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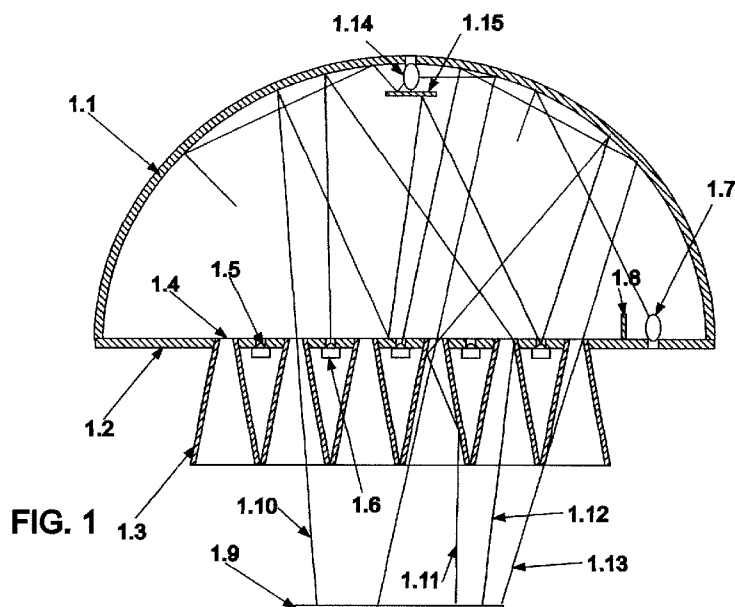
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(54) Title: LIGHT SOURCE FOR TESTING A PHOTOVOLTAIC PANEL OR CELL



(57) Abstract: A large spectrum light source for homogeneously irradiating surface of photovoltaic cells and modules for testing purposes. Light from various source types (1.5, 1.7, 1.14) is integrated in a cavity with highly reflective diffusing coating resulting in light of combined wavelengths randomly diffused inside before leaving the cavity. Light is exiting the cavity by an array of small output ports (1.4) equally spaced on a flat surface (1.2) of the integrating cavity resulting in homogeneous light irradiance received by plane sensor area (1.9). Mirror reflective deflectors, cones or tapered light pipes (1.3), placed in front of each output port (1.4) are a means of collimating emitted light.

LIGHT SOURCE FOR TESTING A PHOTOVOLTAIC PANEL OR CELL

Reference data

[0001] This application claims priority from Swiss patent applications 11/00610 and 11/0749 filed on 5th April 2011, respectively 3rd May 2011, the contents whereof are hereby incorporated.

Field of the invention

[0002] The present invention relates to optical devices combined in order to generate a light similar to sun one in terms of spectrum, intensity and collimation. Solar simulation for photovoltaic devices testing is the main technical field of the invention, which, however, can be applied to many other domains like, for example: testing of photovoltaic equipment; indoor or outdoor lighting; photography lighting; video recording lighting; technical lighting; stage lighting; agriculture; residential lighting; color mixing; animal husbandry; biotechnologies; material testing; aviation; car making; military. In general terms, the present invention is particularly suited to applications in which it is necessary to combine collimated lighting, uniformity of illumination and energy efficiency.

Description of related art

[0003] Installations for photovoltaic energy generation belong to a very competitive market where customers are requesting better quality at lower production costs. Photovoltaic cells and modules testers are the equipments at the end of the production process. A critical element of such testers is the solar simulator that is expected to deliver an illumination as similar as possible to the one received by photovoltaic modules when installed in energy production plants. The illumination must adhere, as a rule, to stringent specifications and norms, and often are the major contributor to the cost and complexity of a tester module.

[0004] Spectrum: sunlight spectrum is today very well simulated by Xenon bulbs. Additional optical filters can be used to shape their spectrum in order to be closer to the spectrum of solar light. Halogen lamps provide a simpler alternative to build a solar simulator, though their spectrum is lacking in the UV and visible bands. Both sources have infrared light spectrum extending beyond the limit required for the test of Silicon based cells, which are insensitive to wavelengths over 1100nm.

[0005] These sources have lower efficiency, higher energy demands and their operational life is shorter than other sources like LEDs, whose luminous efficiency is ever increasing. Thus, LEDs are more and more interesting for solar simulators as well as other lighting systems.

[0006] A drawback of LEDs is their limited spectral width, so that several source emitting at various wavelengths need to be combined in order to simulate a spectrally rich source like the Sun. It becomes difficult, however, to ensure that the target, for example a photovoltaic cell, receives the same spectrum on all points on its surface. There is therefore a need for an optical system overcoming this limitation.

[0007] Irradiance uniformity: photovoltaic modules are flat panels usually built of a few photovoltaic cells connected together and placed on same plane. Best working conditions are when the direction of sun rays is normal to its surface. Less efficient photovoltaic power conversion occurs at other angles of incidence. At any incidence angle of the sun, the irradiance is uniform across the cell's surface. When testing modules, irradiance uniformity of light received on module surface needs to be as constant as possible for better testing quality. Such specification is achieved usually either by a single light source far from the target cell/module, or by multiple light sources at closer distances.

[0008] Light collimation: Solar light is composed of essentially parallel rays that arrive all at the photovoltaic module with the same incidence angle. In simulations, the incidence angle may not be the same for all rays, and this could provide unexpected results on cell's technology, particularly

when the illumination is not normal to the surface. Additionally, poor collimation could introduce sensitivities to module positioning as well as to accuracy mounting accuracy of cells in module.

[0009] Simulators using a single source far from the target suffer from low photometric efficiency, because a large fraction of the emitted light rays is not directed towards the target cell/module, and are in general bulky pieces of equipments. Instruments with multiple sources at closer distances, on the other hand, exhibit often a poorer light collimation. There is therefore a need for a compact optical system able to deliver uniform light with high efficiency and without sacrificing collimation.

[0010] It is an aim of the present invention to provide a system overcoming the limitations of the prior art.

[0011] Where the following uses the wordings 'top', 'bottom', 'above', 'below', 'under', 'aside', 'horizontal', 'vertical' and the like, these terms refer to the standard conventional orientation of a solar simulator and a photovoltaic panel under test, that is also represented in the figures. They refer namely to an arrangement in which a flat photovoltaic device lies on a horizontal plane while a simulation sources is placed above it and sends its light downwards. It must be understood that these wordings are used only in a non-limiting sense to illustrate examples of the invention, which includes in its scope also sources having any orientation in space.

Brief summary of the invention

[0012] According to the invention, these aims are achieved by means of the object of the appended claims. The integrating cavity of the invention allows using light sources of various types having different spectral power, angular distribution and total power and brings the mean to mix completely all those differences in order to present at output ports a uniform distribution of these parameters. In particular, the aims of the invention are achieved by means of a light source having a light integrating cavity with reflective and diffusing internal layer; one or more individual

light sources arranged to emit light in an inside volume of said integrating cavity; one or more apertures in said light integrating cavity, each aperture coupled with a light conveyor means arranged to convey light to the photovoltaic panel or cell under test.

Brief Description of the Drawings

[0013] The invention will be better understood with the aid of the description of an embodiment given by way of example and illustrated by the figures, in which:

Fig. 1 is a sectional schematic view of one embodiment of the solar simulator of the invention incorporating a "half-moon" integrating cavity.

Fig. 2 is a sectional schematic view of one embodiment of solar simulator incorporating a rectangular or cylindrical integrating cavity.

Fig. 3 is a schematic view of the base plate of the solar simulator of the invention from below.

Fig. 4 and 5 represents two variants of the bottom plate of the solar simulation of the invention.

Fig. 6 is a ray tracing simulation plot of the irradiance distribution provided by the invention. Fig. 7 is a two dimensional mapping of the simulated distribution of Fig. 6.

Fig. 8 illustrates schematically a variant of the embodiment of Fig. 1.

Fig. 9 shows an alternative structure of the base plate of the solar simulation of the invention.

Fig. 10 illustrates schematically a variant of the invention with additional side mirrors.

Detailed Description of possible embodiments of the Invention

[0014] With reference to Fig. 1, one preferred embodiment of the present invention relates to a light source for a solar simulator incorporating an "half-moon" integrating cavity delimited by a flat bottom plate 1.2 and by a dome 1.1 that may have, for example an hemispherical shape.

[0015] The invention preferably comprises a one or more light sources that shine towards the inside volume of the integrating cavity. The embodiment of Fig. 1 includes an array of LED sources 1.5 that are disposed in a regular or irregular arrangement on the bottom plate 1.2, as well as halogen light bulbs and/or xenon lamps 1.7 and 1.14. Where necessary, shading baffles 1.8, 1.15 are used to block direct lines of sight between the light sources and the output ports 1.4.

[0016] The bottom plate 1.2 presents a plurality of apertures 1.4 in a regular or irregular arrangement that interface with corresponding hollow conical reflectors 1.3 functioning as light conveyor means, or light pipes and conveying the light from the light sources 1.5, 1.7, 1.14 to a photovoltaic cell or module 1.9. The target 1.9 is placed in front of the output ports of the conical reflectors 1.3 and receives a uniform irradiation. 1.10, 1.11, 1.12, and 1.13 represent light rays. Rays 1.10, 1.13, 2.11, 2.13 (on Fig. 2) do not reflect on internal sides when crossing light pipes while rays 1.11, 1.12, 2.10, and 2.12 (on Fig. 2) do. Preferably the LED individual light sources have access means 1.6 to permit their replacement and maintenance from the outside.

[0017] Preferably the inside walls of the integrated cavity are coated by a white diffusive and highly reflective layer like for example a barium sulfate coating. For wider photovoltaic areas, the height of integrating cavity would preferably be reduced so that the light from the light sources is randomly diffused in the cavity before being conveyed to the target 1.9. The inner walls of conical reflectors 1.3 have preferably mirror reflection or of incident light.

[0018] Fig. 2 is a sectional schematic view of one embodiment of solar simulator in which the integrating cavity is formed by a rectangular or cylindrical box 2.1 closed by a bottom plate 2.2. Individual light sources 2.5 are LEDs arranged in a regular or irregular pattern on the bottom plate, and sending their light towards the inner volume of the integrating cavity. They can be replaced or accessed from the outside by the access means 2.6. The light source of Fig. 2 also comprises individual light sources of different nature, for example halogen light bulbs or xenon lamp 2.7, equipped with a shading baffle 2.8 and a halogen light bulbs or xenon lamp inside a reflector 2.15 directed towards the inner volume of the integrating cavity. Other kind of light sources, for example arc lamps (both in the short arc and the long arc variety) can be used if appropriate, in this and other embodiments of the invention.

[0019] In Fig. 2, the light from sources 2.5, 2.7, 2.14 is randomly diffused in the cavity before exiting from apertures 2.5 and being conveyed to the target 2.9 by an array of dielectric light pipes with total internal light reflection 2.3. The light pipes have for example a parabolic or compound parabolic profile or any other appropriate shape and are made of any suitable dielectric or transparent material, for example resin or glass. By compound parabolic profile it is intended, in the frame of this invention, a profile that is composed by several interconnected parabolic arcs.

[0020] 2.10, 2.11, 2.12, and 2.13 represent light rays. The light conveyor means, in this or the other embodiments of the invention, could also be realized by gradient-index optical elements.

[0021] Rectangular or cylindrical cavity shapes 2.1 can be used like schematically shown in Fig.2. With those more flat volumes the light sources of similar type, for example LEDs of same wavelength and power, should be equally spaced inside the cavity in order to pre-homogenize first light reflection on cavity roof resulting in more uniform irradiance spatial distribution at output ports. Other relevant volume shapes are of interest.

[0022] In well designed integrating cavity, light distribution at output ports is not dependent of the angular radiance distribution of the individual sources. For each light source, an emitted ray of any wavelength leaving source at any angle will be split in many rays having randomly defined directions after being scattered on internal cavity surface many times. This initial single ray will then result in multiple rays homogeneously reaching each output port. Multiple light sources types can either be placed inside cavity or their light may be introduced by input ports and/or by optical fibres. For solar simulator design, in order to achieve needed power and light spectrum, a single or all of the following light sources types, among others, can be used: LEDs, halogen bulbs, xenon bulbs, plasma bulbs, with short or long arc. The source list is not limited to the previous one. Each ray of specific wavelength and power emitted by all light sources will be added to result in final total spectral power exiting integrating cavity. Depending on reflectivity of cavity internal coating and of ratio of cavity output ports area over total cavity area some loss power has to be taken in account.

[0023] As mentioned above, the LED light sources 1.5, 2.5 and the light pipes 1.3, 2.3 can follow any regular or irregular disposition. Fig. 3 is a schematic view of the base plate 3.2 of the solar simulator of the invention from below, showing an array of LEDs 3.5 and light pipes in a square arrangement. The reference numbers 3.3 of Fig. 3 indicate the larger extremity of the light pipes facing the target and 3.4 their smaller extremity of the light pipes coupled to the integrating cavity. This embodiment also includes a halogen bulb or xenon lamp 3.7 and its baffle 3.8.

[0024] Fig. 4 represents a variant of the disposition of the solar simulator of the invention in which a base plate 4.2 presents a hexagonal arrangement of LEDs 4.5 and light pipes 4.3 and 4.4. As in previous example, 4.7 stands for a light source, for example a halogen bulb or a gas discharge lamp, and 4.8 is a baffle shading the apertures 4.4 in the base plate from the direct illumination from source 4.7.

[0025] The shape of the light pipes of the invention is also variable, without exiting from the scope of the invention. In the previous embodiments the horizontal sections of the light pipes 1.3, 2.3, 2.3, 4.3 are circular, and this shapes does present some advantages in term of luminous efficiency, but this is by no means a necessary feature of the invention. Fig. 5, for example shows a variant in which the light pipes 5.3 of the base plate 5.2 have a square section. In further non-represented variants, the section of the light pipes could also be triangular, hexagonal, octagonal, and so on; and the invention could possibly encompass embodiments that includes light pipes with dissimilar shapes and various dimensions. 5.7 is an auxiliary light source, for example, a halogen bulb or a gas discharge lamp, and 5.8 is a shading baffle.

[0026] Preferably, to achieve uniform light irradiance on the active area of the photovoltaic module or cell 1.9, 2.9, the light exits the integrating cavity by uniformly spaced output ports 1.4, 2.4, 3.4, 4.4, 5.4 located on a flat base plate 1.2, 2.2, 3.2, 4.2, 5.2 of the integrating cavity. Fig. 3 and Fig. 5 show a square grid arrangement of the output ports openings 3.4, 5.4 while Fig. 4 shows a hexagonal arrangement of output ports 4.4. Advantageously, the latter arrangement allows a higher number of output ports on a given surface of the flat.

[0027] Special care must be taken in positioning light sources in order to achieve best uniformity at output ports. Preferably, as seen in Fig.1, 2, 3, 4, 5, a large number of LED is used, and they have various peak wavelengths and emission spectra. They are preferably between output ports and adjacent to smaller aperture of light pipes 1.4, 2.4, 3.4, 4.4, 5.4. It is preferable to dimension port opening just matching each LED light active surface, and to avoid positioning LEDs on internal upper surface of the integrating cavity, unless their case is also coated with reflective layer. Other types of light sources which have wider spectrum and more unit power than LEDs, like halogen or xenon (1.7, 2.7), are needed in limited number and consequently appear as being point sources so that particular care must be taken to spread their emission evenly spread on cavity roof.

[0028] According to another variant, interesting under the aspect of the ease of manufacturing, the light pipes are made by aluminium foils which are folded and crossed in order to compose the rows and columns sides of light pipes array 5.3. This solution would best fit wider structures for wider photovoltaic modules testing.

[0029] Fig. 6 plots a distribution simulated by a ray-tracing program of the irradiance on a target photovoltaic panel lying on a horizontal plane at a distance equal to one light pipe length from the larger extremities. Curve 1 represents the irradiance from a single active output port/light pipe and curve 2 shows the combined effect of an array of light pipes. Fig. 7 is a two dimensional mapping of the simulated distribution of Fig. 6.

[0030] In the previous embodiments, the number of light pipes corresponded, at least approximately, to the number of LED sources, but this is not an essential feature of the invention. Fig. 8 represents one embodiment of solar simulator of the invention incorporating an "half-moon" type integrating cavity 8.1 and 8.2 carrying, on bottom plate 8.2, a plurality of led sources 8.5 arranged in a regular or irregular array. The cavity includes as well, similarly to the embodiment of fig. 1, auxiliary light sources 8.7 and 8.14, for example halogen or gas discharge sources, and the corresponding baffles 8.8 and 8.15. The light from the led sources and auxiliary sources is randomly diffused inside the integrating cavity. A single hollow conical light pipe 8.3 conveys a uniform illumination to the target photovoltaic module 8.9. In order to combine maximum efficiency and irradiance uniformity on a square cell 8.9 light pipe larger aperture 8.16 is preferably slightly larger than the cell 8.9.

[0031] For square cells, favourable results are obtained with tapered, hollow light pipes with internal mirror reflection, and square section shape. Best results in tests are obtained when the linear ratio of the large aperture over the small aperture of the light pipes is about 4, and the ration between the length of the light pipe above the small aperture is approximately 12. Compared to previous embodiments this one offers simpler light pipe construction and better access to LEDs, while accuracy of

light pipe dimensions and positioning of the cell 8.9 relative to the output aperture 8.16 are critical, if best irradiance uniformity is required. The shape of the Integrating cavity shape is not restricted to a half-moon type.

[0032] Fig. 9 represents schematically the embodiment of Fig. 8 view from below. The base plate 9.2 carries a square arrangement of square LEDs 9.5 and one hollow light pipe with a larger extremity 9.3 facing the target and a smaller extremity 9.4 coupled to the integrating cavity.

[0033] Fig. 10 illustrates schematically a variant of the embodiment in Fig. 1 with additional side mirrors 10.17, 10.18, a larger cell area 10.9 and light rays 10.10, 10.16 reflecting on side mirrors. Without the side mirrors, the irradiance distribution drops near the edges of the illuminated area, as shown in fig. 6 and 7. The side mirrors 10.17, 10.18 extend the uniformly illuminated cell area 10.9, the side areas of which will partially receive light from rays reflected on mirrors like if it was originated from virtual light pipes extending beyond the real ones.

[0034] Even if the present description relates to specific shapes of the integrating cavity and light pipes, it must be understood that the present invention is not so limited, but includes also variants in which the cavity and light pipes have other shapes, possibly irregular shapes. In addition, light pipes are not limited to reflective devices, but can include any refractive elements, lenses, graded-index optical elements, or any suitable collimation means. Output ports can be arranged in a regular or irregular pattern, according to the output uniformity needs. Individual light sources positioning is also not limited to the present description.

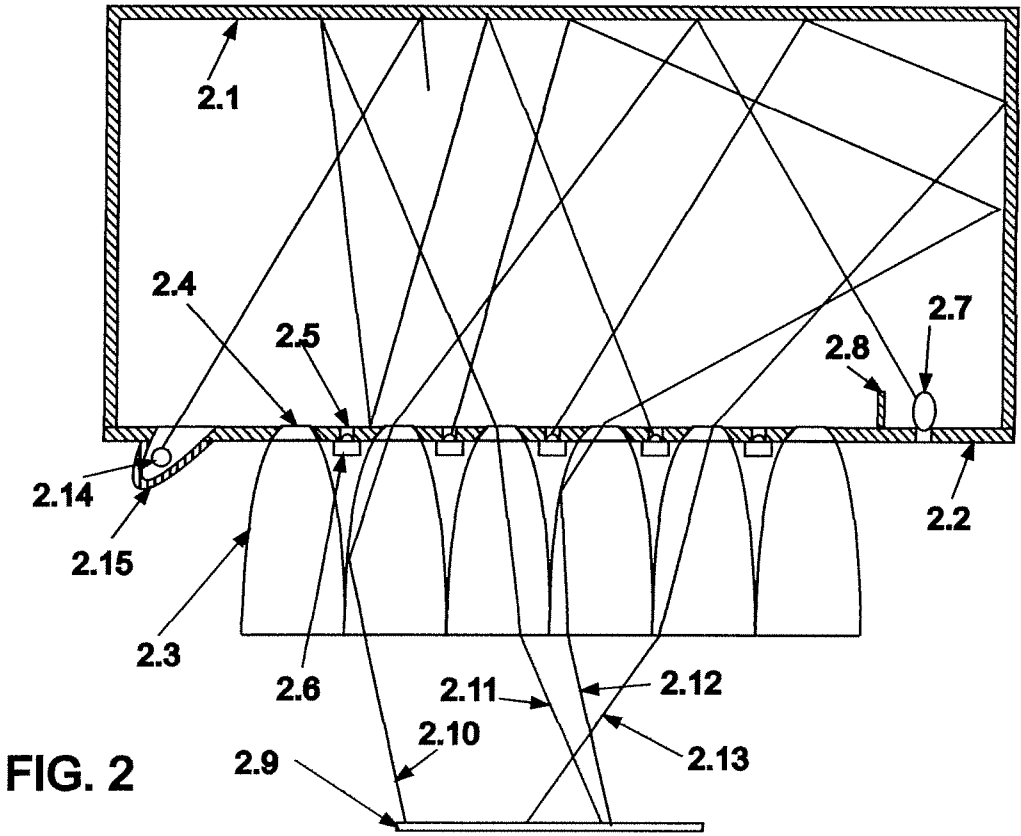
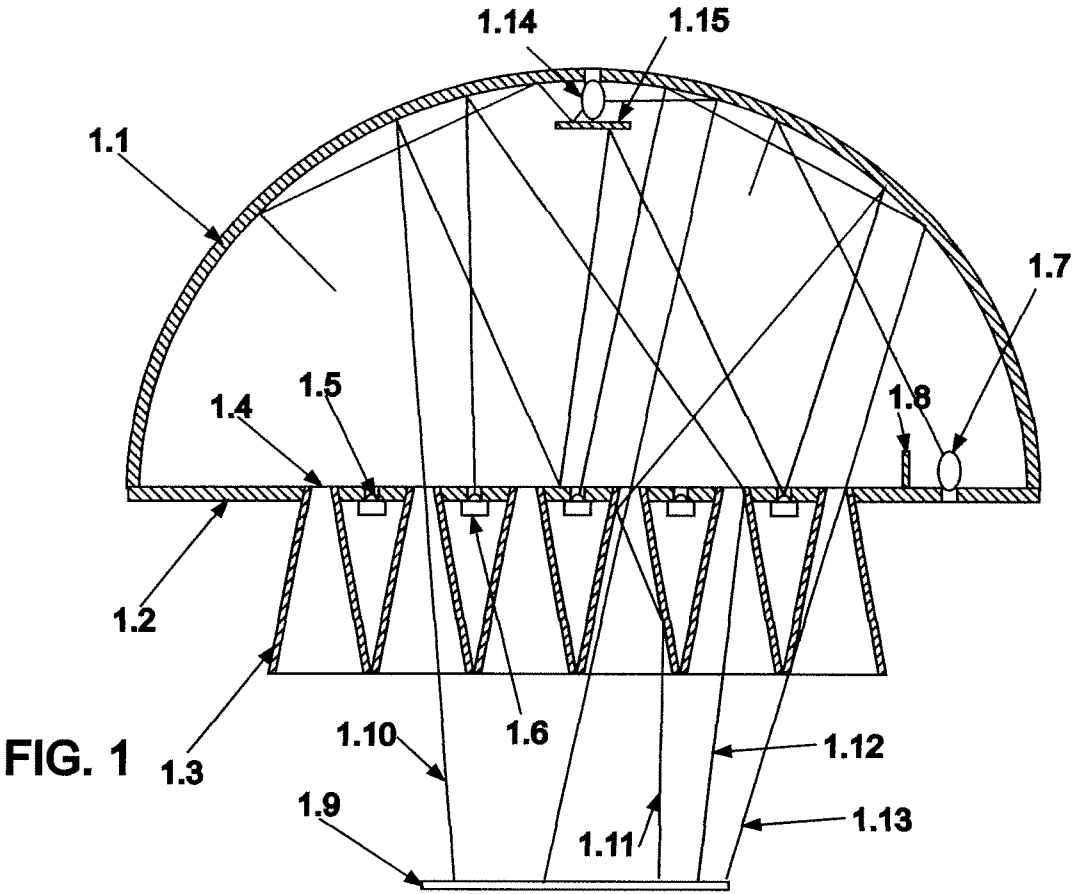
[0035] Where appropriate, the individual light source may be placed not on a side, but externally to the cavity, and emit light inside the cavity by means of an optical fibre or an equivalent light transport means. Also, the individual light sources, and especially the LEDs, may be equipped by lenses or any other appropriate collimation optics.

[0036] Moreover, even if the presented examples deal with a cavity having output ports on a flat surface, it must be understood that the present invention is not so limited, and includes variants in which the output ports are on a curved surface. Such variants may be advantageous, for example, for lighting curved objects.

Claims

1. A light source for testing a photovoltaic panel or cell including:
 - a light integrating cavity with reflective and diffusing internal layer;
 - one or more individual light sources arranged to emit light in an inside volume of said integrating cavity;
 - one or more apertures in said light integrating cavity,
 - each aperture coupled with a light conveyor means arranged to convey light to the photovoltaic panel or cell under test.
2. The light source of the previous claims, wherein said apertures are arranged in a regular grid on a flat side of said integrating cavity.
3. The light source of the previous claim, wherein said individual light sources are positioned between said apertures on said flat side.
4. The light source of any of the previous claims, wherein said individual light sources are one of: LED, halogen bulbs, Xenon, plasma lamps, long or short arc lamps.
5. The light source of any of the previous claims, wherein said light conveyor means comprise light pipes with a larger extremity facing the photovoltaic panel or cell under test, and a smaller extremity coupled with the integrating cavity.
6. The light source of the previous claim, wherein the light pipes are chosen between: hollow tapered pipes and comprise internally reflective mirror walls; solid dielectric or glass bodies with total internal reflection; Gradient-index optical elements.

7. The light source of one of claims 5 or 6, wherein the vertical profile of at least some of the light pipes is conical or parabolic or compound parabolic.
8. The light source of one of claims from 5 to 6, wherein the horizontal section of at least some of the light pipes is circular, square, or hexagonal.
9. The light source of any of the previous claims, wherein at least some individual light sources are LEDs with a collimation optic element.
10. The light source of any of the previous claims, wherein at least some individual light sources are LEDs with different emission spectra.
11. The light source of any of the previous claims, wherein at least some individual light sources are arranged to emit light inside the cavity by means of an optical fibre.
12. Use of a light source according to any of the preceding claims in: solar simulation; testing of photovoltaic equipment; indoor or outdoor lighting; photography lighting; video recording lighting; technical lighting; stage lighting; agriculture; residential lighting; colour mixing; animal husbandry; biotechnologies; material testing; aviation; car making; military; space industry.



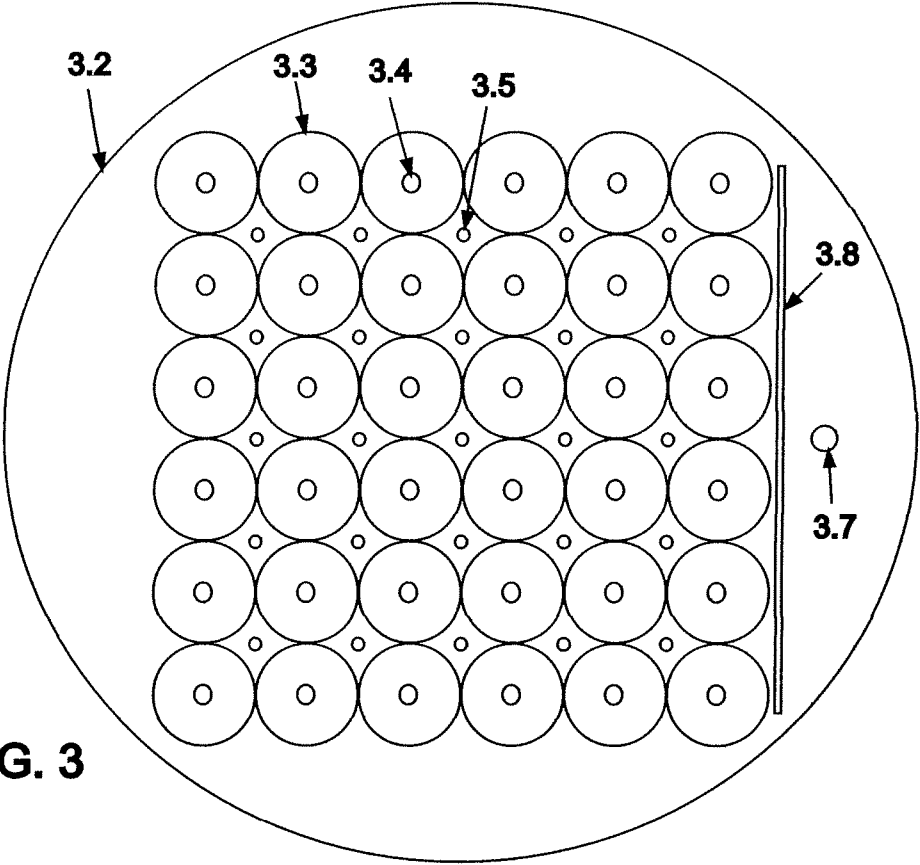


FIG. 3

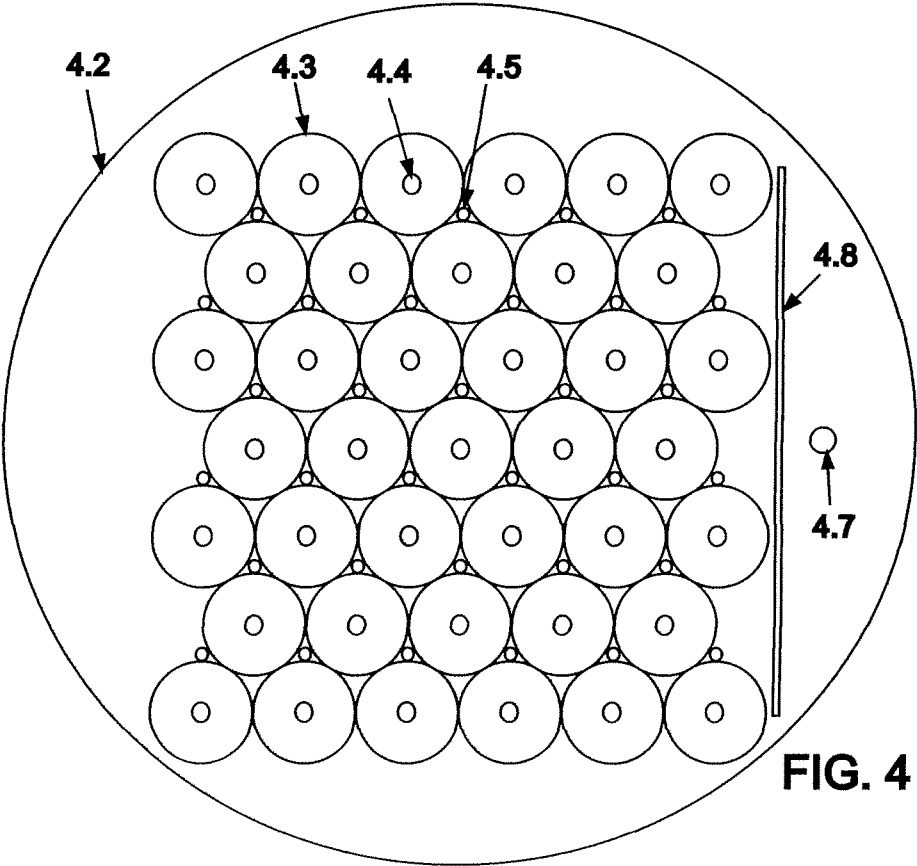
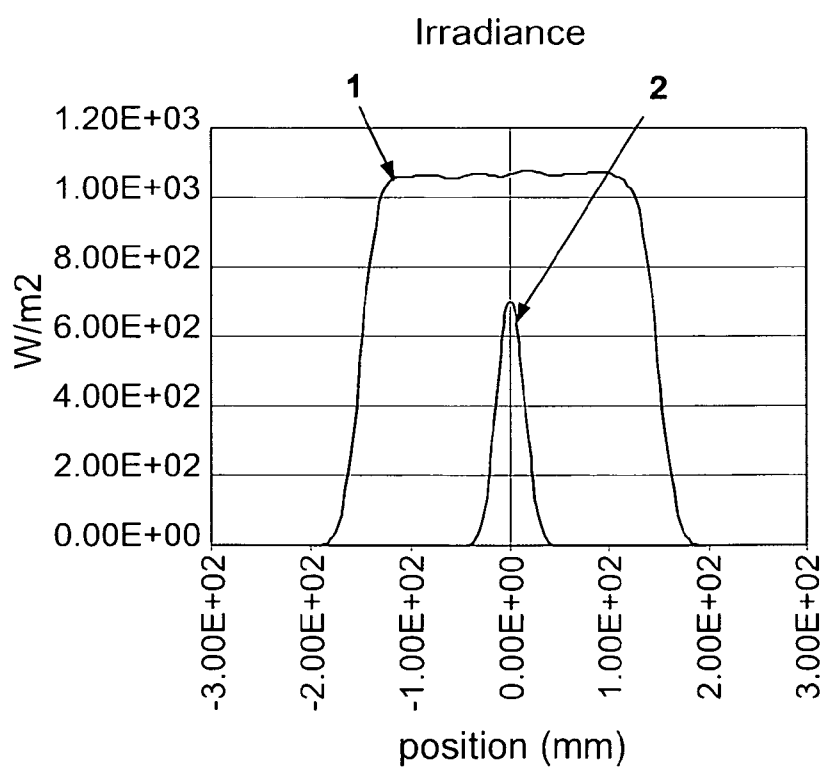
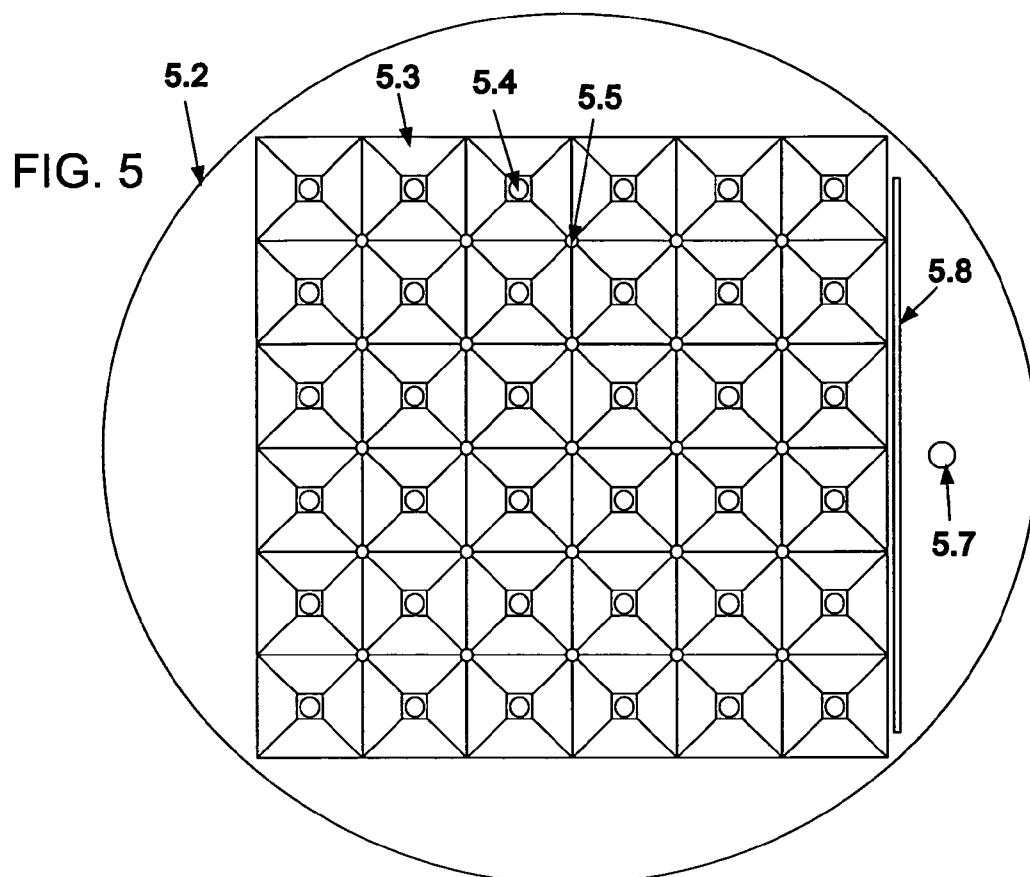


FIG. 4



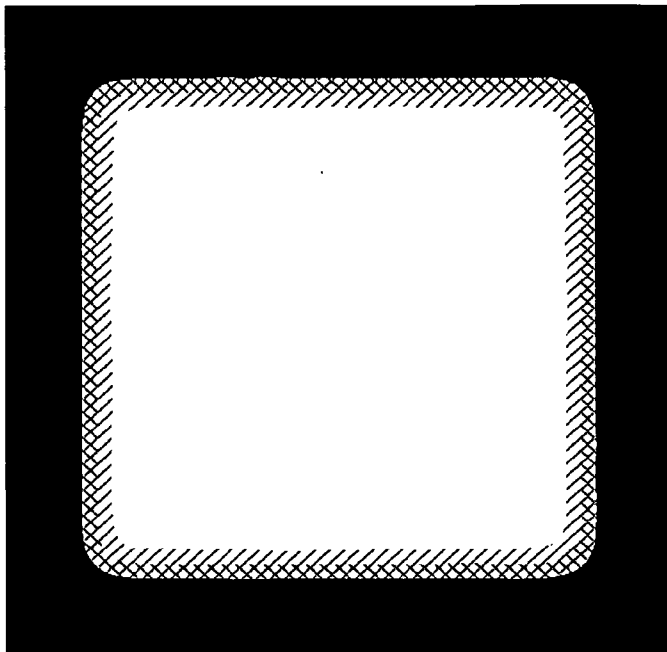


FIG. 7

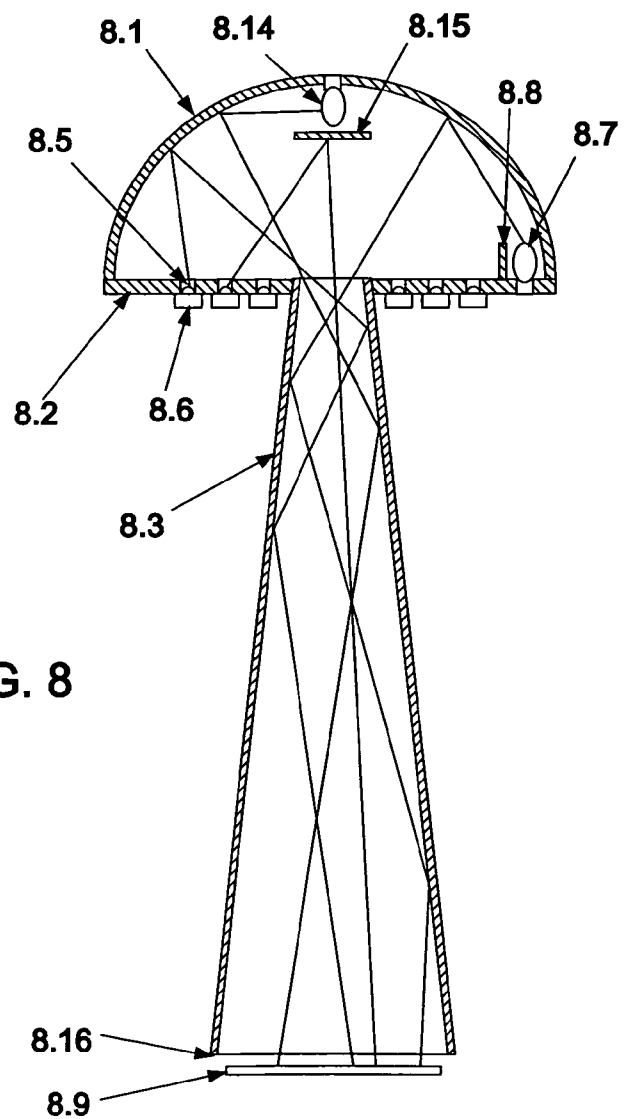
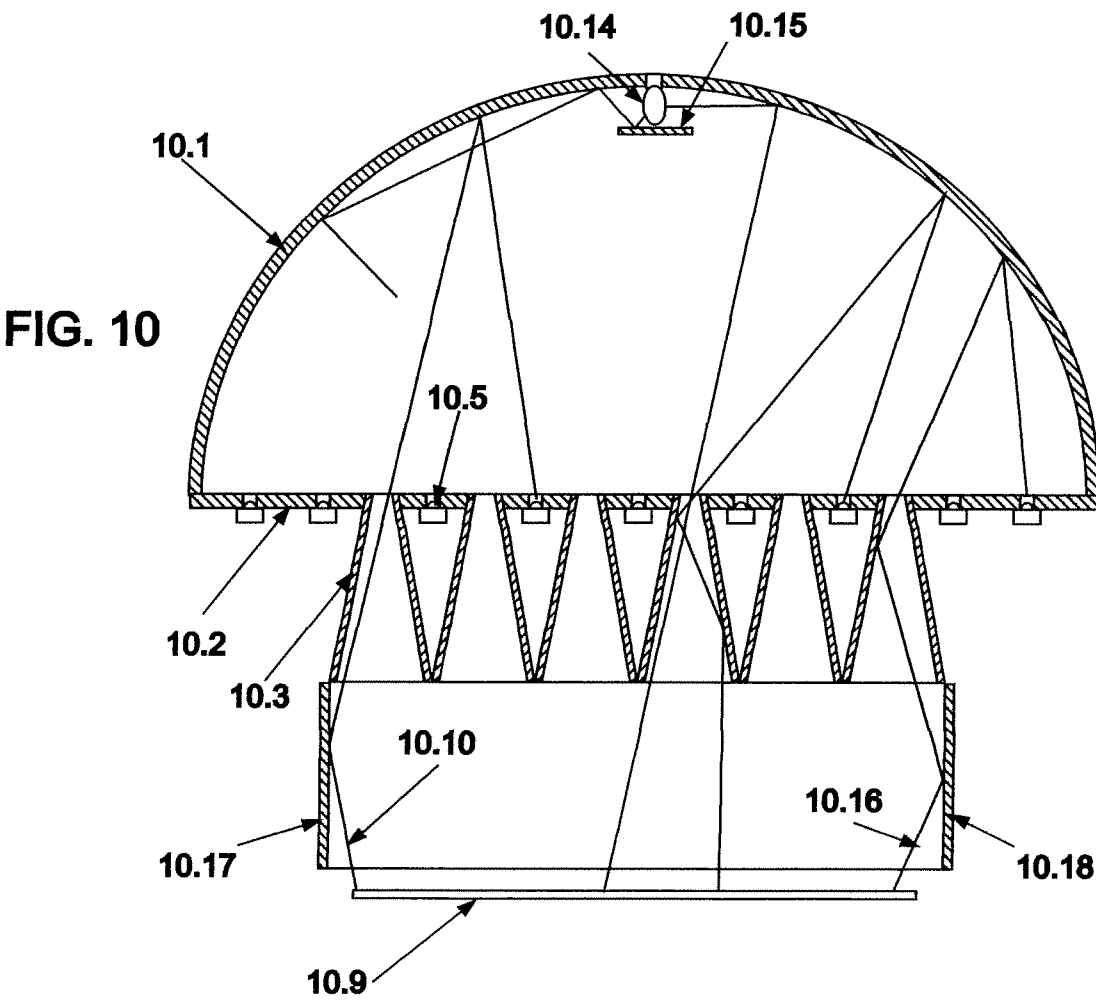
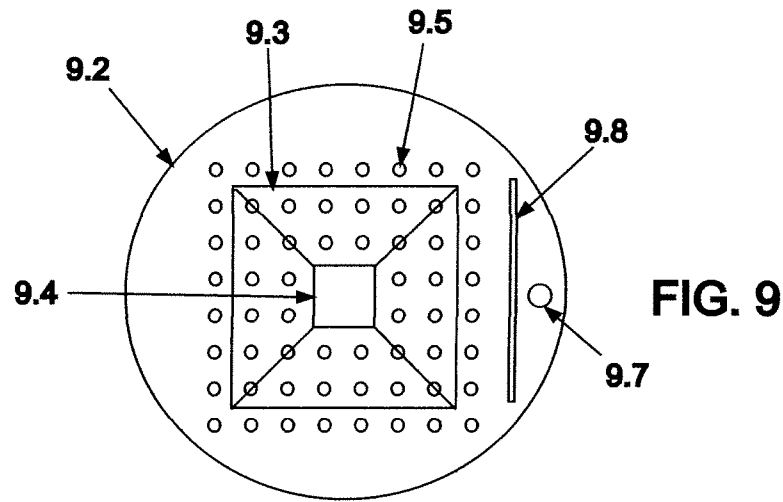


FIG. 8



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER INV. F21S8/00 F21V7/00 G01R31/26 ADD. F21V7/04 F21V7/22 F21Y101/02 F21Y105/00 F21Y113/00 G02B6/00 G02B27/09		
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) F21K F21S F21V 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.
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer von der Hardt, M

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International application No

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