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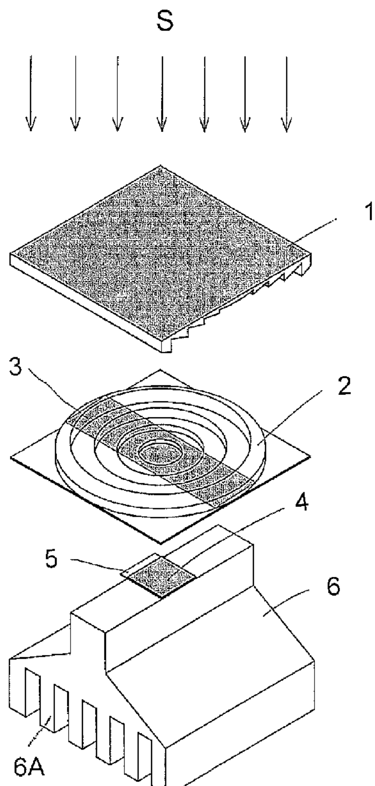

FIG. 2

(57) Abstract: A concentrating photovoltaic apparatus for generating electric current from sunlight includes a photovoltaic cell having a rectangular (usually square) active area for receiving the incident beam and a concentrating assembly for concentrating the sunlight onto the front face in a shape which is generally square rather than circular and matches the active area. The assembly can use a single cylindrical focusing member, usually a Fresnel lens, focusing onto an array of the cells so that a strip formed by the lens is applied onto a strip of the cells. Alternatively the assembly uses two cylindrical lenses arranged to focus the sunlight into a square shape arranged to match a single lens. These can be used in spaced position so as to take a strip formed by the first and to focus the strip into the cell shape or they can be two Fresnel lenses into a common lens structure.

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OPTICAL ASSEMBLY FOR CONCENTRATING PHOTOVOLTAICS

This invention relates to the field of concentrating photovoltaics (CPV), more particularly an optical assembly that collects, concentrates and feeds sunlight to high efficiency solar cells.

BACKGROUND OF THE INVENTION

Photovoltaic (PV) solar cells for CPV systems have a very small active area and, being produced by integrated circuits fabrication technologies, are essentially square or rectangular in shape. At the same time, the output of most optical assemblies is a round focus in which a high photonic power of 50-100 W/cm2 is concentrated.

In order to match the focus of an optical assembly with the size and shape of the CPV cell, prior art describes the use of an optical rod placed in the focus of a primary optical part such as a convergent Fresnel lens or in the focus of the secondary mirror of a Cassegrain concentrator.

If the intersection of the intensified light beam created by some converging optics (refractive or reflective) with an off-focus plane, further named Intensified Light Footprint (ILF), is circular and if the said plane is containing an essentially square solar cell, then this leads to a reduced Cell Illumination Efficiency (CIE) of a CPV assembly.

In Figure 1 are presented four situations, in respect with a square solar cell having 1.00cm2 active area:

a) ILF is a square, perfectly matching the solar cell active area – ILF area is 1.00 cm2 and CIE = 100%;

b) ILF is a circle 1.00 cm DIA (center circle) – ILF area is .785 cm2 and CIE = 78%;

c) ILF is a circle 1.20 cm DIA – ILF area is 1.14 cm2 and CIE = 75% (some areas are missed);

d) ILF is a circle 1.41 cm DIA – ILF area is 1.57 cm2 and CIE = 63%.

The Raw Optical Power (ROP) reaching the active area of the solar cell in a CPV power unit is:

(1) ROP = DNI X CR X OCE X CIE

where DNI is the solar Direct Normal Irradiance (W/m2), CR is the Concentration Ratio, OCE is the Optical Components Efficiency and CIE is the Cell Illumination Efficiency.

A more accurate match of the ILF with the CPV cell active area is important not only for efficiency reasons but also for avoiding damage through overheating or even catastrophic failure of neighboring parts such as bypass diodes, wires and substrate. In situations c) and d) of Figure1, these can happen even if the CPV system is supported by a perfectly aligned solar tracker.

In conclusion, any mismatch between ILF and the solar cell active area leads to a significant CIE degradation and to potentially hazardous situations.

SUMMARY OF THE INVENTION

It is one object of the invention to provide an apparatus which may provide a partial or complete solution for addressing this problem by using optics.

According to one aspect of the invention there is provided a concentrating photovoltaic apparatus for generating electric current from sunlight comprising:

a photovoltaic cell for receiving the sunlight as an incident beam and for generating an output current from the incident beam;

the cell having a rectangular active area for receiving the incident beam;

the assembly including the focusing member being arranged relative to the cell to form a rectangular strip which is focused onto the active area of the cell to substantially match the rectangular shape of the active area.

In one arrangement the cylindrical focusing member is a lens and particularly a cylindrical Fresnel lens.

In another arrangement the cylindrical focusing member is a parabolic mirror preferably used in a Cassegrain construction, that is the mirror is parabolic in side elevation and is part cylindrical along its length.

In one arrangement the cylindrical focusing member is a primary focusing member for forming the rectangular strip at a position spaced from the focal length of the primary focusing member and wherein the rectangular strip is focused by a secondary focusing member into a rectangle matching the active area of the cell ..

In this case the secondary focusing member can be a circular Fresnel lens, although the use of circular lenses is not preferred as these can introduce some distortion.

Preferably therefore the secondary focusing member is a second cylindrical Fresnel lens arranged at right angles to the first and arranged to focus the strip into a rectangular patch matching the active area of the cell.

Preferably the primary and secondary lenses are Fresnel lenses which are connected back to back.

Preferably one of the Fresnel lenses is defined by four sections each defined by a base defining one side of the lens and two sides converging to an apex at a center of the lens where each of the sections has the grooves thereof parallel to the base and wherein the other of the Fresnel lenses is defined by four sections each defined by a base defining one side of the lens and two sides converging to an apex at a center of the lens where each of the sections has the grooves thereof at right angles to the base.

Preferably the secondary focusing member is shaped in plan to match the focus of the cylindrical focusing member by omitting unnecessary parts of the member where no light is falling.

Thus the secondary focusing member can be formed into a strip shape or a cross shape.

Thus in a particularly preferred arrangement the secondary focusing member is a Fresnel lens formed into a strip shape or a cross shape.

In this arrangement where the cross shape is formed, the cylindrical focusing primary member may be formed of a first and a second cylindrical focusing portion with the portions arranged at right angles and in a common array such that the two cylindrical focusing portions focus the sunlight into a right angle cross. Each of the two portions can be defined by two triangular portions arranged pointing inwardly to an apex and arranged into an array which is diagonal joining at the apex at a center of the array.

In this arrangement the cylindrical secondary focusing member may be also formed of a first and a second cylindrical focusing portion with the portions arranged at right angles and in a common array in a symmetrical manner to the primary but arranged at 90 degrees to the primary. Thus again, each of the two portions is defined by two triangular portions arranged pointing inwardly to an apex and arranged into an array which is diagonal joining at the apex at a center of the array.

In an alternative arrangement where no secondary lens or focussing member is used and the light is arranged to fall directly in the cell, there is provided a plurality of cells arranged in an array, where the array is shaped to match the focus of the cylindrical focusing member with the light from the cylindrical focusing member falling directly onto the array of cells. Thus the array can be formed into a strip shape or a cross shape.

According to a second preferred aspect of the invention there is provided a concentrating photovoltaic apparatus for generating electric current from sunlight comprising:

a photovoltaic cell for receiving the sunlight as an incident beam and for generating an output current from the incident beam;

the cell having a rectangular front active area for receiving the incident beam;

and a concentrating assembly for concentrating sunlight onto the active area , the concentrating assembly comprising a first Fresnel lens arranged to receive the sunlight and a second Fresnel lens arranged downstream of the first lens for receiving the light therefrom;

wherein the first Fresnel lens is formed by four sections each having a base defining one side of the lens and two sides converging to an apex at a center of the lens where each of the sections has the grooves thereof parallel to the base;

and wherein the second Fresnel lens is formed by four sections each having a base defining one side of the lens and two sides converging to an apex at a center of the lens where each of the sections has the grooves thereof at right angles to the base.

Preferably the second Fresnel lens is located immediately downstream of the first and is connected thereto as a common lens structure.

BRIEF DESCRIPTION OF THE DRAWINGS

One embodiment of the invention will now be described in conjunction with the accompanying drawings in which:

Figure 1 is a schematic illustration of the incident light on a rectangular cell showing calculations of the efficiency.

Figure 2 is an isometric view of a first embodiment of an apparatus according to the present invention showing two lenses for focussing onto a single cell.

Figure 3 is an isometric view of a second embodiment of an apparatus according to the present invention showing two lenses for focussing onto a single cell.

Figure 4A is a plan view of the primary lens of Figure 2.

Figure 4B is a plan view of the primary lens of Figure 3.

Figure 5 is an isometric view of a third embodiment of an apparatus according to the present invention similar to that of Figure 2 with the secondary lens shaped to match the pattern of light falling from the primary lens and thus the secondary lens is strip shaped.

Figure 6 is an isometric view of a fourth embodiment of an apparatus according to the present invention similar to that of Figure 3 with the secondary lens shaped to match the pattern of light falling from the primary lens and thus the secondary lens is cross shaped.

Figure 7 is an isometric view of a fifth embodiment of an apparatus according to the present invention showing two cylindrical Fresnel lenses for focussing onto a single cell.

Figure 8 is an isometric view of a sixth embodiment of an apparatus according to the present invention similar to Figure 7 with the secondary lens shaped to match the pattern of light falling from the primary lens and thus the secondary lens is strip shaped.

Figure 9A is a plan view of the primary lens of Figure 7.

Figure 9B is a plan view of the secondary lens of Figure 7.

Figure 10A is a plan view of a primary lens of a seventh embodiment similar to that of Figure 7 which uses the four part divided primary lens of Figure 3.

Figure 10B is a plan view of a secondary lens of seventh embodiment of Figure 10A, which is similar to that of Figure 7, and which uses a four part divided secondary lens in conjunction with the four part primary lens of Figure 10A.

Figure 11 is an isometric view of an eighth embodiment of an apparatus according to the present invention showing a single lens focussing onto a strip shaped array of cells.

Figure 12 is an isometric view of a ninth embodiment of an apparatus according to the present invention showing a single lens focussing onto two strip shaped arrays of cells thus defining a cross shaped array of cells.

Figure 13 shows the process of cutting a single cylindrical Fresnel lens into four pieces in diagonal directions.

Figure 14A is an isometric view of a first one of two lenses which are assembled from the pieces of Figure 13.

Figure 14B is an isometric view of a second one of two lenses which are assembled from the pieces of Figure 13.

Figure 15A is an isometric view from the top of the optical assembly made of the lenses in Figures 14A and 14B.

Figure 15B is an isometric view from the bottom of the optical assembly made of the lenses in Figures 14A and 14B.

Figure 16 is an isometric view of a PV module comprising the optical assembly of Figures 15A and 15B.

Figure 17 is an isometric view of a tenth embodiment of an apparatus according to the present invention showing two mirrors in a Cassegrain arrangement for focussing onto a single cell.

Figure 18 is an exploded view of the primary mirror of Figure 17.

Figure 19 is an isometric view of an eleventh embodiment of an apparatus according to the present invention showing two mirrors in a Cassegrain arrangement for focussing onto a single cell.

In the drawings like characters of reference indicate corresponding parts in the different Figures.

DETAILED DESCRIPTION

Each of the embodiments shown herein includes a photovoltaic cell 5 mounted on a support or substrate 6 which is commonly finned at 6A to act as a heat sink. The cell has a front face defining an active area onto which the light is incident with two leads not shown for conducting the current generated by the photovoltaic effect. The active area is rectangular and generally, although not essentially, square thus generating the inefficiencies previously described if the incident light beam is circular.

Figure 2 shows a combination of a cylindrical Fresnel lens 1 used as a primary optical concentrator and a circular Fresnel lens 2 used as a secondary optical concentrator.

Circular Fresnel lenses have the conventional lens grooves of a circular lens arranged in circles on the flat base. Cylindrical Fresnel lenses have the lens grooves of a cylindrical lens arranged in a parallel array on the flat base. Such lenses are previously known for many other purposes and are commonly made from plastics material by a molding process and hence can be relatively inexpensive. The detail of the construction and the methods of manufacture are therefore generally known to a person skilled in this art.

Thus the incident light S is focussed by the primary optical concentrator onto the secondary and is again focussed by the secondary onto the cell. The focus pattern is shown in grey tones at 3 and 4.

The known effect of a cylindrical lens which is either formed as a cylinder or as a Fresnel type lens made for individual lens grooves is that the incident light defined as a parallel beam is focussed at its focal length into a line.

However it will be appreciated that, if the secondary 2 is placed at a shorter distance than the focal distance of the lens 1, the light is formed into a strip which is thus rectangular. Lens 1 thus produces the rectangular strip focus 3, parallel with its linear grooves The lens 2 projects the strip 3 onto the focus 4, which is a reduced image of focus 3. This focus 4 is thus rectangular and preferably square. The assembly of lenses is designed in focal length and dimensions of the lens and the distances between the lenses and the focus in such a way that focus 4 perfectly matches the size and shape of the CPV cell 5 mounted on the substrate 6. The focus 4 is rectangular or square due to the initial formation of the strip 3 which is then reduced primarily in length but also in width to form a rectangular focus 4. However, focus 4 may have 2 opposite sides slightly rounded (barrel shape), which makes this optical assembly a better option than a round focus but not the perfect one.

Figure 3 presents another embodiment of the present invention in which lens 1 of FIG. 2 is replaced with lens 7 which is made, as shown in Figure 10B, of two cylindrical convergent Fresnel lenses pieces 7A and 7B each cut at 45° into two triangular pieces making a total of four pieces which are assembled into a square, meeting at a center apex 7C. It will be appreciated that this generates two strip focuses at right angles to form an orthogonal cross 8 on lens 2. Again the cross is formed at the off-focus location so as to form two strips at right angles forming the cross. Lens 2 then provides a matched ILF 4 with the active area of the cell 5, which is a compressed image of the focus 8. The advantage of this layout over that of Figure 2 is that lens 2 works at half of the light intensity per unit area as the area is roughly double, compared with lens 2 in Figure 2. For this reason, the embodiment of Figure 2 is more suitable for low and medium concentration CPV systems. As an alternative to lens 2, the construction shown in Figure 10A can be used which is again made from four triangular pieces 7H, 7J, 7K and 7L where the pieces meet at a center apex and each piece has a base of the triangle forming one side of the square lens structure. In this construction the grooves of the Fresnel construction lie at right angles to the base of the triangle. This lens structure will focus the cross formed by the first lens of Figure 10B into a square which can be dimensioned by selecting the spaces between the planes of the lenses and the cell to match the dimensions of the cell.

In Figures 2 and 3, the aperture of the primary lens and the foci of both lenses are shown in grey tone.

The Fresnel lenses 1 and 7 are shown in Figure 4A and Figure 4B, respectively, for better understanding the direction of their grooves. Thus the grooves of the two pieces 7A are mutually parallel as indicated at 7D and the grooves 7E of the pieces 7B are also mutually parallel and at right angles to the pieces 7A.

It is recommended that the lenses be made of Acrylic Plastic with 92% transmission but any other material for visible light and stability under UV radiation, commercially available or under development, can be considered.

In a mass production of such concentrators, savings in optical grade material can be of importance. For this reason, Figure 5 shows that the secondary lens 21 can actually be plastic-molded in a strip shape matching the focus from the primary lens with unused areas being eliminated. Similarly figure 6 shows that the secondary lens 21 can be molded in a cross shape matching the focus from the primary lens. This feature also contributes to a weight reduction of large modules and arrays.

While the above embodiments use as the secondary lens circular Fresnel lenses, this may not be preferred due to possible distortions that may be introduced. Hence other embodiments are very similar in construction and use the same primary lens but replace the circular Fresnel lens as the secondary lens with a cylindrical Fresnel lens. Thus, as shown in Figure 7 and Figure 8, the secondary lens is formed by a cylindrical Fresnel lens 8 and 8A respectively.

As shown in Figure 7 and in Figures 9A and 9B, the grooves of the secondary lens 8 have to be oriented at 90° in respect to the grooves of the primary lens 1.

It is understood that the same principle of elimination of the unused areas of the secondary lens, as shown for example in Figure 5, so that its dimensions match only the focus from the primary, can be applied as shown in Figure 8 at the cylindrical lens 8A, for optical material savings.

The above arrangements use primary and secondary lenses. However in low and medium concentration CPV systems, the solar cells can be directly illuminated by the strip or orthogonal cross off-focus of the primary lens 1 or 7, respectively, as shown in Figure 11 and Figure 12, without the provision of the secondary lens. Thus the primary lens forms a strip as shown In Figure 11 or a cross as shown in Figure 12. Instead of these being further focussed and concentrated by a secondary, in these embodiments, additional cells 5 are provided and formed into an array matching the shape of the pattern from the primary.

In this case, the aperture of the primary lens has to be significantly wider. However, not using the secondary lens makes the ROP to gain 7-8% depending on how the module is designed and attached to the solar tracker.

The most preferred embodiment of the invention that can have an economic impact on all concentrating photovoltaic categories (low, medium and high concentration) when using refractive optics is shown in Figure 16.

A process of fabrication of a prototype of this optical assembly is explained in Figures 13 to 15 in order to better explain the arrangement and operation of this lens. However it will be appreciated that the construction in practice will be made by molding a composite lens of the construction shown in Figure 16 rather than by fabrication of separate pieces as shown in Figure 13 to 15. The lenses of Figures 13 to 15 are in fact the same lenses as previously shown in Figure 10A and 10B.

When a conventional cylindrical Fresnel lens, as shown schematically in Figure 13, is cut along the diagonal directions, four triangular pieces result of two different types. They two types are labelled as TYPE A and TYPE B.

In TYPE A the grooves are at right angles to the base A1 of the triangular cut piece and in TYPE B the grooves are parallel to the base B1. The TYPE A pieces converge to an apex A2 and the TYPE B pieces converge to an apex B2.

In Figure 14A, four pieces of TYPE A are assembled into Lens 100 where the bases A1 form the sides of the rectangular lens and the apexes A2 meet at the center. Thus the grooves extend at right angles to the sides A1. and in Figure 14B four pieces of TYPE B are assembled in Lens 200 where the bases B1 form the sides of the rectangular lens and the apexes B2 meet at the center. Thus the grooves extend parallel to the sides B1. In both lenses. The grooves lie wholly on one surface and the other surface is planar.

It is easily understood that the process is actually starting from cutting two cylindrical Fresnel lenses. Finally, Lens 100 and Lens 200 are glued together with their planar surfaces facing each other. Figures 15A and 15B each show an isometric view from the top and bottom of the final optical assembly. Thus instead of the lenses being spaced so that the second acts at the image of the first on the second, the lenses are formed into a composite structure operating on the light substantially at a common plane (spaced only by the physical structure necessary to form the composite lens). The resultant path of the light is however basically the same whether the lens pieces are spaced or combined and they act to form a square image which is matched to the dimension of the cell by selecting the required spacing between the lens and the cell. Thus the composite lens is a non-imaging lens system.

Figure 16 illustrates how a photovoltaic module can utilize this optical assembly formed by lenses 100 and 200 when a square or rectangular solar cell is placed in the PV cell plane situated above the focal point F. In this case, the ILF will perfectly match the active area of the PV cell and the CIE will be very close to 100%, provided the solar tracker accuracy. Compared to modules using only a primary circular Fresnel lens, the application of this optical assembly can improve the electrical energy yield by 22%. It is necessary that the lens 200 acts on the light in advance of the lens 100. However the individual lenses can be reversed relative to the light so that instead of being back to back as shown with the flat surfaces in contact, they can be front to front, bearing in mind that all the shapes and grooves required are molded into an outer surface of a two sided lens structure.

Modules comprising a secondary optical lens experience a supplementary energy loss due to the heating of the secondary lens that has to handle the whole concentrated photonic power in a very small volume. The main advantage of the optical assembly shown in Figure 16 is the fact that it provides all necessary optical features, that is concentration and PV cell uniform illumination in a perfectly matched ILF to the PV cell active area in just one step, with one molded plastic component forming a single composite lens. Compared with modules comprising a secondary optical piece, this optical assembly can improve the module yield by 5-7%, increase the reliability and decrease its price.

The above arrangements use cylindrical lenses and particularly although not necessarily Fresnel lenses as the focusing members of the concentrating assembly. However the arrangement can be generated not only with lenses but also with mirrors using for example the conventional and well known Cassegrain mirror system.

Thus Figure 17 illustrates a Cassegrain type optical assembly with a converging primary mirror and a secondary mirror directing through a hole in the primary. The primary mirror 10 is made of four cylindrical parabolic parts 10A, 10B, 10C and 10 D cut at 45° as seen in the exploded view of Figure 18. They are made of molded plastic parts covered with a highly reflective layer on the parabolic side. The reflective layer can be an aluminum multi-layer adhesive foil or obtained through vacuum metal deposition of silver or aluminum. The pieces 10A to 10D as shown in Figure 18 are each parabolic in side elevation and part cylindrical along their length.

The four parts 10A to 10D are assembled on a rigid base 13. The secondary mirror 14 is placed under the focal plane of the primary mirror 10 and is cross-shaped to match the concentration pattern of mirror 10. Unlike traditional Cassegrain secondary mirrors, mirror 14 is not only convex-spherical in one plane as indicated at 14A but also convex-spherical in an orthogonal plane 14B, in such a way to project through the opening 15 of mirror 10 a compressed image of the cross focus of the primary mirror. T his image, through a correct optical design, will perfectly match the size and shape of the CPV solar cell 5.

In comparison with prior art arrangements, this can provide over 1500 suns CR and the shadow area of mirror 14 is under 6% of the entire aperture of mirror 10, which makes this solution highly competitive to the prior art. As the secondary optical rod is not necessary, the overall efficiency of the optical assembly is over 86%. Another advantage is that the manufacturing of cylindrical-parabolic mirrors is much simpler than spherical-parabolic ones and the parabolic profile can even be made of linear segments. In other words, the reflective surface can be made of cheap sheets of reflective material.

Figure 19 illustrates a similar embodiment to that of Figure 17 using the parabolic/cylindrical mirrors of Figure 17 except that it is arranged to form a strip shape focus from the primary mirror 17 and uses a single strip shaped secondary mirror 18 shaped to match the focus of the primary as previously described. This in this case the primary is formed in effect of a single cylindrical mirror which is shaped in side elevation to form a parabola so as to focus the incoming light into the strip along the center line above the mirror 17. A center strip 19 divides the mirror 17 into two portions and this does not need to be reflective as it is shaded by the secondary mirror 18. A central hole 20 on the strip 19 allows the light focussed by the secondary 18 to pass through the primary onto the cell 5. The secondary mirror 18 can be concave as shown so as to be convergent or can be convex as in FIG. 17 so as to be divergent. The mirrors can be simply formed from flat strips side by side at an angle to each other to simulate the parabolic shape without excessive distortion.

A combination of reflective and refractive non-imaging optics is also possible, such as covering each of the four segments 10A-10D of mirror 10 in Figures 17 and 18 with preferably stretched (curved) pieces of TYPE A from Figure 13, in which case the secondary mirror is no more necessary.

Since various modifications can be made in my invention as herein above described, and many apparently widely different embodiments of same made within the spirit and scope of the claims without department from such spirit and scope, it is intended that all matter contained in the accompanying specification shall be interpreted as illustrative only and not in a limiting sense.

CLAIMS:

1. A concentrating photovoltaic apparatus for generating electric current from sunlight comprising:

a photovoltaic cell for receiving the sunlight as an incident beam and for generating an output current from the incident beam;

the cell having a rectangular active area for receiving the incident beam;

and a concentrating assembly for concentrating sunlight onto the active area, the concentrating assembly comprising a cylindrical focusing member arranged to receive the sunlight and to focus the sunlight;

the assembly including the focusing member being arranged relative to the cell to form a rectangular strip which is focused onto the active area of the cell to substantially match the rectangular shape of the active area.

2. The apparatus according to Claim 1 wherein the cylindrical focusing member is a lens.

3. The apparatus according to Claim 1 wherein the cylindrical focusing member is a cylindrical Fresnel lens.

4. The apparatus according to Claim 1 wherein the cylindrical focusing member is a mirror.

5. The apparatus according to any one of claims 1 to 4 wherein the cylindrical focusing member is a primary focusing member for forming the rectangular strip at a position spaced from the focal length of the primary focusing member and wherein the rectangular strip is focused by a secondary focusing member into a rectangle matching the active area.

6. The apparatus according to Claim 5 wherein the secondary focusing member is a Fresnel lens.

7. The apparatus according to Claim 5 or 6 wherein the secondary focusing member is shaped in plan to match the focus of the cylindrical focusing member.

8. The apparatus according to any one of Claims 5 to 7 wherein the primary and secondary lenses are Fresnel lenses which are connected into a common structure with the lenses operating on the light at a common location.

9. The apparatus according to Claim 8 wherein one of the Fresnel lenses is defined by four sections each defined by a base defining one side of the lens and two sides converging to an apex at a center of the lens where each of the sections has the grooves thereof parallel to the base and wherein the other of the Fresnel lenses is defined by four sections each defined by a base defining one side of the lens and two sides converging to an apex at a center of the lens where each of the sections has the grooves thereof at right angles to the base.

10. The apparatus according to Claim 5, 6 or 7 wherein the secondary focusing member is shaped in plan to match the rectangular strip formed by the cylindrical focusing member.

11. The apparatus according to Claim 10 wherein the secondary focusing member is a cylindrical Fresnel lens shaped in plan to form a rectangular strip shape.

12. The apparatus according to Claim 10 wherein the secondary focusing member is a second cylindrical Fresnel lens arranged at right angles to the first and arranged to focus the strip into a rectangular patch matching the active area of the cell.

13. The apparatus according to any one of claims 10 to 12 wherein the primary cylindrical focusing member includes a first and a second cylindrical focusing portion with the portions arranged at right angles and in a common array such that the two cylindrical focusing portions focus the sunlight into a right angle cross.

14. The apparatus according to Claim 13 wherein the two portions are arranged into an array which is diagonal joining at a center of the array.

15. The apparatus according to Claim 13 or 14 wherein the secondary focusing member is shaped in plan to match the cross-shaped strip formed by the cylindrical focusing member.

16. The apparatus according to Claim 15 wherein the secondary focusing member is a cylindrical Fresnel lens.

17. The apparatus according to Claim 1 to 4 wherein there is provided a plurality of cells arranged in array where the array is shaped in plan to match the shape of the rectangular strip formed by the cylindrical focusing member which strip is arranged to fall directly onto the array of cells.

18. The apparatus according to Claim 17 wherein the array is formed into a strip shape.

19. The apparatus according to Claim 17 wherein the array is formed into two strips defining a cross shape.

20. A concentrating photovoltaic apparatus for generating electric current from sunlight comprising:

a photovoltaic cell for receiving the sunlight as an incident beam and for generating an output current from the incident beam;

the cell having a rectangular active area for receiving the incident beam;

and a concentrating assembly for concentrating sunlight onto the active area, the concentrating assembly comprising a first Fresnel lens arranged to receive the sunlight and a second Fresnel lens arranged downstream of the first lens for receiving the light therefrom;

wherein the first Fresnel lens is formed by four sections each having a base defining one side of the lens and two sides converging to an apex at a center of the lens where each of the sections has the grooves thereof parallel to the base;

and wherein the second Fresnel lens is formed by four sections each having a base defining one side of the lens and two sides converging to an apex at a center of the lens where each of the sections has the grooves thereof at right angles to the base.

21. The apparatus according to claim 20 wherein the second Fresnel lens is located immediately downstream of the first and is connected thereto as a common lens structure.

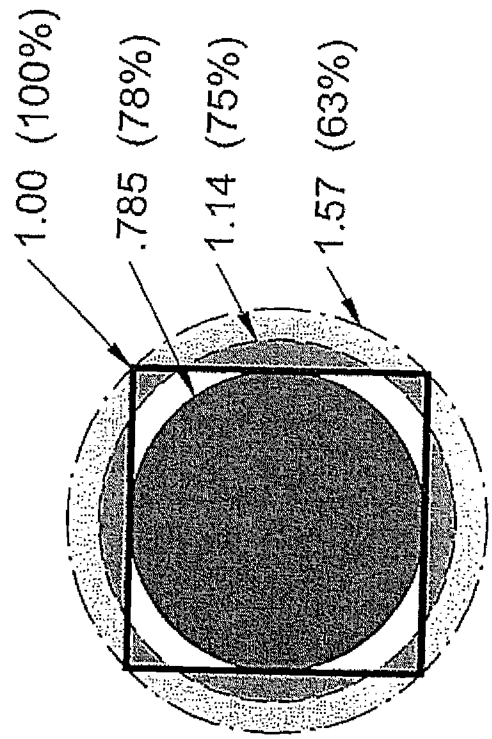


FIG. 1

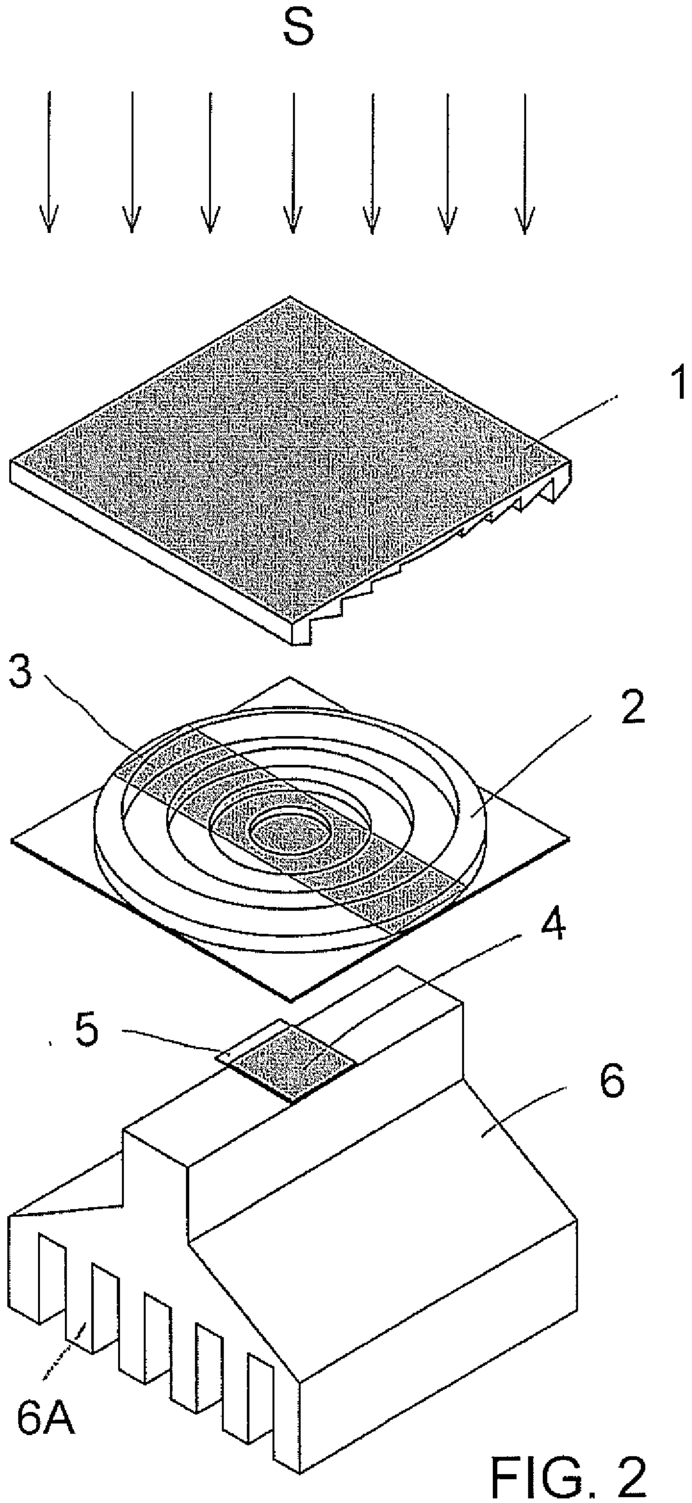


FIG. 2

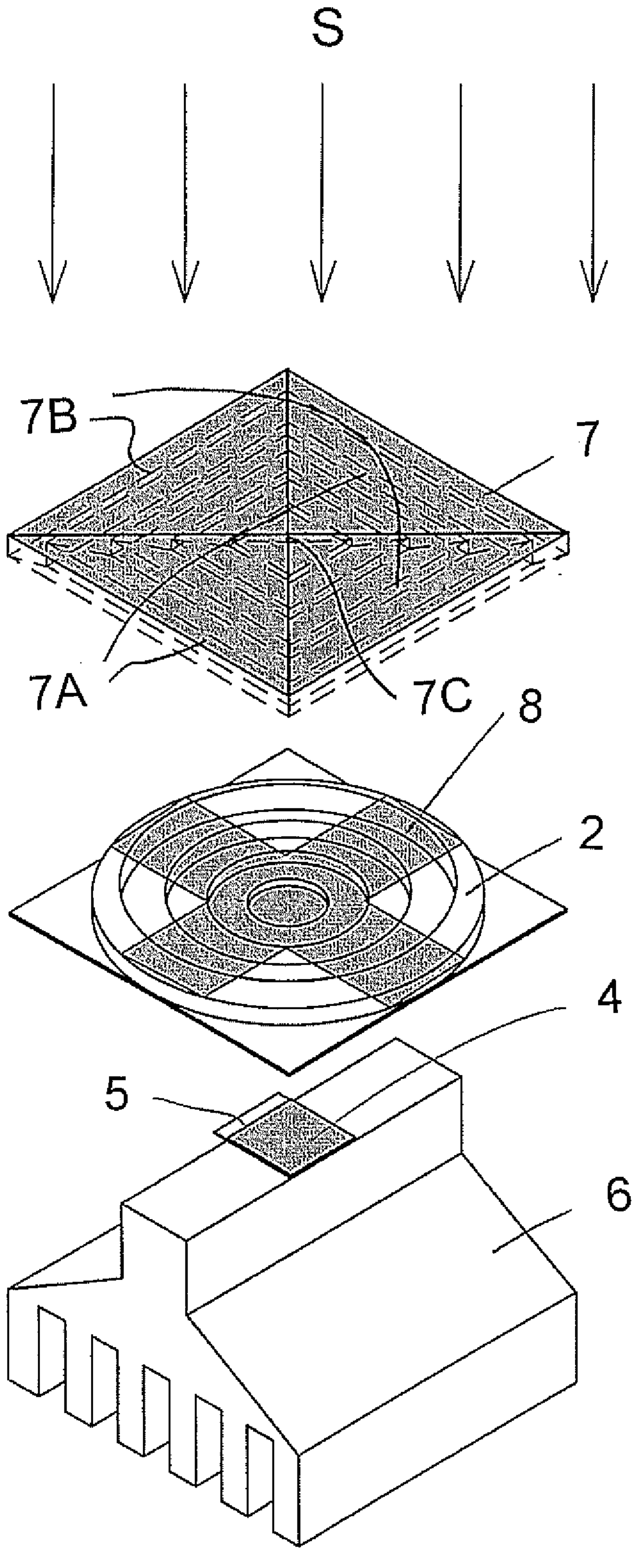


FIG. 3

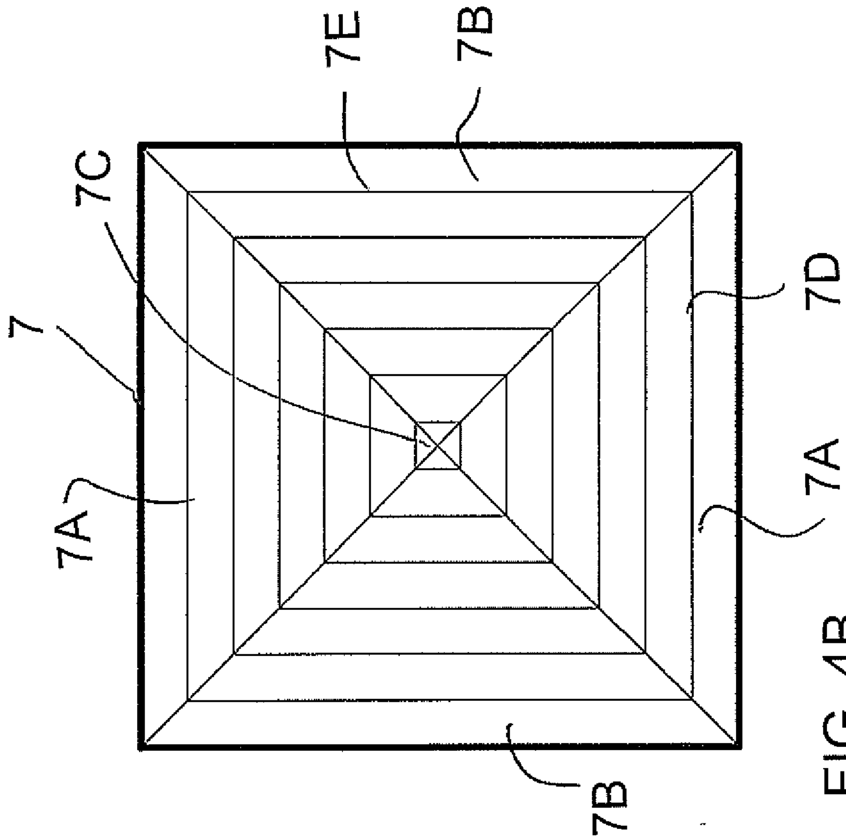


FIG. 4B

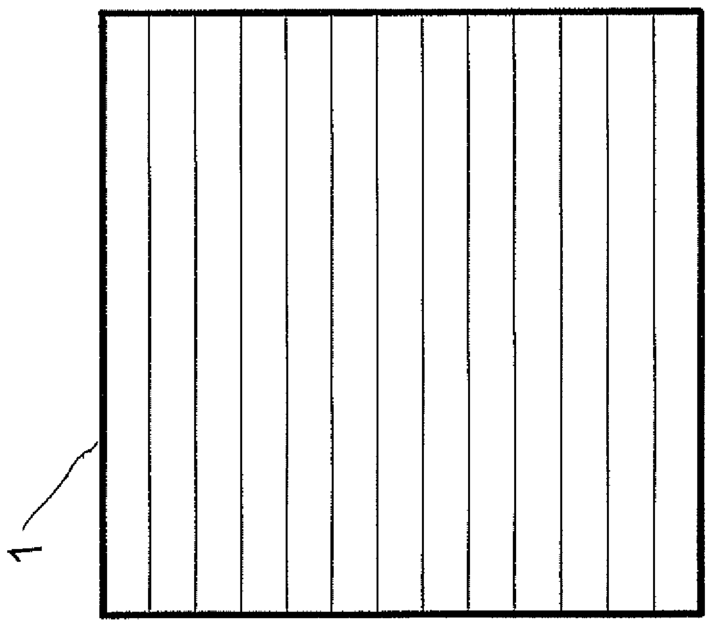


FIG. 4A

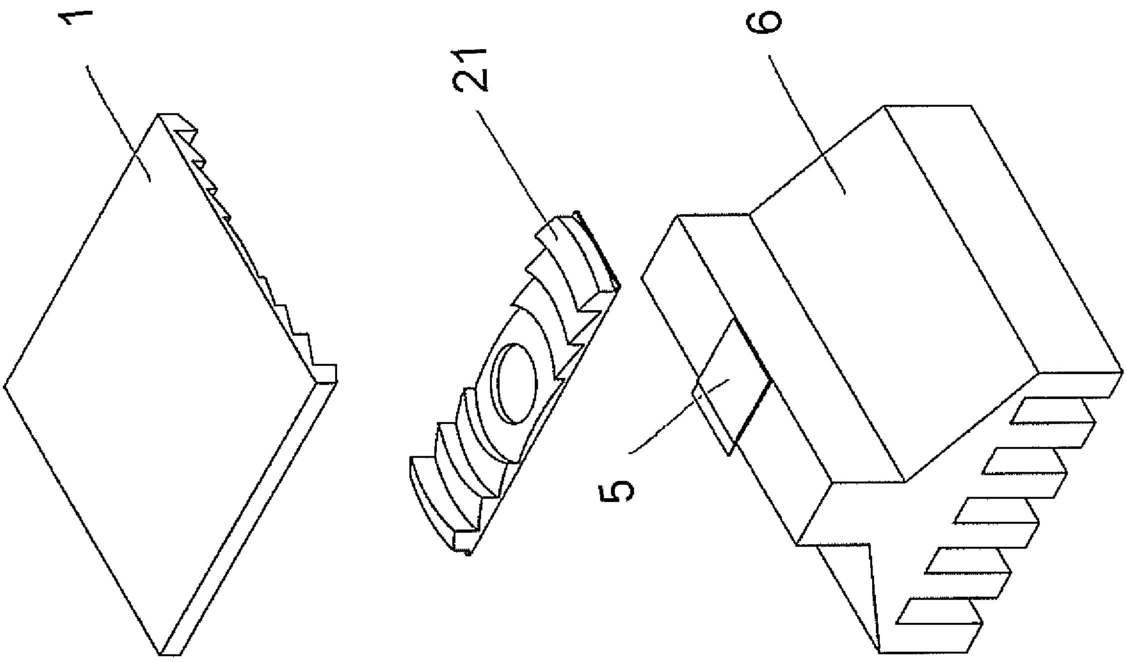


FIG. 5

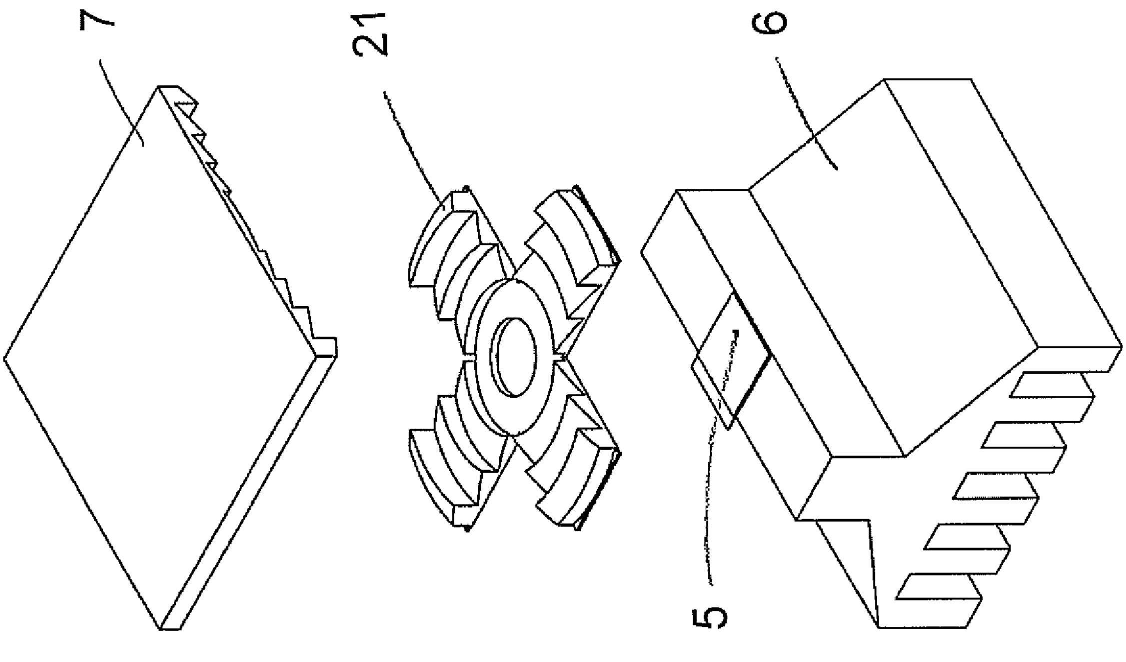


FIG. 6

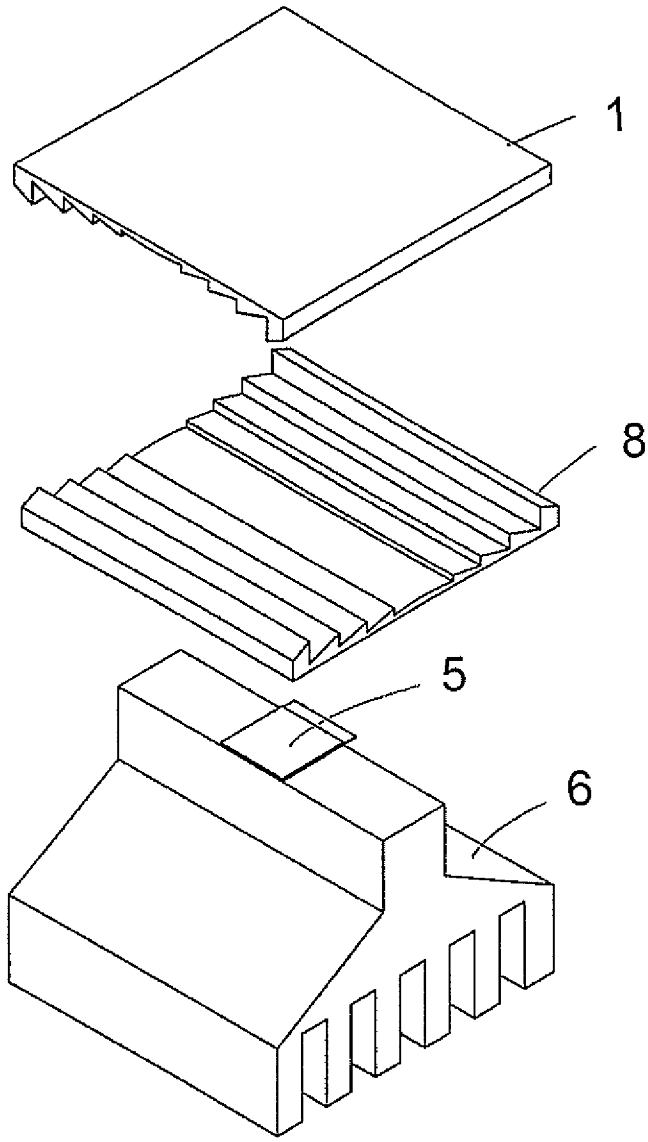


FIG. 7

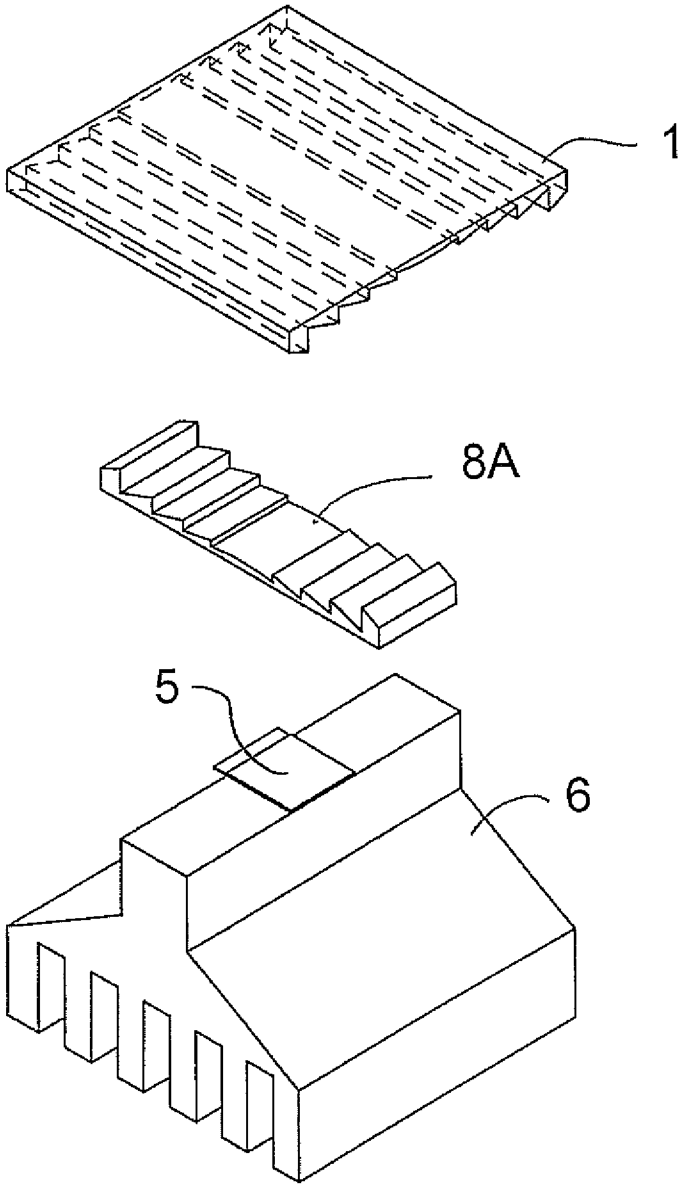


FIG. 8

FIG. 10A

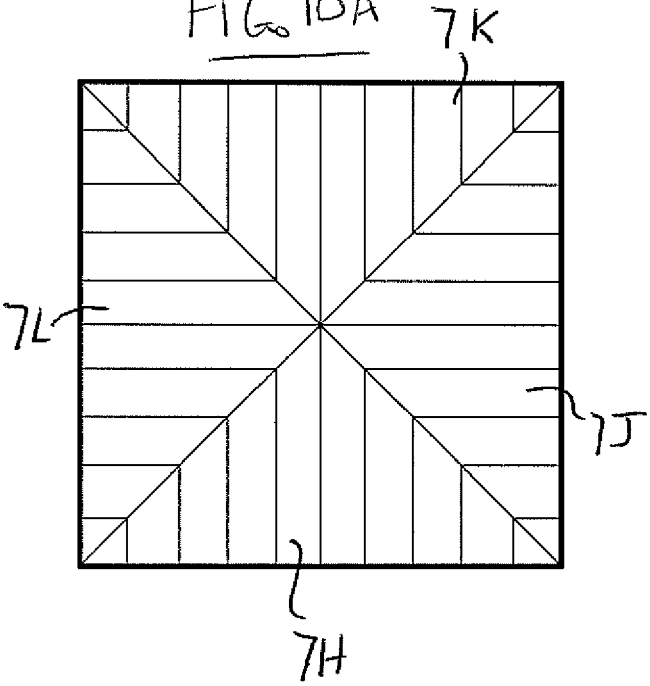


FIG. 10B

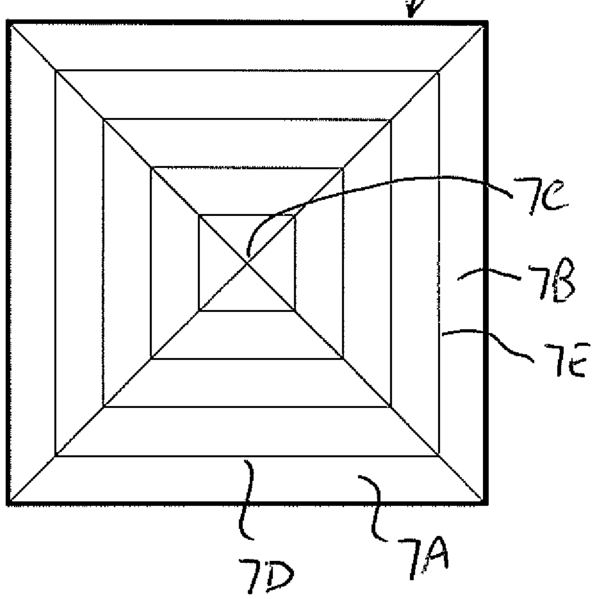


FIG. 9A

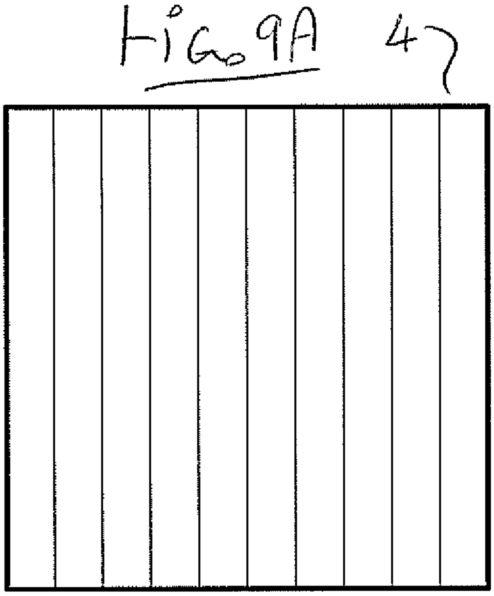
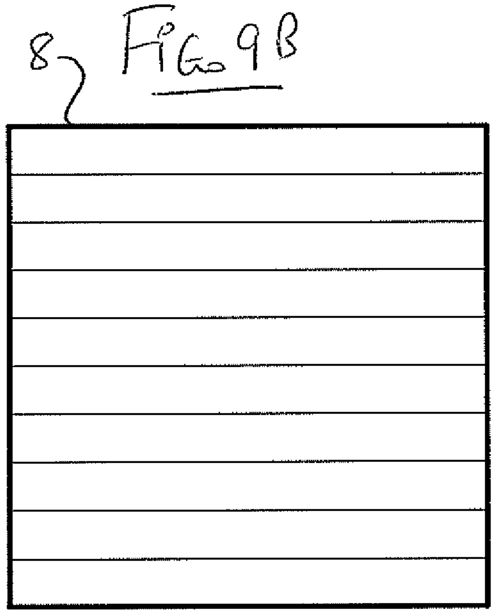


FIG. 9B



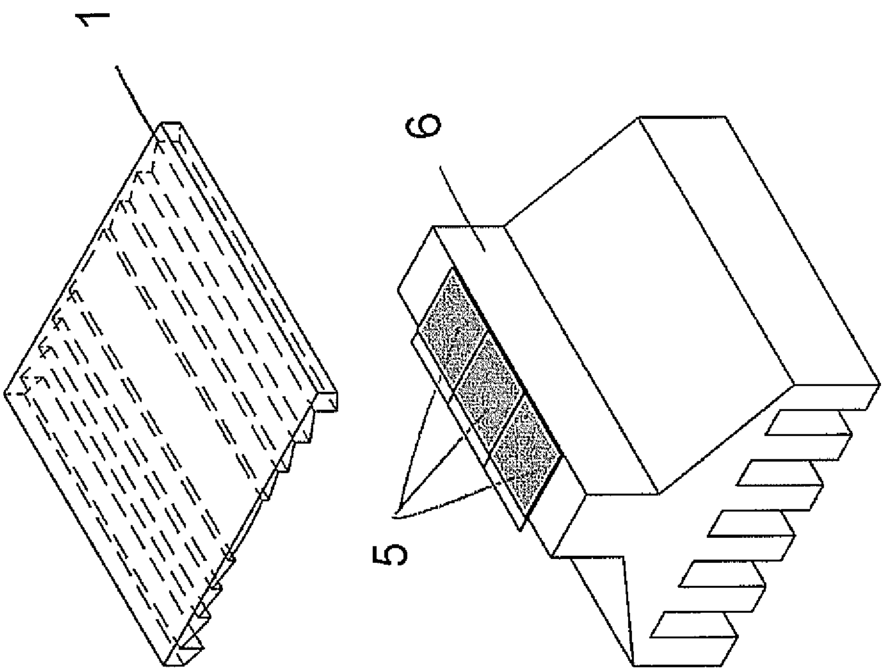


FIG. 11

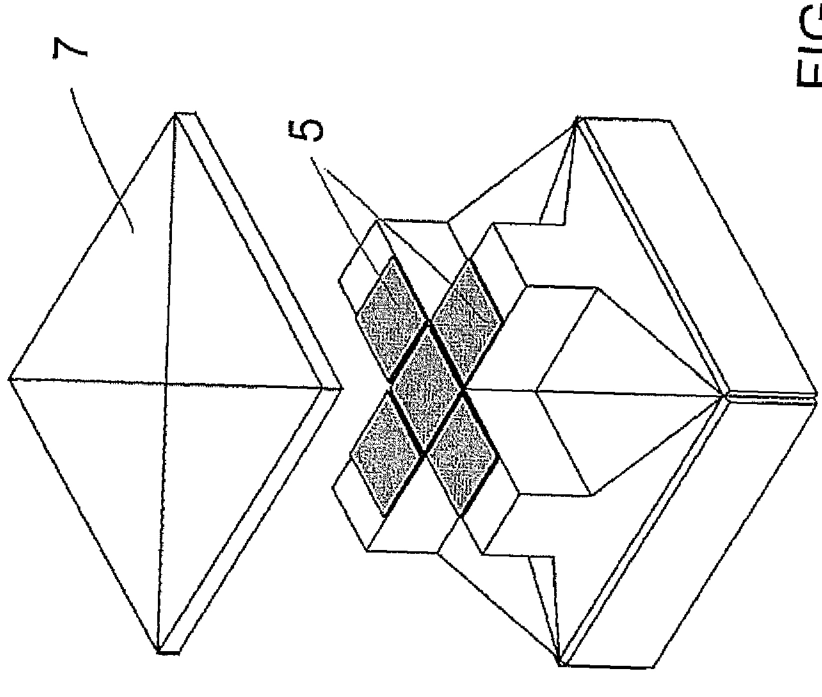


FIG. 12

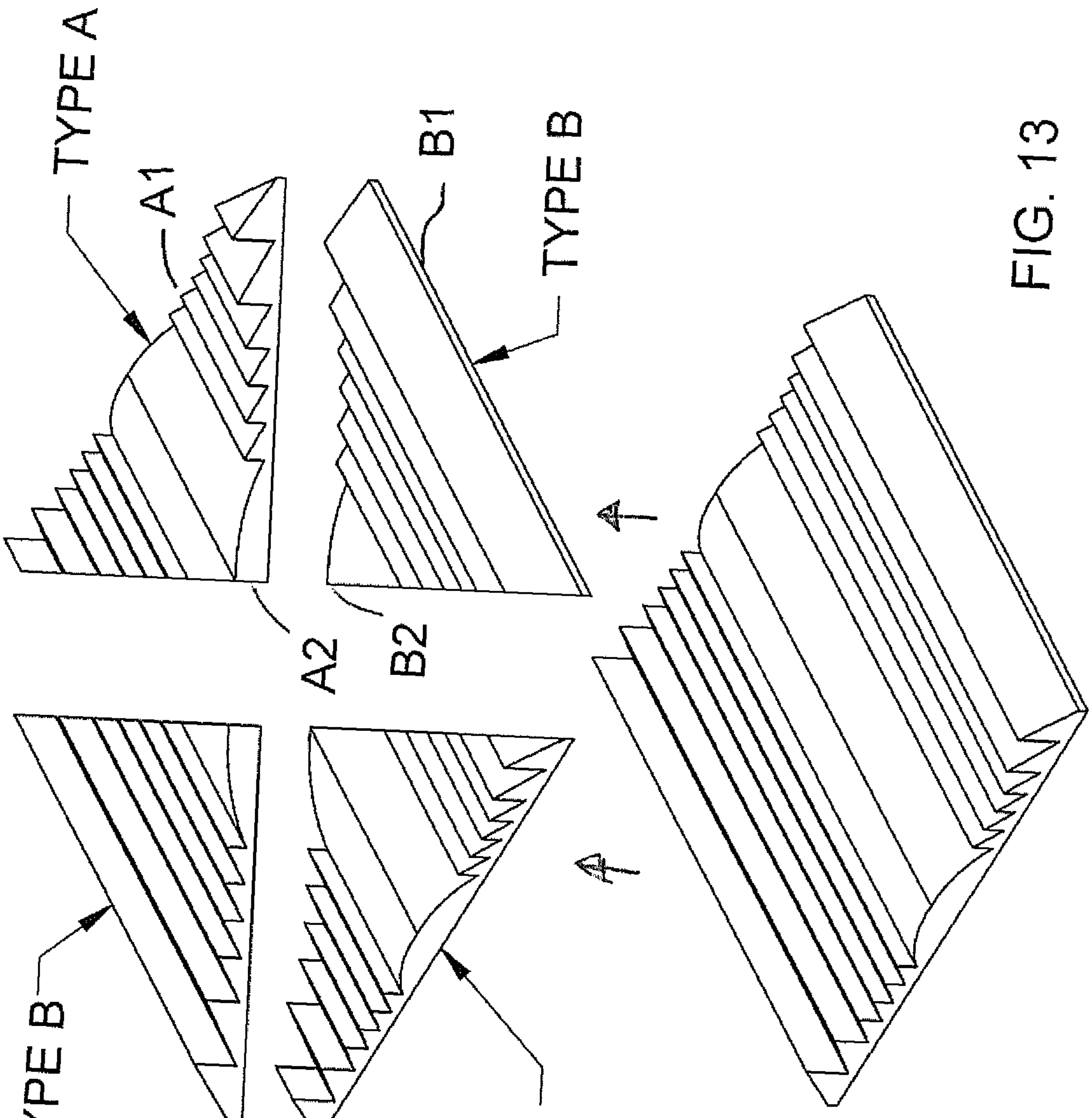


FIG. 13

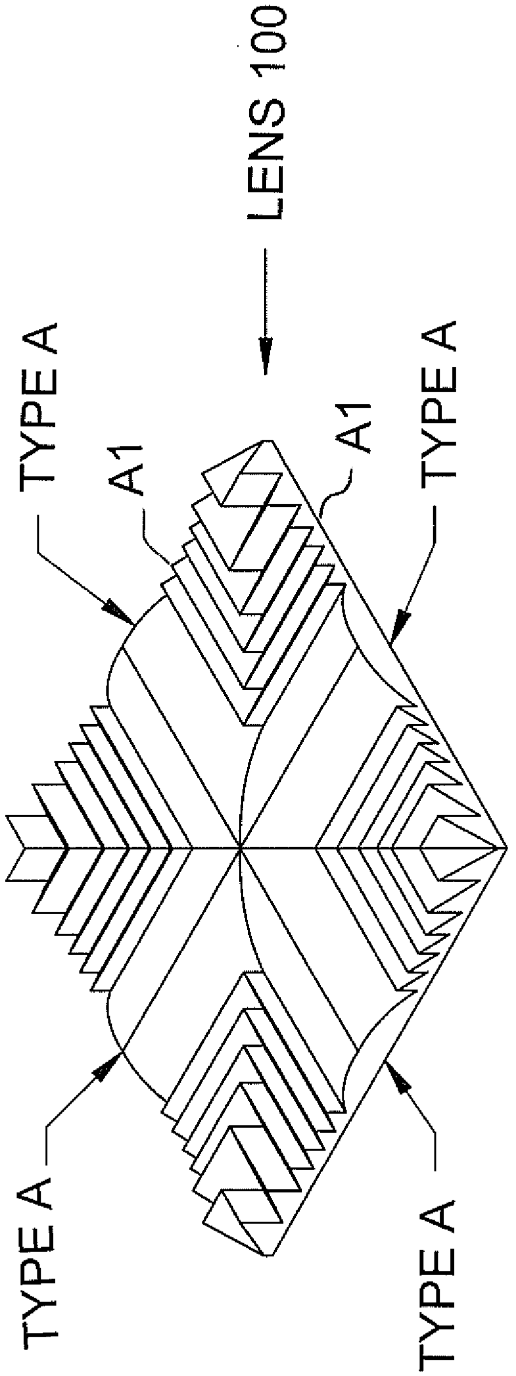


FIG. 14A

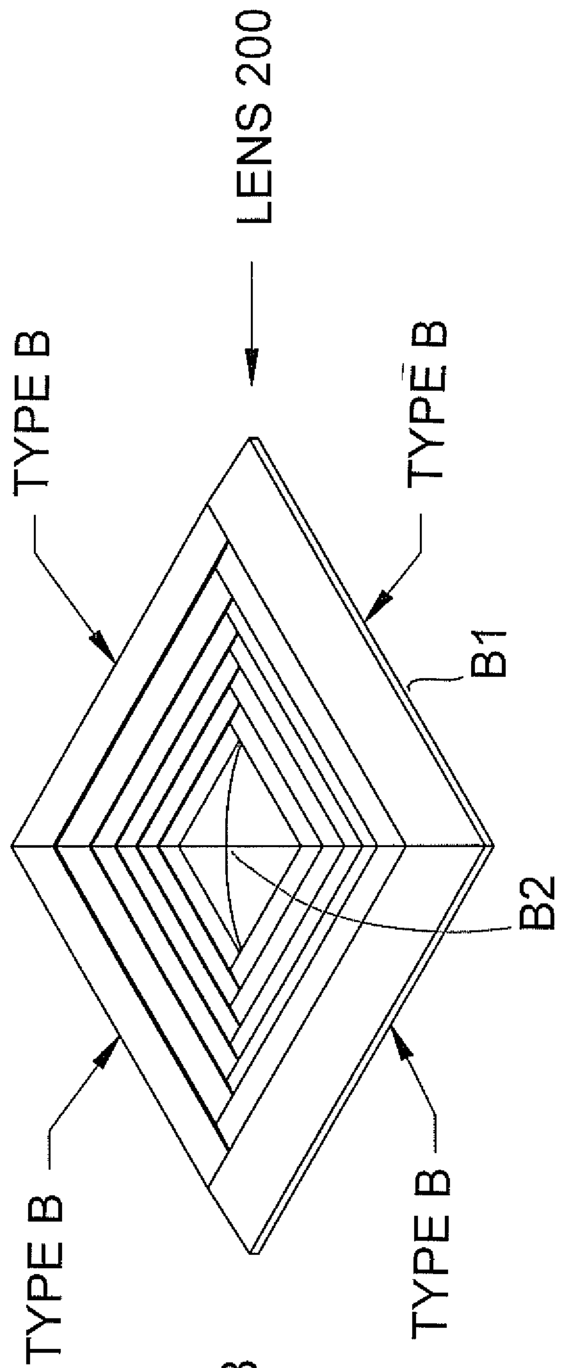


FIG. 14B

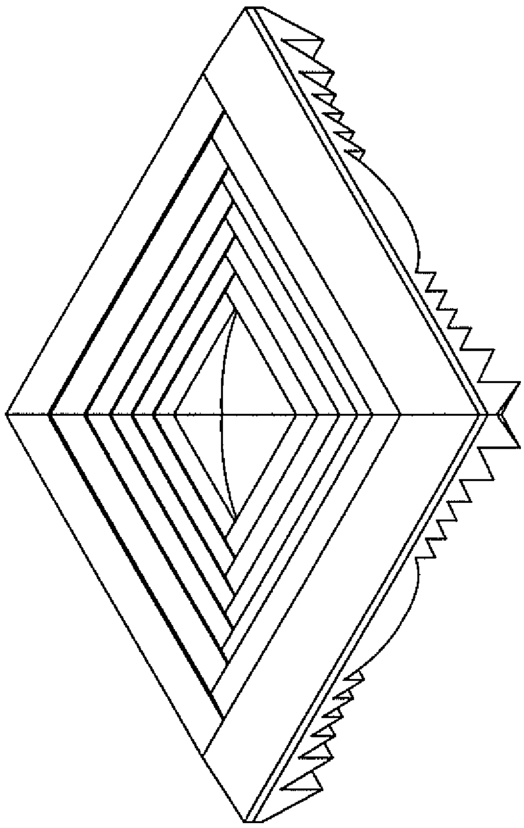


FIG. 15A

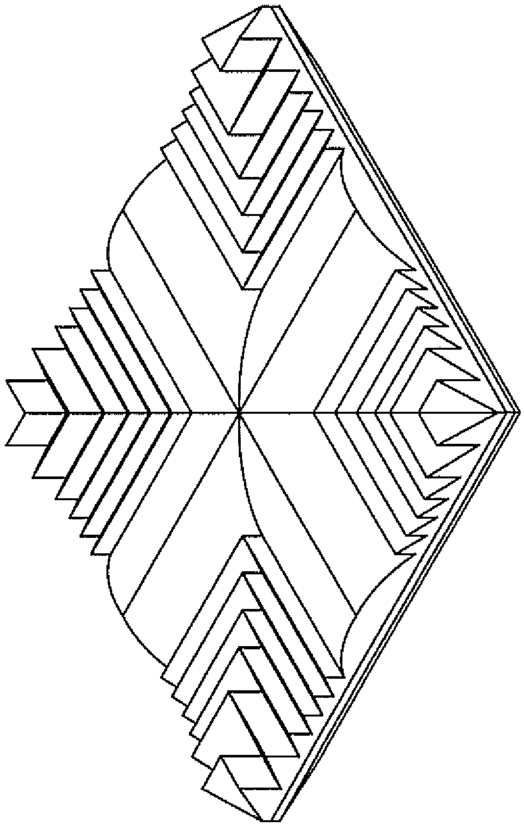


FIG. 15B

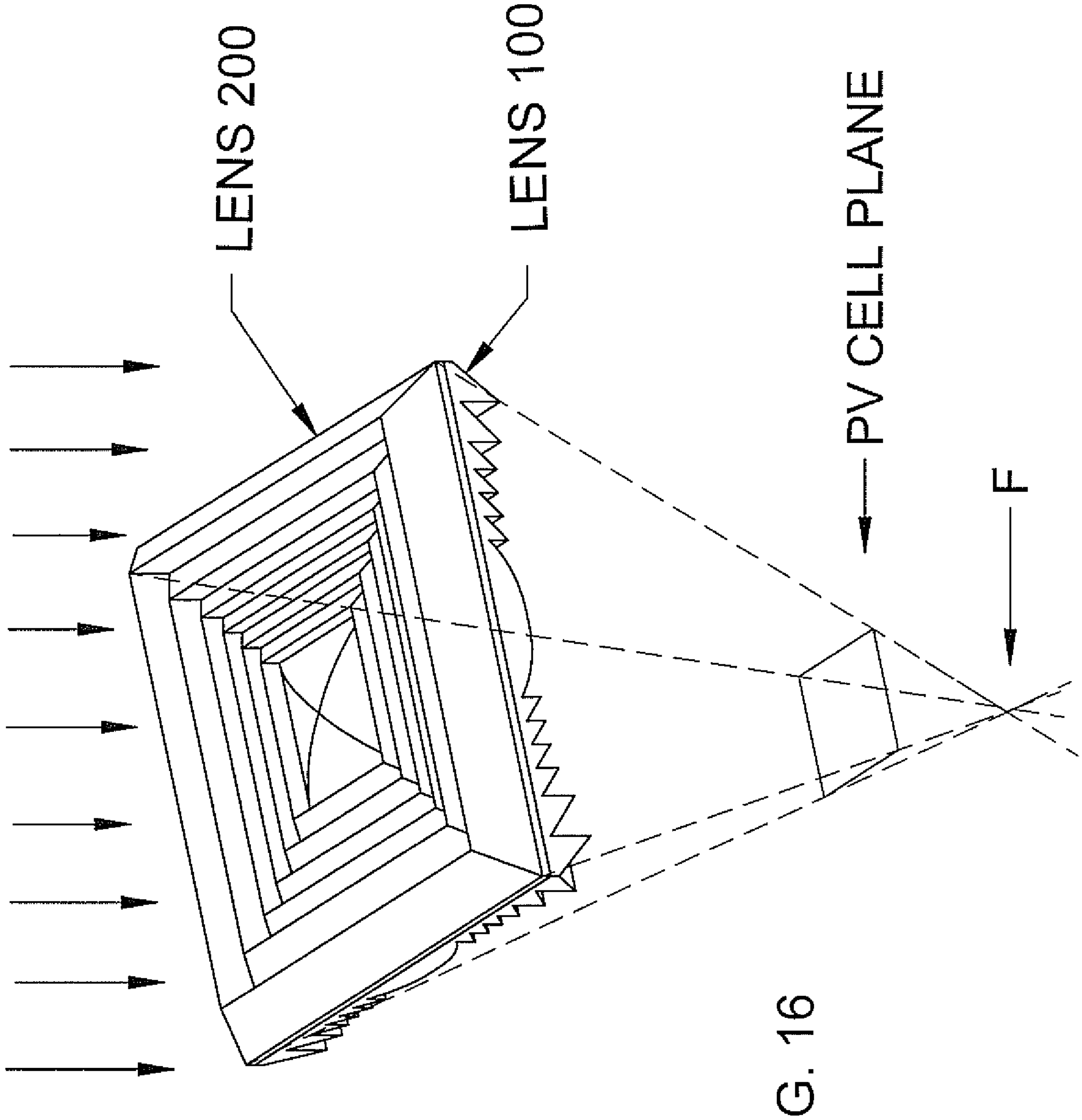


FIG. 16

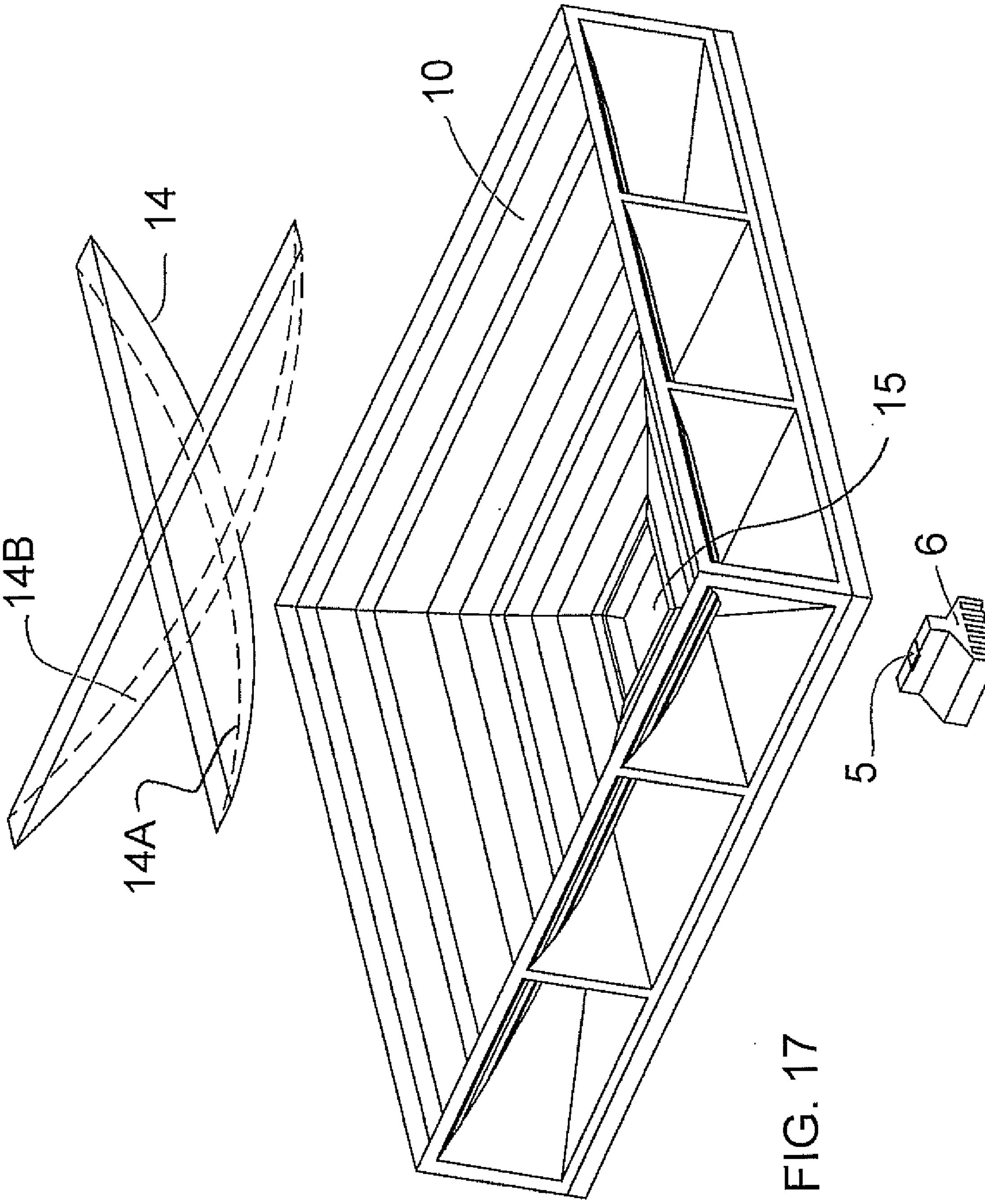


FIG. 17

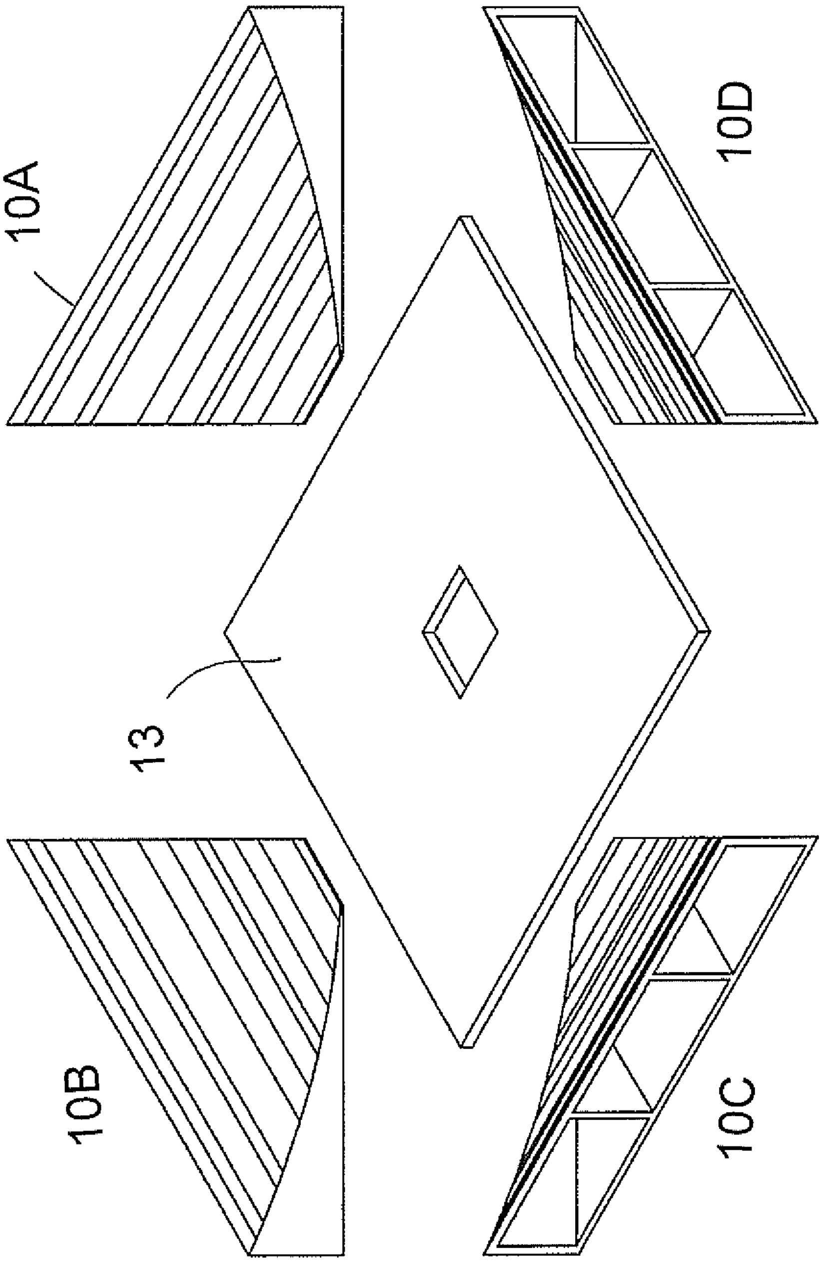


FIG. 18

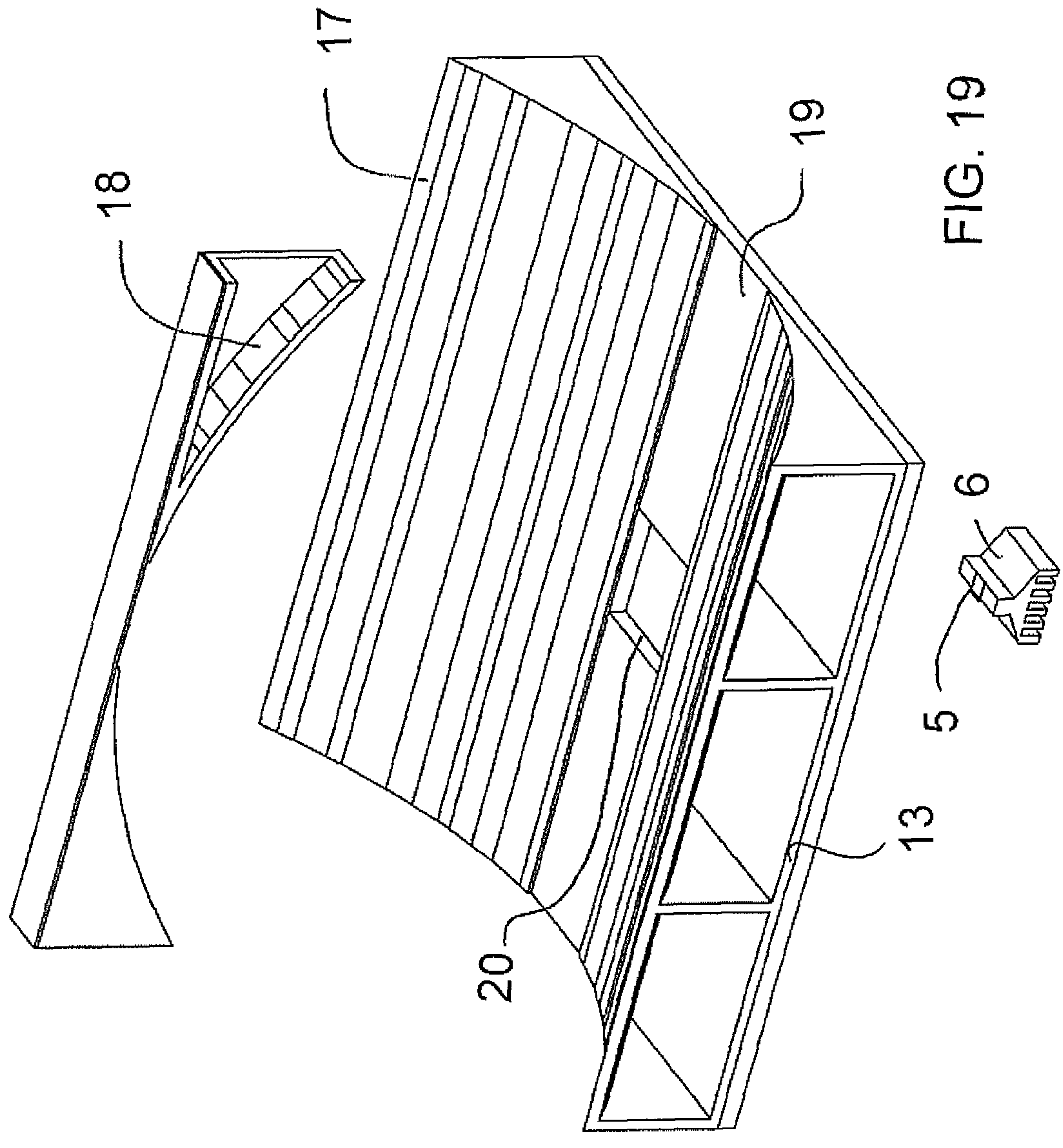


FIG. 19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2009/000424

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***H01L 31/052*** (2006.01) , ***H01L 31/0232*** (2006.01) , ***H01L 31/042*** (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)
IPC: H01L

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Databases: Canadian Patent Database, WEST, Delphion and Espacenet
Search terms used: solar, photovoltaic, cylindrical, Fresnel, primary, secondary, lens, mirror

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,665,174, 9 September 1997, Laing et al. *see figure 2; abstract and column 2, line 45, to column 3, line 22	1-21
X	US 2007/0289622 A1, 20 December 2007, Hecht. *see figure 5; and paragraphs 0027-0032	1-21
P, X	US 2008/0314436 A1, 25 December 2008, O'Connell et al. *see entire document	1-21
A	WO 2008/039509 A2, 3 April 2008, Johnson *see entire document	1-21

[ ] Further documents are listed in the continuation of Box C. [X] 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
"E" earlier application or patent but published on or after the international filing date
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"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	Date of mailing of the international search report
10 June 2009 (10-06-2009)	9 July 2009 (09-07-2009)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Kazem Ziaie 819- 934-2667

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2009/000424

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
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US 2008314436A1	25-12-2008	None	
WO 2008039509A2	03-04-2008	US 2008135096A1	12-06-2008
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		WO 2008039510A1	03-04-2008