embodied CCC. In this way, it is envisioned that economical realization of solar-thermal, concentrated photovoltaic, and combinations of both can be realized with relatively inexpensive cost-of-ownership. Accordingly, the CCC of the first embodiments is constructed largely of linear metal stock that is readily available and is typically the least costly embodiment of a particular commercial metal alloy. In accordance with the first embodiments, low-cost is also achieved by use of tensioned steel cables, rather than rigid structural elements, where ever practical.

Accordingly, each reflective sheet segment **(78)**, in **FIG. 3**, comprising the reflector material required for one conic frustum, comprising a flat sheet that is preferably formed prior to construction of the frustum. In some alternative embodiments, afunction of the pre-fabricated segments of reflector material is in providing pre-determined registration features **(101)** that result in unique positioning and alignment of the reflector material when fastened by such registration holes to uniquely positioned fastener positions in the embodied support strut **(71)** and support rings **(72)**. In this way, the reflector material is restrained to conform to the desired conical shape, and in addition, provides additional tensioning means for increasing rigidity of the frustum structure. With the placement of holes for fasteners in the reflector sheet, all dimensions and angle of the conical structure are uniquely determined, as the reflector sheet adds an additional tensioning structure. The flattened reflector material segments are typically larger in dimension than available rolled reflector material and are preferably constructed by joining linear pieces of rolled reflector material, preferably by spot-welding or otherwise providing a fused linear seam **(79)**.

In **FIG. 4(a)**, a previously disclosed, modified hot-finger assembly (utilized for a here for a MJPV assembly) is preferably protected by a retractable protective sleeve **(68)** for protection against undesirable irradiation during start-up, shut-down, tracking realignment, emergency shut-down, and other such circumstances. The protective sleeve may block light from entering the receiver tube by either absorption or reflection. In an alternative embodiment, the sleeve is partially transmitting -- by incorporating transmitting surfaces or open slits -- so as to allow some attenuated irradiation of the hot-finger assembly for assessing operating conditions prior to exposing the absorbing media of the hot-finger assembly to full irradiation. The protective sleeve is also usefully utilized to protect from potentially damaging weather, mechanical damage by sandstorms, and during transportation. It will be preferred under certain circumstances that the protective sleeve be integrated into the receiver tube assembly ("hotfinger assembly"), so that mechanical translation of the protective sleeve is actuated by sleeve mechanical actuating means that are incorporated into the hotfinger assembly, such as by telescoping or pneumatic actuators. Having the protective sleeve and associated actuation mechanisms integrated into the hotfinger assembly allows for control of such sleeve actuating means to be powered by the same electrical interconnection that monitors sensors of the hotfinger assembly. Accordingly, there is preferably a CPV module electrical interconnect **(128)** mounted on the hotfinger assembly below, or in some cases above, the mounting flange, wherein such electronic control connector provides communication with a computerized logic system for monitoring temperature sensing means such as thermocouples, RTD's, pyrometers, transducers, mass flow sensors, and other sensors that are integrated into the hotfinger assembly for monitoring its operation, so that such sensing may provide feedback to a computer for monitoring and controlling mass flow, determining over-temperature conditions, non-standard operating conditions, etc, wherein such monitoring is performed in relation to one or more logic controllers that activate translation of the sleeve along the optical axis **(73)** to a protective position. While the present MJPV module, in **FIG. 4(a)**, is embodied in conjunction with a two-axis feedthrough assembly, lower temperature operation (<300C) will considerably reduce restrictions on feedthrough design, so that flexible bellows or tubing utilizing flexible synthetic materials may be utilized.

The CCC of the first preferred embodiments is preferably constructed utilizing materials and manufacturing processes that minimize manufacturing costs, while maintaining high precision and rigidity in a light-weight construction. These objectives are satisfied in the preferred embodiments of the embodied CCC structure through the implementation of embodied manufacturing process and frustum structure wherein cylindrical preforms are constructed from multiply layered systems, the preforms in particular comprising alternating layers of sheet metal and a hollow-core material layer, preferably an aluminum honeycomb core material.

Single-core, aluminum-based, honeycomb-reinforced panels of the prior art, in **FIG. 4(b)**, are commonly manufactured and commercially available with a laminated aluminum core. The aluminum honeycomb core of the reinforced panel comprises a 3-dimensional structure wherein hexagonal cells of the honeycomb core are formed out of aluminum strip of width determining the depth of the cells. The honeycomb core **(148)** thus comprises a hexagonal structure composed of relatively thin aluminum sidewalls **(152)** that are periodically laminated and expanded to form hexagonal cavity spaces **(160)**. This honeycomb core is typically sandwiched between two planar sheets of cladding sheet metal **(147)**, which are adhered to the honeycomb core by typically an adhesive film **(149)** of an adhesive such as an epoxy or silicone.

Such Aluminum honeycomb-reinforced panels are widely available from multiple vendors worldwide. These panels are readily purchased from a large variety of vendors of such honeycomb panels, including Hexcel, Inc, Pacific Panel, Inc (US) Plascore (US, Gmbh), Paneltek Corp (US), Universal Metaltek (India). In-depth explanation of the various materials, processes, and structures that are utilized in such honeycomb panels are treated in numerous texts, including, "Honeycomb Technology: Materials, design, manufacturing, applications and testing" by T.N. Bitzer, which is included herein by reference, as well as by various technical and product data sheets available from Hexcel. Accordingly, such panel construction is embodied particularly herein utilizing aluminum honeycomb core structure in its preferred embodiments, whereas a variety of other materials and core structures may be utilized. The honeycomb panel construction has been used extensively in prior art solar reflectors wherein the honeycomb core **(148)** with its sidewall structure **(152)** is shaped so that a reflective material comprising the outer metal cladding **(147)** or "skin" is given an aspheric or similarly curved profile for purposes of providing a linear-trough solar concentrator.

In a preferred embodiment, the conical frustum sections are manufactured in accordance with a manufacturing method and various particular structural embodiments comprising rigidity-enhancing embodiments that may be used in conjunction with the preferred embodiments or in other, alternative embodiments utilizing circular solar concentrators. In addition to the frustum construction system of the previous embodiments, it is provided in the present preferred embodiment, that the conically formed reflector material of the previously embodied conic frustums incorporate a light-weight double-walled structure that preferably incorporates expanded honeycomb -- or alternatively, other light-weight, expanded, metal mesh -- that is sandwiched between two metallic sheet-metal walls(154, 155).

As previously described in conjunction with prior art honeycomb panels, the present preferred embodiment preferably incorporates a construction utilizing flat planar sheets comprising a double-walled enclosure reinforced by a core layer that is predominantly an open-space structure, most preferably having a honeycomb (hexagonal) network of supporting walls.
sheet having mid-plane **(151)**, though other low-density structured materials may be utilized.

In particular, in the preferred embodiments, conic frustums of the invention are formed through successive sectioning of a multilayer preform, wherein the preform **(158)** preferably comprises a plurality of stacked layers of the flat planar, honeycomb-reinforced, sheets **(153)**, in **FIG. 5**. Such flat sheets are preferably those currently commercially available, and preferably comprise a first planar surface **(154)** and a second planar surface **(155)** of the planar, honeycomb-reinforced, sheet, such first surface and second surface preferably comprising thin sheet metal, preferably aluminum. The planar sheet metal of the planar, reinforced sheet preferably comprises an aluminum alloy, or alternatively a stainless steel, other alloy, plastic, glass, or poly-ceramic material. The first and second surfaces of the planar reinforced sheets are preferably separated by a layer of a metal mesh or network material, preferably an expanded metal, and more preferably the embodied aluminum honeycomb structure, in **FIG. 5(b)**, the expanded aluminum having vertical structural walls **(152)** of honeycomb structure and interior spaces **(160)** of honeycomb structure formed by the vertical structural walls, as is commercially standard. The thickness k of planar, honeycomb-reinforced, sheets are preferably – but not necessarily – less than the thickness t of subsequently formed self-standing frustums, and are accordingly 0.1cm to 3cm in thickness, though other thicknesses are readily utilized.

In this described parting of the toroidal preform, the number of frustum sections - i, ii, iii, iv, and so on - , in **FIG. 5(d)**, that may be provided in the parting and laminating of a single preform is accordingly quite large, wherein the toroidal preform is preferably formed onto the rotating bed as a vertical cylinder having an axial depth of up to several or several tens of meters. Accordingly, a preform of the preferred embodiments may provide tens to thousands of individual frustums, depending on the optimum thickness, t , of the free-standing frustums that are formed by this process. Preferably the thickness t measured normal to inner and outer surfaces in a plane containing the optical axis, is such that 0.3cm < t < 10cm, depending on frustum size.

In particular, an embodied multilayer preform **(158)** of the preferred embodiments preferably comprises a monolithic glued or otherwise laminated stack of such planar, honeycomb-reinforced, sheets, in **FIG. 5(c-d)**. Accordingly the layers of the preform preferably comprise stacked planar layers of the reinforced sheet that each comprise double-walled, honeycomb sheets of the prior art, which are preferably adhered into a stack of such reinforced sheets by means of an adhesive, preferably an epoxy, or alternatively a silicone, thermoplastic, or any other suitable adhesive, such adhesive providing a solid bond between the respective surfaces of adjacent flat reinforced sheet **(153)**, so that an interface **(156)** is accordingly formed between the planar reinforced sheets, such interface preferably comprising the first and second surfaces of the embodied reinforced sheet **(153)**, and the adhesive utilized to bond these adjacent reinforced sheets, but may alternatively incorporate additional strengthening materials such as additional layers of sheet metal (preferably an aluminum alloy); or, alternatively, such interfaces **(156)** may comprise only a single metal sheet in such cases that the preform is constructed by simply alternating layers of an expanded metal mesh and single layers of a sheet metal. Alternatively, the toroidal preform may also be constructed with graphite composites (such as resin infiltrated graphite fiber), plastics, ceramics, poly-ceramics, or glasses. Also, it is not necessary that the reinforcing core be strictly hexagonal, as a variety of other reinforcing cores may be utilized, and alternative core layers comprising mostly open space with a regular lattice of supporting material may be utilized.

So as to efficiently provide the embodied frustum shapes of the previous embodiments, it is accordingly preferred that the preform be formed as a toroid, or cylinder, and that the resulting toroidal preform is formed onto a base **(159)** of a rotating table, so that the toroidal preform can be rotated about the optical axis **(73)** of a subsequently formed conic frustum, which axis is coincident with the central axis of the toroidal preform in **FIG. 5(c)**.

Once the toroidal preform **(158)** is formed, there is provided means for sectioning, or parting, of the preform into a series of, preferably, substantially identical conical frustums. The sectioning of the preform is provided at successively deeper parting lines **(157)** by a material cutting means that cuts the straight profile of the desired conic frustum profile, so that a cutting instrument providing the desired parting line accordingly provides a cut profile having the embodied linear profile, such cutting means preferably comprising an appropriately narrow scroll-saw blade, or alternatively a wire saw, laser beam, water-jet, or any other cutting means suitable for providing such linear cutting profiles in accordance with the embodied frustum profiles. Accordingly, the linear cut along a parting line **(157)** is advanced through the preform preferably by means of rotating the underlying rotating table and toroidal preform about the optical axis **(73)** of the frustum being formed. In this rotation of the toroidal preform, a frustum section of the preferred embodiments is accordingly separated from the previously embodied preform by the linear cutting means, so that a freestanding conic frustum having preferably parallel inner and outer parted surfaces **(170) (171)** is formed, in **FIG. 6**. Such parted surfaces accordingly comprise exposed structural elements including honeycomb walls **(152)** and interfacial layer **(156)** comprising the honeycomb panel cladding layers **(154)** 155) that were parted and accordingly exposed during the parting operation.

It is preferred that parted surfaces **(170) (171)** of a parted frustum of the present embodiments, formed in accordance with the parting lines **(157)** by the previously described parting operation, be utilized for aligning and supporting a subsequently attached, preferably metallic, flexible sheet material **(161) (162)**, comprising a reflective sheet material **(161)** attached to the inner parted surface **(170)** and a second flexible sheet material **(162)** attached to the outer parted surface **(171)**, in **FIGS. 23(a-b)**

It is accordingly preferred that the inner parted surface **(170)**, be provided any desired finishing while still integral to the preform, since the rigidity of the embodied preform allows precise finishing of such parted surfaces, prior to the parting the respective frustum. Final finishing is preferably provided by laser trimming or similar material removal means along similar linear path as the parting tool.

It is additionally preferred that the flexible laminating reflector material **(161)** be applied to a finished inner parting surface **(170)** of the presently embodied conical frustum also prior to the respective frustum being parted from the preform, so that the frustum is preferably provided additional rigidity by the laminated reflector material prior to being separated from the preform.

Once a conical frustum section of the preferred embodiments is laminated with reflective material on its first parted surface **(170)** and subsequently parted from the cylindrical preform, thereby forming outer parted surface **(171)** comprising exposed surfaces of the parted preform, it is preferably flipped on its optical axis, and the outer parted surface **(171)** of the frustum section is then laminated with a backside material, preferably comprising the second laminating thin sheet metal, wherein adhesion is again preferably provided as an epoxy or silicone, and so that the inner surface **(161)** and outer surface**(162)** of the embodied frustum are accordingly formed by these laminated surface layers.

In the present preferred embodiment, the reflective frustum surface **(110)** is thus provided adjacent the inner parted surface **(170)** of the frustum by means of conforming and attaching the flexible reflective sheet **(161)** to this inner parted surface, such sheet having preferably less than 2mm thickness, and adhered to the inner parted surface by means of organic adhesives, preferably an epoxy. Alternatively, other bonding means such as resistive or laser welding of interfacing metal surfaces may be utilized. The flexible reflective sheet material **(161)** preferably comprises a metal strip, preferably aluminum, with integral reflective surface already formed. Such reflective aluminum strip is available from Vega (Italy), Alanod (Germany), as well as other vendors. Alternatively the flexible reflective sheet material **(161)** may comprise any other suitable material, such as polymeric-based (e.g., Reflectech) or a stainless steel-based flexible material. In a preferred embodiment, the flexible reflective material **(161)** comprises aluminum sheet that has additionally a protected silver coating for optimum reflectance; for example comprising a thin film multilayer of sequence substrate/chrome/silver/zirconia.

Accordingly the flexible reflective material **(161)** thus imparts to the embodied frustum an inner-facing reflective frustum surface similar to earlier embodiments. Similarly, the second flexible metal sheet **(162)**, preferably aluminum, is conformed and adhered to the outer parted surface **(171)** of the parted frustum by similar adhesive means, the second flexible metal sheet accordingly providing the outer surface of the finished frustum, and thus providing additional structural integrity and rigidity to the embodied frustum. The second flexible metal sheet is primarily for structural purposes, and may accordingly be provided with any additional structural attributes for enhancing structural integrity of the embodied frustum, including adhesion-enhancing surface finishes, vent-holes, etc.

Such free-standing conical frustums of the present embodiments may thus be effectively utilized in place of the conically formed reflective sheet **(78)** segments of the earlier preferred embodiments, while providing structural means that reduce additional costs of added support structures in the variously embodied hot-finger/CCC assembly, wherein the flexible sheet segment **(78)** of previous embodiments, in **FIG. 3**, is essentially interchangeable in form and function to the flexible reflective sheet **(161)** laminated onto the parted frustum, in **FIG. 6(a-b)**, except that alignment holes are not required, and a polymeric adhesive is instead utilized. The reinforced frustums of the present embodiments are also found advantageous for being easily stacked in densely populated concentric volumes, leading to an according cost advantage in storage and transportation.

A conic frustum structure with inner and outer frustum surfaces formed by respectively the first, reflective sheet material **(161)** and second sheet material **(162)** will accordingly have upper and lower circular edges in accordance with the established form of a conic frustum. These upper and lower edges may be terminated variously, but are preferably terminated as either horizontal flat surfaces, or else by cylindrical vertical surfaces. Which of these two edge terminations is most effective will depend on the application. For example, in the first preferred embodiment, larger and stationary CCC's that primarily benefit from maximum uniformity in surface mating between adjacent frustums, may be preferably constructed with horizontal surface termination, in **FIG. 6(a)**; whereas, in a second preferred embodiment, smaller CCC's, semi-portable CCC's, or CCC's wherein material and transportation costs must be minimized, will typically be constructed with the preferred cylindrical edge-walls **(172) (173)**, in **FIG. 5(b)**, such exterior edge-surfaces thus providing external surfaces that bridge the gap between inner frustum surface **(161)** and parallel outer frustum **(162)** surface at the respective top and bottom edges of the embodied frustum structure, in **FIG. 6(b)**.

In addition to the finished inner and outer surfaces **(161) (162)** of the presently embodied conical frustum preferably comprising parallel conical surfaces, it is also preferred that top edge-surface **(134)** and bottom edge-surface **(135)** are parallel to one another, such top and bottom surface comprising alignment surfaces of the embodied conic frustum. Such top and bottom surfaces preferably comprise surfaces that result by finishing the respective top and bottom edges of the parted frustum with a correspondingly sized strip of sheet metal, though such surfaces may also be provided by exposing a planar surface of the imbedded interfacial layers **(156)** of the parted preform -- e.g., such as the cladding layers of stacked honeycomb panels **(155) (154)**. Thus, in accordance with the present preferred embodiments, parallel top and bottom edge-surfaces **(135)(134)**of the embodied frustum comprise top planar alignment surface **(165)**, and bottom planar alignment surface **(166)** of frustum **(80)** , wherein these planar-parallel edge-surfaces are both orthogonal to the optical axis, in **FIG. 6(a)**. While it is preferred that the inner and outer frustum surfaces be substantially parallel to one another in the manner described, and that top and bottom edge-surfaces be substantially parallel to one another in the manner described, in **FIG. 6**, various alternative embodiments in which these pairs of surfaces are tapered or otherwise configured may be readily envisioned without departing from the scope of the invention. Other alternative embodiments may b envisioned wherein lower frustums are of greater thickness, t, than the upper frustums of the CCC.

Conversely, in accordance with another preferred embodiment of the edge-surfaces, in **FIG. 6(b)**, the bottom edge-surface **(135)** comprises, in particular, bottom cylindrical alignment surface **(172)** , and the top edge-surface **(134)** comprises, in particular, top cylindrical alignment surface **(173)** , wherein these edge-surfaces accordingly comprise vertical alignment surfaces for subsequent mating to, similarly terminated, adjacent frustums of a CCC in the present embodiments, and as embodied in further detail later, in **FIG. 9**.

In the present preferred embodiment, it is accordingly provided that conic frustums of the preferred embodiments possess a sectional profile along its external surfaces comprising substantially a four-sided parallelogram, in **FIG. 6(a-b)**, wherein such profile preferably comprises a sectional profile taken through a plane containing the optical axis of the embodied frustum. Additionally, the inventive conic frustum of the present embodiments is provided so that the inner reflective surface comprising a thin sheet of conforming material (whether such sheet be a single material, multilayer, or a composite) is supported by a multitude of the planar supporting surfaces **(156)** that contact or otherwise support the reflective layer, such planar surfaces preferably orthogonal, substantially, to the optic axis of the frustum in the first preferred embodiments. Additionally it is accordingly provided that the reinforcing expanded metal mesh of the preferred embodiments, comprising a honeycomb structure, comprises inner mesh walls **(152)** of the honeycomb structure, which are preferably parallel to the optical axis of the frustum, so that both inner mesh walls and planar support surfaces of the embodied conic frustum are preferably connected to the reflective material - or any integral multilayer structure thereof - at acute angles and complementary obtuse angles, in the embodied sectional profile. Alternative embodiments may optionally include profiles having normal angles similar to the planar reinforced sheet of the prior art.

Such reinforced, double-walled, free-standing, frustum structures of the present invention provide additional advantages particularly suited for application in the conic frustums of the present invention. Such frustum structures of the present invention are provided exceptional rigidity by virtue of the many non-normal angles provided in the resulting frustum structure, in **FIG. 6**, provided by the parting process of the present embodiments. In accordance with the preferred embodiments, a multitude of non-normal contact angles are provided between the preferred honeycomb structure, the inner surface **(161)** and outer surface **(162)** of the embodied frustum of the present embodiments, in **FIG. 6(a)**. It is accordingly preferred that an angle γ exist between the vertical walls **(152)** of the incorporated honeycomb structure and the preferably parallel inner and outer surfaces **(161)** **(162)**, such that, preferably $10^\circ < \gamma < 80^\circ$, such angle measured in a major plane of the frustum (major plane defined herein as a plane containing the central optical axis). Such oblique angles, similar to advantages in "space frame" constructions, are found additionally advantageous for achieving exceptional rigidity and strength.

The stackable conic frustums of the embodied CCC structure are, in a preferred embodiment, provided with the reinforcing embodiments provided herein, in **FIGS. 5-6**. Accordingly, the top and bottom joining surfaces **(134)(135)** of each frustum in the embodied CCC preferably attach to adjacent conical frustums at the embodied planar and parallel surfaces comprising joining surfaces, in **FIG. 6(a)**, so that such frustum interfaces **(168)**, comprising top and bottom planar surfaces **(165)** **(166)** of adjacent frustums of the inventive CCC structure, are preferably orthogonal, in relation to the central optical axis of the CCC structure, in **FIG. 7**. It is preferred that such joining surfaces are additionally formed with alignment means comprising alignment pins **(164)** that mate to corresponding holes in the adjacent frustum edge-surface, so that joining surfaces of adjacent frustums are guided by such alignment means prior to contacting of such adjoining edge-surfaces of concentric adjacent frustums, and so that frustums are preferably guided by such alignment means so as to join in a unique concentric alignment. Alternatively, the parallel edge-surfaces, in accordance with **FIG. 5(b)**, are coaxial to the optical axis **(73)**.

In yet another further embodiment, in **FIG. 7**, the inventive CCC structure comprises a (N=11) stack of the embodied optically-reflecting frustums, the CCC mutually providing high optical power density within a volume comprising a cylindrical annulus concentric to the optical axis, so that, within a major plane (herein a plane containing the central optical axis), the mutual foci of the CCC reside along a displaced focal line that is displaced from the central optical axis **(73)** by a displacement x, where x may be a linear distance on order of centimeters to meters. In such alternative embodiments, the original absorbing tube and receiver tube are scaled with accordingly larger radii, and a greater proportion of the radiation from upper frustums **(a-f)** may be directed into the interior of the absorbing tube from above, as embodied earlier. Accordingly, it may also be seen that by appropriate adjustment of frustum angles, x may be rendered to provide a cylinder of radius x, or alternatively, the grouping of foci may resemble a cone, an hourglass shape, or a stepped profile.

An alternative preferred embodiment is further provided, in **FIG. 7**, comprising a second, inner absorber element **(167)** that is concentric to the tube axis **(9)** and preferably extends above the previously embodied absorbing tube **(23)** so that radiation arriving from reflection by top regions of the frustums will irradiate this inner absorbing element, which preferably comprises a tube, the tube containing the previously embodied insulated tube and return passage of the HTF. Such latter embodiments are useful in higher-N CCC's or wherein most radiation is provided from reflectors surface residing above the focal region, z.

Optionally, the grouping of foci from the frustums above the receiver tube may have a different, preferably higher, location than the grouping of foci resulting from frustums residing at or below the height of the receiver tube. Accordingly, frustums "a"-"f", in **FIG.** 7, may accordingly provide a grouping of foci that is, on average, displaced from the grouping of foci determined by frustums "g"-"k". For example. it may be preferred that light reflected from the upper set of frustums preferentially irradiate the top of the receiver tube, preferably so that substantial irradiation of the interior of the first outer absorbing tube **(23)** takes place, in addition to preferably irradiation of the alternative inner absorbing tube **(167)**. Accordingly, in such alternative embodiments wherein the interior of the embodied receiver tube's first absorbing tube **(23)** , of previous embodiments, is irradiated by the upper frustums of the CCC, it is preferred that the interior of this first outer absorbing tube be coated or otherwise terminated with a low-emissivity, IR-reflective coating, such as gold or any other appropriate material. In such alternative embodiments, the thermal insulating of the inner, return path, by insulating tube in earlier embodiments, so as to prevent cooling of the return HTF, may be replaced by the insulating function of such IR-reflective internal walls of the outer absorbing tube **(23)**, as well as by an accordingly large annulus of non-flowing HTF that resides between the first outer absorbing tube **(23)** and inner absorbing tube **(167)**.

In the present alternative preferred embodiment, there is accordingly an approximate length z of the cylindrical surface **(169)** of foci, wherein such cylindrical surface reduces to a line, as in previous embodiments, as its radius x goes to zero. In accordance with the present embodiments wherein solar radiation enters the interior of the absorbing tube **(23)** from its top entrance, the absorbing length z' of the first absorbing tube **(23)** may be substantially equal or less than the surface-of-foci length z, whereas the second, inner, absorbing tube **(167)** may extend above the first absorbing tube **(23)** as well as above the surface-of-foci **(169)**. In such latter cases, it may be seen that the effective absorbing length of the receiver tube need not be limited to the surface of foci as determined by one side of the CCC profile.

The inner absorber element **(167)** preferably extends above the previously embodied absorbing tube **(23)** so that radiation arriving from reflection from top regions of the frustums will irradiate this inner absorbing element, which preferably comprises a tube housing the previously embodied return passage of the HTF.

In a preferred embodiment, the consecutively stacked layers of honeycomb core material and the interleaved sheet metal interface layers are arranged so that the honeycomb core material of adjacent layers in the stack are disposed with an angular displacement, φ, relative to one another, wherein the angular displacement is preferably such that 5 degrees < φ < 175 degrees, in the case that anisotropy of the mesh due to lamination is accounted for and the structure has two-fold rotational symmetry, and preferably such that 5 degrees < φ < 55 degrees in the case that 6-fold symmetry of hexagons are assumed. Accordingly, this angular displacement can be with or without respect to anisotropies regarding a periodic lamination direction of the core material, or the lamination direction of the core in an unexpanded state.

Additionally, it is preferred that the successive angular displacement of each adjacent core layer **(148)** with respect to the previous core layer, be provided in a cyclic fashion. For example, in **FIG. 8(d)**. if the angular displacement of consecutive layers is +30°, -30°, +30°, -30°, +30°,..., wherein the designated vertices, a', b', correspond to the periodic lamination direction of the honeycomb core, then every other sectional profile of the resulting freestanding frustum **(80)** will have substantially identical orientation. Alternatively, the angular displacement may be such that the orientation of the honeycomb core repeats itself with a longer period, such as every third or fourth layer, and so on. Angular displacements are accordingly preferred so as to allow a repeating cycle of alternating honeycomb orientation in the successive layers of the n-layer preform and derivative clad frustum structure, wherein the angle may also be 10°,12°, 15°, 20°, etc.

In either of the preferred preform embodiments, whether comprised of a stack of flat honeycomb sheets, or, alternatively, by the concentric cylindrical or wound sheet metal layers **(163)** that are disposed between adjacent honeycomb core layers of a later-embodied wound preform embodiment, in **FIG. 12**, it is in any case preferred that the inner reflective material **(161)** and outer frustum surface **(162)** both be laminated to the layered honeycomb core structure so as to result in tetrahedra, or tri-lateral pyramid, structures being formed in the union of the inner reflective layer **(161)**, honeycomb core material **(152)**, and interface layers **(156)**. Such tetrahedral shapes are preferably formed as well as in the union of the outer frustum layer **(162)**, honeycomb core walls **(152)**, and interface layer **(156)**; whether the interface layer is formed by the cladding layers **(154)** **(155)** of the stacked planar honeycomb sheets or by singular interleaved sheets, A tetrahedron **(137)** or, equivalently, trilateral pyramid, will be defined here, as is uniformly presented in mathematics, as a pyramid having a base and three sides, or equivalently, a pyramid structure comprising four triangular facets, in **FIG. 8(b)**. The tetrahedron accordingly is characterized by four vertices **(139)** that each define intersection points of three adjacent faces of the structure, or equivalently such vertices each comprise the intersection point of three line segments **(138)** , of the total six line segments comprising a tetrahedron, wherein an angle, α, exists between each line segments of the tetrahedron, wherein preferably α is provided such that $15^\circ < \alpha < 90^\circ$.

Such reinforcing tetrahedral structures provide extremely high rigidity to the resulting frustum structure of the preferred embodiments, resulting from an interlocking tetrahedral space-frame geometry, wherein the abstracted line segments of a tetrahedron coincide with a continuous length of solid material that intersects adjacent continuous lengths of solid material in accordance with the tetrahedral shape. The embodied tetrahedral structures are formed by alternately either honeycomb sidewall **(152)**, interface layer **(156)**, or a frustum surface layer **(161)(162)**, so that each element contributes to the structural integrity of the frustum. It is not typically the case that the reinforcing tetrahedral structures will be "regular" and comprise equilateral triangles, since a variety of non-regular tetrahedral structures will typically be formed in any particular frustum of the preferred embodiments. Also, while it is preferred that reinforcing structures effectively formed in joining the reflective material **(161)(162)** , the interfacial material layer **(156)** and honeycomb structure **(152)**, be tetrahedra, various slightly truncated tetrahedral shapes may additionally result without departing from the scope or spirit of the invention. In the embodied conic frustum, such tetrahedra result in conjunction with both laminated inner frustum surface **(161)** and outer frustum surface **(162)**, so that a 3-dimensional network of interlocking tetrahedral structures are realized, thus results in an according truss-like structure in the sectional profile of the embodied frustum, in **FIG. 8(c)**.

Alternatively, an alternative embodiment utilizing different core material has a quadrilateral pyramid coordination formed by the three structural elements comprising reflective material layer , alternative core material layer, and interface layer, that may instead result in pyramid reinforcement structures having quadrilateral bases (a roughly square or rectangular pyramid base with four sides).

In conjunction with these preferred embodiments, a preform comprising stacked planar layers, in **FIG. 8(d)** , is composed of at least several parallel layers of a honeycomb core material. These layers may have identical orientation, with respect to the hexagonal pattern, or other regular pattern, but preferably are rotated or staggered in this orientation through the depth of the preform, so that planes of consecutive core material have their axes of symmetry displaced relative to the next by an angle, φ, when viewed orthogonally to those planes, from above in direction of optical axisas viewed in the z-direction along the, in **FIG. 8 (a)**, adjacent honeycomb core layers will be disposed with an angular displacement, φ, relative to on another. Accordingly, a single free-standing frustum of the preferred embodiments will comprise n consecutive layers, [1, 2, 3,...**(n-2)**, **(n-1)**, n], in **FIG. 8(d)** of the honeycomb layers, wherein n is such that, preferably, $3 < n < 100$.

As in the case of prior art honeycomb panels there is preferably silicone, or other, adhesive **(186)** is preferably utilized for laminating the reflective layer **(161)** comprising the inner surface of the completed frustum, as well as the outer material layer **(162)** comprising outer surface of the embodied frustum, to the respective parted surfaces **(170)(171)**. Inner and outer frustum surface layers **(161)(162)**, laminated to the respective parted surfaces **(170)(171)**of the parted honeycomb-layered core structure, are preferably also finished at their interface to the top and bottom edge-surface layers by a resin bead **(188)**, preferably silicone or alternatively and epoxy, that is preferably disposed along the seam formed between frustum edge-surface and the reflective material, as well as the seam formed between frustum edge-surface and outer sheet metal frustum layer **(162)**, in **FIG. 9**.

A CCC of the present preferred embodiments is preferably assembled in accordance with assembly means, in **FIGS. 9-11**, wherein a CCC structure assembled from the honeycomb-reinforced frustum embodiments, in **FIGS. 5-6**, is readily assembled and disassembled, which is preferred for applications wherein such characteristics as portability, ease of maintenance, and retract-ability, are of relatively high value.

More preferably, in the present alternative preferred embodiments, in **FIG. 9(a-b)**, frustums having previously embodied bottom edge-surface **(135)** particularly embodied as lower cylindrical alignment surface **(172)** and top edge-surface **(134)** particularly embodied as upper cylindrical alignment surface **(173)**, wherein such concentric and cylindrical edge-surfaces are preferred in a telescoping embodiment of the inventive CCC.

What will be generically referred to herein as "interlocking" mechanisms are those means whereby adjacent frustums are fastened or aligned with respect to each other, preferably using alignment means comprising top and bottom alignment surfaces. The adjacent frustums are preferably fastened with regards to one another by means of a plurality of fastening locations (**175**) positioned about the periphery of each circular interface (**168**) between respective upper and lower alignment surfaces of the respective joined frustums.

Preferably, the interlocking mechanism between adjacent frustums of the CCC include a plurality of lower clamp structures (**181**) that are integral to the bottom portion of the higher frustum of the interlocking pair, each lower clamping structure interlocking with an upper clamp structure (**182**) that is accordingly integral to the upper-most region of the lower frustum in the frustum pair.

Clamp region (**175**) containing preferred clamping means for registration of adjacent frustum surfaces with respect to each other incorporates a clamp mechanism (**176**) that preferably provides clamping means that are operable in determining alignment of frustum surfaces, including preferably a retractable spring-loaded clip (**177**) that engages against locking surface (**179**) within the clamping mechanism once the two frustums to be mutually aligned, wherein the two respective frustums that are interlocked by the clamp mechanism are brought substantially into the preferred aligned position with respect to optical concentration. There is also preferably disposed a polymeric edge-surface layer (**187**), comprising essentially a polymeric liner, on at least one of the aligning surfaces that protects and guides the alignment surfaces of the respective frustums relative to one another. The interlocking mechanisms also preferably incorporate a clamp stop surface (**178**) that provides a limiting stop for extension of the telescoping frustum assembly.

The clamping/interconnect means embodied are intended for purposes of teaching the invention, whereas a wide variety of clamping mechanisms may be found effective and in fact preferable under various specific circumstances. For example, joined frustums may be locked into position relative to each other by virtue of keyed alignment surfaces utilized in a twist-lock mechanism whereby rotation about the optical axis of one frustum relative to the adjacent frustum engages interlocking surfaces. Similarly, an alternative clamping mechanism can comprise a plurality of spring-loaded interlocking pins that are translated tangentially to the frustum alignment surfaces by an equal number of guiding surfaces. Accordingly, a large variety of interlocking and clamping mechanisms may be envisioned.

Assembled CCC's formed of stacked frustums in accordance with the previous embodiments are preferably held rigidly in position by tensioning means that compressively load the CCC along its optical axis, so that a tensioning force exists that pushes the top frustum and bottom-most frustum of the CCC toward one another along the optical axis. In this way, compressive forces are distributed evenly around the perimeter of each frustum, and the CCC is maintained with a high degree of concentricity in its optical performance.

Accordingly, CCC straps **(190)** are preferably utilized to provide tensioning means for mechanically loading the CCC along its optical axis and are preferably a thin flat, flexible, metal strap of 0.02-1.0 mm thickness. Such straps are preferably fastened along the upper most rim of the CCC's top frustum, and run to a lower fastening means adjacent the bottom base structure **(131)** of the CCC, so that the straps, when pulled tight, pull the interlocked frustums of the CCC together under a compressive force.

A CCC lower strap tensioning ring **(193)**, which resides concentric to and registered against the CCC base, provides an array of fastening positions for the multitude of CCC straps **(190)** so that the lower tensioning ring applies compressive pressure to base through tensioned strap interconnections to the oppositely positioned CCC upper interconnection means **(194)**. Upper strap interconnections **(194)** fasten the straps to an upper tensioning ring, which is preferably a relatively thick upper edge-surface of the top-most frustum in the embodied CCC. Upper interconnects also preferably comprise load-spreading structures so that tensile loading of the straps are transferred evenly to a corresponding compressive loading of the adjacent portion of the uppermost frustum's top edge at multiple, regularly spaced positions. According such load-spreading means of the CCC upper strap interconnect preferably comprise an extended structure utilizing truss-like members for attaching to CCC upper strap fastening means. A resulting CCC structure utilizing tetrahedra-reinforced frustums in conjunction with the embodied compressive strapping and interlocking mechanisms, in **FIGS. 10-11**, will preferably incorporate separate pre-cut segments of reflector material, as embodied in the earlier CCC embodiments, in **FIG. 3**, whereas the additional support members of those earlier CCC embodiments are preferably not incorporated into the tetrahedra-reinforced CCC of the present alternative preferred embodiment.

In a telescoping embodiment of the inventive CCC structure, frustums, marked a-g, and base unit **(131)** are thus disposed so as to be readily condensed into a retracted form, in **FIG. 11(a)**, so that the components of the embodied CCC may be shipped or stored within a transport container **(141)** of considerably reduced volume, whereas the assembly of frustum and base unit may be extended in a telescoping fashion, in accordance with the vertical edge-wall embodiments, in **FIG. 6(b)**, and clamping mechanisms previously embodied. The CCC base unit **(131)** is preferably formed as an integral and rigid piece comprising the lower-most sections of the reflector, preferably including the first, innermost, three frustum surfaces of the CCC in its machined surfaces. Circular bolt-pattern formed in the base unit **(131)** provides corresponding mounting means for the preferred solar-thermal, or alternative PV, receiver tube assembly, similar to mounting base means **(118)** in previous embodiments, in **FIG. 2**.

In the contracted form, the telescoping concentrator is preferably expanded to its extended form, in **FIG. 11(b)**, by successively raising each frustum, consecutively or simultaneously, so that each frustum interlocks to the immediately inner and adjacent frustum by an interlocking mechanism, wherein the outer frustum is guided by preferably plastic-terminated surfaces. The interfacing region between adjacent frustums is preferably occupied by a polymer lining **(187)** attached to at least one edge surface, for prevention of debris and ease of disassembly. A variety of automated means may be readily incorporated for contracting and extending the assembly by those skilled in the art.

After the telescoping CCC assembly is expanded to its expanded state, in **FIG. 11(b)**, tensioning means are preferably utilized for compressively loading the CCC along its optical axis. In particular, it is preferred that a plurality of flexible straps – metal or alternatively fabric or plastic, or any suitable material – extend between the upper region and lower region of the CCC with tensioning means so as to bring the straps under tension, thereby bringing the CCC structure under compressive force. CCC tensioning ring **(192)** is disposed intermediate to and concentric to the upper and lower strap fastening means, so that the tensioning means preferably comprise a spacing means for spacing the straps uniformly from the CCC structure, such spacing means preferably comprising CCC tensioning ring **(192)**, such that the ring uniformly increases tensile loading of the straps by advancement of the ring downward toward the CCC base until a desired tensile loading of the straps is realized. Such tensioning means will preferably also include CCC tensioning clamps **(191)** that preferably comprises a clamping device that determines the position of the tensioning ring. Accordingly, advancement of the tensioning ring downward uniformly provides a commensurate tightening, or tensile loading, of the straps, thereby compressively loading the stack of interfacing frustums.

It is also pointed out in conjunction with the present embodiment that, as previously indicated, the absorber length, h', may be considerably longer than the length, z , of abstracted line or cylinder corresponding to line or surface of highest solar concentration in accordance with the embodied CCC. Accordingly, the embodied CCC is also effective for concentration of indirect sunlight by means of providing a longer absorbing length in the absorbing media of the receiver tube than what is necessary to receive direct sunlight directed along the optical axis. The CCC tensioning ring **(192)** is also a preferred means of fastening to mounting means of a tracker, such as to an equatorial mount.

In an alternative embodiment, the preferred hollow-core aluminum-based frustums are parted from an alternative preform construction comprising vertically oriented honeycomb – or other suitable mesh – layers, utilizing, rather than the previous horizontal-planar orientation, in **FIG. 6**, instead a wound preform, in **FIG. 12**, comprising preferably a series of concentric sleeves of sheet metal interspersed with the hollow-core material, though a spiral formation of a continuously wound structure may be envisioned. This concentric arrangement is an alternative means of obtaining the tetrahedra-reinforced conic frustums of the preferred embodiments, similar to the preferred aluminum honeycomb core of the preferred preform construction in previous embodiments.

The alternative wound preform results in a major section of the resulting annulus, in **FIG. 12(a)**, with cut-away region **(140)** revealing interior honeycomb core layers. As in previous preform embodiments, a sheet metal interface layer **(163)** and honeycomb core layers **(148)** of the wound preform are preferably of substantially constant thickness yielding frustums with roughly parallel inner and outer frustum surfaces; preferably with a resulting inner core of the resulting conic frustum comprising a plurality of support members that are alternately perpendicular and parallel to the optical axis of the embodied frustum. Hot-pressing of the wound preform of the present embodiments is preferably performed in an isostatic press using plastic bagging material in accordance with accepted practices, or alternatively by methods performed in conjunction with wound honeycomb structures of the prior art, such as provided by Hexcel Corp..

As in previous embodiments, linear cutting means **(130)** for parting the preform may be performed by a variety of cutting means, including but not limited to ultrasonic cutting blades, wiresaws, bandsaws, and acid string saws. Alternatively, the toroidal preform may be left stationary and cutting means rotated about the preform to produce the conical frustum. Mitered cuts made into the preform may also be performed on a turret lathe, boring mill, or other such conventional tools common to large machine shops.

Also, finishing of parted perform surfaces may be performed by any suitable method of the art, including wet-sanding methods commonly used in finishing honeycomb materials of the prior art, though laser-trimming, electro-etching, chemical polishing, or any other appropriate finishing method may be utilized, utilizing the circular rotating table **(146)** for these finishing stages in the usual manner.

Frustum core structures of the present alternative embodiments using wound preforms provide similar tetrahedral reinforcement and frustum structures similar to previous embodiments, and accordingly are similarly laminated with the inner and out frustum surface layers using similar bonding means such as silicone or epoxy interfacial adhesives.

As previously discussed, hollow core panels utilized in the construction of the inventive conic frustums are not limited to strictly aluminum and adhesive construction of the core or cladding material, or to layered honeycomb interior structures. For example, other materials utilized may include those commonly used in hollow-core panels of the prior art, such as graphite, titanium, stainless steel, paper, plastics, Teflon, TFE, polyimides, polyan , Numex, Kevlar, polyvinylchloride, ABS, PEEK, Ultem, etc., and particularly wherein the honey comb core comprises various multilayer laminates of these materials. Whereas, frustums may be constructed of graphite-reinforced composites, aluminum hollow-core construction is preferred for both cost and environmental cycling resistance.

Fabrication of the core may be likewise conducted by a variety of bonding or lamination means, such as established and utilized in construction of commercially available hollow-core materials, including laser welding, resistive welded, adhesive bonding of corrugated metal, etc.

A variety of core constructions is available, and may possess mechanical characteristics that render such core material more suitable for the horizontal-planar construction, or alternatively more suitable for the wound construction of the embodied preforms. For wound preforms, various core materials are available that allow relatively high curvature of the core material. For example, Hexcel provides a variety of such alternative core materials including "Flexcore," and others include "Doubleflex", Benoflex", Ox-core, reinforce honeycomb, "Doubleflex", Benoflex".

Likewise, the interior core of the preferred planar hollow-core sheet is not limited to strictly honeycomb cores, as a variety of alternative core structures may also provide adequate rigidity, such as those comprised of hexagonally stacked tubes, octagonal structures, cubic structures, , "square cell," etc.

Concentric CCC-based solar concentrators of the preferred embodiments provide advantages, relative to similar concentrators, in part due to significantly lower shipping costs that are possible with the stacked-frustums approach embodied herein. In a preferred embodiment, the hollow-cored frustums of the present stacked CCC structure are stored and shipped in a condensed/collapsed form, and wherein many component frustums corresponding to a large multitude of CCC's are stacked along the optical axis of the CCC for stowage in a condensed volume **(141)**.

Since the embodied conic frustums are preferably formed separately, frustums of substantially identical diameter and slope are stacked together in shipping containers **(141)** that are disposed for containing and shipping at least several concentric stacks of the embodied frustums, so that the same amount of cylindrical volume required to house one CCC of the embodiments may be utilized in shipping and storage to contain a large multitude of the same CCC, in unassembled form, in **FIG. 13(a)**. In addition, CCC's constructed of frustums having cylindrical edge-surfaces, in accordance with earlier embodiments, may accordingly be condensed into concentric stacks of frustums, wherein each stack comprises a multitude of one frustum size. Accordingly, a multitude – for example, one hundred – of substantially identical CCC's having a total of seven frustums each can be contained, stored, and shipped, as a concentric arrangement of seven concentric stacks, wherein each stack comprises a multitude of one of the respective seven frustums of the seven-frustum CCC, and so that the stack **(197)** of frustums comprises, for example, one-hundred or more substantially identical frustums. Preferably each shipped or stored stack is interspersed with frustum separating spacers **(199)** and wrapped around its periphery with a stretched plastic wrap or other packaging means **(196)**. Of course, assemble CCC's may also be stacked as well for shipping purposes, though with less resulting packing density.

In a another alternative embodiment utilizing photovoltaic modules and receiver tubes, a multi-junction photovoltaic (MJPV) receiver tube, as embodied in **FIGS. 4(a) and FIGS. 13-15**, as well as in the prior disclosures cited herein, is modified to provide optical shielding of the MJPV module by an appropriate HTF, wherein the HTF is preferably a fluid with absorption characteristics that absorb ancillary optical radiation from the incoming solar spectrum, wherein such ancillary optical radiation is radiation that is outside of or in excess of the usable spectral bandwidth of the MJPV arrays. As is well understood, a typical MJPV array absorbs several adjacent regions of the available solar spectrum through utilization of several semiconductor junctions of distinct compositions and crystalline structure wherein one junction provides useful conversion of one region of the spectrum by virtue of its band-gap residing at the low-energy end of the respective absorbed region. In **FIG. 13(b)**, an exemplary terrestrial solar spectrum **(203)** converted by the MJPV may correspond to conditions at sea-level, high-altitude, direct-sun, or diffuse light conditions.

In contrast to earlier embodiments utilizing photo-absorbing media in a circulating molten salt, wherein transmission of solar radiation through the salt is substantially absorbed and/or attenuated throughout the visible and near-IR spectrum, preferably so that the photo-absorbing salt suspension absorbs most of the incident power across this region of the solar spectrum; in the present embodiment, a majority of solar radiation incident on the presently embodied MJPV/CHP tube that is in the visible and near-IR is transmitted by a relatively low-temperature (less than 300 Celcius) HTF so as to be absorbed by absorbing surfaces comprising the MJPV module.

For example, three regions A, B, C, of the spectrum are accordingly absorbed by a three-junction MJPV wherein each junction is characterized by an associated band-gap energy (204a, 204b, 204c) , and each particular junction of the MJPV has an associated energy conversion efficiency (205a, 205b, 205c) provided by the specific junction of the MJPV that is disposed for absorption of the respective spectral region (A,B,C), in **FIG. 13(b)**,

In the present embodiment, the HTF possesses a HTF spectral absorption feature **(207)** that comprises optical absorption of the solar spectrum by the HTF with regards to the near and far infrared (IR), typically in the spectral region of 1.5 to 10 micrometer wavelength.

Also, in the present alternative embodiment, there is also an adjustable HTF additive added to or removed from the base HTF fluid, the HTF additive having an HTF-additive spectral absorption feature **(208)** that comprises a second optical absorption characteristic, the second optical absorption characteristic preferably providing an increased absorption of the solar spectrum by the HTF-additive with regards to the near-IR and far-IR, preferably in the region of 1.4 to 10 micrometer wavelength, and preferably also includes additional HTF-additive spectral absorption peak **(209)** that comprises optical absorption of the solar spectrum by the HTF-additive in a spectral region (preferably region C) of the MJPV. Particularly, the additional absorption peak **(209)** of the HTF-additive is preferably in the short wavelength portion of the spectral region absorbed preferentially by a Ge junction of a Ge/GaAs/GaInP MJPV, wherein such spectral absorption peak is preferably provided by an HTF-additive comprising water, or, alternatively, a similar absorption singularity can also be provided by commercially available silicone oils.

Accordingly, IR radiation in the incident solar radiation that is unused for electricity generation by the MJPV is absorbed preferentially by the HTF, so that useful heating of the HTF is provided after the fluid has already passed through the interior tube **(123)** where cooling of the MJPV is provided by heat transfer to the HTF. Preferably the HTF thus enters the cylindrical return passage **(211)** after undergoing an initial heating within the MJPV-cooling portion of the circuit, so that the HTF preferably is already heated to a temperature of between 50-200C, depending on the type of MJPV used and other specific requirements of the installation. The HTF is then further heated in the return passage **(211)** due to both the absorption properties of the HTF, as well as due to the heating of an adjacent, apertured, absorber coating **(217)** that is disposed on a surface of the concentric tubes forming the return passage.

In particular, it is preferred that the HTF be passed through a substantially transparent envelope disposed directly infront of the MJPV array, so that incoming solar radiation passes through the interior of the HTF fluid prior to irradiating the MJPV, and wherein the HTF absorbs the infrared portions of the solar spectrum comprising wavelengths longer than wavelengths corresponding to the smallest band-gap of the MJPV. For example, if the MJPV comprises a Ge/GaAs/GaInP 3-junction MJPV, then the longest wavelength usefully converted to electrical power by this MJPV is typically that corresponding to the approximately 0.67 eV bandgap of Ge. Accordingly, a HTF of the current preferred embodiments would provide relatively high absorption of IR solar radiation corresponding to the infrared spectrum of photon energy less than 0.67 eV, in **FIG. 13(b)**. Such HTF properties are preferably provided by a glycol, and more preferably ethylene glycol. Alternatively, a large assortment of alternative HTF compositions may be utilized in the present embodiments. For example, silicone oils, glycerol/glycerin, soybean oil or other vegetable oils, and any other oil or fluid compatible with preferred 100C-plus operation. In certain alternative embodiments, gaseous or vaporous heat transfer media may also be envisioned. In the present embodiment, the second absorbing liquid comprising HTF-additive is added to or subtracted from the HTF so as to modify its absorbing properties in real time, in response to local solar conditions, as well as potentially in response to changes in the load requirements for delivered energy of the MJPV/CHP receiver tube so that relatively more electricity or relatively more thermal energy may be delivered in accordance with the amount of the HTF-additive that is incorporated into the HTF solution. For example, the use of an ethylene glycol with its high water solubility allows for the addition and removal of water for modifying the absorption properties. Such adding and subtracting of water content may be readily accomplished by various known desiccation means in the fluid circuit. In particular, it is preferred that the absorption-modifying HTF-additive provide absorption within the active spectral region of the MJPV, preferably in the long-wavelength region of a Ge/GaAs/GaInP MJPV, where photon flux in that region is in excess of that required for current balancing, and thus adds unnecessary heating of the MJPV under normal operating conditions.

Various other components of the PV modules, including protection diodes, specific die-mount compounds, wire-bonding schemes, specific die-edge termination means, etc., may be incorporated within the embodied MJPV modules by those skilled in the art and as is commonly taught in the art.

In particular, the present alternative embodiment utilizes a similar tubulated enclosure as in the previous MJPV/CHP embodiments, with an inner transparent tube **(214)** that separates HTF return passage **(211)** from the PV modules **(85)**, the inner transparent tube having an apertured absorber coating **(217)** formed on at least one of either inner or outer surfaces of the transparent tubes, preferably the outer surface of the inner tube **(214)**. Accordingly, a HTF return passage **(211)** is formed between the inner transparent tube **(214)** and outer transparent tube **(215)**.

The outer transparent tube **(215)** thus forms an outer concentric wall of the HTF return passage **(211)**, so that the preferably transparent returning HTF preferably forms a continuous cylinder of flowing liquid in the according cylindrical volume of the embodied HTF return passage.

Accordingly, the absorbing coating **(217)** that is patterned with apertures is preferably formed on the outer surface of the inner transparent tube **(214)** so that, in addition to preventing unnecessary irradiation and heating of the front-side bus contacts **(88)** , the absorber also preferably contributes significantly to the efficient heating of the HTF fluid within the HTF return passage **(211)**.

The absorbing coating **(217)** preferably includes absorber coating segments **(218)** that shadow front-side bus contacts **(88)** , so that such segments of the absorber coating accordingly border preferably rectangular apertures **(219)** in absorbing coating **(217)** that allow transmission of solar radiation to the active region of the underlying MJPV (or alternatively other PV). In a preferred alternative embodiment, the apertures are rectangular to accommodate proportionately rectangular long MJPV arrays (e.g. 1cm by 10cm) that are cut from wafers, with long axis parallel to the optical axis **(73)** of the CCC, so as to minimize losses associated with smaller (e.g., 1cm x 1cm) PV arrays. The absorbing coating preferably comprises a robust broad-band absorber material that is vapor deposited layer of a highly absorbing neutral absorber preferably comprising a black chrome, or alternatively any of various other suitable solar absorbing materials including titanium oxynitride, copper cermets, carbon-filled resin, and other solar absorber coatings of the prior art.

The interior of the inner transparent tube **(214)** thus comprises a PV module enclosure volume **(221)** for housing the PV module **(85)**, wherein the enclosure volume is preferably back-filled or circulated with a low thermal conductivity media, such as Argon or a vacuum.

As in previous embodiments, thermal-sinking to the interior supply tube is provided by main bus bars, wherein preferably the plurality of back-plane main bus-bars **(91)** form continuous thermal contact to the heat-sinking interior tube **(123)**.

A receiver-tube end-cap **(224)** seals the top end of the receiver tube and also provides an end-cap passage-way **(225)** that provides passage of HTF between the supply HTF passageway **(124)** , provided by axial supply tube **(123)** , and the return HTF passage-way **(211)**.

While the end-cap of the HTF-shielded MJPV module and associated receiver tube of the present embodiments may be sealed by any of a variety of means well-know to the art, including glass-to-glass seals, glass-to-metal seals, ceramic seals, etc, silicone o-rings **(226)** are preferred for sealing the top-end of the receiver tube in the present embodiments wherein an HTF temperature of around 250C or less is preferred in the present embodiment for many solar-thermal applications such as swing-shift refrigeration, water heating, evaporators, etc.

While the CCC/MJPV embodiments herein are ideally embodied for simultaneous production of electricity and heat for various CHP and related applications, these energy forms may be accordingly converted to other forms of energy as an integral function of the CCC apparatus and its associated integral structures. For example, the produce electrical power may be converted to chemical energy in the form of hydrogen or other useful substance of relatively high free energy.

Alternatively, the embodied MJPV insert module may allow to be utilized in conjunction with relatively low-temperature (<300C) electrically insulating and transparent heat-transfer fluids, such as ethylene glycol or mineral oil, wherein such HTF's are allowed to circulate on both interior and over the exterior surfaces of the MJPV insert assembly **(85)**. Such embodiments may be implemented with additional protective coatings applied to the MJPV modules.

A dual purpose MJPV/solar-thermal receiver tube is accordingly provided, in **FIG. 15** , wherein the MJPV insert assembly **(85)** is preferably integrated with the embodied tubulated receiver tube of **FIGS. 16-17**. In the present alternative embodiments, a central tube **(123)** provides the HTF coolant supply passage **(124)** and is preferably comprised of an electrically conductive metal, preferably copper, or alternatively, and aluminum alloy. The central tube **(123)** is, in the present alternative embodiments, fashioned so as to provide sliding contact with the preferably parallel array of current bus bars that correspond to either positive or negative polarity of the embodied MJPV modules. In the present embodiments, it is preferred that the central tube is fashioned so as to provide sliding and conductive contact comprising sliding insert channels **(125)** with the MJPV-front-side main bus-bars **(90)** providing an electrical bus to the front-side contacts of the MJPV modules. The central tube thus provides a mechanical guide surface for maintaining position of the PV insert assembly within the transparent receiver tube. It is preferred that the central tube, thus acting as a guide rail, is machined so as to further incorporate parallel grooves in its outer surface so that the front-side main bus-bars **(90)** slide along the central tube with the bus-bars guided and contacted by the interior surfaces of these parallel grooves.

It is preferred that electrical interconnection between the main bus bars of the MJPV insert assembly and an external work load powered by embodied MJPV assembly be made by means of high-current electrical bulk-head contacts in the form of preferably two rings **(94, 95)** - or, collars - that encircle the receiver tube mounting nipple **(37)**, wherein each provide an external electrical contact for one of either the negative or positive polarity of the embodied MJPV assembly. A multitude of high-current metal-ceramic feed-trough's are disposed in each ring in number corresponding to the number of main bus-bars being contacted, wherein contact of each feed-through to its adjacent main bus is preferably by means of sliding, clamp-able rail contacts. High-current copper strapping may then be utilized for carrying current to/from the ring contacts to the desired work-load for the application being powered. The central tube (123) thus is provided connection to the slip-fit interconnect fitting **(36)** of the previous embodiments so as to provide similar annular and central fluid passages for supply and return of an HTF. Accordingly, the embodied MJPV assembly may be incorporated into an alternative PV-hot-finger assembly, in **FIG. 4(a)**, which may be exchanged with the previously embodied hot-finger assembly in the various CCC/hot-finger embodiments of the present invention.

It will be understood by those skilled in the solar art that the solar concentrator of the preferred embodiments may be utilized in conjunction with a variety of solar energy-conversion devices, such as the previous PV embodiments._ In the frist preferred embodiment, the energy conversion apparatus, in **FIGS. 16-17(a-b)**, is a single-ended, tubulated solar receiver and integrated 2-axis rotating union, comprising a **(a)** front-sectional view, and **(b)** front view, comprising a high-temperature solar-thermal receiver tube.

The previously embodied transparent-receiver-tube embodiments are preferably utilized in a tubulated "hot-finger" configuration comprising a single-ended receiver tube assembly **(15)**, in **FIG. 16-17** that is preferably utilized in the embodied CCC In the present disclosure, the term "hot-finger" will be equivalent to the disclosed single-ended receiver tube assembly **(15)**. The term "single-ended" will herein refer to a structural characteristic wherein HTF return and supply connections of the embodied solar-thermal receiver tube are located at one end of the receiver tube, and no other limitations are implied by this term.

A primary advantage of the present embodiment is in providing a solar-thermal receiver tube that can withstand continued temperature cycling between operating temperatures between 600C to 900C, and non-operating temperatures that are typically room temperature. For this to be done reliably, it is preferable that the fasteners, metal flanges, and other load-bearing structural elements are substantially removed from the higher-temperature regions of the operating receiver tube assembly. The central absorbing element of the present preferred embodiment is once again a preferably optically absorbing tube **(23)**. Accordingly, the receiver tube assembly of the present embodiments possesses an inner high-temperature region that is preferably the HTF return portion of the receiver tube assembly's fluid circuit. The inner region is preferably insulated from an outer region of the tube assembly by incorporating a multi-walled - double-walled in the preferred embodiment - structure comprising , high-Ni alloy, central insulating enclosure **(31)** preferably having the aspect of roughly a tube, though any insulated cavity suitable for transporting and insulating the returning HTF may be utilized in the preferred embodiments. The central insulating enclosure is provided with insulating spaces **(32)** or gaps that separate walls of the double-walled (or triple-walled, quadruple-walled, etc) enclosure that insulate the HTF return passage from the coaxial absorbing tube **(23)**, such enclosures are preferably further insulated by a low-thermal-conductivity gas within the spaces **(32)** formed within the multi-wall thermal barrier, preferably Argon, which is disposed within the accordingly cylindrical insulating space formed by the preferably tubular double-walled enclosure. Alternatively such thermally insulating space may be provided as a vacuum barrier. It is additionally preferred that the double-walled insulating enclosure have a low-emissivity coating on at least its surfaces that form the insulating space, preferably comprising gold, but alternatively any suitable low-emissivity coating of the prior art. The double-walled enclosure is preferably located along the central axis of the tube assembly, and within the interior of the earlier central absorbing element, so that a central HTF return flow passage **(21)** is preferably disposed so as to provide a return path for the HTF after having traveled the length of the annular flow space wherein it is preferably heated to its desired high output temperature.

Preferably the enclosure is disposed as a tubular element within the central absorbing tube **(23)**, so that the absorbing tube and insulating enclosure may be separately serviceable or replaced.

In the present preferred embodiments, the transparent receiver tube is formed as a monolithic fused silica (or fused quartz) assembly that preferably includes a vacuum layer and outer tube as in previous embodiments. While various high-temperature metal-glass seals and glass-ceramic seals are known and practiced in the prior art (see, for example, well-known texts) is preferred that the transparent receiver tube, outer vacuum tube, and transparent receiver tube mounting flange **(20)** be constructed from silica, so that no expansion joints are necessary in this monolithic assembly.

Thermal expansion differences between the fused silica mounting flange **(20)** and the preferably metal alloy connecting flange **(25)** of the mounting nipple are provided for preferably by means of non-binding surfaces provided on the respective mating surfaces of these two flanges, which, combined with the described optical planarization of these surfaces, allows for these surfaces to slide relative to each other during heating and cooling. This is additionally accomplished by means of the compliant tensioning means **(107)** that are utilized to provide suitable pressure for clamping together these mating surfaces. Preferably the tensioning means comprise Inconel Belleville washers utilized in conjunction with bolts **(108)** that hold the two flanges together. Tensioning of the Belleville spring washers is preferably such that the total force holding the two flanges together is equivalent to less than 50lbs. Such light loading is acceptable in the preferred embodiments, wherein the annular HTF passages are preferably maintained at low pressure of less than 10psi, and HTF flow is enabled by return side pumping of the fluid. The mating of the fused silica flange to the mounting nipple **(37)** of the embodied hot-finger assembly is accomplished by means of an alloy clamping ring **(35)** (preferably with silica glass wool padding) and compliant fasteners comprising a plurality of bolts **(108)** and compliant tensioning means **(107)**. Alternatively, a glass-to-metal seal may be utilized for conversion of the glass receiver tube to a demountable metal flange assembly.

The mounting nipple connecting flange **(25)** of the mounting nipple **(37)** is preferably planarized and polished, similarly to the fused silica flange **(20)**, so that mating of the two flanges will be accordingly provided with sub-micron, preferably less than quarter-micron, clearances between the mating surfaces. The mounting flange of the mounting nipple is preferably coated with an inert low-surface energy material that provides minimum reaction with the salt or fused silica, and further additionally impedes any leakage preferably by virtue of a high wetting angle by the molten salt on the coated material. Alumina is preferred for the coating, though a variety of other coating materials may also provide suitable performance, such as boron nitride, titanium boride, zirconium boride, silicon carbide, or diamond-like carbon coatings.

It is preferred that the fused silica flange and other planar sealing surfaces of the embodiments are planarized and polished to surface RMS < 5 micro-inches on its external mating surface, with surface figure preferably better than 1/4-lambda at standard HeNe wavelength of 530nm. The flange is typically on order of 1/4" to 1/2" thickness material to provide adequate rigidity.

As in earlier embodiments wherein the preferred HTF of molten salts are being heated by the receiver tube, it is preferred that the inside of the fused silica Receiver tube be coated by a vapor deposition method to provide a diffusion barrier between the silica and the molten salt. Preferred coatings for this purpose are aluminum oxide, chromium oxide, various metal fluorides,

As noted previously, the central absorbing tube can be fashioned or extruded with any suitable cross-section to enhance absorption, so that the external surface need not be circular as in the first preferred embodiments. Accordingly, the profile of the central linear absorption element of the embodied solar thermal receiver tube can be a tube or any other profile, such as a star or polygonal shape. In some alternative embodiments it may include an assembly of rods. Alternatively, the supporting fin-shaped brackets of earlier embodiments may extend the length of the embodied absorbing central tube, so that such fins serve both to position the tube within the mounting nipple **(37)** as well as to extend into the absorbing section of the receiver tube to enhance solar absorption.

Other rotating unions that provide the tilt and pivot rotations required for two-axis tracking may be utilized without departing from the scope of the present invention. For example, it may be adequate in certain circumstances to utilize a universal rotation union provided in the form of a ball-joint, such as provided by mating concave and convex spherical surfaces, similar to ball-joints of the prior art, made of appropriate refractory materials that may comprise coated high-temperature alloys, glasses, and ceramics.

The various tube coatings of the preferred embodiments are preferably formed prior to fusing of glass parts to form the embodied transparent receiver tube, though, in an alternative embodiment, the inner transparent receiver tube is attached to the fused silica flange prior to coating, and an outer vacuum tube is not incorporated. The fused silica flange is preferably mated to a metal mounting nipple that, as with other metal structural components of the assembly, is composed of a suitable high-temperature alloy, preferably Incolloy, or alternatively Waspalloy, Inconel 625, etc.

In the preferred embodiments, HTF within the annular passage **(22)** of the receiver tube is heated by solar radiation propagating through the transparent receiver tube as it travels the length of the receiver tube to its sealed end, at which point it returns back by reversing direction in the hemispheric portion **(16)** of the tube and passing through the central HTF return passage **(21)**. Accordingly, in the preferred embodiments, wherein the HTF is loaded with an absorbing medium, such as a graphite powder or powdered inorganic coatings, the radiatively exposed HTF will have a considerably higher temperature in the bottom region **(112)** than it will in the top region **(111)** of the embodied receiver tube's annular passage **(22)**.

In accordance with the present preferred embodiments, the receiver tube assembly, when positioned in the embodied concentrating conical concentrators (CCC's) of the present invention, provide for heating of an HTF to temperatures in excess of 800C, and is preferably and most effectively employed for heating of HTF's to temperatures in excess of 900C. This is accomplished preferably by supplying the HTF at suitably liquid temperatures and pressure to the outer annular passage of the receiver tube, so that a processed volume of the HTF travels up the annular passage to the hemi-spherically sealed end **(16)** of the receiver tube assembly, where it then reverses direction to return though the central insulated passage formed by the insulating enclosure. A slip-fit, absorbing tube interconnect fitting **(36)** preferably constructed from metal alloy is utilized to join the absorbing tube **(23)** to vertical tube extension of a perforated retainer sleeve within a preferred adjoining rotating union, or an appropriate connector on an alternative connecting component.

Due to the very high concentrating capabilities (preferably greater than 500 suns) of the embodied CCC **(70)**, it is embodied that the solar flux into the embodied receiver tube will provide for a desired temperature increase of the HTF volume within a relatively short travel distance, relative to thermal receiver tubes of the prior art, so that the embodied receiver tube assembly is quite short (preferably less than 2 meters in length), while enabling a temperature rise of typically 100-450C within the short travel distance of the HTF volume within the embodied annular passage. Preferably the travel velocity of the HTF is such that a given HTF volume travels the length of the receiver tube in less than a minute, and preferably in less than 0.5 minutes. Accordingly, a high temperature gradient is formed within this length of traveling HTF in the annular passage, so that it is realized and preferred that the embodied receiver tube provides a linear temperature gradient in the heated HTF within the annular passage of $\Delta T \geq$

100C per meter, or a temperature difference of greater than 100 Celsius in a meter or less of flow distance.

In combination with the absorbing molten salts (a HTF, or "thermal transfer fluid") of the high-temperature solar-thermal embodiments, the embodied radial thermal gradients due to low salt thermal conductivity (e.g., typically less than 1 watt/m.K), in earlier embodiments of previous disclosures included herein by reference, and irradiation of the hemispheric end **(16)** of the hot-finger assembly with top-hat heat-shield, in accordance with the preferred embodiments, in **FIG. 1**, a solar-thermal receiver tube is realized wherein the heated HTF of the embodied receiver tube is processed to substantially higher temperatures than any emitting surface measured along the linear length of the tube. Conversely, if emissivity of the overall tube is calculated for that of the temperature of the molten salt provided by the receiver tube, the calculated effective average emissivity of the cylindrical receiver tube will result in an effective emissivity of less than 0.05. Since emissivity is by definition an equilibrium measurement, and the present embodiments are by design a highly non-equilibrium device, such emissivity measurements are herein necessarily "effective" quantities.

In this way, the temperature of flanges and fasteners of the receiver tube assembly are maintained at roughly the temperature of the cooler molten salt that is entering the annular passage of the assembly before heating of this salt, whereas the hotter HTF is present at the opposite end of the receiver tube, or else preferably within the insulated enclosure, which preferably sustains less mechanical stress, provides minimal structural bearing functions, and can be encapsulated in an inert gas such as Argon during down-time.

HTF's of the invention may comprise any molten salt including chlorides and fluorides, oil, water, a gas, a super-critical fluid, or any combination of these that is suitable as an effective HTF.

The hot-finger assembly **(15)** , in **FIG. 16**, comprising the transparent receiver tube **(11)** and outer vacuum tube **(12)**, inner absorbing element/tube **(23)**, any supporting brackets **(24)**, mounting nipple **(37)**, central insulating enclosure **(31)** (preferably multi-walled insulated tube), compliant tensioning means **(107)**, and absorbing tube interconnect fitting **(36)** is preferably incorporated in an assembly that allows pivot and tilt of the receiver tube for two-axis tracking of the sun, preferably wherein the optical axis of the tracked direct sunlight is maintained roughly coincident with the central axis **(9)** of the embodied receiver tube. Whereas this movement may be provided by alternative rotating unions comprising such solutions as high-temperature, universal ball-joints, it is preferably accomplished by a two-axis rotating union.

The single-ended receiver tube assembly **(15)** is preferably connected and supported by a 2-axis rotating-union assembly **(40)**, in **FIG. 17**, which comprises an upper tilt union **(41)** and a lower pivot union **(50)**. In accordance with the preferred embodiments, the upper tilt union has a horizontal tilt axis **(42)** for rotational altitude adjustment of the hot-finger in the hot-finger/CCC tracker assembly described later, and the lower pivot union has a vertical pivot axis **(62)** for rotation of the hot-finger and CCC assembly in the horizontal plane.

The tilt union assembly **(41)** is housed by tilt union fork **(43)** providing mechanical function of a tilting axis support similar to that commonly used in telescopes, turret guns, and transits. The tilit union fork supports a rotating portion of the tilt union assembly comprising tilt-union rotating 'T' joint **(49)** resembling essentially a metal alloy 'T' pipe fitting with precision formed surfaces, wherein the orthogonal portion of the 'T' is connected to the embodied hot-finger assembly by means of an integral sealing flange **(46)**, and the coaxial legs of the 'T' provide are coaxial to the tilt axis **(42)**, so that the attached hot-finger assembly **(15)** is attached to the rotating 'T' joint so as to provide a rotation by T joint about the tilt axis. Coaxial supply and return passages for the HTF are accordingly provided along the tilt axis similar to dual-flow rotating unions utilized for lower-temperature applications. In the preferred embodiments

An inner, perforated retainer sleeve 'T' assembly **(34)** comprises a retainer sleeve coaxial to the tilt axis **(42)** and disposed to provide a coaxial positioning between integral sealing flange **(46)** and the bushing plates **(47)**. The retainer sleeve incorporates a plurality of hole structures for allowing passage of the supply-side HTF into the region of the tilt axis. Additionally, the retainer sleeve also incorporates an orthogonal tubular element that is maintained coaxial to the orthogonal portion of the tilt union's rotating 'T' joint, and provides connection and alignment to the absorbing tube **(23)** of the hot-finger assembly, via slip-fit absorbing tube interconnect fitting **(36)** . The slip-fit interconnection thus provides a housing and guide for the resistance-fit connection of the exit end of the embodied central insulated return tube **(31)** of the hot-finger assembly, and a upper pivot-axis insulated tube **(145)** that provides a return passage for the returning HTF in the rotating 'T' joint of the tilt assembly.

Fluid communication between upper pivot-axis insulated-tube **(145)** and a lower pivot-axis insulated-tube **(45)** is provided by insulated-tube return 'C' insert **(39)**, which is removed and installed by way of removing tilt union side plates **(44)** that sealingly cover and the internally machined fork housing for the 'C' inserts. The insulated C-insert is provided within a similarly C-shaped cavity in the fork, so that the fork houses the C-insert and additionally provides an annular space **(22)** substantially encompassing the insulated C-insert, so that the embodied annular supply passages and central return passages within the C-insert, are incorporated within the union fork structure **(43)** for transport of the HTF between the hot-finger assembly and the lower pivot assembly **(50)**.

The rotating tilt union provides fluid passage between the tilted hot-finger assembly and the lower, non-tilting pivot union by means of inorganic rotating seals, comprising precision bushing plates **(47)** , that are disposed coaxial to the tilt axis at either side of the rotating 'T' joint **(49)** and positioned to couple the tilting 'T' joint to the non-tilting union fork.

The bushing plates **(47)** preferably comprise coated disks comprising the same alloy as employed in the fork construction, so that thermal expansion is uniform. The bushing plates are preferably polished and planarized to within optical tolerances, so that parallelism of the bushing plates is within 2 microns, and more preferably within 0.5 microns. Similarly, optical flatness of either planar surface of the plates is such that their resulting polished surface figure is flat to within 0.5 microns. Such polishing methods and tolerances are commonly practiced in the optical and magnetic disk fields, and numerous vendors are available that can provide appropriate fabrication services to produce the embodied bushing plates. It is preferred that the bushing plates are subsequently coated with well-adhering chromium oxide thin film of about 0.25 micron thickness, followed by 100nm of alumina, so as to act as a diffusion barrier and wear surface in the operation of the rotating unions. Alternative wear surfaces may be utilized, and will depend largely on the chemistry of the preferred molten salt HTF. In the preferred case that the HTF is a chloride salt, or alternatively a fluoride salt, the embodied bushing plate provides suitable corrosion resistance. Likewise, the mating planar surfaces of the 'T' joint that form a rotating interface with the bushing plates are preferably fabricated with similar tolerances and coatings. The embodied rotating unions of the first preferred embodiment are operable on the basis of precisely aligned and parallel bushing surfaces that require minimum mechanical loading due to a high precision in their alignment and microscopic clearances that exist between the rotating union surfaces **(54)** that rotate with respect to one another. Accordingly, non-rotating surfaces of the fork element 43 the bearing disks are mounted to are surfaced for positioning the bushing plates within 2.5 microns of the adjacent rotating surfaces of the 'T' joint. It is accordingly preferred that the rotating unions of the present invention are assembled in a clean room environment. Alternative coatings utilized are preferably selected from group comprising boron nitride, graphite, silicon carbide, alumina, borides, nitrides, and fluorides.

absorbing tube interconnect fitting **(36)** provides a union between the embodied absorbing tube that has preferably an optically absorbing outer surface, and the embodied retainer sleeve 'T' assembly **(34)** of the tilt union assembly. Since this fluid interconnect is preferably coaxial to the outer flow region of the receiver tube, it does not necessarily require a positive seal, so that slip-fit or resistance fit clearance between the interconnect fitting and its respective connecting tube sections is sufficient.

This mounting nipple is preferably constructed from an appropriate metal alloy that is compatible with the operating temperatures of the HTF. In the case that it is a high temperature molten salt, it will be appropriately constructed of Inconel or other appropriate nickel alloy. The mounting nipple may also include an appropriate vacuum or inert gas barrier shielding as is typical in the construction of high-temperature fluid plumbing.

The embodied 2-axis rotating union assembly provides supply and return flow between the solar tracking hot-finger assembly and a stationary HTF connection **(115)** to a work-load (which workload may comprise a steam turbine, Stirling engine, swing-cycle refrigeration and air-conditioning, materials processing, materials refining, electrolytic processing of materials, etc.) benefiting from the solar heating of the HTF. The 2-axis rotating union thus preferably provides two rotating axes for tilt and pivot of the receiver tube, preferably in unison with the attached CCC structure **(70)**.

The concentrator mount flange **(38)** of the mounting nipple disposed for connection to the 2-axis rotating union preferably also comprises a mount flange for attachment to the concentrator base, wherein this flange is appropriately larger in diameter so as to provide connection to the cavity base structure **(131)**, in **FIGS. 10-11**, in the preferred embodiments, or alternatively, base means **(118)** of the CCC structure **(70)**, in **FIG. 2**. Since the concentrator mount flange is preferably at elevated temperatures, relative to the concentrator structure, it is preferred that there be a conventional glass fiber gasket installed to impede heat flow between the two elements.

Joints that exist in the preferred embodiments between the insulated tubes are preferably formed as swaged fittings, wherein mating between male and female tapers results in a non-welded resistance-fit. In the case that the union between joined insulating tubes is rotating, since there is no appreciable mechanical load and very minute leakage into the annular supply passage is not problematic, such rotating unions of the HTF-submerged insulating tube can be made by a simple rotating union between machined male-female slip-joints, in **FIG. 17**.

Whereas it is preferred that the various non-dielectric components be fabricated from corrosion-resistant high-nickel alloys, such a Hastelloy-X, Hastelloy-N, Incolloys, Haynes 230, etc., it may be found advantageous under certain operating conditions to fabricate these parts from pyrolytic graphite instead. In cases that such a relatively brittle material is utilized, or that mechanical loads are relatively high due to weather conditions, receiver scaling, etc., it is then preferred that additional mechanical means are used to reinforce the embodied rotating tilt union. For example, it may be found advantageous to additionally implement supplemental, co-axial rotating joints that fasten to both sides of the embodied tilt union, thereby reinforcing the mechanical rigidity of the specified rotation axis, similar to an orthopedic reinforcement of a human leg, or as is commonly practiced in other areas of the mechanical arts. Such addition of commonly practiced mechanical reinforcement methods and structures, as with additional tensioned cable and strut reinforcements in the larger CCC tracking assembly (120), can be provided in conjunction with the embodied invention as is suited to a specific preferred installation or application.

As is typical with rotating unions and flow pumps of the prior art that are employed for the purpose of manipulating a high-temperature molten salt, additional enclosures for capturing and re-using any leaked molten salt may be implemented in conjunction with the embodied rotating union. Such additional structures as drip pans, "fling" enclosures, heat shields, and additional insulating structures for minimizing thermal losses, may be readily specified by one skilled in the art, and utilized in conjunction with the preferred embodiments, but are not shown herein for the purpose of clearly pointing out the preferred embodiments.

A rotating nipple **(51)** preferably provides a bottom bushing flange that provides a rotating planarized surface **(54)** for mating to a bushing plate **(47)** that is housed in the pivot union's static housing plate **(52)**. Preferably, the entire hot-finger /rotating-union assembly is encompassed by an IR-reflective shield during actual operation.

Beneath the rotating tilt union of the two-axis rotating union is a rotating pivot union **(50)** that provides means for rotation of the single-ended receiver tube assembly about the pivot axis **(62)**, thereby allowing the hot-finger and rotating tilt union **(41)** to pivot with the CCC structure while simultaneously the HTF fluid is transferred between the rotating single-ended receiver tube assembly and the static work load connected through the pedestal at work-load connector **(115)**.

The lower pivot union **(50)** incorporates the rotating nipple **(51)** that is coaxial to the pivot axis **(62)** and is attached to bottom surface of the tilt union fork by means of an integral sealing flange **(46)**. As similarly embodied in the tilt union assembly, the manifolding of the rotating pivot union provides a central lower insulated tube (145) and an annular HTF supply passage **(22)** peripheral and surrounding this lower insulated tube. The high temperature rotating unions of the present invention differ from such prior art rotating unions in that preferably no organic materials are used in sealing, and leak-tight seals are obtained instead by the mating of optically figured planarized surfaces so as to form very parallel and precise interfaces **(54)** terminated with high-temperature tribological coatings similar to the bushing plates of the tilt union.

As previously embodied, *in* **FIGS. 1-17**, in conjunction with embodiments having a CCC/receiver-tube combination for heating a molten salt HTF, oil, or alternatively a photovoltaic array, the inventive CCC/receiver tube combination can be utilized in conjunction with a variety of energy conversion processes. In an alternative embodiment, the disclosed solar concentrator is implemented for providing solar-thermal energy to fuel cells and electrolyzers for accordingly providing thermal energy for their various endothermic processes, such as hydrogen generation/reformation. In the present embodiments, in **FIG. 18**, an alternative application utilizing the CCC **(70)** in conjunction with an electrolyzer **(514)** and/or fuel cell **(515)** is embodied, wherein direct irradiation of a catalytic hydrogen generation apparatus is ideally provided by the inventive CCC, and wherein preferably the hydrogen generation apparatus is a solid-oxide electrolyzer that accordingly conducts oxygen ions through a solid oxide electrolyte so that preferably a hydrogen-bearing gas flowing through the apparatus and exposed to the reducing side of the electrolyzer cell is enriched in its molar hydrogen content, or alternatively in its Gibb's free energy, whereas a gas on the opposite (oxidizing) side of the electrolyte in the electrolyzer cell is normally enriched in its oxygen content, as is normally obtained in conjunction with such devices. In the present embodiment, direct irradiation of the electrolyzer is preferably provided so that solar radiation is incident on the reducing catalytic electrode of the electrolyzer so that the embodied catalytic hydrogen-generating apparatus is preferably a photocatalytic apparatus, and so that, accordingly, photo-absorption processes are beneficial and preferred for enabling generation of a desired chemical product in the embodied electrolyzer, namely an oxidizable fuel.

Integration of high temperature fuel cells and solid oxide electrolyzers with a CCC-based solar-thermal energy source is previously disclosed by same applicant in co-pending US patent application 12/803,213 (Hilliard) and in PCT application PCT/US2010/002178 (Hilliard), which are included herein by reference in their entirety. It is further disclosed in these previous applications by applicant that an annular high-temperature fuel cell apparatus, preferably SOFC, is integrated to the CCC so as to benefit from either direct heating or from a hydrogen generation means powered by the CCC. Accordingly, solar-thermal generated heat from the CCC may be used directly or indirectly for providing thermal energy required for any of a variety of hydrogen-forming or reducing processes.

In the previous patent applications of same applicant, an annular, solid-oxide electrolyte based apparatus is disclosed for electrolyzing applications such as oxygen/hydrogen separation, "syngas" processing (i.e., hydrogen and carbon monoxide), coal gasification, and other methods of increasing hydrogen content or otherwise increasing the available free energy of a resultant hydrogen-bearing gas over that of a precursor gas, wherein this electrolyzer is mounted in the focusing region of a solar concentrator, most preferably a CCC. This combination is again pointed out in the present embodiment, further utilizing, in particular, a CCC constructed in accordance with the preferred embodiments herein, preferably utilizing high-N CCC's formed from individually constructed frustums, and, more particularly, in accordance with subsequently embodied tetrahedra-reinforced frustums, in **FIGS. 4-13**.

As disclosed in the previous applications and embodied herein, in **FIG. 18**, multi-frustum solar concentrators may be utilized in conjunction with hydrogen electrolyzer/formation means and fuel cells of the prior art in integral packages wherein a fuel cell **(515)** is mounted below the frustum base, preferably in combination with a storage tank **(510)** for storing an energy-storing medium, preferably as either chemical-energy or thermal-energy, and more preferably as a hydrogen-containing gas.

Accordingly, solid-oxide electrolyzers of the prior art and herein may be identified as either hydrogen generators (or reformers) or oxygen generations systems (OGS), by virtue of the according oxygen-ion conduction provided in all such devices, wherein specific input gases and specific electrode compositions of the solid oxide electrolyzer may be more specifically disposed for a particular desired gas-generating application. The integral assembly of electrodes and electrolyte, and, in the preferred embodiments, also a supporting metallic grid, is frequently referred to as a membrane/electrode assembly (MEA) in the prior art, or monolithic electrolyte assembly. In the present embodiment, such electrolyzers having solid oxide MEA's are preferably illuminated on the hydrogen-rich (reducing) side of the MEA, and this is preferably accomplished by allowing solar radiation to enter from the peripheral edges of each MEA in the preferred annular electrolyzer stack, wherein openings typically utilized for the circulating gas are additionally utilized as according optical apertures for entrance of the solar radiation, as further detailed in the cited co-pending applications. Since the electrolyzer is preferably operated by conduction of an ionic current through the electrolyte, it is thus appropriate to identify the embodied electrolyzer as additionally a photo-electro-catalytic hydrogen generator, wherein photochemical activity may be provided by photoabsorption at the embodied titania-metal composite electrode for photocatalysis associated with what is described as semiconductor surface interaction, or alternatively provided by any other photo-absorption process known to enable chemistry, such as pertaining to photoelectron emission, irradiation of low-work function insulator surfaces, direct photo-absorption by reactive species, quantum tunneling, quantum well resonance, quantum dots, etc. Accordingly, in a CCC/receiver tube arrangement that is an alternative to the present embodiment, the embodied photoelectrocatalytic generator may comprise instead a plurality of Gratzel cells utilizing titania nanotubes, or other such relatively low-temperature electrolyzing cells that utilize the electrolyzing properties of a semiconductor/liquid or semiconductor/vapor surface, with or without photo-absorbing dyes/solutes, that is incorporated in an electronic circuit by communication with adjacent electrodes.

In particular, in the present embodiment, the embodied CCC is utilized to irradiate a centrally disposed, annular, solid oxide electrolyzing stack **(514)**, so that the annular electrolyzing (gas generating) stack is accordingly irradiated and heated by the solar concentrator for separating and accordingly forming hydrogen-rich and oxygen-rich gases and/or vapors at opposing porous electrodes of the MEA. There is accordingly utilized a central support tube **(505)** preferably disposed for containing return flow of oxygen from oxygen emitting side of the solid oxide gas separation device **(514)** with oxygen return passage **(506)** for oxygen-rich gas produced from the solid oxide gas separation device **(514)**. A transparent enclosure **(507)** encloses the annular gas-separation stack for containing the hydrogen-rich gases, preferably comprising a supply passage to the stack, the enclosure preferably comprising a hemi-spherically-terminated glass tube composed of preferably a borosilicate or more preferably a fused silica glass tube terminated on top with a hemispherical end. Accordingly, the solid oxide gas separation device is disposed concentrically in the glass enclosure space **(509)** formed by the transparent enclosure further disposed for containing water-vapor or other oxygen-bearing vapor/gas for delivery to the oxygen-adsorbing electrodes of the solid oxide electrolyzer, whereby hydrogen gas is preferably assisted in its dissociation at the electrode surfaces by catalysis, and more particularly photocatalysis, rendering the gas circuit of the glass enclosure space hydrogen rich. Such annular solid oxide stacks in fluid communication with an outer enclosure space are taught in the prior art, such as the electrolyzer stack taught in US Pat. Appln. 10/411,938 (particularly in association with **FIG. 9** of that application). The transparent enclosure for transmitting solar radiation therein is preferably supported by a concentric stack mounting structure **(519)** insulating the glass enclosure thermally from the concentric CCC. Similar fuel cell mounting means **(518)** are provided for insulating the high-temperature fuel cell **(515)** from the concentrator as well.

Porous electrode compositions utilized as catalyzing electrodes in the present SOFC embodiments may be any of those utilized in such solid oxide devices of the prior art, but preferably are based on perovskite materials selected from group containing manganates, lanthanates, titanates, zirconates, and tantalates for the cathode side, and nickel compositions on the anode side. In the case of the embodied electrolyzer, electrodes incorporate combinations of titania/platinum, titania/silver, and titanium/nickel. Alternatively, any other appropriate materials of the prior art may be incorporated in the various porous electrode compositions, electrolytes, and interconnects of the embodied, both SOFC and electrolyzer, solid oxide electrolytic stacks.

In particular, the oxygen-adsorbing and hydrogen-rich (reducing side) electrode of the centrally-disposed oxygen/hydrogen generation electrolyzer stack **(514)** is accordingly formed as a porous electrode that incorporates photo-catalytic compositions, preferably a platinum-TiO_2 composition that efficiently dissociates water into hydrogen gas and oxygen ions, typically in conjunction with a hydrocarbon and/or carbon dioxide, such that the oxygen ions subsequently conduct through the solid oxide membrane, or alternatively compositions including LSM or any appropriate photocatalytic electrode composition found suitable in the art of solid-oxide-based photocatalysis. Alternatively, the annular electrolyzer component **(514)** of the present embodiments may comprise a tubular MEA as taught in the tubular fuel cell and electrolyzer art.

Fuel cell apparatus and CHP systems that combine a solid oxide fuel cell apparatus with an external electrolyzer or other external reformer are numerous and well-developed in the prior art. Accordingly, the associated plumbing and circuitry interconnecting these systems are incorporated in the "balance-of-plant" **(511)** portion of this combination.

In the present embodiment, a preferably annular solid oxide electrolyzer, with central axis **(517)**, is irradiated with solar radiation λ from the concentrically positioned CCC, wherein the gas separation device is accordingly heated to high temperatures (typically greater than 600C) suitable for efficient generation of a hydrogen-rich gas, which gas is stored in an integral storage tank **(510)** for usage by a coaxially mounted, annular solid oxide fuel cell. It is preferred that the oxide electrolyte layer be implemented with sub-micrometer -- and preferably less than 500 nanometers -- thickness, so that the sampling rate of oxygen vacancies to a specific area of an adjacent, porous, catalytic electrode, can be much higher than that allowed by thicker electrolyte layers. Such reduced-thickness, thin film electrolytes seen herein as essential if the sampling rate of the oxygen vacancies at the electrolyte/catalytic electrode interface is to not be a limiting rate in the ability of the catalyst to execute the preferred reaction steps that lead to an oxygen ion being transported through the solid oxide electrolyte of the irradiated electrolyzer. Likewise, and in accordance with cited earlier disclosures by applicant, the SOFC of the present embodiment preferably utilizes similarly dimensioned, thin film, solid oxide electrolytes, as well.

It is further preferred that the oxygen-rich side of the MEA's of the electrolyzer stack are accessed through a central support tube **(505)**. Movement of oxygen-rich gas from the oxygen rich-side of the MEA is provided at least in part by the oxygen-ion conduction of the solid oxide electrolyte accordingly providing a positive pressure on the oxygen-rich side of the MEA, and wherein this electrolytically transported oxygen is preferably provided through the inner sealing region to the oxygen return passage **(506)**. Accordingly propagation of solar radiation preferably enters the disk-shaped flow spaces interleaving MEA's of the electrolyzer stack, these disposed for a supplied water vapor/carbon-bearing gas interleaving the embodied MEA's of the embodied annular stack.

A storage tank **(510)** is preferably mounted integrally to the presently embodied assembly, preferably integral to a balance-of-plant (BOP) assembly **(511)** integrally mounted to the embodied assembly for providing fuel (preferably hydrogen) to the solid oxide fuel cell mounted below the solar concentrator. The BOP assembly is constructed in accordance with the gas flow, compositional control, temperature-control, and cut-off mechanisms commonly incorporated in the known art of solid oxide fuel cells, such BOP means preferably controlling hydrogen fuel pressures and flows to and from the hydrogen storage tank, and preferably supplying appropriate hydrogen rich gases and exhaust control for the preferred annular solid oxide fuel cell **(515)**, also having central axis **(517)**, by means of SOFC air-side gas interconnection **(523)** and SOFC fuel-side gas interconnection **(524)**. In the preferred embodiment wherein a storage tank is utilized for hydrogen storage, there may be accordingly be incorporated in the storage tank various hydrogen adsorption/desorption media including carbon. The solid oxide fuel cell **(515)**, preferably is an annular solid oxide fuel cell in accordance with previous disclosures by author cited herein, and is disposed concentric to the central axis of the solar concentrator, so that the optical axis **(73)** and central axis **(517)** of the annular solid oxide embodiments are, preferably, substantially coincident. Hydrogen that is stored in the hydrogen storage tank is then available for powering the fuel cell stack, which can accordingly produce electrical power based on the load requirements.

As is disclosed in previous cited patent applications by same author, the receiver tube, with associated fluid circuits and storage tanks, can be integral to the CCC structure, so that, accordingly, no rotational or pivot unions are required. As will be appreciated by one skilled in the art, such integrated configurations incorporating integral storage tanks and fluid circuits may be utilized in conjunction with any of the variety of energy transporting fluids and gases utilized in the CHP art, such as the various embodied solar-thermal fluids and gases, precursor gases, or any gases used in conjunction with the previously disclosed solid oxide system including syngas, methane, butane, oxygen, natural gas, etc. Accordingly, various other storage volumes may also be integrated as needed for a specific application.

It will be appreciated by those skilled in the art that, whereas the catalytic hydrogen generating means of the present preferred embodiment is particularly embodied for the purposes of pointing out the invention, any hydrogen-generating means of the prior art that is known to require a heat source may be readily combined with the CCC reflector embodied herein, whether such hydrogen-forming apparatus is disposed for fueling a fuel cell, as in the present embodiments, or is utilized for storing a fuel for other purposes such as distributed generation for hydrogen-driven automobile fueling.

While the CCC structure of the preferred embodiments, and the various associated energy conversion apparatus embodied, in **FIGS. 1-18** and other alternative embodiments included herein by reference, are provided so as to teach the various novel structures and operating principles set forth, it is not intended that the inventive matter set forth herein be limited to those particular embodiments, and it will be appreciated by those skilled in the art that many further embodiments may be readily envisioned without departing from the scope and spirit of the inventive matter set forth herein. In particular, whereas each of the various embodiments in **FIGS. 1-18** are directed to the invention in a particular aspect or preferred application, it will be readily appreciated by those skilled in the art that various features of the multiple embodiments set forth herein may be readily combined with one another as may suite a specific set of circumstances.

Accordingly, and in light of the various prior art energy storage, conversion, and generation processes and apparatus that are regularly incorporated in energy-conversion and combined-heat-and-power (CHP) systems of the prior art, it will be readily understood by those of normal skill in the art that a vast number of variations and combinations utilizing such known components and processes in combination with the disclosed embodiments may be readily envisioned by those of normal skill in the art.

Accordingly, flow-chart "engineering" of some specific combination of well-known structures and processes of the prior art of CHP systems that is merely combining such known processes and apparatus of the prior art so as to interact according to demonstrated and well-known principles is readily performed by those of normal skill in the art, and therefore such combination of the disclosed solar-thermal embodiments as a heat source in such prior-art combinations that are known to benefit from a heat source is readily anticipated by and within the scope of the disclosed solar-thermal apparatus. For example, a wide array of solar-thermal and solar-electrochemical receiver tubes and apparatus may be utilized in conjunction with the disclosed CCC, such as, for example, various solar apparatus for use with solar concentrators that are reviewed in "Solar Fuels and Materials" by Aldo Steinfeld and Anton Meier (copyright 2004) which is included herein by reference.

In particular, use of the disclosed solar-thermal embodiments in any energy conversion or energy generation process that is known to benefit, or may be readily seen to benefit, from a supplemental, auxiliary, or primary heat source would be obvious to those of normal skill in the art, and would therefore be anticipated by the disclosed preferred embodiments.

It will be further appreciated that the present embodiments may be readily integrated with or modified to include, by those of normal skill in the art, various mechanical structures, support members, feed-throughs, heat exchangers, compliant members, fasteners, bellows, and other commonly combined mechanical means utilized in solar-thermal and solar-thermal CHP, so as to provide well-known advantages in various specific applications. It will accordingly be further appreciated that the disclosed solar-thermal embodiments may also be readily integrated by those skilled in the art with one or more of these prior art components so as to be structurally "integral", "modular", "monolithic", or "portable" without departing substantially from the scope or spirit of the invention.

As previously embodied, the preferred embodiments are readily combined with broadly established apparatus and processes for transferring or storing energy, including those means comprising thermal energy, chemical energy, optical energy, electromagnetic energy, or mechanical energy. Such means for transferring and storing energy will generally include or be enabled by energy sources including wind, solar, hydroelectric, nuclear, coal, natural gas, oil, and various other hydrocarbons and fossil fuels.

Accordingly, the embodied concentrator and related solar-thermal embodiments are not intended to be limited to any particular work-load or end-use. As will be readily appreciated by those skilled in the art, the disclosed embodiments may be readily adapted for use in such energy uses as transportation, including marine and land-based, building heating and cooling, industrial processing including refining, chemical processing, mining, water desalinization, as well as any other application known to benefit from cost-effective solar-thermal or solar-electric power generation.

In addition, it will be readily understood by those skilled in the art that processes and apparatus for electrical power generation whether localized, power-plant, on-site CHP, distributed-generation, portable, modular, integrated, roof-top, auxiliary power units (APU) including marine-based or other transportation-based APU's, or any other such mode of utilizing electrical power generation apparatus and processes may be readily combined and variously integrated by those skilled in the art with the solar embodiments herein without departing from the intended scope and applications.

Similarly, and in accordance with the preferred embodiments, the disclosed solar-thermal and CHP embodiments may be readily utilized to provide thermal energy for conversion to chemical energy by combination with any known chemical energy conversion processes and apparatus of the prior art, including such applications as materials processing and refinement, gas and liquid processing and refinement, fuel conversion processes, methane conversion, hydrocarbon conversion, electrolytic processes, gas-shift reactions, gas reformation, steam conversions and reformation, external reformation, fuel-cell warm-up means, balance-of-plant (BOP) processes, gasification including coal gasification processes, and any other well-known thermo-chemical and thermo-materials conversion processes and apparatus, wherein such processes and apparatus are already known to benefit from combination with a cost-effective heat source; such processes and apparatus are readily combined with the disclosed solar-thermal embodiments in accordance with principles well-understood by those skilled in the art of these respective thermodynamic processes, and accordingly are not outside the scope of the disclosed inventive matter.

Thus, in accordance with these well-known and understood applications of the prior art, the disclosed solar apparatus may accordingly be combined by those of normal skill in the art with known components common to such well-known energy conversion cycles, processes, and apparatus, particularly those proposed and/or used for power generation and combined heat and power (CHP) systems. Such components include but are not limited to, gas or steam turbines, hydrogen generation means including thermo-chemical, electrolytic and photo-catalytic hydrogen generation means , nuclear reactors, Stirling engines, internal combustion engines, solar PV panels, any fuel cells including proton-exchange membrane fuel cells (PEMFC), direct-methanol fuel cells, solid oxide fuel cells, molten carbonate fuel cells, any storage device including batteries, fuel cells, and any appropriate tank or storage volume for a thermal-energy or chemical-energy storage medium, swing-cycle cooling apparatus and refrigeration cycle components, various absorbent beds and thermally-cycled desiccants volumes, heat exchangers, and any other such related components that could benefit by combination with a supplemental or primary heat generating source, and accordingly such prior art CHP components can be combined with the disclosed solar apparatus without departing from the intended scope and spirit of the disclosed invention.

Inventive matter of this specification and drawings was disclosed to SolarSiliconUSA, represented by Andy Hilgers of Los Angeles, CA, USA, and Dick Bos, (also of GET IT Co ltd, Thailand) under a formally executed non-disclosure agreement (January 08, 2010).

It is not intended that the core material of the disclosed hollow-core frustums be limited to media of the preferred embodiments, as any appropriate material may be substituted by those skilled in the art. The preferred core material provides adequate rigidity, strength, and lightness of a structured framework, such that the core is predominantly open space; accordingly, any core material having such embodied properties may be utilized, including core materials with either ordered or disordered structures. Open spaces of the core material may be on the order of thickness of the embodied frustum structures, or may be much smaller or even microscopic. In the preferred embodiment where the core material includes a corrugated thin sheet metal, such corrugation may exist in any suitable aspect, orientation, or format. for example, in the alternative preferred embodiment of a wound preform, such preform may be constructed core layers comprising a single corrugated sheet.

It is also not intended that there be any restriction on scaling of the inventive CCC structure, since it may readily be fabricated in smaller or larger sizes than those contemplated herein. For example, miniature versions of the inventive CCC structure and manufacturing means may be implemented for construction of solar panels incorporating a plurality of such concentrators in a periodic array for irradiating a corresponding number of individual receiver modules in accordance with the preferred embodiments.

It is also not intended that the disclosed solar concentrator be limited in its application in any way, as any means for collecting solar energy may be ly benefit from appropriate combination with the embodied concentrator. Such means for collecting and/or transferring solar-generated energy may include but are not limited to any heat transfer fluid, gas or vapor, expanding medium in a closed circuit heat pipe, etc; also any means of providing any form of electromotive force whether by photovoltaics, thermoelectric, electrolyte, or other. Similarly any form of storing chemical energy may be incorporated, whether by electrolysis, phase-change mediums, heat storage fluids, chemical energy storage, etc.

Like parts correspond to like parts in different embodiments; for example, the centerline (9) representing the central axis of the embodied tubular symmetry is to be regarded as such major axis with respect to the specific embodiments in which it is pointed out.

Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, process, block, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in the present embodiment" or "in another embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

Although the present invention has been described in detail with reference to the embodiments shown in the drawing, it is not intended that the invention be restricted to such embodiments. It will be apparent to one practiced in the art that various departures from the foregoing description and drawings may be made without departure from the scope or spirit of the invention.

CLAIMS

What is claimed is:

1. A process for making a frustum-shaped structure having a solar-reflecting surface, including the steps:
   a.) constructing a substantially toroidal preform structure, the preform structure comprising a multitude of first material layers, the first layers comprising thin sheet material, the multitude of first layers interleaved with a multitude of low-density layers, the low-density layers comprising a structured material so that the low-density layer comprises predominantly open space by volume; and,
   b.) separating a conical section from the preform; and,
   c.) attaching a reflective material layer to the conical section, the reflective material layer forming an inner conical surface integral to the conical section, the reflective material layer having the solar-reflective surface.

2. The process of Claim 1, wherein the low-density layers comprise a corrugated structure.

3. The process of Claim 2, wherein the corrugated structure is formed as a honeycomb structure.

4. The process of Claim 3, wherein the honeycomb structure comprises an aluminum-containing material.

5. The process of Claim 1, wherein the low-density layers comprise a periodic structure formed from a sheet material.

6. The process of Claim 1, wherein the low-density layers comprise a disordered structure.

7. The process of Claim 1, further comprising the step wherein the conical section is laminated with a second material layer, the second material layer comprising an outer surface of the conical section.

8. The process of Claim 1, further comprising the step of forming alignment surfaces disposed for aligning a first conical section to a second conical section, the alignment surfaces disposed for aligning first conical section and second conical section into a concentric orientation.

9. The process of Claim 1, wherein step (c) is performed before step (b).

10. The process of Claim 1, further comprising the step of resurfacing a separated surface of the conical section by a surfacing means.

11. The process of Claim 1, wherein the toroidal preform comprises a substantially cylindrical structure.

12. The process of Claim 1, wherein the first material layers and low-density layers are stacked as planar sheets, the toroidal preform having an axis of symmetry, the planar sheets substantially orthogonal to the axis.

13. The process of Claim 1, wherein the first material layers and low-density layers are wound about a common axis of toroidal symmetry.

14. The process of Claim 1, wherein the step of separating the conical section is performed by means of a linear cutting device, the linear cutting device one of a group including string saws, lasers, scroll saw blades, acid saws, a fluid-jet, and particle-filled fluid jet.

15. A process for making a conical structure having a solar-reflecting surface, including the steps:

    a.) constructing a preform structure, the preform structure having a central axis, the preform structure comprising a multitude of first material layers, the first layers comprising thin sheet material, the multitude of first layers interleaved with a multitude of low-density layers, the low-density layers comprising a structured material so that the low-density layer comprises predominantly open space as measured by volume; and,

    b.) parting a multitude of conical sections from the preform, the conical sections formed by parting cuts that form a conical surface of rotation about the central axis; and,

    c.) attaching a reflective material layer to the conical section, the reflective material layer forming an inward-facing conical surface integral to the conical section, the reflective material layer having the solar-reflective surface.

16. A conical reflector having reflective inner surface providing reflectivity to a visible solar spectrum, the reflector comprising:
    - a.) a first material layer, the first material layer having a first surface in the form of a first conical frustum, the first conical frustum substantially concentric about a first central axis, the first material layer integral to a first edge surface with a first radius, the frustum integral to a second edge surface with a second radius, the second radius larger than the first radius, the first edge surface substantially parallel to the second edge surface;
    - b.) a second material layer, the second material layer in the form of a second conical frustum, the second conical frustum concentric about a second central axis, the second central axis substantially collinear to the first central axis, the second material layer disposed externally to the first material layer so as to surround the first material layer, so that a frustum-shaped volume is disposed between the first material layer and second material layer; and,
    - c.) a low-density layer disposed within the frustum-shaped volume, the low-density layer comprising a structured material, so that the frustum-shaped volume comprises mostly open space as measured by volume.

18. The reflector of Claim 16, wherein divergence of the reflective surface is within 1% of an ideal frustum surface.

19. The reflector of Claim 16, wherein the low-density layers comprise a corrugated structure.

20. The reflector of Claim 16, wherein the corrugated structure is formed as an aluminum honeycomb.

21. The reflector of Claim 16, wherein at least one of the surfaces is discontinuous.

22. The reflector of Claim 16, wherein the first material layer is a flexible metal sheet incorporating a vacuum-deposited reflector.

22. A solar concentrator comprising a multitude of concentric reflective surfaces, the concentrator comprising:

a.) a multitude of substantially concentric conical structures, the conical structures each comprising an aspect of a conical frustum, the conical structures concentric to a central axis, the structures arranged in a linear sequence wherein a the conical structures comprise successively smaller diameters, so that the linear sequence has a first end comprising a conical structure having relatively large diameter and a second end comprising a conical structure having relatively small diameter;

b.) alignment means connecting adjacent conical structures, the alignment means comprising alignment surfaces, the alignment surfaces disposed so as to align adjacent conical structures to one another; and,

c.) receiver fastening means disposed near the second end of the sequence, the fastening means disposed for providing a rigid structural relationship to a solar-energy receiving device located at the central axis.

23. The concentrator of Claim 23, wherein a transparent receiver tube having fluid supply and return passages disposed at a first end, the tube coaxial with the central axis, the first end mounted so as to translate with the concentrator, the first end disposed so that the passages are in fluid communication with fluid transport means located in the vicinity of the mounting means .

24. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a solar-thermal receiver apparatus.

25. The solar concentrator of Claim 23, wherein the solar-energy receiving device provides heating of molten salts

26. The solar concentrator of Claim 23, wherein the solar-energy receiving device provides heating of heat transfer fluids comprising oils.

27. The solar concentrator of Claim 23, wherein the device is disposed so as to receive direct solar radiation.

28. The solar concentrator of Claim 23, wherein the device is disposed so as to receive diffuse solar radiation.

29. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a photovoltaic array.

30. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a substantially cylindrical assembly having a cylindrical axis, the assembly comprising rows of multi-junction photovoltaic modules disposed at substantially regular intervals about the assembly, the rows formed with linear direction substantially parallel to the axis.

31. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a photochemical process device.

32. The solar concentrator of Claim 23, wherein the solar-energy receiving device is an electrolyzing device.

33. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a solid oxide fuel cell.

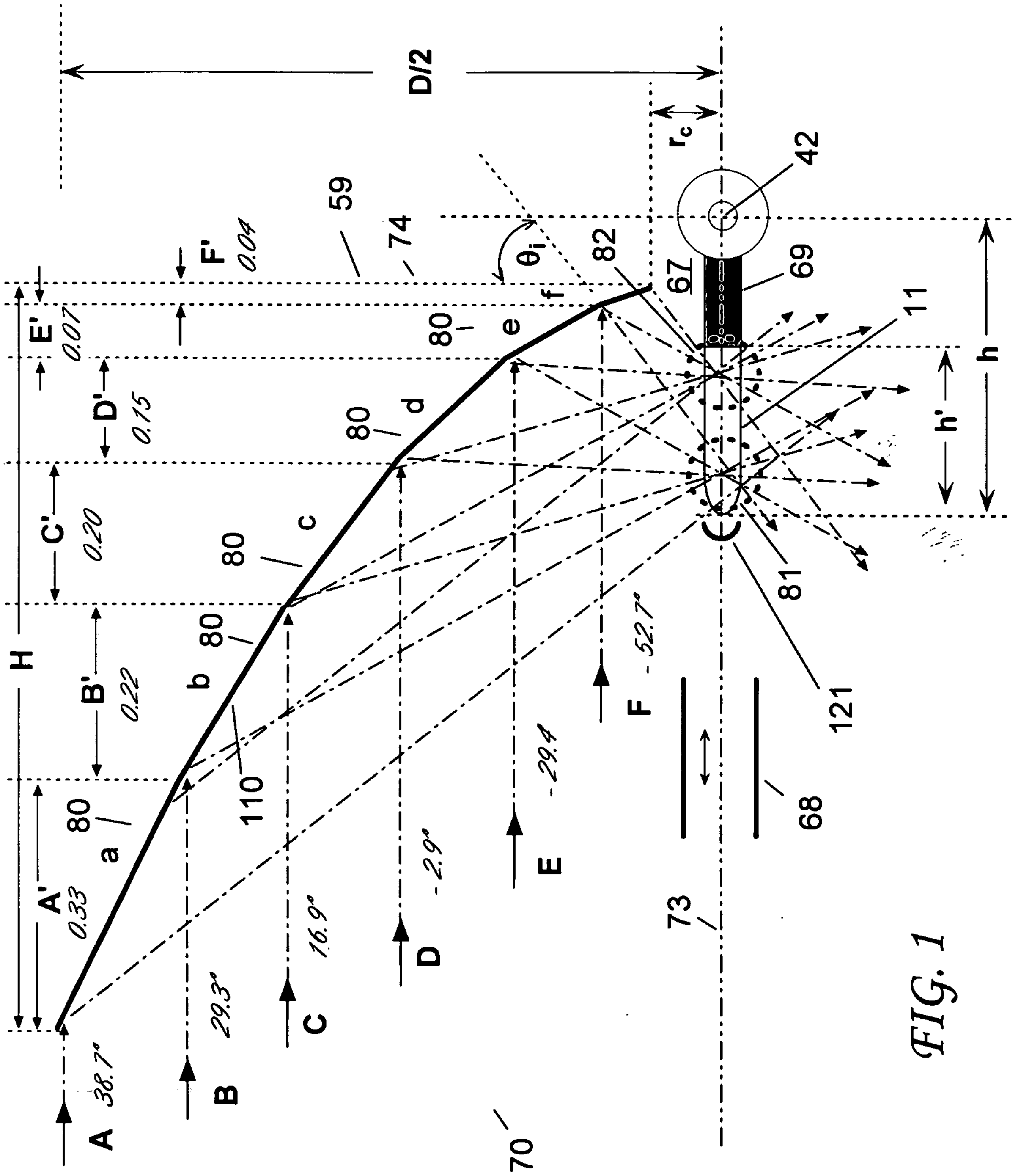
34. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a Gratzel cell.

35. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a component of a combined-heat-and-power system.

36. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a combination of multi-junction photovoltaic arrays and heat-transporting structures for providing heat and electricity to an external load.

37. The solar concentrator of Claim 23, wherein the solar-energy receiving device is a photocatalytic device.

38. The solar concentrator of Claim 23, wherein the concentrator is utilized in a power plant comprising an array of concentrators utilized in conjunction with molten-salt processing receiver tubes, the array coupled to a utility for generating power.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38.7°
B
29.3°
C
16.9°
D
-2.9°
E
-29.4
F
-52.7°
A'
0.33
B'
0.22
C'
0.20
D'
0.15
E'
0.07
F'
0.04
H
D/2
r_c
42
59
74
θ_i
82
67
69
11
h
h'
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FIG. 1

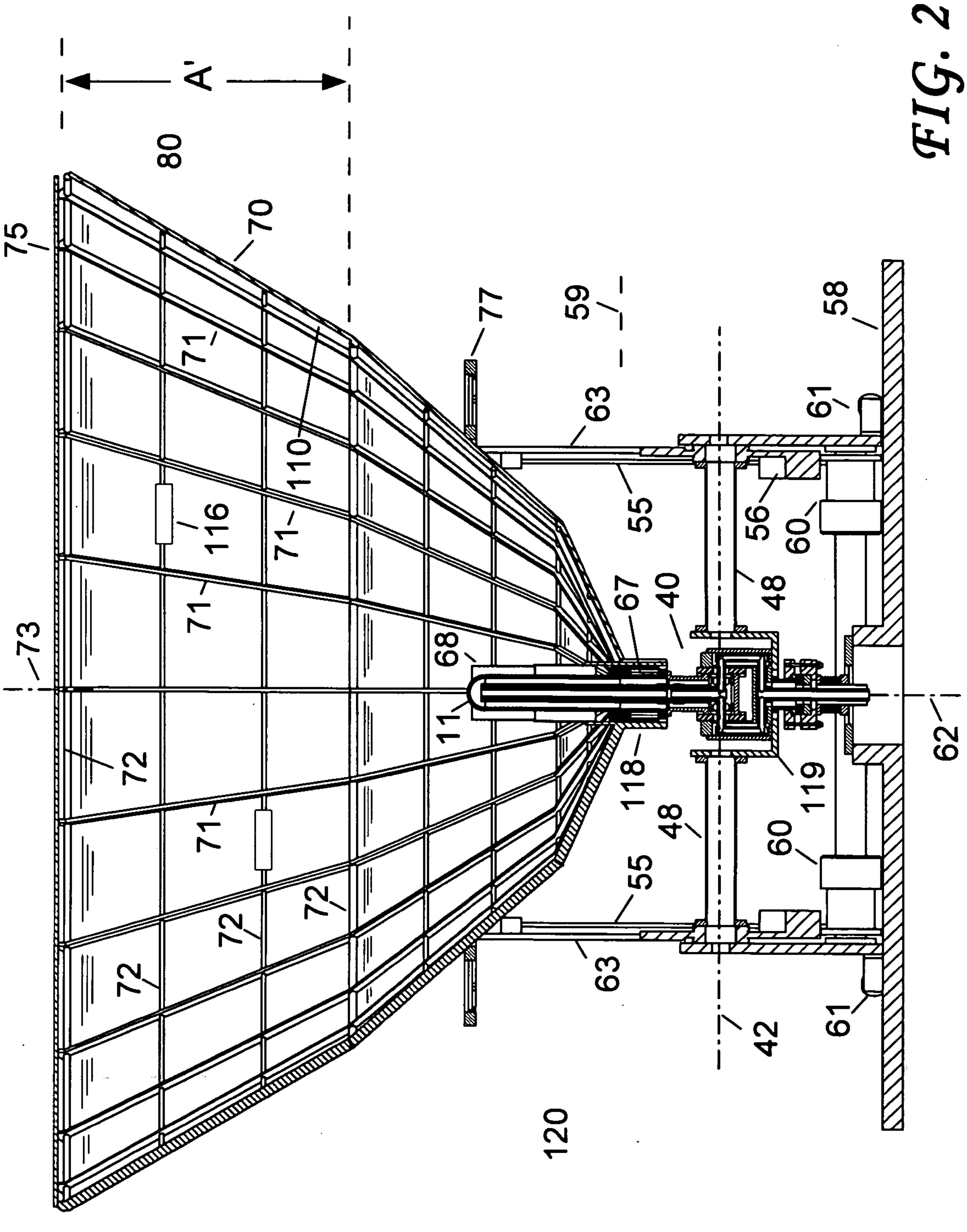
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FIG. 2

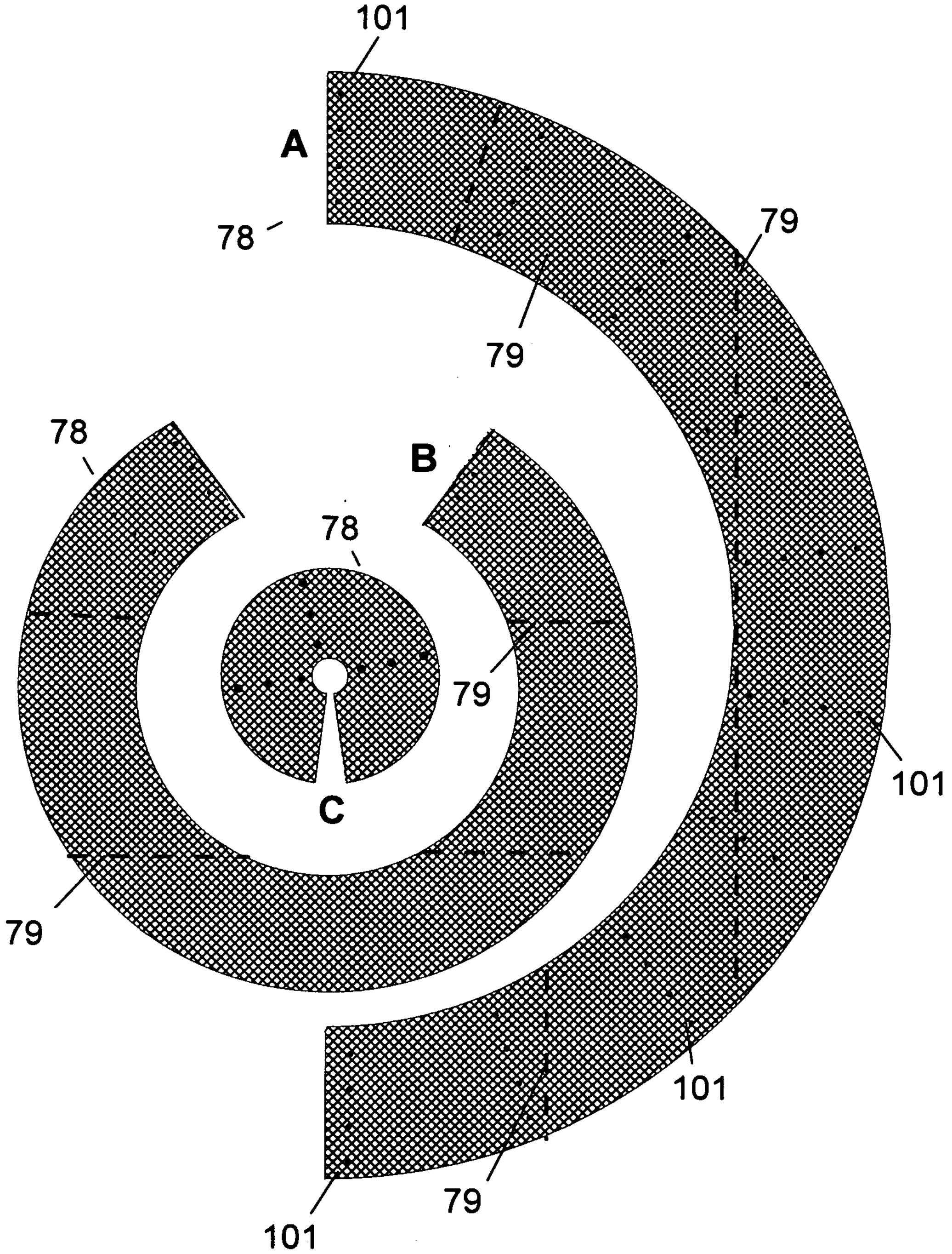


FIG. 3

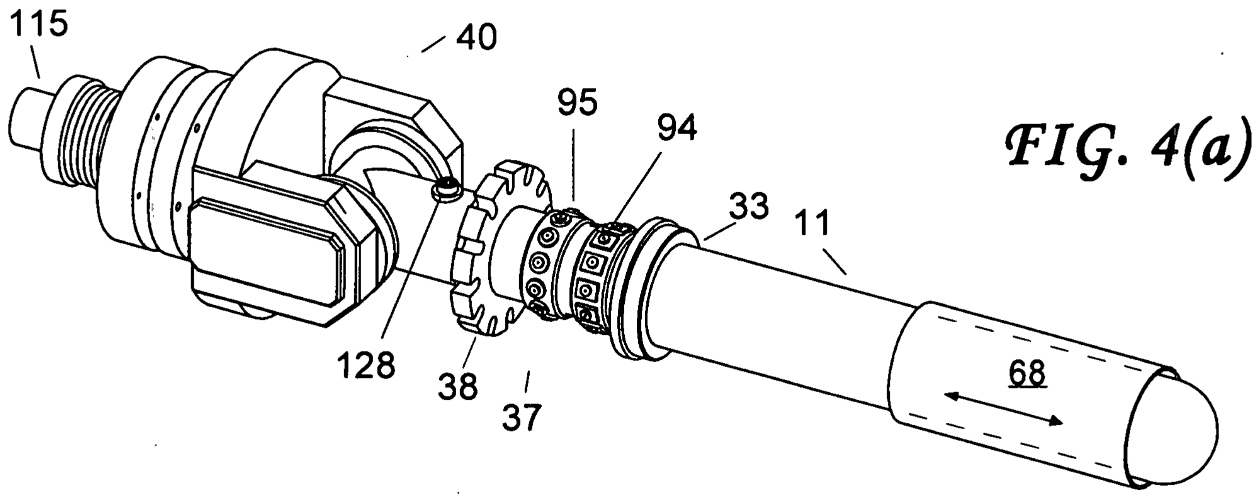


FIG. 4(a)

FIG. 4(b)
(PRIOR ART)

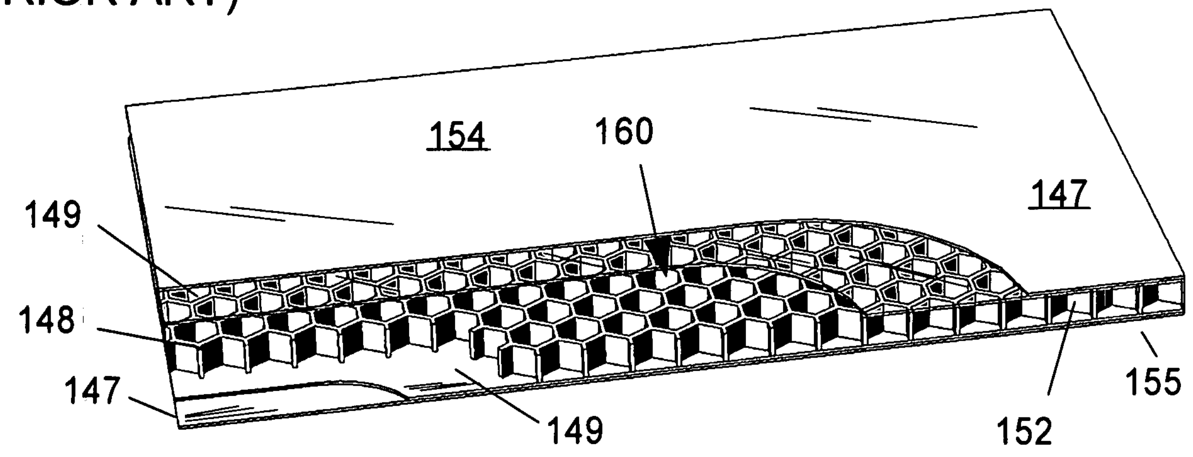
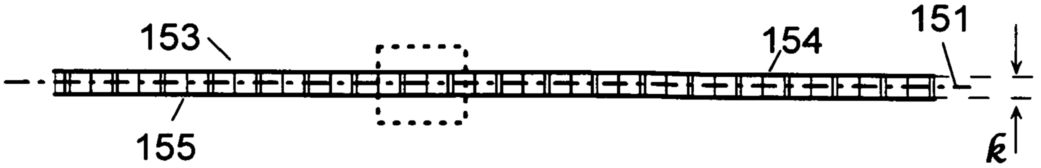


FIG. 5(a)



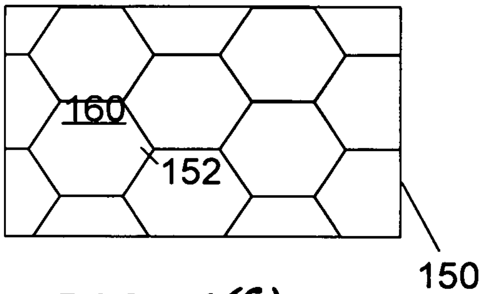


FIG. 5(b)

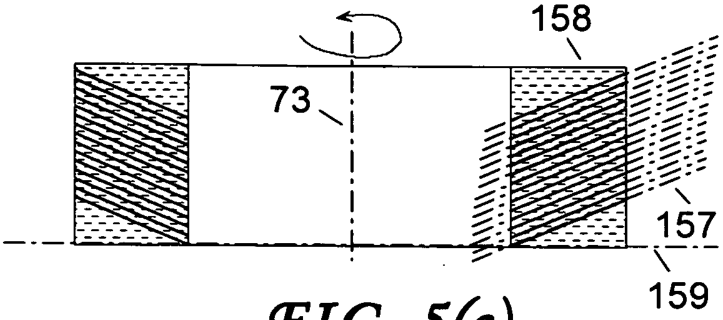


FIG. 5(c)

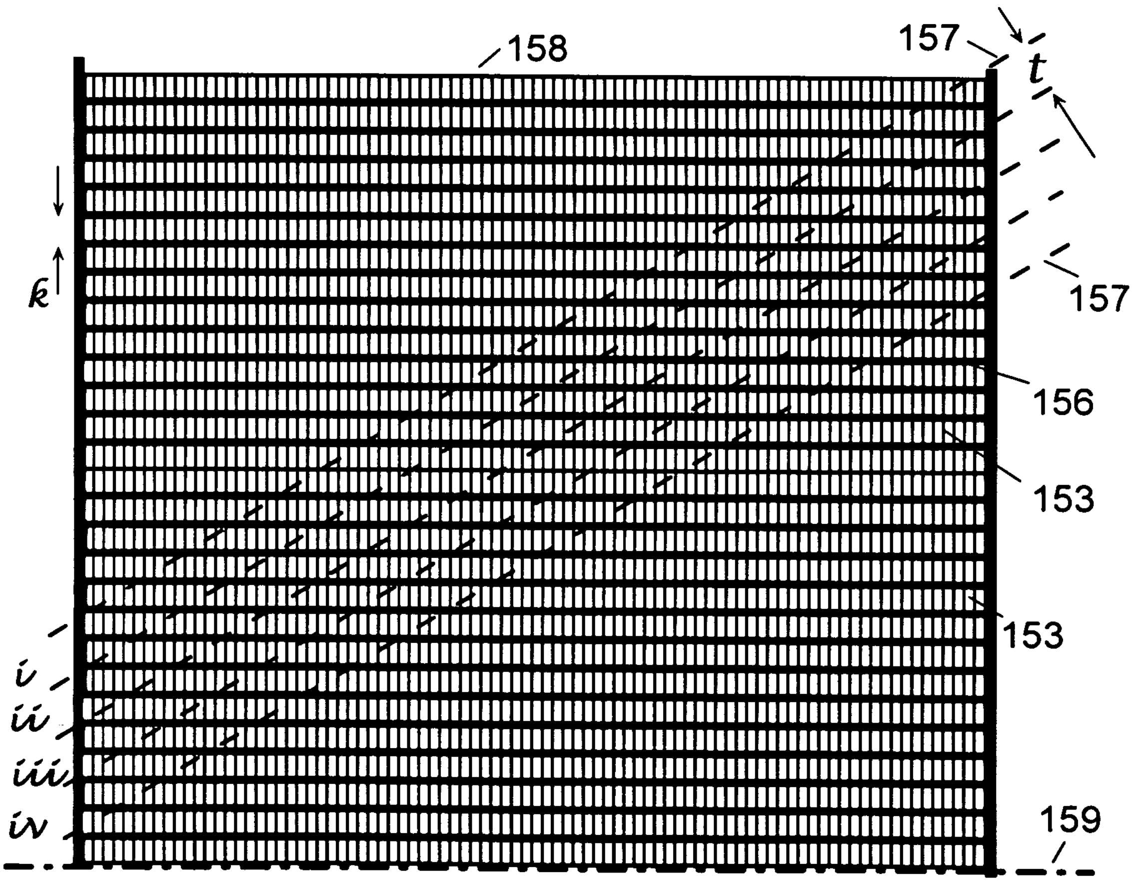


FIG. 5(d)

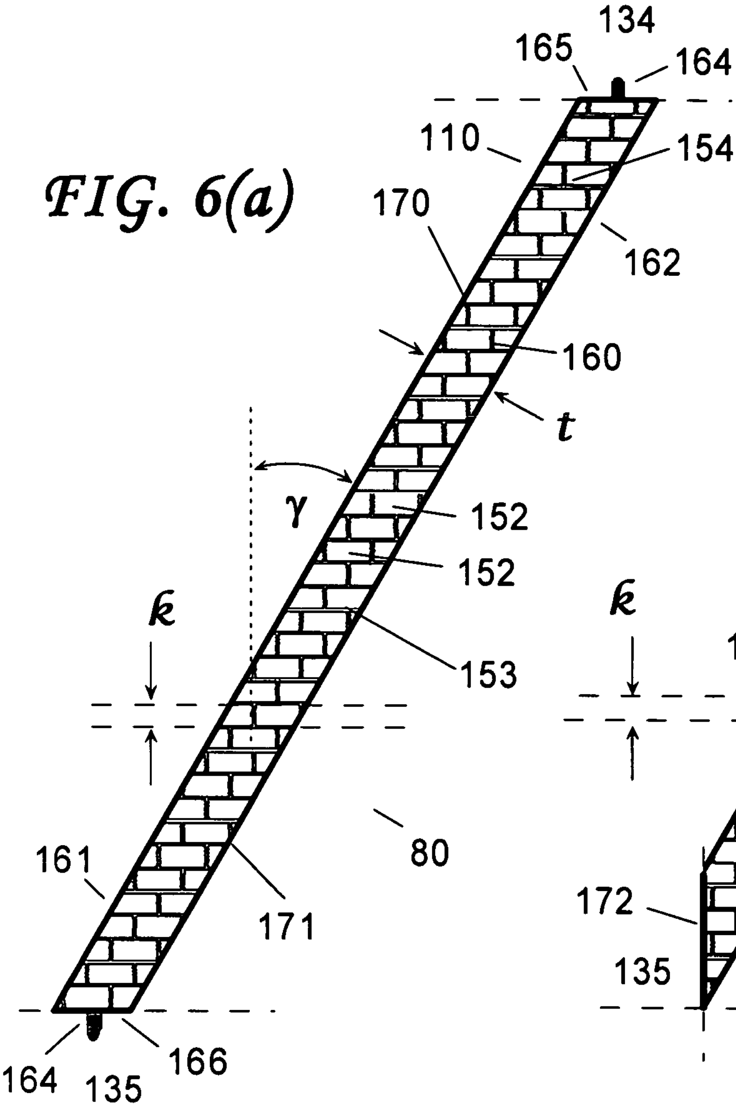


FIG. 6(a)

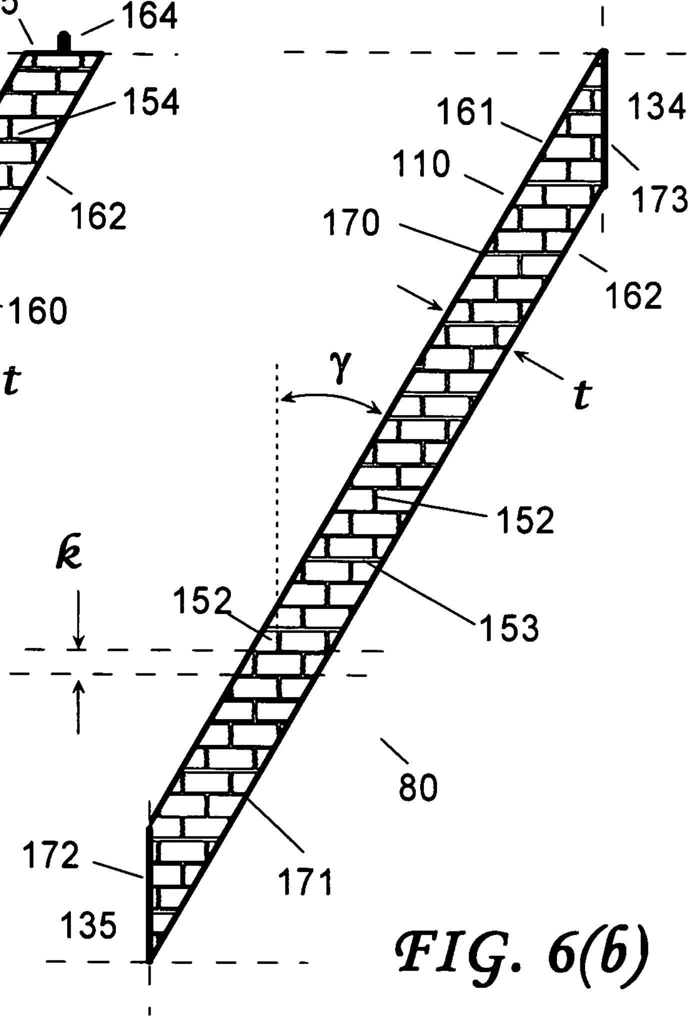


FIG. 6(b)

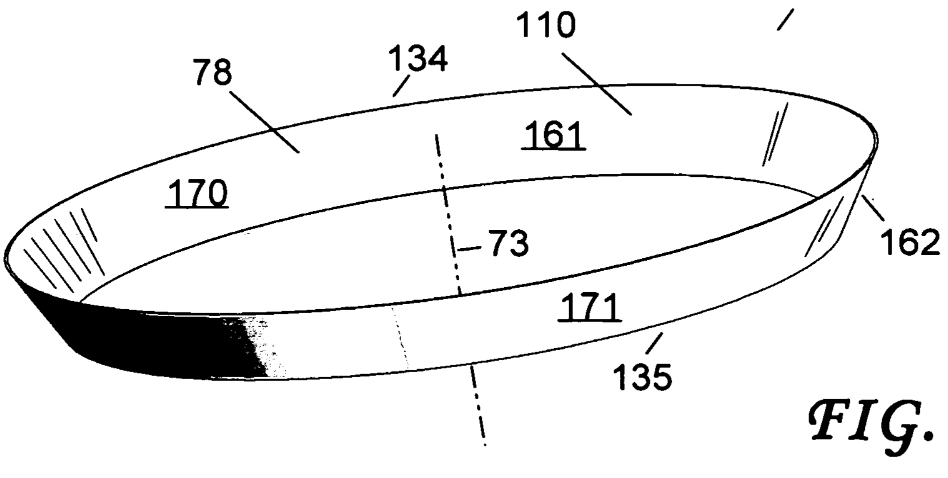


FIG. 6(c)

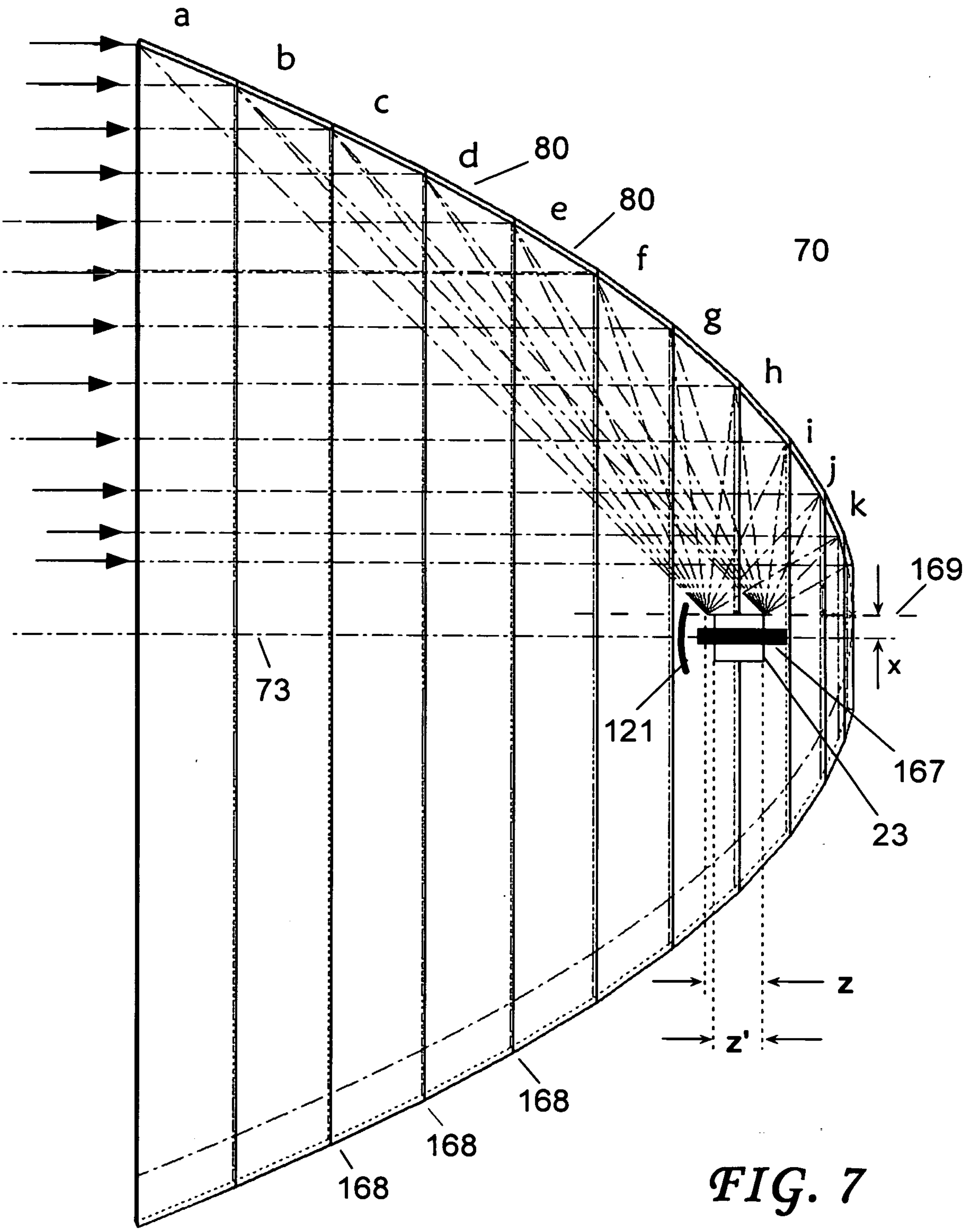


FIG. 7

FIG. 8(a)

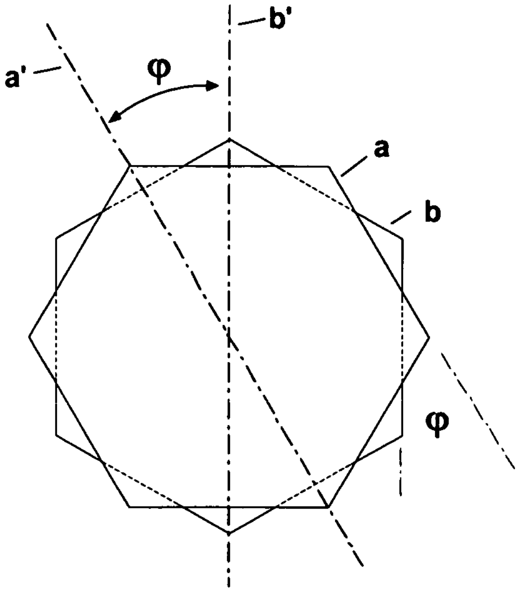
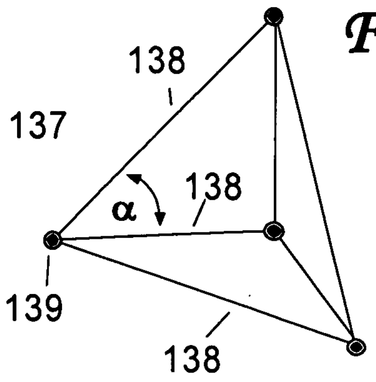


FIG. 8(b)



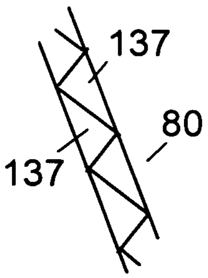


FIG. 8(c)

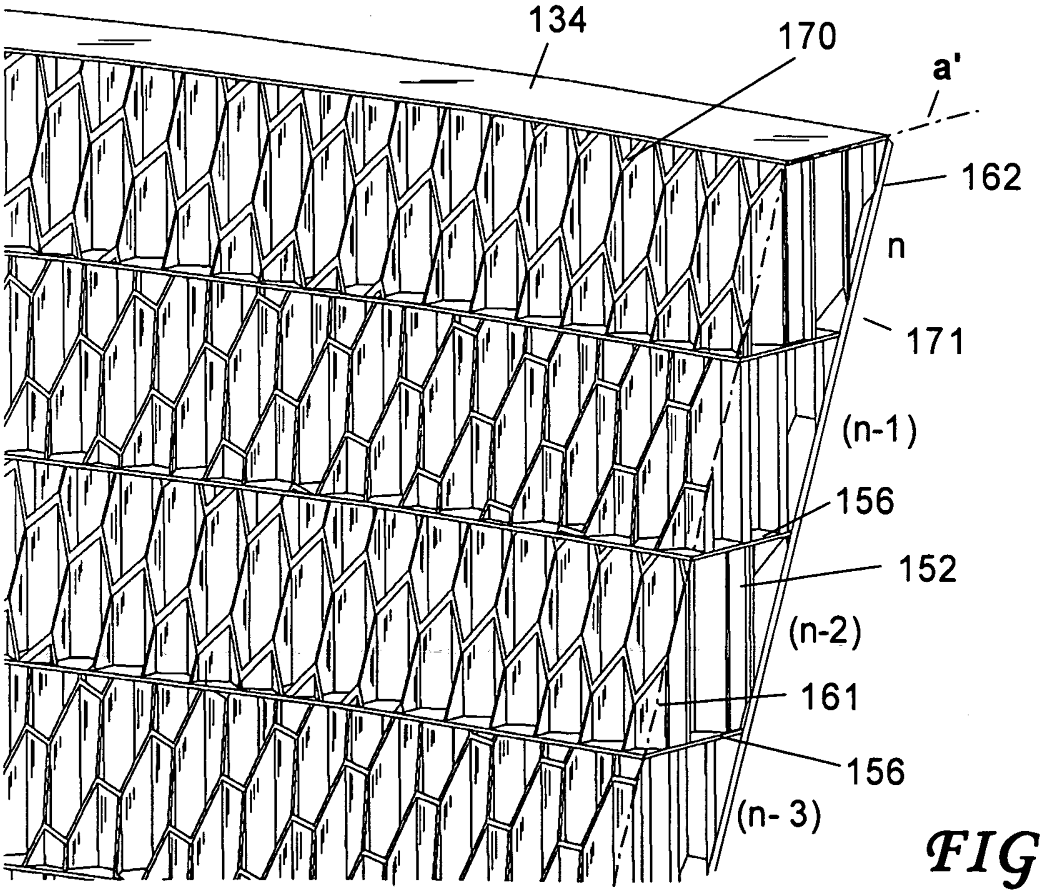


FIG. 8d)

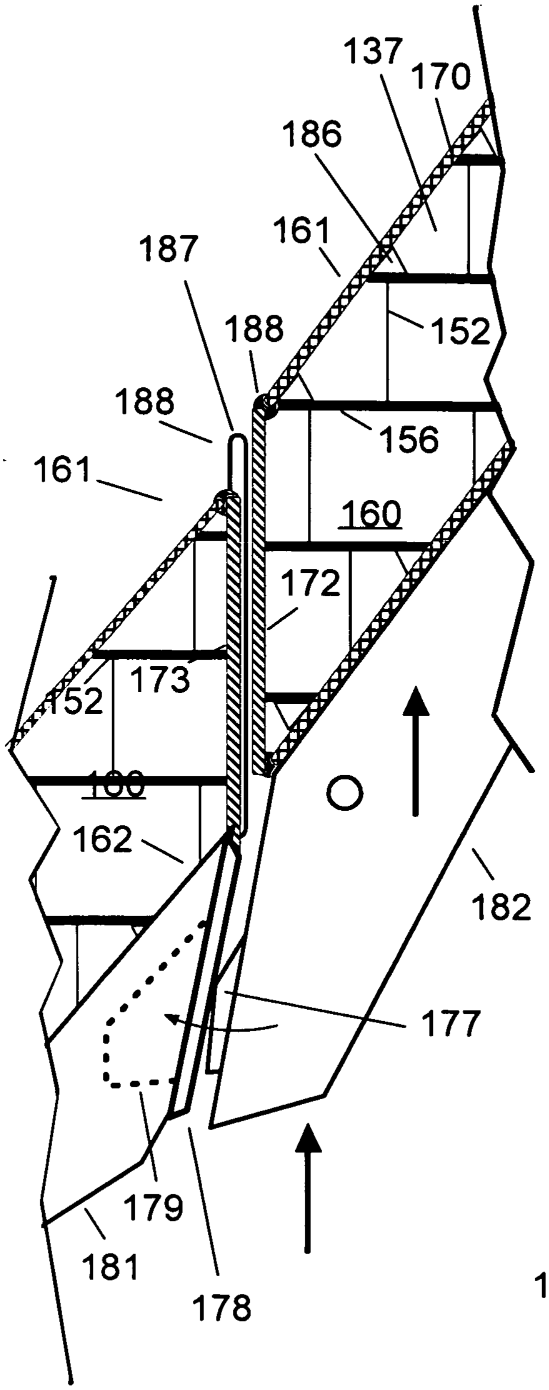

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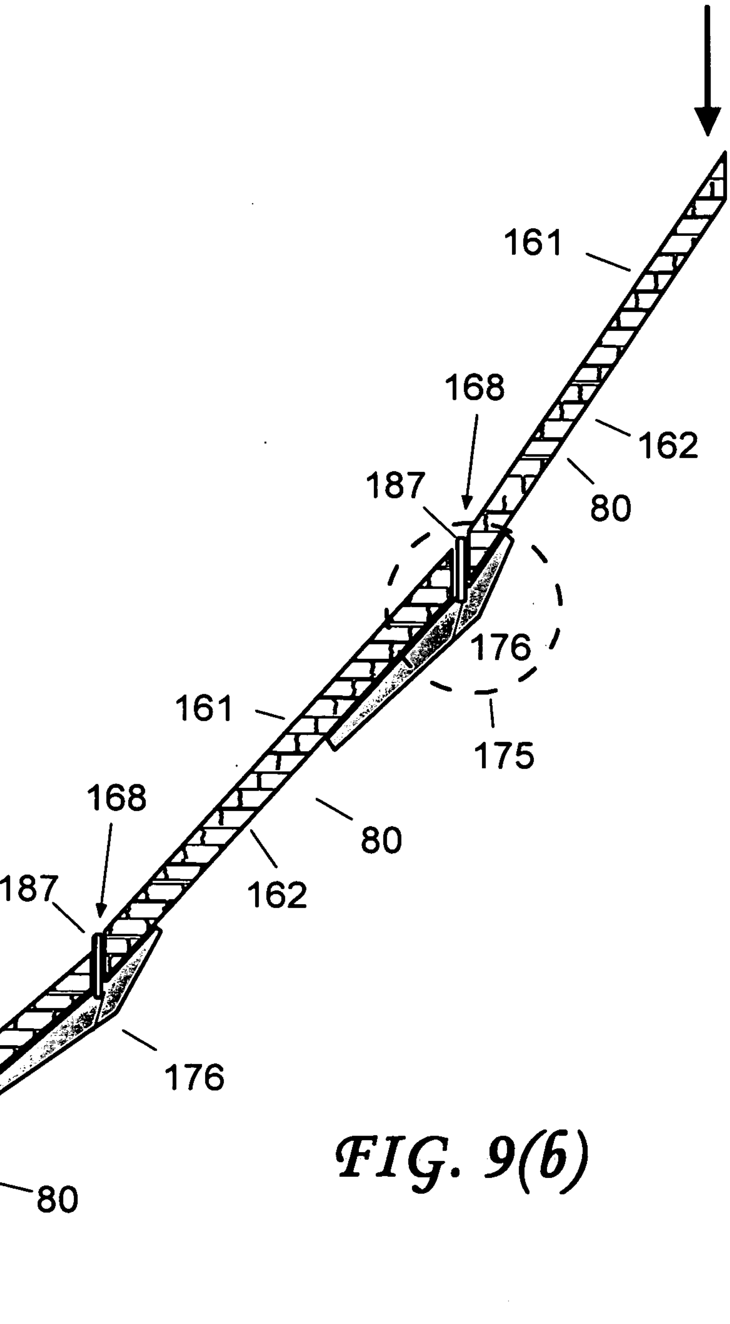
FIG. 9(a)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162

FIG. 9(b)

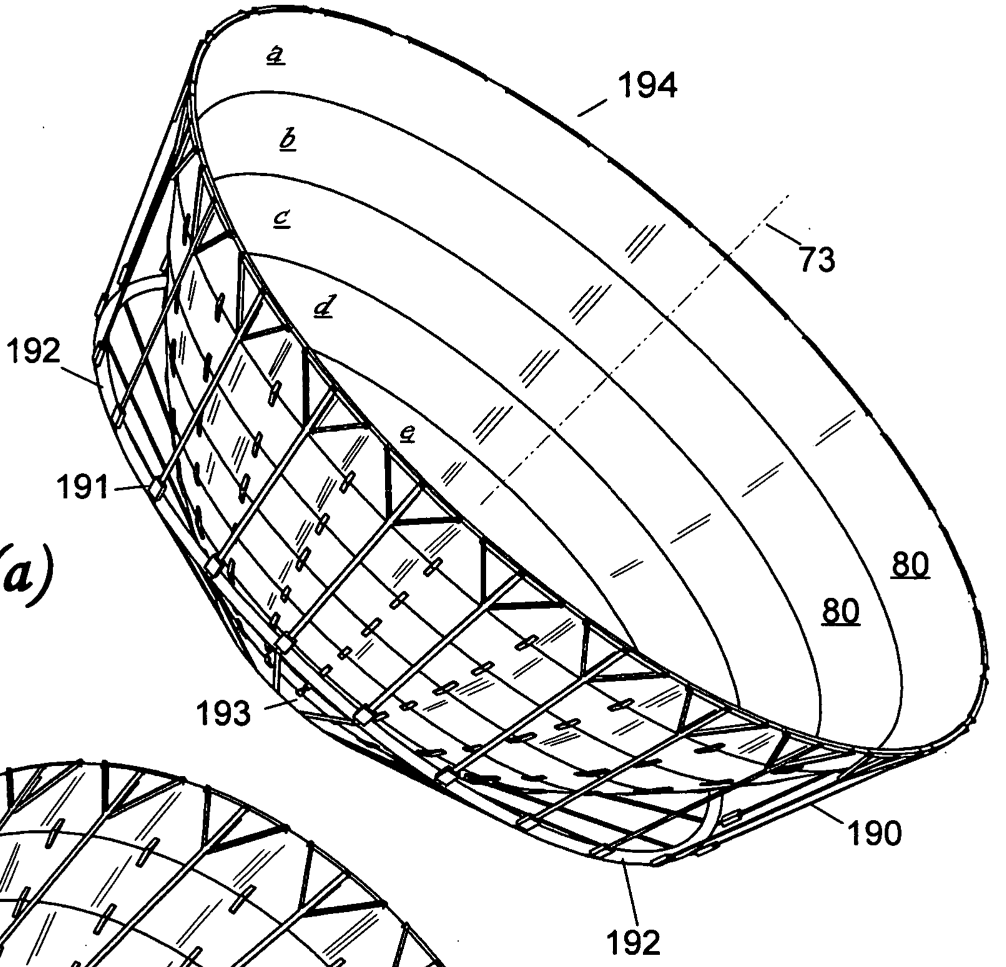


FIG. 10(a)

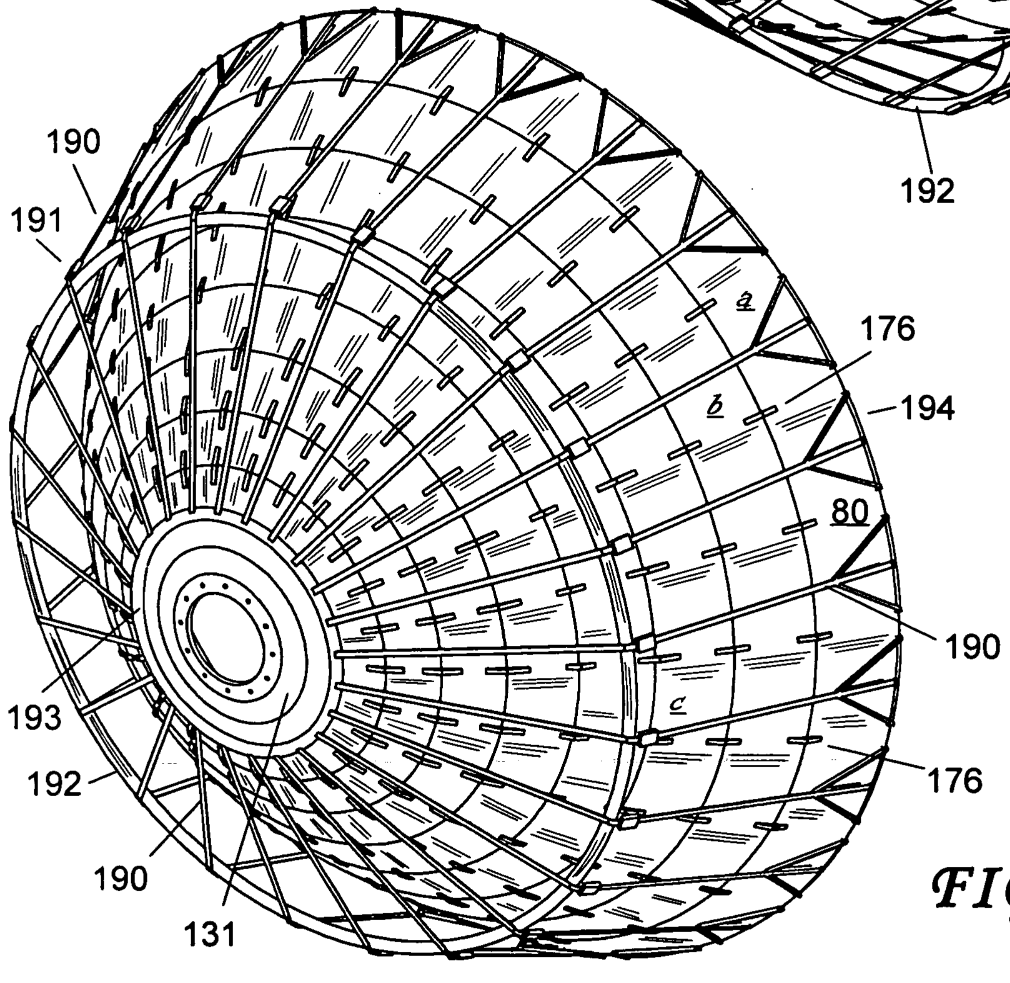


FIG. 10(b)

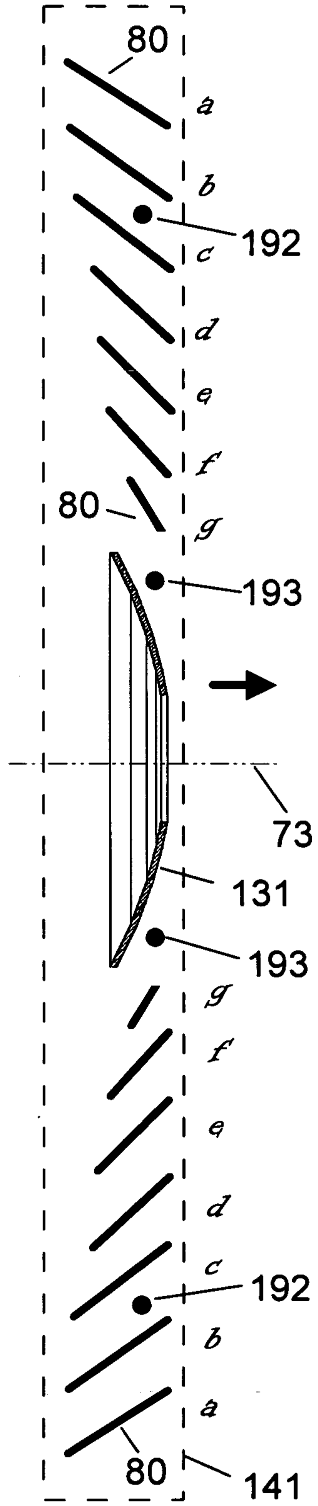
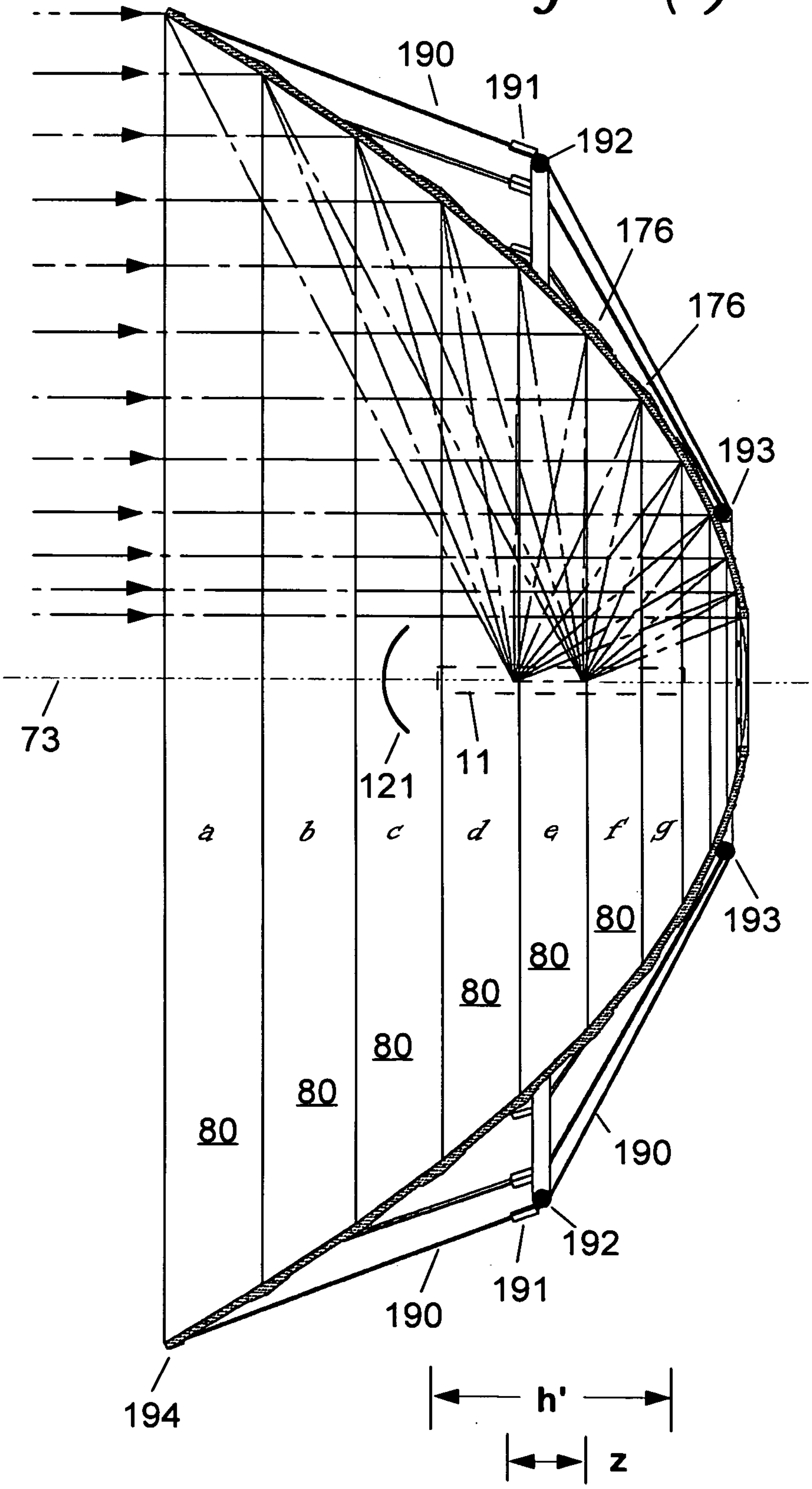


FIG. 11(a)

FIG. 11(b)



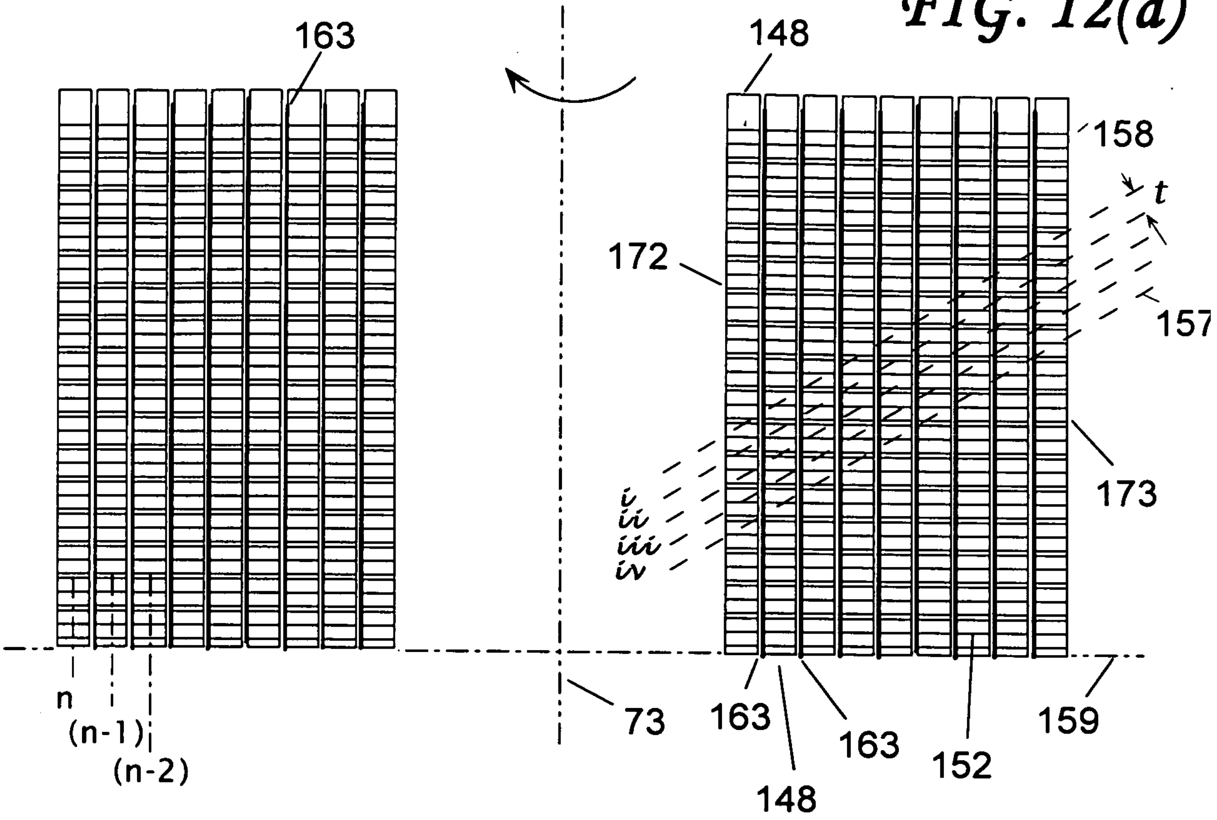


FIG. 12(a)

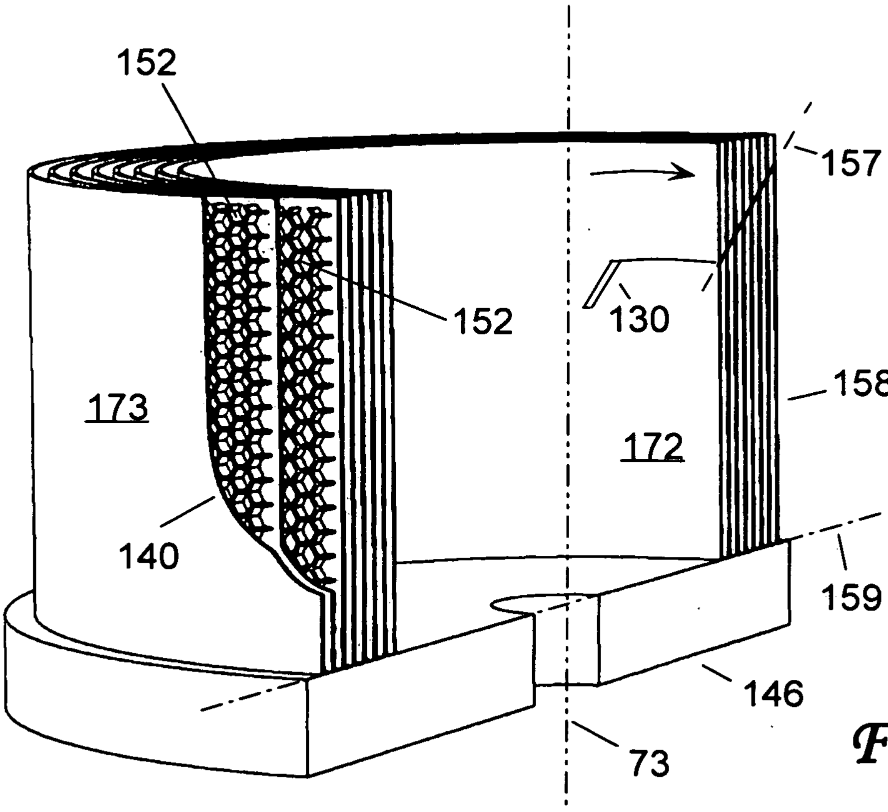


FIG. 12(b)

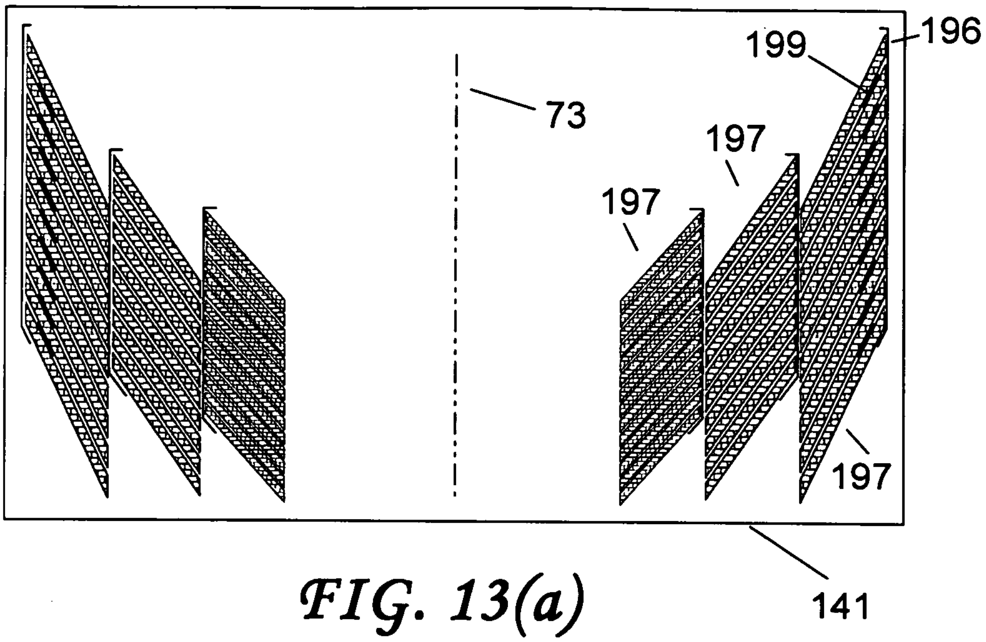


FIG. 13(a)

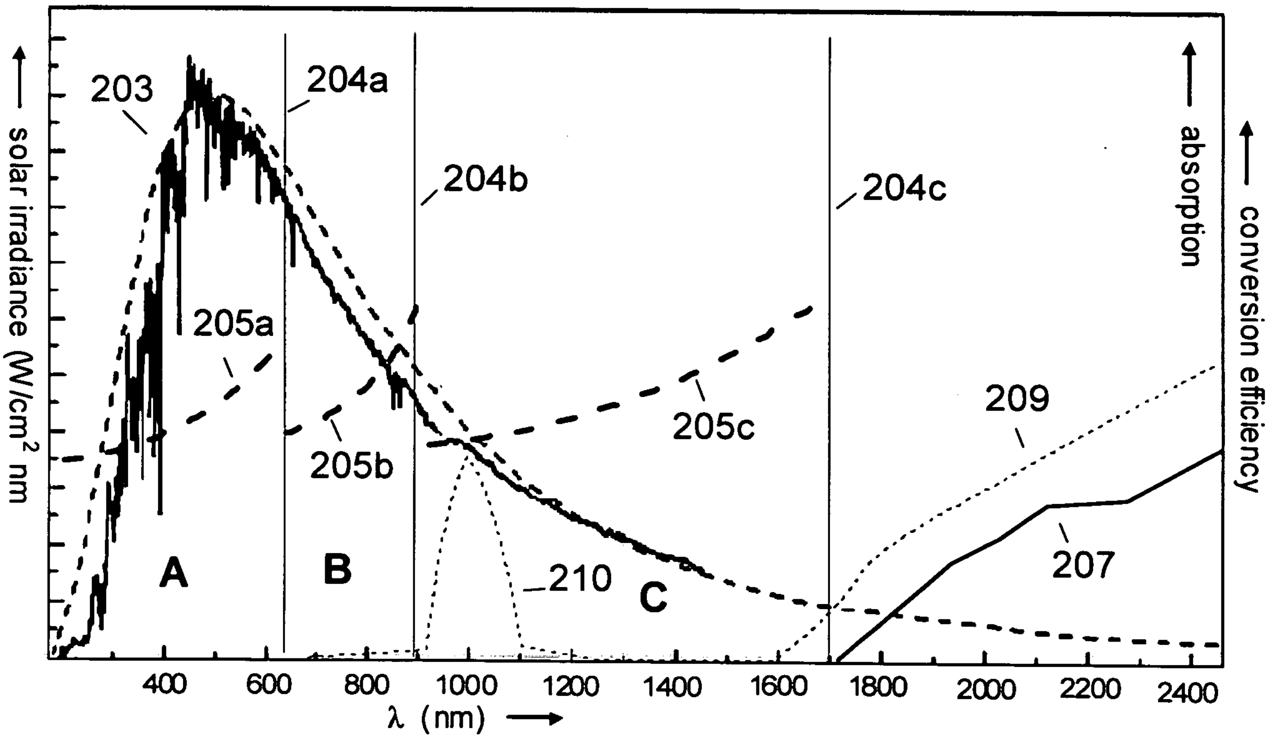


FIG. 13(b)

FIG. 14(a)

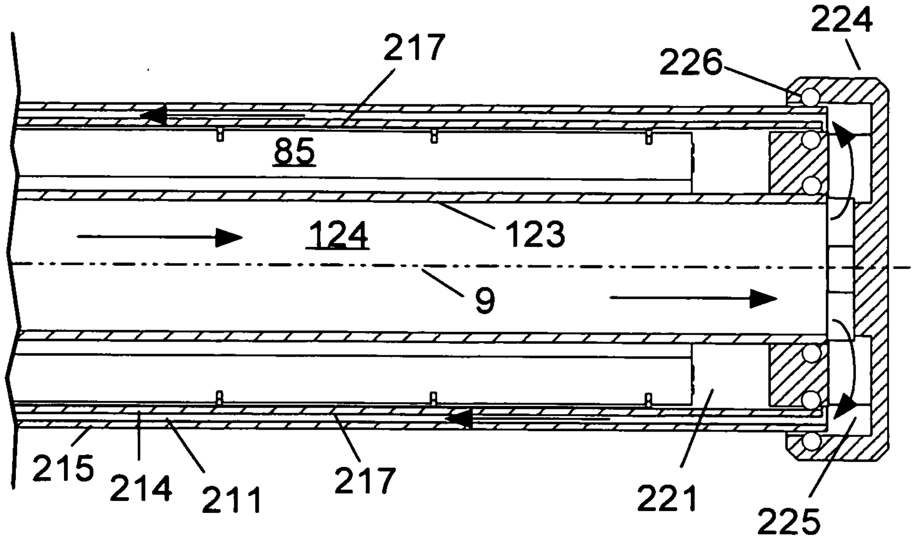


FIG. 14(b)

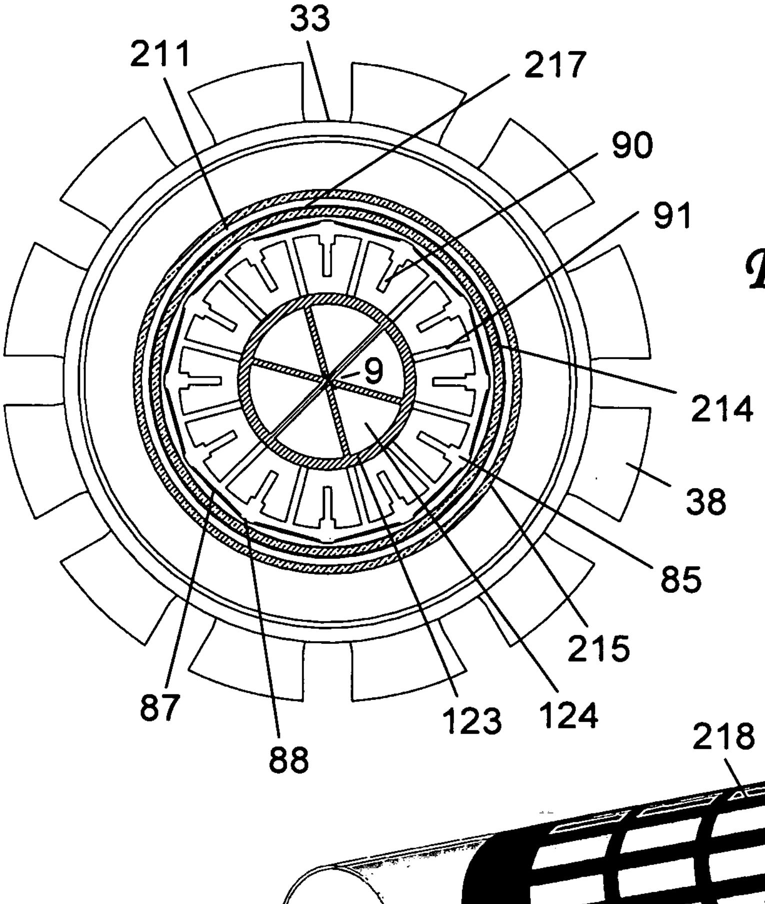
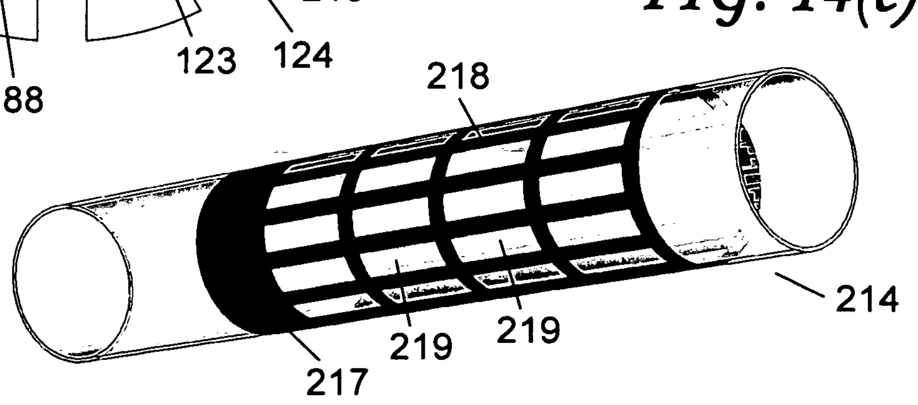


FIG. 14(c)



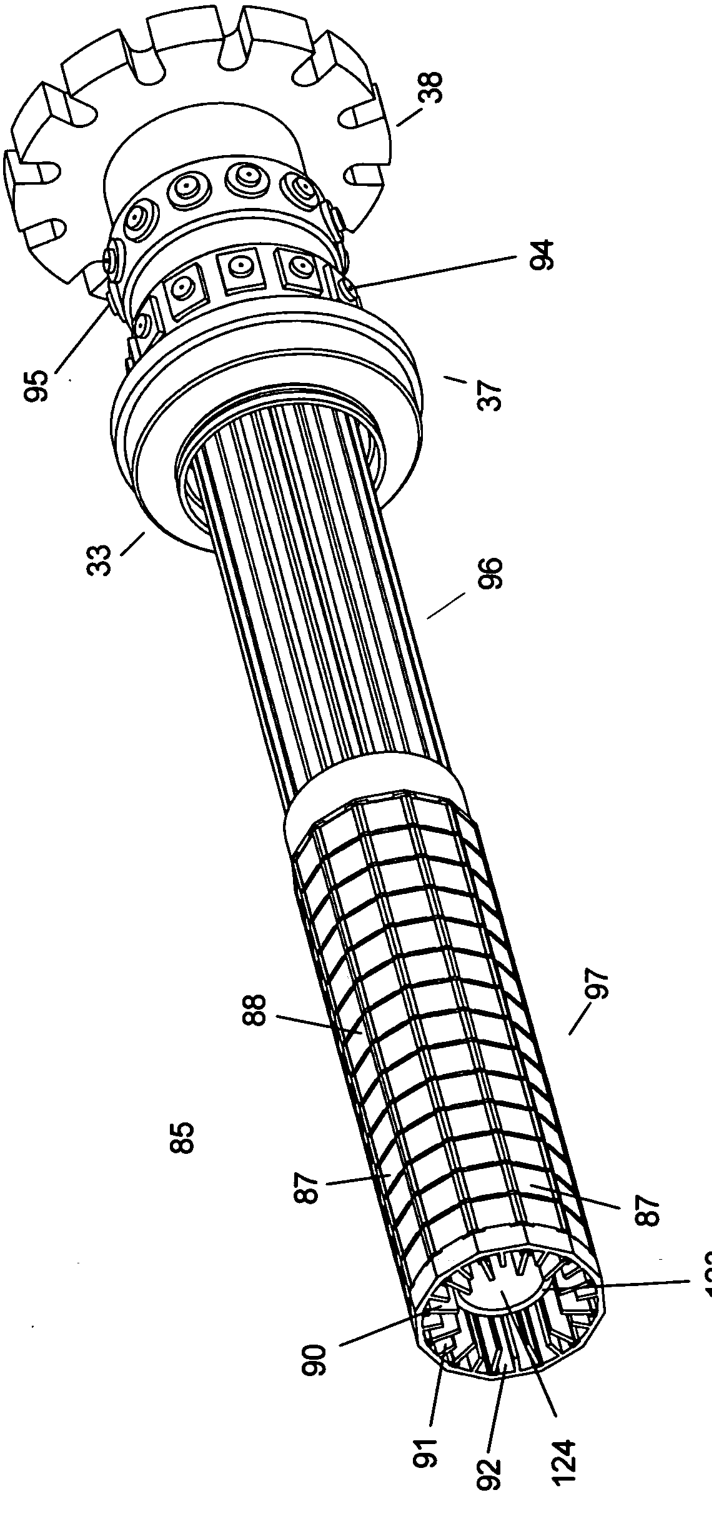


FIG. 15

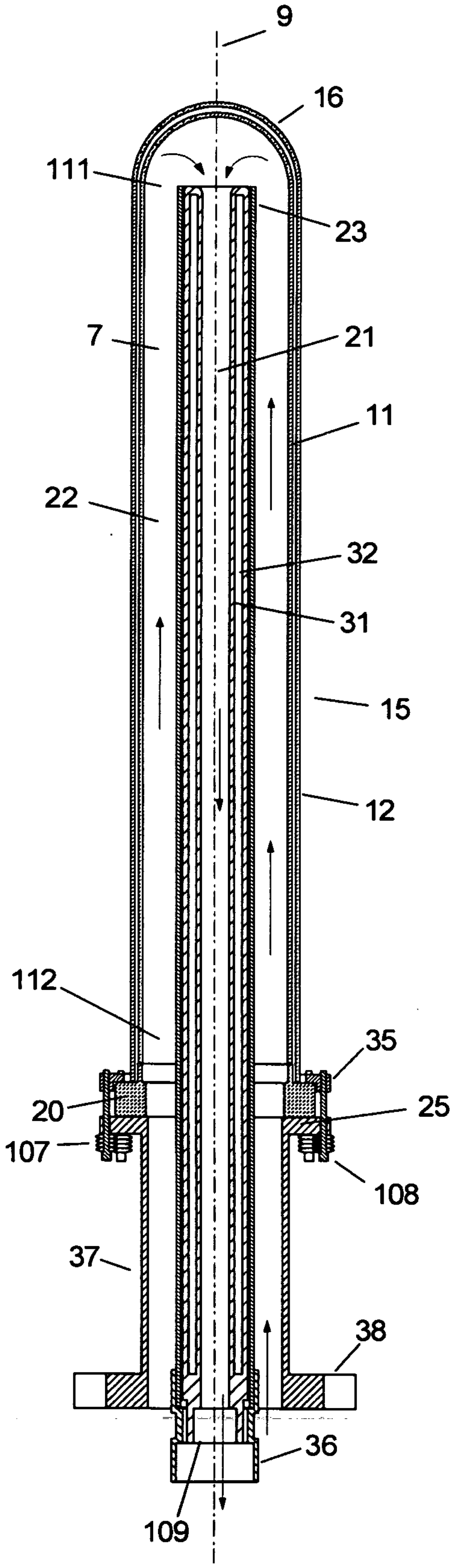


FIG. 16(a)

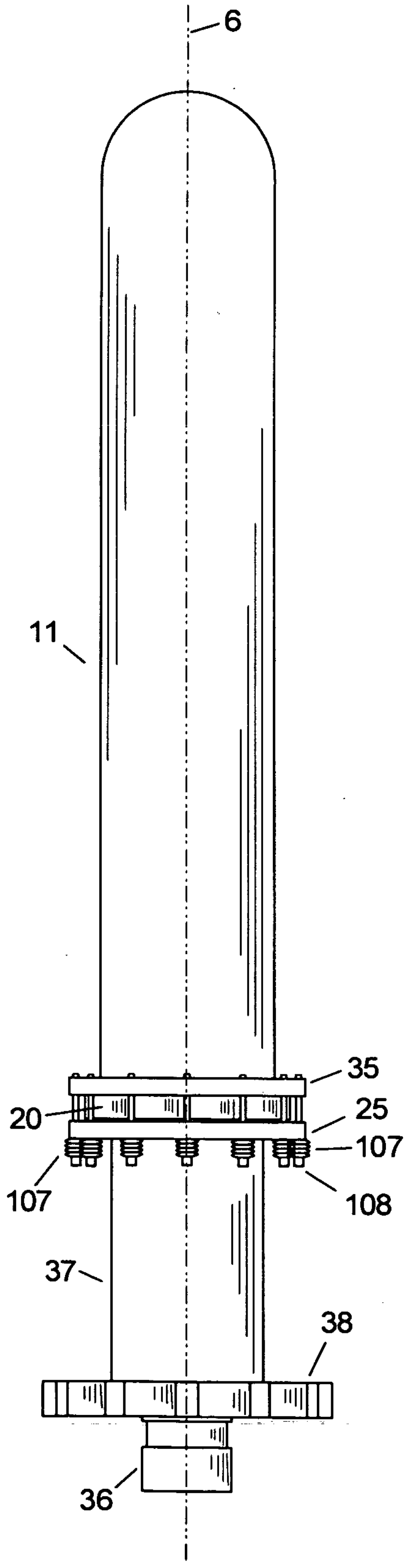


FIG. 16(b)

FIG. 17(a)

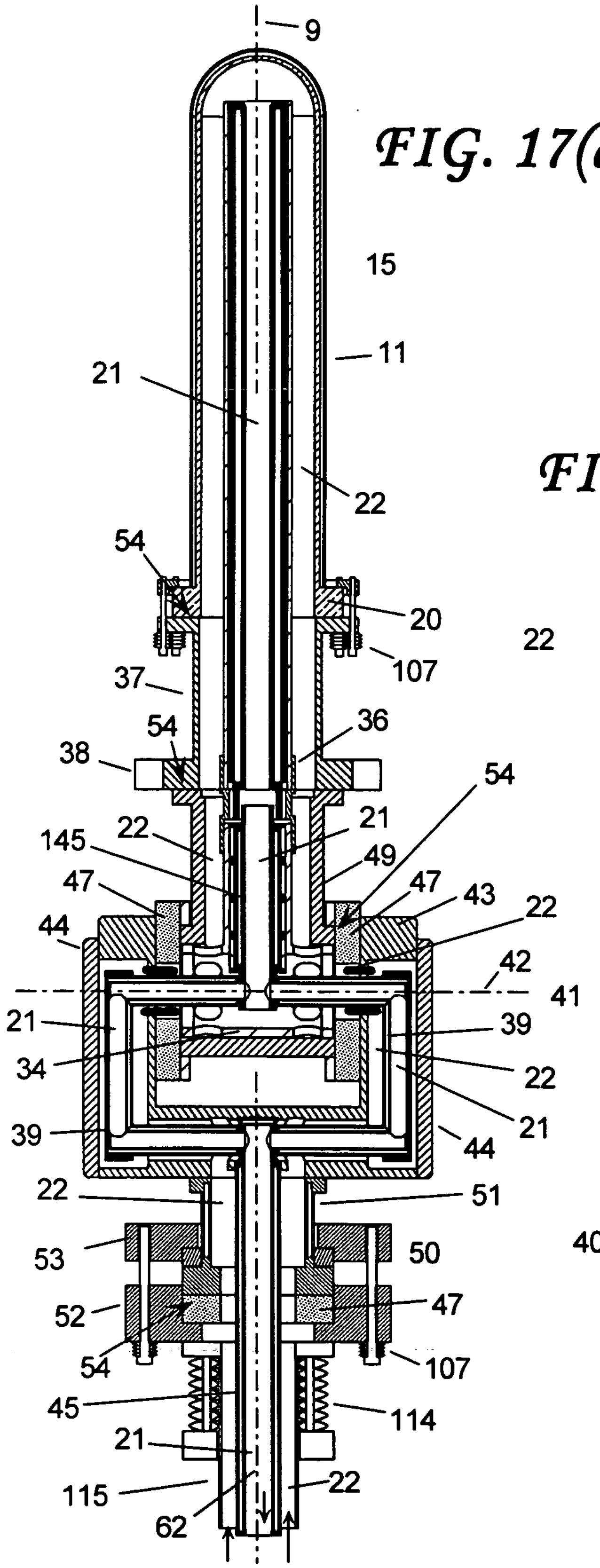
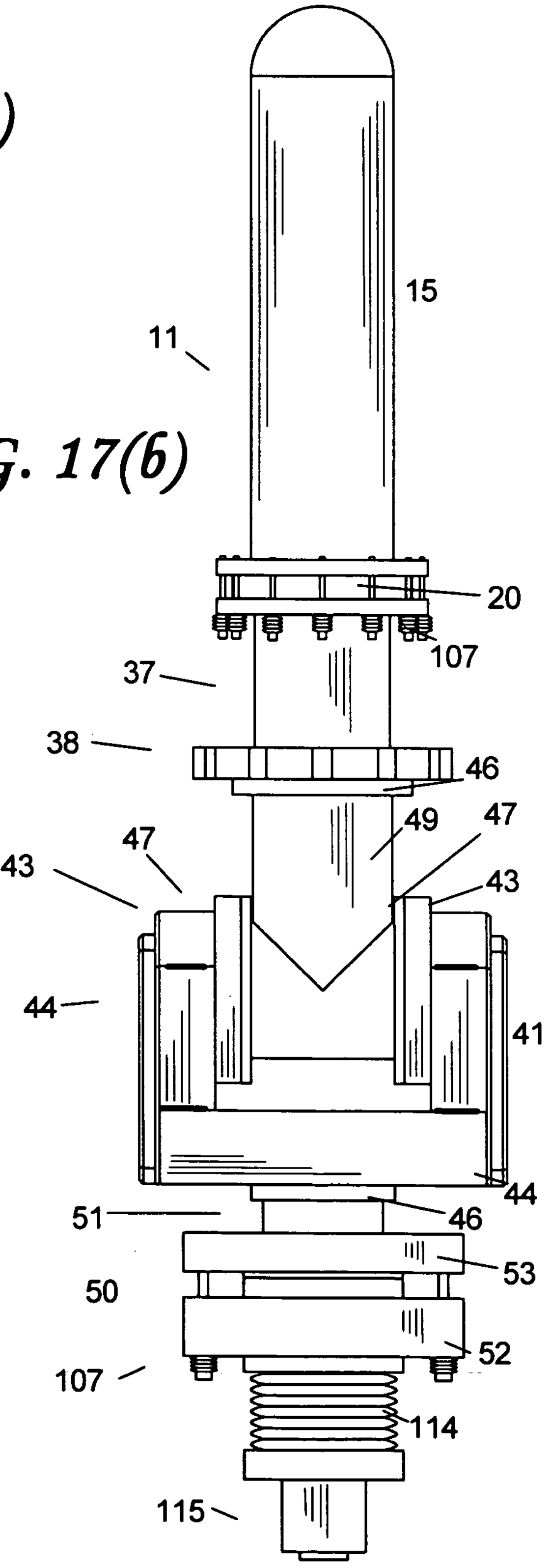


FIG. 17(b)



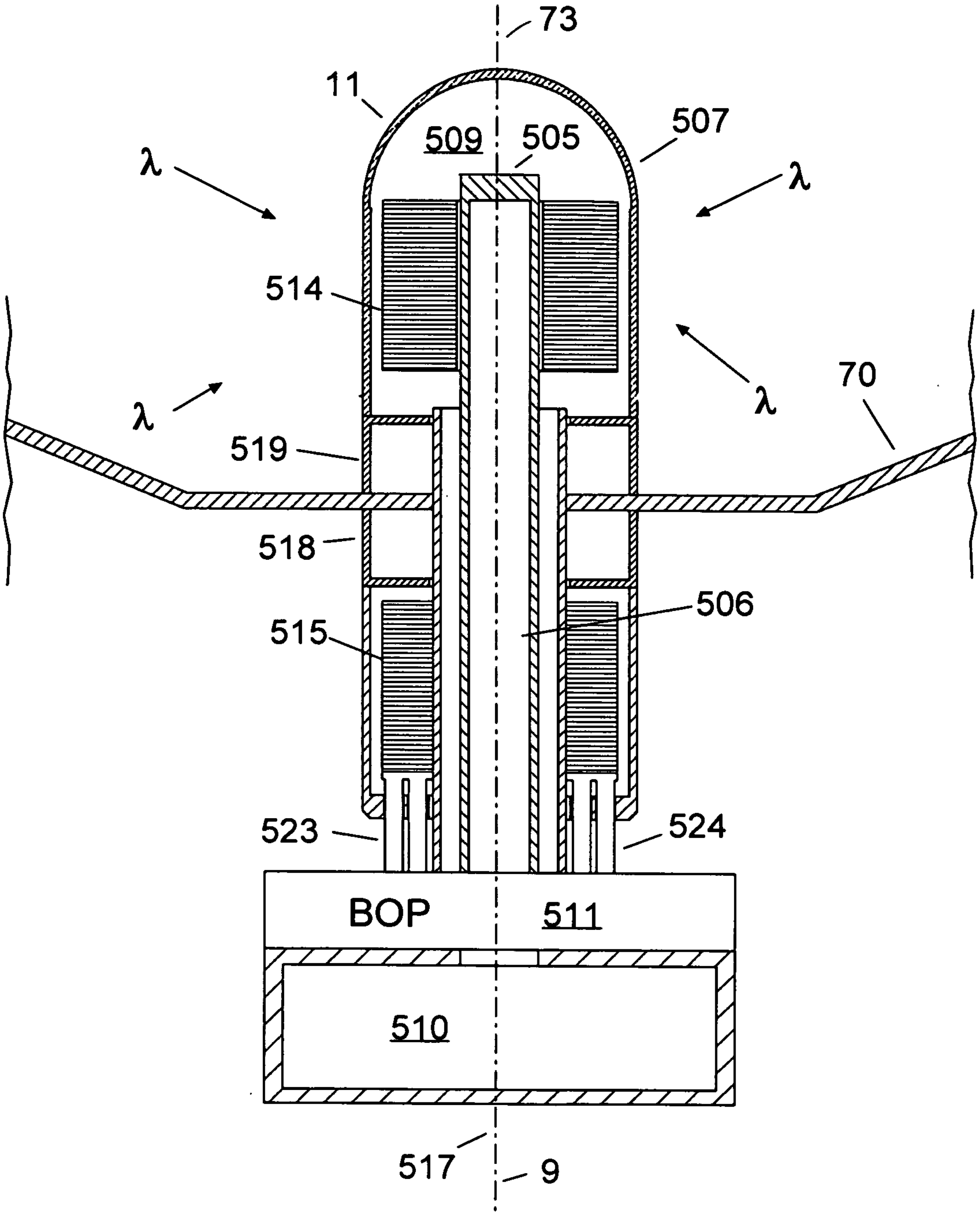

73
11
509
505
507
λ
λ
514
λ
λ
70
519
518
506
515
523
524
BOP
511
510
517
9

FIG. 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 11/00966

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F24J 2/46 (2011.01)
USPC - 136/206
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 136/206

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 136/201, 136/206, 136/214, 136/246, 126/678, 126/679, 126/684, 359/838, 853, 869 (keyword limited - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST(USPT,PGPB,EPAB,JPAB); Google Search Terms Used: solar, torus, toroidal, cylinder, cylindrical, preform, conic, conical, frustoconical, sections, honeycomb, wound, layers, reflect, concentrator, utility, array, molten, salt, oil, sandwich, difuse, photocalaytic, photochemical, fuel cell, solid oxide, gratzel, stacked, multilayer, cone, liq

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,153,780 A (JORGENSEN et al.) 06 October 1992 (06.10.1992), entire document especially Abstract; Fig 1, 5; col 1, ln 15-44; col 3, ln 6-15; col 4, ln 3-20; col 4, ln 3-20 and ln 37 -44; col 4, ln 65 to col 5, ln 1; col 5, ln 64 to col 6, ln 15; col 6, ln 35-38 and 52-57; col 7, ln 9-18	1-16, 18-22, 22A, 23-38
Y	Filament Wound Graphite Fiber Reinforced Al & Mg Composites for High Specific Stiffness Structural Applications, Datasheet [online], Metal Matrix Cast Composites, January 2006 (01.2006) [retrieved on 21 September 2011 (21.09.2011)]. Retrieved from the Internet: <URL: http://www.mmccinc.com/Continuous%20Fiber%20Structural%20Composites.pdf>	1-16, 18-22
Y	US 2009/0205636 A1 (GANGEMI) 20 August 2009 (20.08.2009), Abstract; Fig 1; para [0033], [0035], [0036]	22A, 23-38
Y	US 6,893,733 B2 (OBESHAW) 17 May 2005 (17.05.2005), Fig 3, 5, 20E; col 2, ln 60 to col 3, ln 33; col 5, ln 38-48; col 6, ln 40-51; col 7, ln 25-37; col 17, ln 14-25; col 18, ln 37-65	1-15, 19
Y	US 4,301,321 A (BARTELS) 17 November 1981 (17.11.1981), col 5, ln 10-16	22
Y	US 2006/0090747 A1 (HARRINGTON) 04 May 2006 (04.05.2006), Abstract; para [0003], [0060]	23-38

☒ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 22 September 2011 (22.09.2011)	Date of mailing of the international search report 11 OCT 2011
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CORNIE et al., Development of Graphite Fiber Reinforced Magnesium Alloys for Lightweight Mirror Substrates and Zero CTE Metering [online], June 2004 (06.2004) [retrieved on 21 September 2011 (21.09.2011)]. Retrieved from the Internet:<URL: http://optics.nasa.gov/tech_days/tech_days_2004/docs/18%20Aug%202004/22%20MMCC%20Graphite%20Fiber%20Reinforced%20Magnesium%20Alloys.pdf>	6
Y	US 2004/0030021 A1 (MITSUNAGA et al.) 12 February 2004 (12.02.2004), para [0214]	9
Y	US 5,445,861 A (NEWTON et al.) 25 August 1995 (25.08.1995), col 9, ln 64-68	14
Y	US 2009/0314280 A1 (BANERJEE) 24 December 2009 (24.12.2009), para [0058]-[0059]	25, 36
Y	US 4,215,182 A (ANG et al.) 29 July 1980 (29.07.1980), col 2, ln 33 to col 3, ln 37	31, 32
Y	US 2008/0254326 A1 (BORGSTROM et al.) 16 October 2008 (16.10.2008), Abstract; para [0009]	33
Y	US 2007/0204906 A1 (ABE et al.) 06 September 2007 (06.09.2007), para [0002]-[0003], [0006], [0037]	34, 37
Y	US 2009/0038608 A1 (CALDWELL) 12 February 2009 (12.02.2009), Fig 1, 3; para [0019], [0134]	38
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Y	US 3,755,038 A (ATTECK) 28 August 1973 (28.08.1973), entire document especially col 4, ln 24-31	1-15
A	US 4,223,174 A (MOELLER) 16 September 1980 (16.09.1980), entire document especially Fig 4; col 4, ln 32-44	1-38
A	US 5,347,986 A (CORDY) 20 September 1994 (20.09.1994), entire document especially Fig 8, 15, 28A; col 9, ln 25-41	1-38