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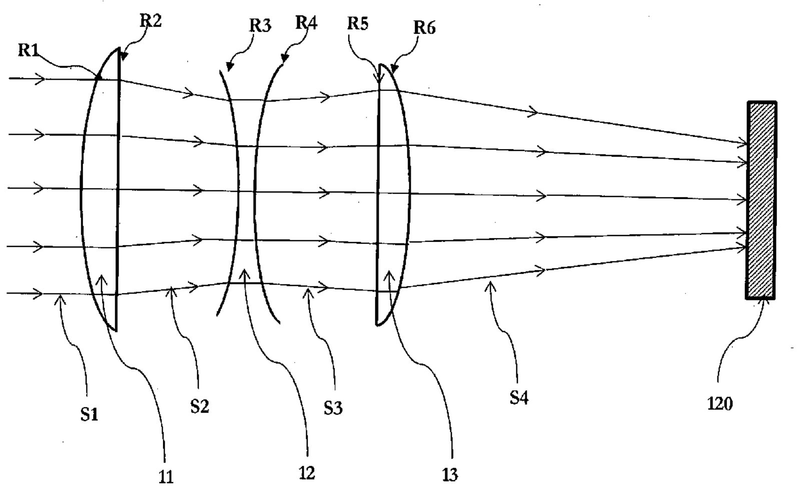

(57) Abstract: A refraction method and a compound lens is disclosed for concentrating solar beam in a non-imaging manner for its heat to be harvested and utilized, for example, for generating electricity with thermo-electric or thermocouple circuit when its hot junction is heated. Solar beam (SI), which may be collected over a wide span of the sun's movement without need for tracking, is first refracted with a first positive refractory element which may preferably be an asperical biconvex lens (11). The exiting, i.e. second solar beam (S2), at a still convergent angle is then refracted by a second negative refractory element which may preferably be a biconcave lens (12). The exiting, i.e. third solar beam (S3), converges upon a third positive refractory element, preferably another aspherical biconvex lens (13), which concentrates the exiting solar beam (S4) onto the predetermined heat collection surface area (120). The sum of all the curvature surfaces of the compound lens times the indices of refraction is about zero such that the field of focus is flat. Preferably, the sum of refractive powers of the first and third aspherical biconvex lenses is substantially counter-bal-anced by the refractive power of the second biconcave lens placed thereinbetween said first and third lenses.

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Compound lens for solar heat collection

TECHNICAL FIELD

[001] This invention generally relates to an apparatus for collecting solar beam, particularly solar heat, for converting to electricity. Specifically, the apparatus uses optical elements such as compound lens for concentrating the solar beam to a heat collecting surface of a thermo-electricity generator.

BACKGROUND ART

[002] Apart from photovoltaic cells which generates electricity from the solar light collected, the other common solar energy device is the thermoelectric generator which produces electricity from solar heat collected using the Seebeck effect. With current thermo-electric generation technology, the use of bismuth telluride Bi_2Te_3 semiconductor *p-n* junctions in between the hot junction and cold junctions of the solid state thermo-electric generator device have been able to achieve efficiencies at about 5 – 10%.

[003] As the small amount of electricity generated is proportionate to the temperature difference between the hot junction and cold junction, i.e. about 1 – 70 μV/°C depending on the metal combination efficiency of the device, at least 4°C of sustained temperature difference should be collected in order for electricity generation to be feasible. Sunlight, as an omnipresent heat source along with its solar spectrum is collected and concentrated onto the surface of the hot junction typically by a concentrating lens. The typical single imaging lens would collect and focusses solar beam onto a focal spot creating a hotspot. As shown in FIGURE 1 (Prior Art), simulation results of focussed light by imaging lens produced hotspot of very high intensity in modelling distribution. Modelling results using aspherical lens and Fresnel lens give almost the same results with presence of hotspots.

[004] Hotspot creates a point of very high temperature on the heat absorbing surface of the hot junction on a prolonged basis, causing degradation of the hot plate or junction material and subsequent reduced heat absorption by the thermal harveting device, ultimately leading to an early functional failure and thus shortening the life of the device. Attempts have been made to collect solar heat by optical elements which endeavour to avoid hotspots while concentrating the solar beam onto the heat collecting surface. Some of these prior art methods are dicussed hereinafter. A 3-piece compound lens is disclosed as an embodiment (Figure 9B) of United States Patent Publication No. **2008/0060696** (Delta Electronics) using a refraction method described and represented (by Figure 3) therein.

[005] Another aspect of solar beam collection is to provide for uniform concentration onto a small static area without much need for accurate tracking the sun as it moves slowly and steadily across the sky. United States Patent Publication No. **20090250094** (Solbeam) and Japanese Patent Publication No. **62-22207** (Dainippon) are examples of such collection systems tolerant of the sun's movement. These prior art methods still suffer the disadvantage of having hot spots. While distribution of focussed light may be allowed to be concentrated on a small reagion out-of-focus by adjusting the hot junction surface to be shorter or longer than the focal distance, the hotspot remains and is merely magnified accordingly.

SUMMARY OF INVENTION

[006] It is therefore desirous to provide for an optical refraction system for concentrating solar beam onto a small area for heat absorption whereby hotspot may be avoid on the absorption surface. It is a further aim to provide for such an optical system which is tolerable to shifting solar beam incidence without requiring constant tracking of the sun to achieve aforesaid concentration. Our invention also strives to such an optical refraction system as a compound lens that is compact enough to be incorporated into an apparatus so that it may collect and concentrate solar beams to a heat-absorbing surface of a hot junction such that heat differential between the hot junction and a cold junction of a thermo-electric device in a configuration that is compact, cost-effective and has longer operational life in

generating a electrical supply. Throughout this patent specification, the term "solar beam", "sunlight" "solar light", etc. are used interchangeably to mean light rays from the sun that includes the solar heat carried therewith.

[007] In one aspect of our invention, a method of concentrating solar beam onto a predetermined surface area is provided in a non-imaging manner comprising converging first solar beam with a first positive refractory medium such that second solar beam emerging therefrom are convergent upon a second negative refractory medium at about the optical axis, the second solar beam incident upon a second negative refractory medium at convergent angle such that third solar beam emerging therefrom continues to be convergent upon a third positive refractory medium, and wherein the third refractory medium converging the third solar beam onto the predetermined surface area.

[008] In one specific embodiment of the method, solar beam is concentrated onto a predetermined surface area in a non-imaging manner, the method comprises the following steps:

[009] (i) refracting first solar beam to converge with a first refractory boundary followed by a second refractory boundary; wherein the first and second refractory boundaries form respective front and back boundaries of a first aspherical biconvex medium; and the first refractory boundary convex curvature is higher than that of second refractory boundary.

[010] (ii) receiving second solar beam exiting the second refractory boundary, the second solar beam being refracted to converge close to the optical axis, upon on a third refractory boundary followed by a fourth refractory boundary, wherein the third refractory boundary and fourth refractory boundary form respective front and back boundaries of a biconcave medium; the third and fourth refractory boundaries continue converging said second solar beam due to second solar beam's convergent angle of incidence.

[011] (iii) refracting third solar beam exiting the fourth refractory boundary, the third solar beam being refracted to converge by a fifth refractory boundary followed

by a sixth refractory boundary; wherein the fifth refractory boundary and sixth refractory boundary form respective front and back boundaries of a second aspherical biconvex medium; wherein the fifth refractory boundary convex curvature is lower than that of sixth refractory boundary; and wherein the fourth solar beam exiting said sixth refractory boundary is converged upon the predetermined surface area.

[012] In a second aspect of our invention, solar beam-concentrating compound lens is disclosed, comprising a plurality of optical elements having multiple curvature surfaces including at least of the following in series:

- a first positive lens comprising an aspherical biconvex lens having a higher convex curvature surface provided in front than the curvature at the back;
- a second negative lens comprising a biconcave lens; and
- a third positive lens comprising an aspherical biconvex lens having a lower convex curvature surface in front than the curvature at the back

wherein said compound lens so constituted is capable of converging solar beam and heat onto a predetermined surface area of a thermal collector in a non-imaging manner. In this specification, the term "aspherical biconvex" lens is to be understood to include more specific optical equivalents such as "plano-convex" lens to achieve the equivalent refractory functions.

[013] One preferred embodiment of the compound lens is to provide the first lens to refract incident solar beam from various angles as well as collimating sunlight to converge onto the second lens close to the optical axis, such that the sun beam exiting the first lens and striking the second biconcave lens close to optical axis is refracted by the second biconcave lens to converge further. More preferably, the light exiting said second biconcave lens is refracted by the third lens to converge in about uniform intensity upon the heat absorption surface.

[014] In a third aspect, the sum of all the curvature surfaces of the compound lens times the indices of refraction is about zero such that the field of focus is flat. Preferably, the sum of refractive powers of the first and third aspherical biconvex lenses is substantially counter-balanced by the refractive power of the second biconcave lens placed thereinbetween said first and third lenses. More preferably,

the light-incident surfaces (14, 15, 16) of each of the lenses is coated with anti-reflective coatings.

[015] In a fourth aspect, the compound lenses' refractive index is less than 1.645, preferably made of typical glass having refractive index of 1.62. A specific embodiment in this aspect provides for the first lens's front, i.e. light-incident, surface to have a curvature radius of about 22 and a rear i.e. light-exiting surface to have a curvature radius about of minus 436, and lens thickness of about 3.26 mm. Preferably, a gap is provided between the first lens and second lens is about 6 mm. The second lens's front i.e. light-incident surface may have a curvature radius of about minus 22.4 and a rear i.e. light-exiting surface may have a curvature radius of about 20.5, and lens thickness of about 1 mm. A gap between the second lens and the third lens of about 4.75 mm may be provided. The third lens's front i.e. light-incidenet surface may have a curvature radius of about 80 and a rear i.e. light-exiting surface (R6) may have a curvature radius of about minus 19, and thickness of about 2.95 mm.

[016] A more specific and preferred embodiment of our compound lens provides for the first lens's front, light-incident surface curvature radius to be 22.0 and the rear, light-exiting surface to have a curvature radius of about minus 436.0 and lens thickness of about 3.26 mm. The second lens's front, light-incident surface is provided with a curvature radius of about minus 22.43 and a rear, light-exiting surface with a curvature radius of about 20.56. The third lens's front, light-incident surface has a curvature radius of 80.12 and the rear, light-exiting surface has a curvature radius of about minus 19.1.

[017] In a fifth aspect, the stacked length of the three lenses comprising the compound lens is less than one-tenth of the sum of the lenses' focal lengths. Our proposed compound lens may be employed in a thermal-electricity generating device to concentrate solar beam and heat onto the thermoelectric circuit's hot junction. A plurality of such devices, e.g. thermocouples, may be electrically connected as a thermopile so that the electricity generated is feasible.

LIST OF ACCOMPANYING DRAWINGS

[018] The drawings accompanying this specification as listed below may provide a better understanding of our invention and its advantages when referred in conjunction with the detailed description that follows hereinafter. They should however be taken as exemplary and non-limiting embodiments of the invention.

[019] FIGURE 1 (Prior Art) comprises Fig. 1(a) showing a normal aspherical biconvex lens' refraction pattern, Fig. 1(b) showing heat intensity spectrum and Fig. 1(c) showing heat intensity graph with presence of hotspot.

[020] FIGURE 2 illustrates a general schematic drawing of a solar light and/or heat collecting device with electricity-generating means incorporating a compound lens according to our present invention.

[021] FIGURE 3 shows a schematic drawing of the stages of refraction of solar beam across refractory boundaries according to our invention.

[022] FIGURE 4 embodies two disassembled views – Fig. 3(a) and Fig. 3(b) – of the optical elements forming the compound lens according to one embodiment of our invention.

[023] FIGURE 5 exemplifies the simulated refraction pattern of a compound lens embodiment according to our invention.

[024] FIGURE 6 comprises Fig. 6(a) showing simulated heat intensity spectrum and Fig. 6(b) showing heat intensity graph without hotspot.

DETAILED DESCRIPTION OF SPECIFIC AND PREFERRED EMBODIMENTS

[025] An exemplary device implementing the teachings of our invention is shown in FIGURE 2 in form of a general schematic drawing wherein solar light and/or

heat is collected for electricity-generation. The device generally employs the Seebeck principle such as that used in a thermoelectric circuit for direct conversion to electricity from a temperature gradient between the hot (130) and cold (160) junctions. As previously mentioned, a threshold of 4°C temperature gradient is required for electricity generation to be feasible because only a very small amount of potential difference, i.e. up to only 70 μV is produced for each °C of temperature difference between the hot junction (130) and cold junction (160), depending on the metal type used for the p-type element (140) and n-type element (150). The p-type and n-type pairing of elements may be chosen based on specific range of temperature range and sensitivity needed.

[026] For example, a E-type thermcouple is made from chromel (90% nickel and 10% chromium) and constantan (45% nicket and 55% copper) gives a high output of 68 μV/°C even in cryogenic environment compare to the earlier and more common K-type thermocouple's chromel-alumel (95% nickel-2% manganese, 2% aluminium and 1% silicon) pairing providing a sensitivity of about 41 μV/°C over a temperature range of -200°C – 1350°C. The cold junction's (160) p-type end (140) and n-type end (150) may be electrically connected to a load to be electrically driven directly or to an electrical energy storage means such as a rechargeable battery for later or bufferred use.

[027] Therefore, it would be advantageous for as much heat as possible to be collected at the hot junction (130) so that the temperature difference is maximised. A thermal collector layer (120) (also known and labelled "thermal absorber" in FIG. 2) may be advantageously provided atop the hot junction (130) to aid in heat absorption (i.e. non-reflective) and retention as well as for conduction to the hot junction. The thermal absorber (120) may also protect the hot junction from metal surface degradation due to excess heat. The term "**hot junction**" is to be understood throughout this specification as including such thermal collector layer as an alternative embodiment because ultimately the heat has to be delivered to the hot junction with or without such an optional layer. To aid conductivity and minimise air gaps between the thermal absorber (120) and the hot junction (130), thermal paste may be used to thermally adhere the two together.

[028] A salient feature of our invention is therefore collecting and concentrating solar beam onto this hot junction (130) by optical means which endeavours to avoid hotspot. Broadly speaking, this is achievable by concentrating solar beam onto a predetermined surface area which in the embodiment shown in FIG. 2 is equivalent to the thermal absorber (120). The collection and concentration method is achievable in a non-imaging manner comprising converging first solar beam (S1) with a first positive refractory medium such that second solar beam (S2) emerging therefrom are convergent upon a second negative refractory medium at about the optical axis. The emerging second solar beam (S2) would then incident upon a second negative refractory medium at convergent angle such that third solar beam (S3) emerging therefrom continues to be convergent upon a third positive refractory medium. The third refractory medium would then refract to converge the third solar beam (S3) onto the predetermined surface area which is the thermal absorber (120).

[029] In particular, with reference to FIGURE 3, our refraction method of concentrating solar beam onto a predetermined surface area, i.e. a thermal absorber (120), may be achieved in a non-imaging manner with the following steps or stages of refraction:

[030] (i) the first solar beam (S1) may be refracted to converged by a first refractory boundary (R1) followed by a second refractory boundary (R2). It may be noted that the first (R1) and second (R2) refractory boundaries form the respective front and back boundaries of a first aspherical biconvex medium whereby the first refractory boundary (R1) convex curvature is higher than that of second refractory boundary (R2).

[031] (ii) The second solar beam (S2), which is the solar beam exiting the second refractory boundary (R2), is then refracted to converge close to the optical axis and to fall upon on a third refractory boundary (R3) followed by a fourth refractory boundary (R4). It may be noted that the third refractory boundary (R3) and fourth refractory boundary (R4) form the respective front and back boundaries of a biconcave medium. In effect, the third (R3) and fourth (R4) refractory boundaries continue to converge the second solar beam (S2) due to second solar

beam (S2)'s convergent angle of incidence.

[032] (iii) The third solar beam (S3) exiting said fourth refractory boundary (R4) is then refracted to converge by a fifth refractory boundary (R5) followed by a sixth refractory boundary (R6). It may be noted that the fifth refractory boundary (R5) and sixth refractory boundary (R6) form respective front and back boundaries of a second aspherical biconvex medium and that the fifth refractory boundary (R5) convex curvature is lower than that of the sixth refractory boundary (R6). As a result, the fourth solar beam (S4) exiting said sixth refractory boundary (R6) is converged upon the predetermined surface area, i.e. the thermal absorber (120).

[033] To achieve the aforesaid method, we now propose a compound lens which configuration comprises of a plurality of optical elements. In one preferred embodiment as shown in FIGURE 4 comprising FIG 4(a) and FIG. 4(b), the plurality of optical elements comprises of 3 different lenses (11, 12, 13) to provide for multiple curvature surfaces corresponding to the above-described method's refractory boundaries (R1 – R6). The first lens is a positive lens (11) preferably comprising an aspherical biconvex lens which has a higher convex curvature surface provided in front than the curvature at the back. The second lens is a negative lens (12), preferably comprising a biconcave lens, while the third lens is a positive lens (13), preferably comprising an aspherical biconvex lens having a lower convex curvature surface in front than the curvature at the back. In brief, the compound lens (10) so constituted is capable of converging solar beam and heat onto a predetermined surface area of a thermal collector in a non-imaging manner.

[034] The first positive lens (11) is directly exposed to solar light (S1) and is therefore in a position to refract solar beam incident at various angles, as well as collimated solar beam, so that they all converge onto the second lens' front surface (R3) as close to the optical axis as possible. As such, it has wide tolerance to solar movement which would vary the angle of incidence on its front surface R1 during the day without the need for constant and precise tracking of the sun although this does not necessarily replaces the advantages of having a sun tracker.

[035] After being refracted by the first lens' (11) front (R1) and back (R2)

surfaces to become convergent, the exiting refracted solar beam (S2) falls upon the second lens (12) which is a negative lens, typically provided in form of a biconcave lens. Preferably, the refracted solar beam (S2) strikes this second biconcave lens (12) close to the optical axis. The still divergent solar beam (S2) falling upon the second lens (12) means that the solar beam would then be refracted to converge further (rather than diverged as would ordinary collimating light falling on a negative lens be).

[036] The refracted solar beam (S3) exiting the second lens (12) will now be refracted by the third lens whereby the refracted beam exits as solar beam (S4) which is convergent in about a uniform intensity upon the heat absorption surface, which is embodied as thermal absorber (120). The uniform intensity received upon the heat absorption surface (120) means that there is a lack of hotspot as illustrated in FIGURE 5 in form of a simulated refraction pattern of a compound lens embodiment according to our invention. The lack of hotspot is also shown in FIGURE 6 wherein Fig. 6(a) shows a simulated heat intensity spectrum and Fig. 6(b) shows heat intensity graph. Note that the multiple "warm spots" appearing on the heat spectrograph is due to the use of limited numbers of ray beams laid down in FIG. 5 in the simulation calculation; otherwise the heat distribution would be uniform.

[037] In optics, the distribution of light beams passing through an optical system is equal to the sum of all the optical surface curvatures in the system and refractive indices before and after the surface as provided in the following equation

$$D = \sum_{1}^{n} f(R, n_i, n_{i+1})$$

wherein R is the curvature of the surface.

[038] One notable feature of an embodiment of our compound lens' profile or configuration is that the sum of all the curvature surfaces (R1 – R6) of each of the optical elements times the indices of refraction is about zero and, as such. the field of focus is flat. In other words, the negative lens should be as strong as the outer

two combined to achieve zero value. Based on the aforedescribed curvatures of the optical elements comprising the compound lens, another notable feature is that the sum of refractive powers of the first and third aspherical biconvex lenses is substantially counter-balanced by the refractive power of the second biconcave lens placed thereinbetween said first and third lenses. Yet another notable feature of an embodiment of our compound lens is that the stacked length of the three lenses is less than one-tenth of the sum of the lenses' focal lengths.

[039] The rules of light ray tracing follow the result of lens combination. If two lenses are mounted one after the other, then the output, i.e. image, formed by the first lens becomes the object for the second lens. Thus, one can apply the thin lens equation twice to find the output formation by an optical system comprising two thin lenses, where the effective focal length may be calculated from the equation below:

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$$

Optical system which comprises of two positive focal length lenses that are separated by the sum of the focal lengths will produce object rays from infinity (e.g. sun rays), which enter parallel to the optical axis of the internal optics and exit parallel thereto as well, thus providing uniform ray distribution. This essentially means that there is no focal length to the entire system.

[040] However, this arrangement gives sizeable air gap in the optical system. As mentioned above, off-axis rays will focus at different locations, thus creating non-uniformity at the hot junction. The second lens which is a biconcave lens, is purposely placed in the middle about halfway between outer lenses, thus maintaining symmetry and creating flat focus field. With such optical design, the compunded lens thickness is therefore less than one-tenth ($1/10^{th}$) of the total focal lens. The other consideration is to reduce the air gap to make the optical system and overall thermal energy harvester more compact.

[041] To minimise loss of solar beam reflected off the light-incident, i.e. front, surfaces of the 3 lenses, these 3 surfaces may be advantageously coated with anti-

reflective coatings so that the transmission of solar beams through the lenses is maximised. Some of the aforedescribed features may be better understood with the following examples of compound lens constructed or simulated.

Example 1

[042] Based on a glass medium having a refractive index of 1.62, the following parameters of each of the 3 lenses comprising the compound lens may be tabulated below. Note that the gap (G) refers to the space between the respective adjoining lenses.

[043] Table 1
Parameters of lenses with glass medium having refractory index, $n = 1.62$

Surface	Radius of curvature	Thickness or gap (mm)
R1	22	T1 = 3.26
R2	–436	G1 = 6
R3	22.4	T2 = 1
R4	20.5	G2 = 4.75
R5	80	T3 = 2.95
R6	–19	

[044] The compound lens constructed with the above optical elements and parameters have been found to concentrate light on the thermal absorber (120) effectively in a uniform manner without any hotspot.

Example 2

[045] Based on a glass medium having a refractive index of not more than 1.645, each of the 3 lenses have been provided with the following parameters to constitute the compound lens. These parameters, which are more precise than the preceding example, may be tabulated below wherein the gap (G) refers to the space between the respective adjoining lenses.

[046] Table 2
Parameters of lenses with glass medium having refractory index, $n \leq 1.645$

Surface	Radius of curvature	Thickness or gap (mm)
R1	22.0	T1 = 3.26
R2	–436.0	G1 = 6
R3	22.43	T2 = 1
R4	20.56	G2 = 4.75
R5	80.12	T3 = 2.95
R6	–19.1	

[047] The compound lens configured with the above optical elements and afore-tabulated parameters may be taken as a most preferred embodiment which we have found to concentrate light on the thermal absorber (120) uniformly without formation of hotspot.

Example 3

[048] It is to be noted that different dimensions of the hot plate would require different compound lens configuration to get uniform collection and distribution onto the pre-determined collection area. Another configuration of the compound lens to provide heat output to a smaller dimension than the above examples may be disclosed hereinafter wherein each of the 3 lenses has the following parameters tabulated below:

[049] Table 3
Parameters of lenses with glass medium having refractory index, $n \leq 1.645$

Surface	Radius of curvature	Thickness or gap (mm)
R1	23.0	T1 = 3.26
R2	–435	G1 = 4
R3	–22.7	T2 = 1
R4	20.3	G2 = 2.75
R5	79.7	T3 = 3.75
R6	–15.4	

INDUSTRIAL APPLICABILITY

[050] Our proposed compound lens may be employed in many devices and apparatuses requiring solar beam to be collected and concentrated upon an area for heat or light applications in a non-imaging manner. Apart from the afore-described implementation in thermo-electric generation using, for instance a thermocouple circuit, it is also envisageable that a plurality of such devices or thermocouple circuits may be electrically connected in series to become a thermopile to generate electricity supply. Of course, it would also be obvious to adapt our compound lens configuration to a linear, semi-cylindrical manner, for example, to heat a tube of flowing water (or other fluids) in a heater or boiler. Similarly, our present invention may also be adapted as an apparatus to provide a concentrated but uniform solar lighting for indoor purposes.

[051] Apart from the aforedescribed embodiments of our compound lens configuration, methods of refraction and implementation in devices and apparatuses, many aspects, parts or components of our invention which may be presented in other forms, variations, substitution or modifications, particularly in respect of the refraction method, refractory boundaries, refractory medium and indices. Additionally, the profile of each of the lenses comprising our compound lens may also be modified or varied to achieve aforedescribed method or principle of refraction, once understood by a skilled person, so that the end result of the concentrated solar beam on the thermal collector area is uniform and does not produce hotspot. Such suitable variations, alternates, analogs or equivalents are to be considered as falling within the letter and scope of the following claims.

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CLAIMS

What is claimed is:

1. A solar beam-concentrating compound lens (100) comprising a plurality of optical elements (11, 12, 13) having multiple curvature surfaces including at least of the following in series:

- a first positive lens (11) comprising an aspherical biconvex lens having a higher convex curvature surface provided in front than the curvature at the back;
- a second negative lens (12) comprising a biconcave lens; and
- a third positive lens (13) comprising an aspherical biconvex lens having a lower convex curvature surface in front than the curvature at the back

wherein said compound lens (10) so constituted is capable of converging solar beam and heat onto a predetermined surface area of a thermal collector in a non-imaging manner.

2. A solar beam-concentrating compound lens according to Claim 1 wherein said first lens (11) refracts incident solar beam from various angles as well as collimating sunlight to converge onto the second lens (12) close to the optical axis.

3. A solar beam-concentrating compound lens according to Claim 2 wherein sun beam (S2) exiting said first lens (11) and striking the second biconcave lens (12) close to optical axis is further refracted by said second biconcave lens (12) to converge.

4. A solar beam-concentrating compound lens according to Claim 3 wherein light exiting said second biconcave lens (12) is refracted by said third lens (13) to converge in about uniform intensity upon the heat absorption surface.

5. A solar beam-concentrating compound lens according to Claim 1 wherein the sum of all the curvature surfaces of the compound lens times the indices of refraction is about zero such that the field of focus is flat.

6. A solar beam-concentrating compound lens according to Claim 1 wherein

the sum of refractive powers of the first and third aspherical biconvex lenses is substantially counter-balanced by the refractive power of the second biconcave lens placed thereinbetween said first and third lenses.

7. A solar beam-concentrating compound lens according to Claim 1 wherein the light-incident surfaces (14, 15, 16) of each of the lenses is coated with anti-reflective coatings.

8. A solar beam-concentrating compound lens according to Claim 1 wherein the lenses' refractive index is less than 1.645, preferably made of typical glass having refractive index of 1.62.

9. A solar beam-concentrating compound lens according to Claim 8 wherein the first lens (11)'s front, i.e. light-incident, surface (R1) has a curvature radius of about 22 and a rear i.e. light-exiting surface (R2) has a curvature radius about of minus 436, and lens thickness (T1) of about 3.26 mm.

10. A solar beam-concentrating compound lens according to Claim 8 wherein a gap (G1) between the first lens (11) and second lens (12) is about 6 mm.

11. A solar beam-concentrating compound lens according to Claim 8 wherein the second lens (12)'s front i.e. light-incident surface (R3) has a curvature radius of about minus 22.4 and a rear i.e. light-exiting surface (R4) has a curvature radius of about 20.5, and lens thickness (T2) of about 1 mm.

12. A solar beam-concentrating compound lens according to Claim 8 wherein a gap (G2) between the second lens (12) and the third lens (13) is about 4.75 mm.

13. A solar beam-concentrating compound lens according to Claim 8 wherein the third lens (13)'s front i.e. light-incidenet surface (R5) has a curvature radius of about 80 and a rear i.e. light-exiting surface (R6) has a curvature radius of about minus 19, and thickness of about 2.95 mm.

14. A solar beam-concentrating compound lens according to Claim 8 wherein

the first lens (11)'s front, light-incident surface (R1) curvature radius is 22.0 and the rear, light-exiting surface (R2) has a curvature radius of about minus 436.0 and lens thickness (T1) of about 3.26 mm.

15. A solar beam-concentrating compound lens according to Claim 11 wherein the second lens (12)'s front, light-incident surface (R3) has a curvature radius of about minus 22.43 and a rear, light-exiting surface (R4) has a curvature radius of about 20.56.

16. A solar beam-concentrating compound lens according to Claim 11 wherein the third lens (13)'s front, light-incident surface (R5) has a curvature radius of 80.12 and the rear, light-exiting surface (R6) has a curvature radius of about minus 19.1.

17. A solar beam-concentrating compound lens according to Claim 16 wherein the stacked length of the three lenses is less than one-tenth of the sum of the lenses' focal lengths.

18. A method of concentrating solar beam onto a predetermined surface area (120) in a non-imaging manner comprising converging first solar beam (S1) with a first positive refractory medium such that second solar beam (S2) emerging therefrom are convergent upon a second negative refractory medium at about the optical axis, said second solar beam (S2) incident upon a second negative refractory medium at convergent angle such that third solar beam (S3) emerging therefrom continues to be convergent upon a third positive refractory medium, and wherein said third refractory medium converging said third solar beam (S3) onto said predetermined surface area (120).

19. A method of concentrating solar beam onto a predetermined surface area (120) in a non-imaging manner according to Claim 18 comprising the steps of:

(i) refracting first solar beam (S1) to converge with a first refractory boundary (R1) followed by a second refractory boundary (R2), wherein

- said first (R1) and second (R2) refractory boundaries form respective front and back boundaries of a first aspherical biconvex medium; and

- said first refractory boundary (Rl) convex curvature is higher than that of second refractory boundary (R2);

(ii) receiving second solar beam (S2) exiting said second refractory boundary (R2), said second solar beam (S2) being refracted to converge close to the optical axis, upon on a third refractory boundary (R3) followed by a fourth refractory boundary (R4), wherein

- said third refractory boundary (R3) and fourth refractory boundary (R4) form respective front and back boundaries of a biconcave medium;
- said third (R3) and fourth (R4) refractory boundaries continue converging said second solar beam (S2) due to second solar beam (S2)'s convergent angle of incidence;

(iii) refracting third solar beam (S3) exiting said fourth refractory boundary (R4), said third solar beam (S3) being refracted to converge by a fifth refractory boundary (R5) followed by a sixth refractory boundary (R6), wherein

- said fifth refractory boundary (R5) and sixth refractory boundary (R6) form respective front and back boundaries of a second aspherical biconvex medium; and
- said fifth refractory boundary (R5) convex curvature is lower than that of sixth refractory boundary (R6);

and wherein fourth solar beam (S4) exiting said sixth refractory boundary (R6) is converged upon the predetermined surface area (120).

20. A device for thermal-electricity generation comprising a solar beam-concentrating compound lens (100) according to any one of Claims 1 – 16 disposed to concentrate solar beam and heat onto a hot junction (130) of a thermoelectric circuit, e.g. a thermocouple.

21. An apparatus for thermal-electricity generation comprising a plurality of devices according to Claim 20 electrically-connected as a thermopile.

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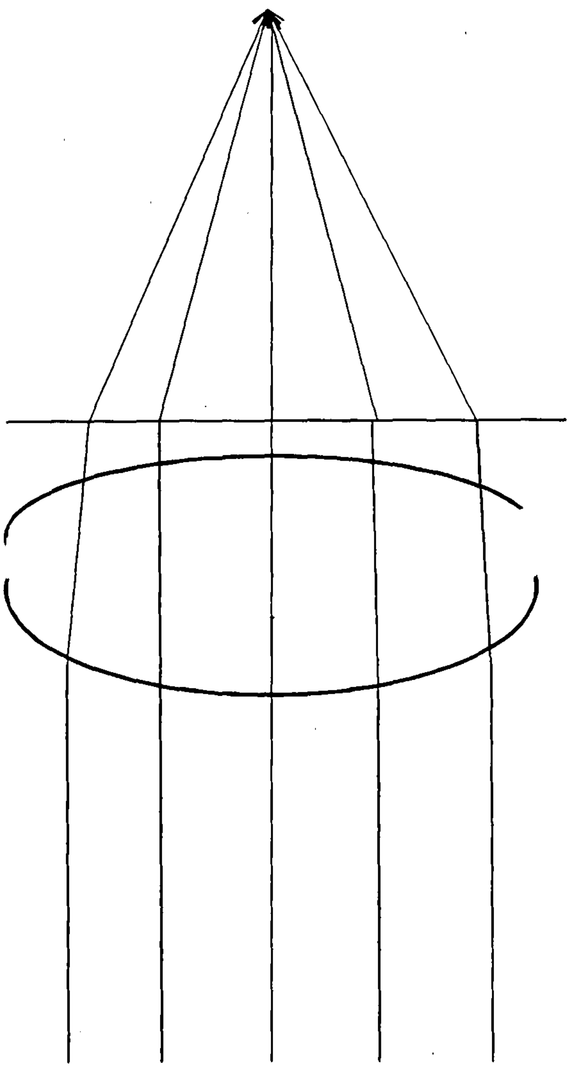
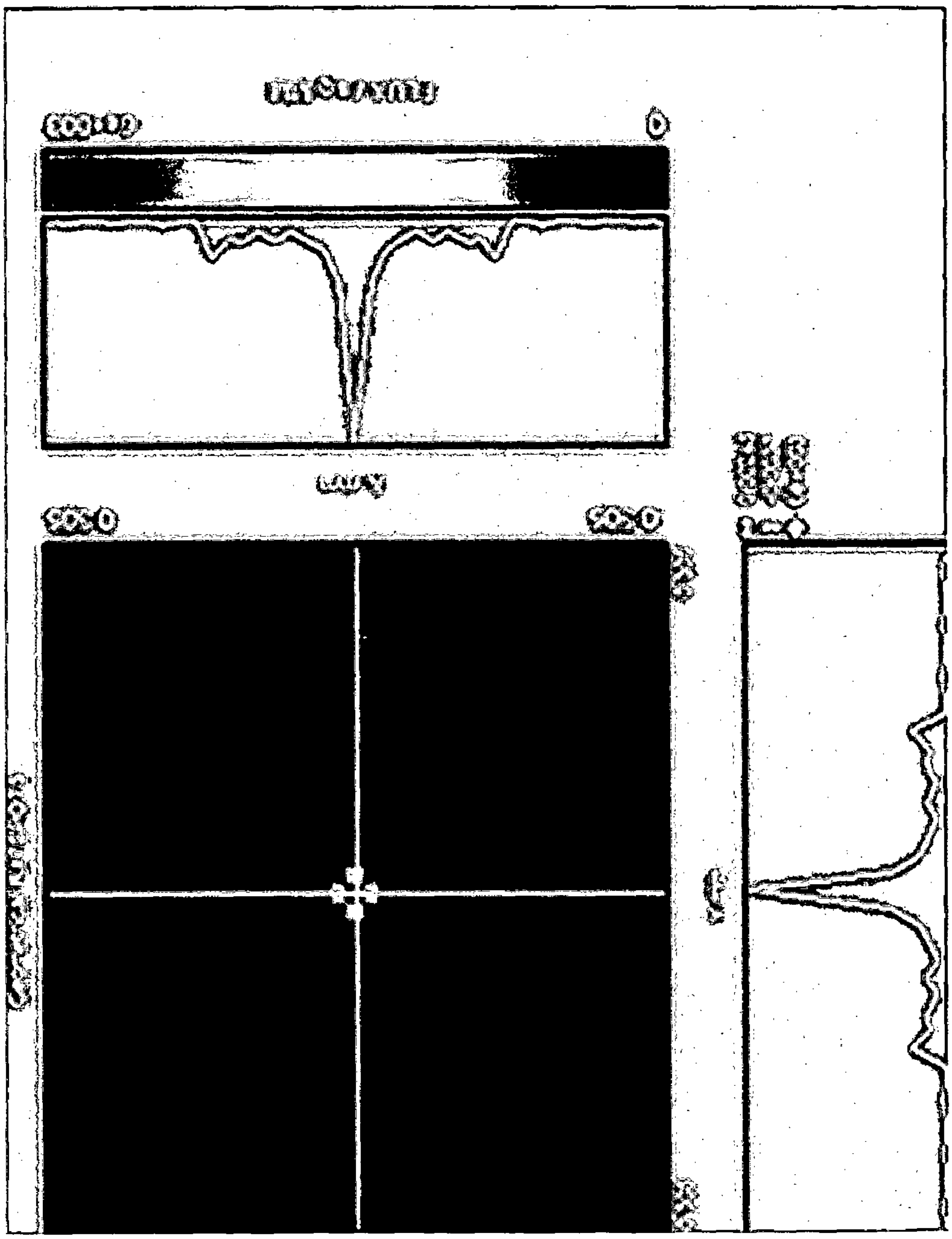


FIGURE 1a

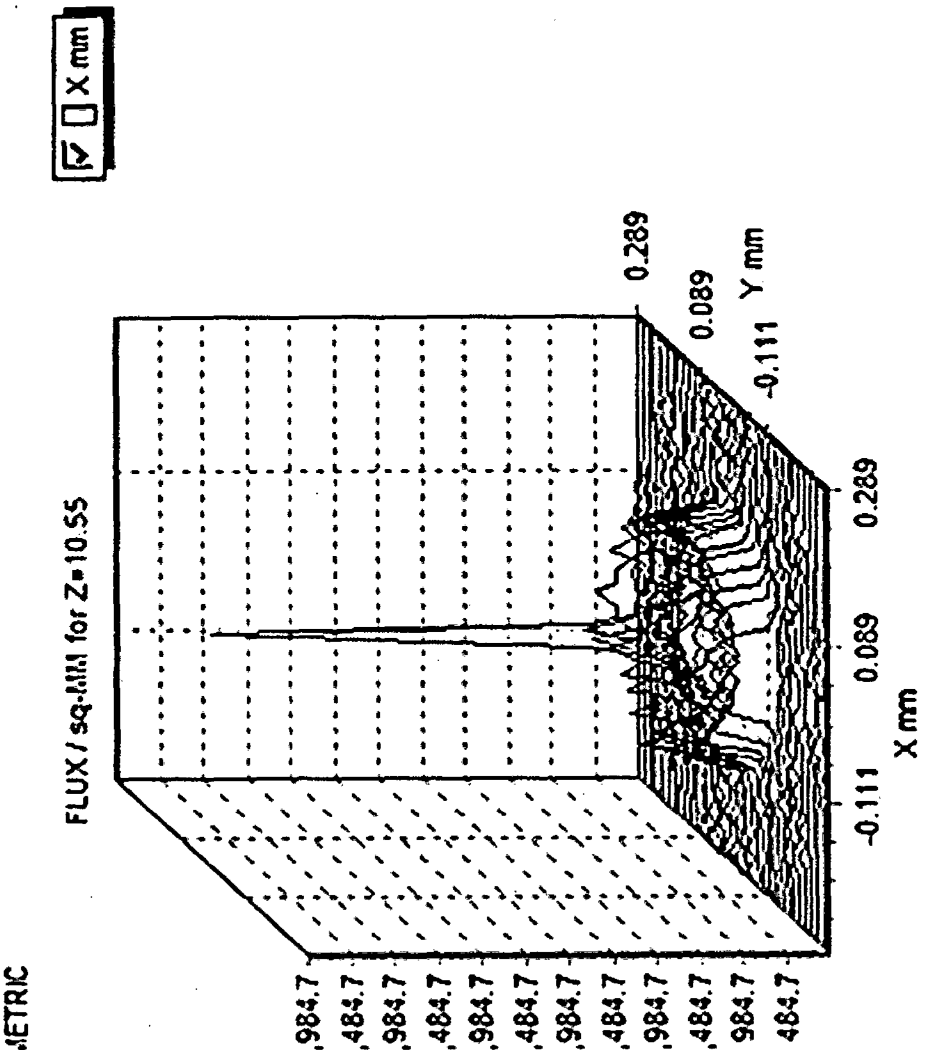
Prior Art

FIGURE 1b



Prior Art

FIGURE 1c



Prior Art

FIGURE 2

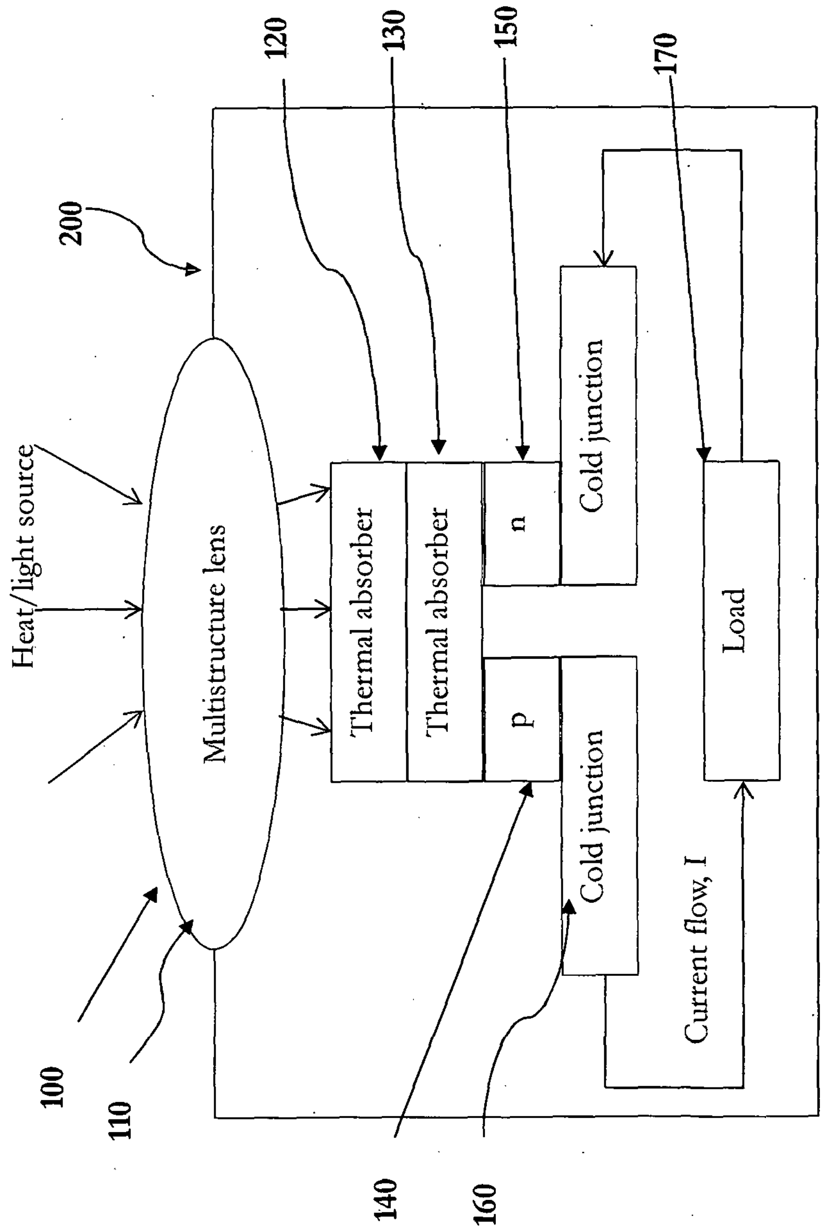

Heat/light source
Multistructure lens
Thermal absorber
Thermal absorber
n
p
Cold junction
Cold junction
Load
Current flow, I
100
110
120
130
140
150
160
170
200

FIGURE 3

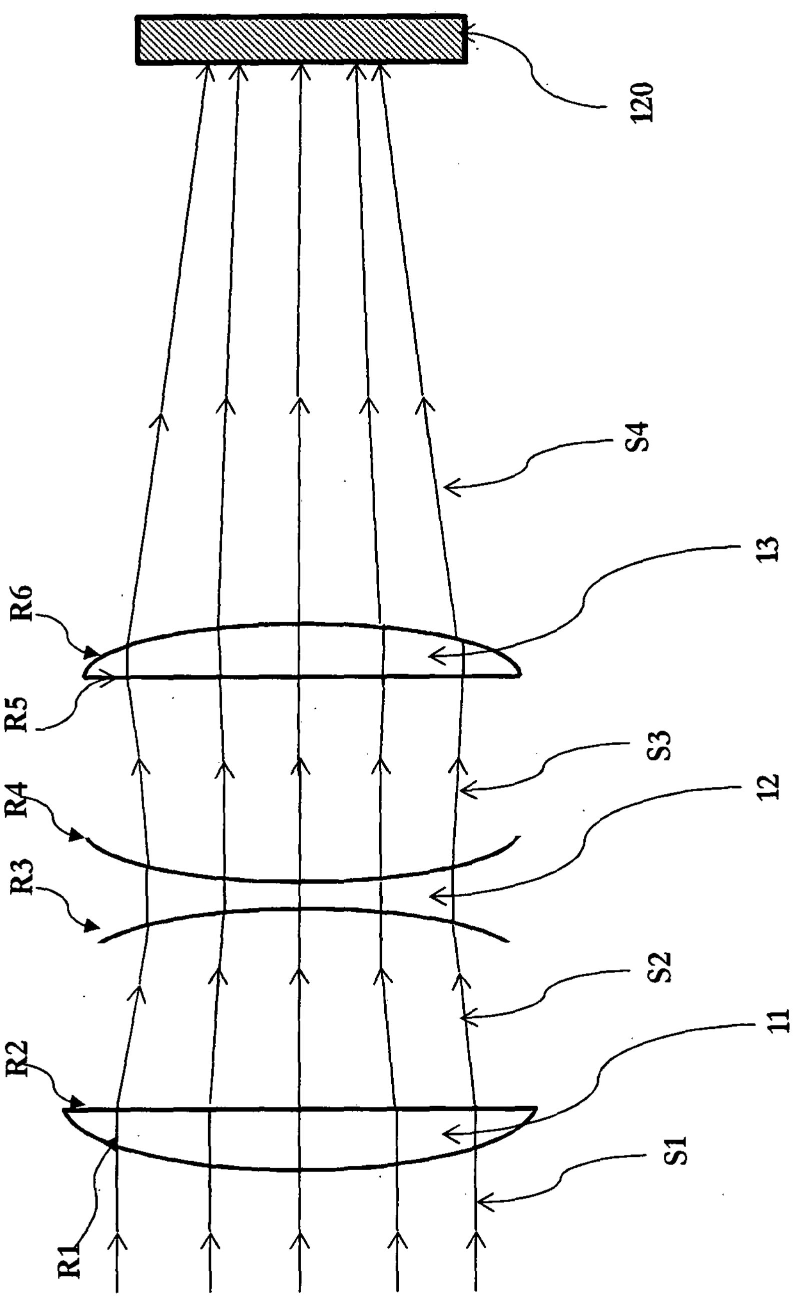
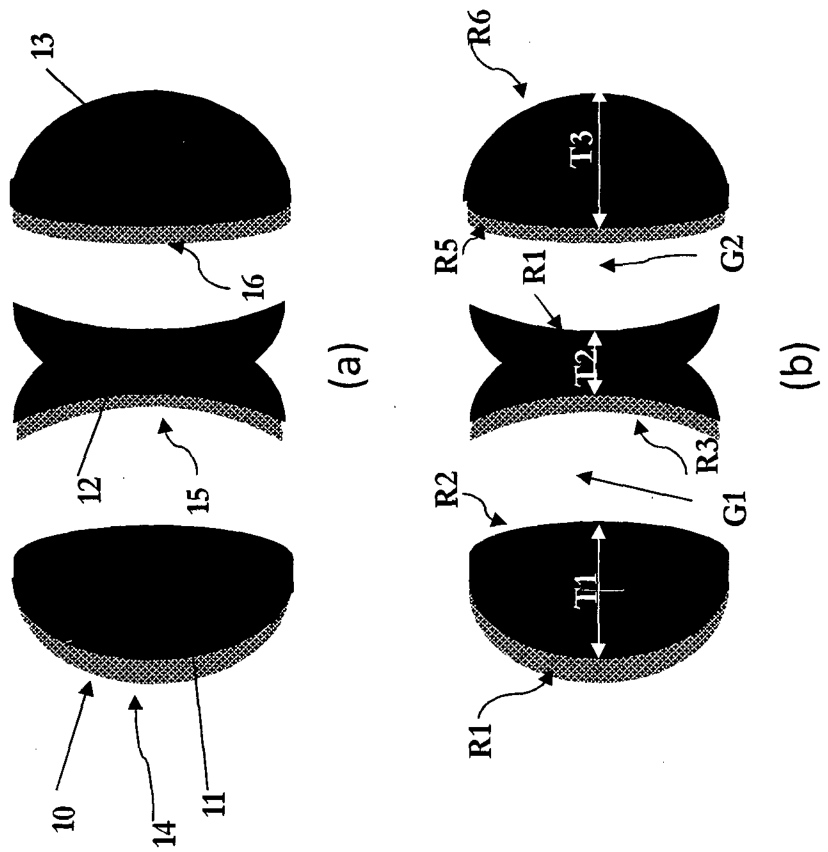


FIGURE 4



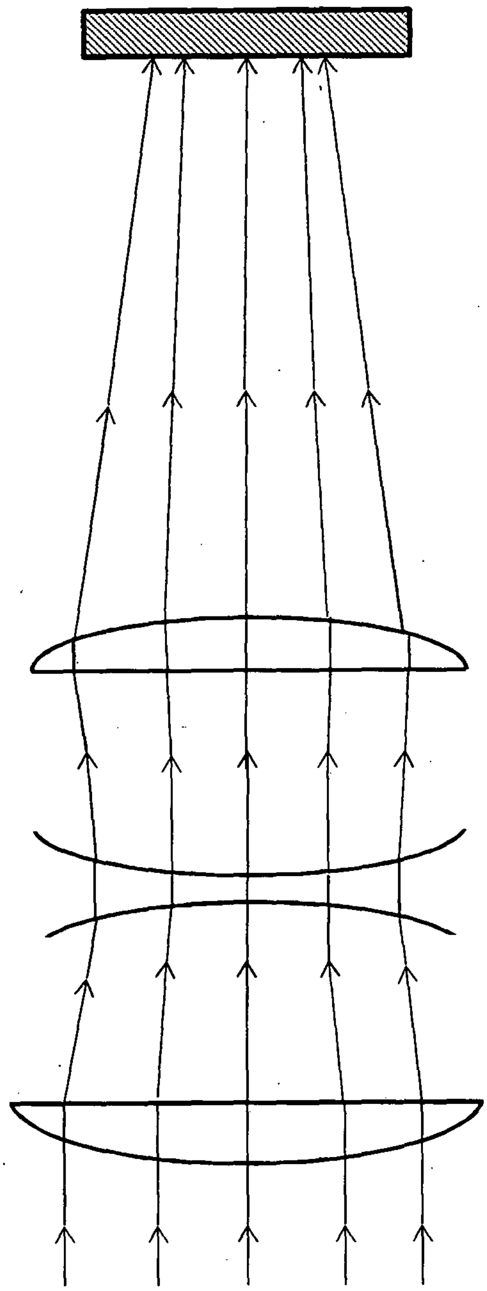


FIGURE 5

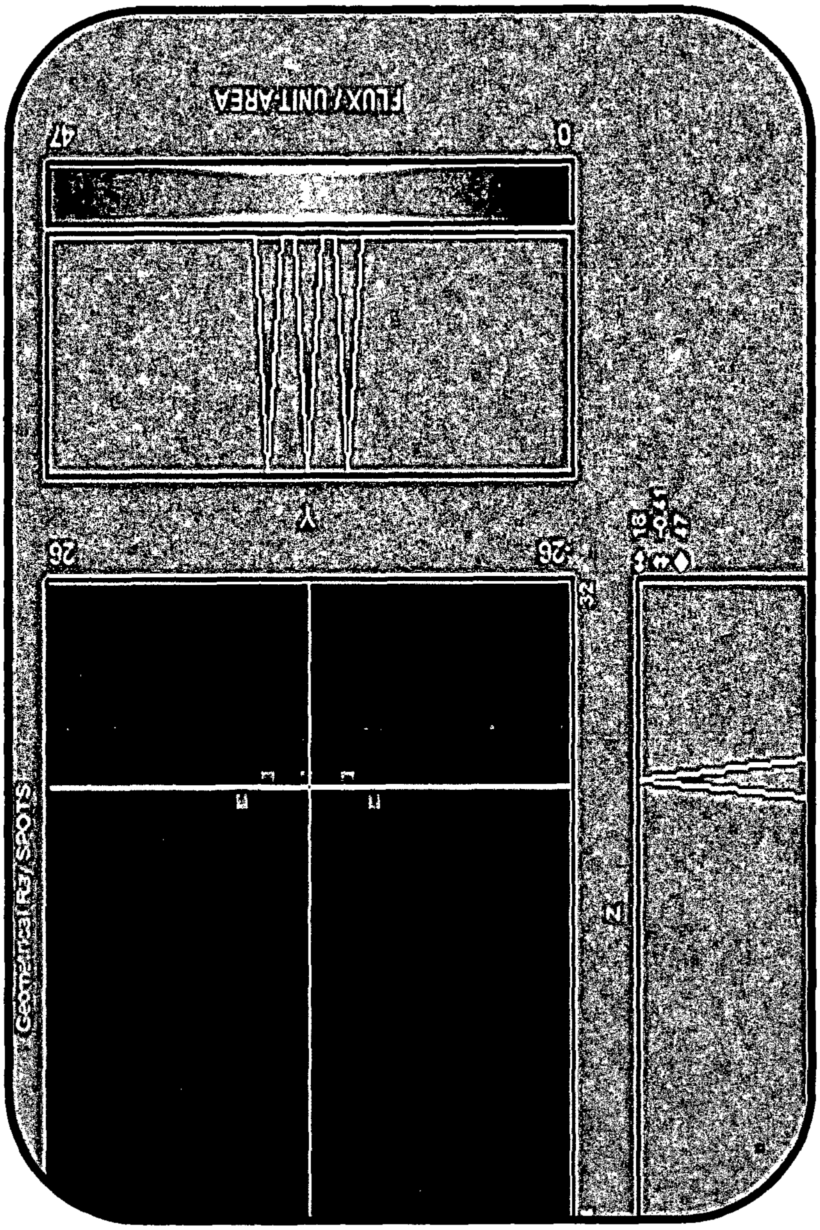
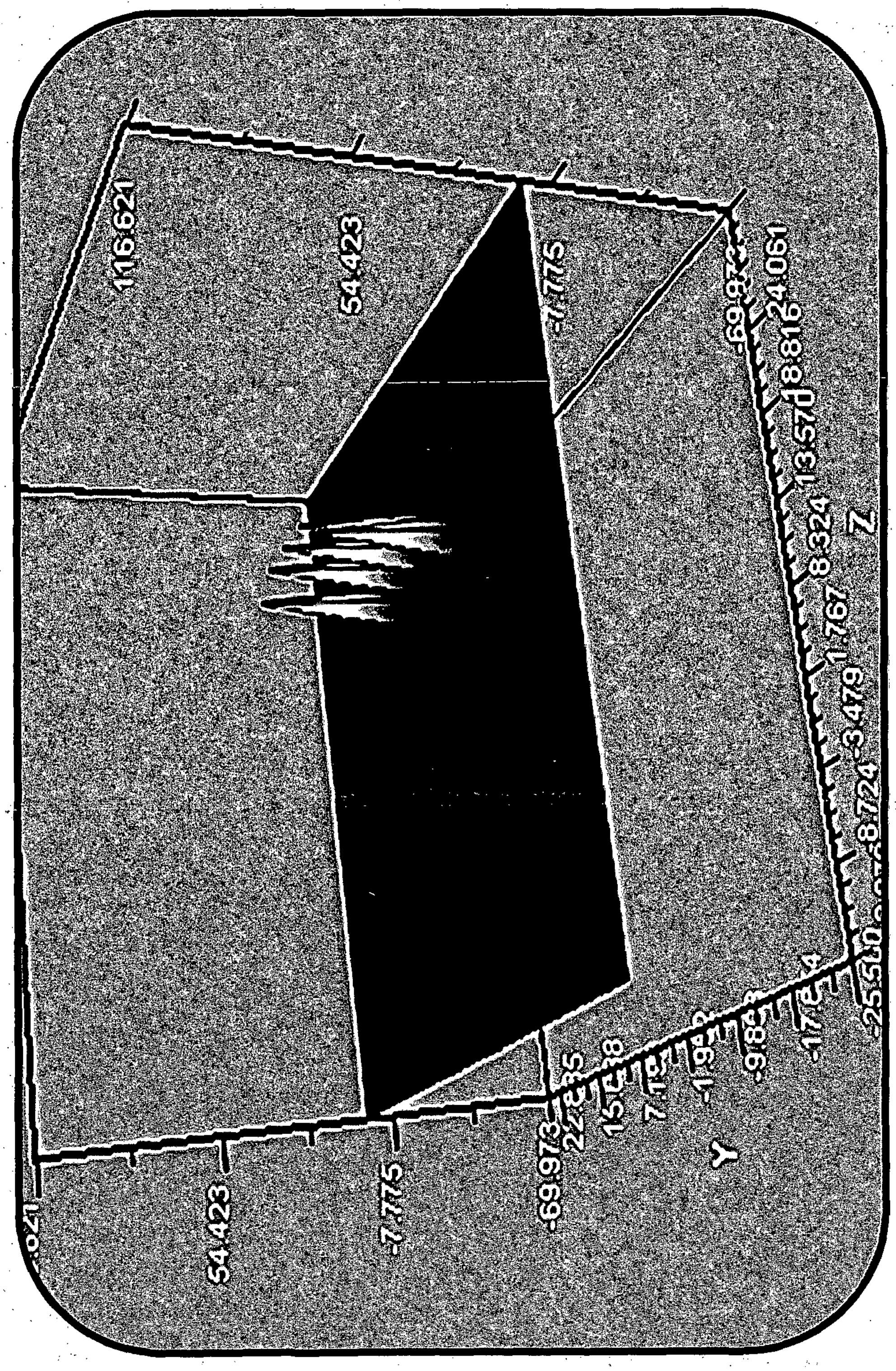


FIGURE 6a

FIGURE 6b



INTERNATIONAL SEARCH REPORT

International application No
PCT/MY2013/000127

A. CLASSIFICATION OF SUBJECT MATTER
INV. F24J2/08 G02B19/00
ADD.

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)
F24J H01L G02B

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP S61 208469 A (HASHIZUME MOTOHARU) 16 September 1986 (1986-09-16) figure 10	18
A	US 2010/089450 A1 (YANG JUN [US] ET AL) 15 April 2010 (2010-04-15) figure 2 paragraph [0014]	1-21
A	WO 2007/143517 A2 (SOLBEAM INC [US]; ROBISON JOHN HENRY [US]; COLBERT DANIEL T [US]; PEND) 13 December 2007 (2007-12-13) figures	1-21
A	US 4 411 490 A (DANIEL MAURICE [US]) 25 October 1983 (1983-10-25) figures	1-21

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 October 2013	25/10/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Fernandez Ambres, A

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 3 912 379 A (DEJAGER DONALD) 14 October 1975 (1975-10-14) figures	1-14
A	US 4 163 604 A (BETENSKY ELLIS I [CA]) 7 August 1979 (1979-08-07) figures	1-14

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/MY2013/000127

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