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(54) Title: MULTI-FACET LIGHT ENGINE

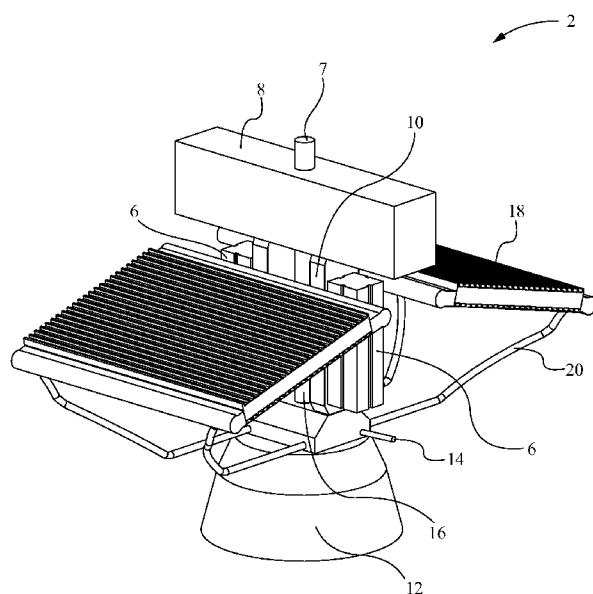


Fig. 1

(57) Abstract: A lighting assembly includes a plurality of LEDs configured as a multi-facet light engine. A first group of LEDs are arrayed as a main light source and the remaining LEDs are angled relative to the first group of LEDs to generate an intended lighting pattern. The first group of LEDs are arrayed on a first planar surface of a first substrate, and the remaining LEDs are arrayed on second planar surfaces of additional substrates positioned around the first substrate. The planar surfaces of the additional substrates are angled relative to the planar surface of the first substrate. The angles of the second planar surfaces to the first planar surface can be application specific and can be acute or obtuse.



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## Multi-Facet Light Engine

### RELATED APPLICATIONS

This Patent Application claims priority under 35 U.S.C. 119 (e) of the co-pending U.S. provisional application, serial number 61/665,179, filed June 27, 2012, and entitled “LED LIGHTING” and U.S. provisional application, serial number 61/673,660, filed July 19, 2012, and entitled “HIGH BAY LED LIGHTING AND HEAT DISSIPATION”, both by these same inventors. This application incorporates U.S. provisional application, serial number 61/665,179 and U.S. provisional application, serial number 61/673,660 in their entireties by reference.

### FIELD OF THE INVENTION:

The present invention is generally directed to the field of light emitting diode (LED) lighting. More specifically, the present invention is directed to a LED device configured as a multi-facet light engine.

### BACKGROUND OF THE INVENTION:

A light-emitting diode (LED) is a semiconductor light source. LEDs are increasingly being used in a wide variety of lighting applications. LEDs continue growing in popularity due in part to their efficiency and extended lifetimes. However, due to the directional nature of the output light, LED lighting produces shadowing effects when the LED lighting is used to directly illuminate an intended area. The shadowing effects increase as the LED lighting is increasingly separated from an intended illumination area. High bay lighting applications are those light structures designed for use in buildings with high ceilings, or “high bays” such as warehouses, manufacturing facilities, or the like where the ceilings can be 30-40 feet high. High bay facilities typically mount lighting devices at or near the ceiling. When used as a direct lighting source, LED lighting used in high bay facilities results in greater shadowing effects than used in standard offices or homes that have 8-10 feet ceilings.

To offset the shadowing effect, lighting assemblies that use LED lighting also include secondary optical elements, such as reflectors and/or lenses, to disperse the light output from the LED lighting. In this manner, the light output from the LED lighting is indirectly provided to the intended illumination source via the secondary optical elements. Although useful to reduce shadowing effects, the additional optical elements reduce efficiency and add cost and complexity

to the lighting assembly.

#### SUMMARY OF THE INVENTION:

A lighting assembly includes a plurality of LEDs configured as a multi-facet light engine.

5 A first group of LEDs are arrayed as a main light source and the remaining LEDs are angled relative to the first group of LEDs to generate an intended lighting pattern. In some embodiments, the first group of LEDs are arrayed on a first planar surface of a first substrate, and the remaining LEDs are arrayed on second planar surfaces of additional substrates positioned around the first substrate. The planar surfaces of the additional substrates are angled relative to the planar surface  
10 of the first substrate. The angles of the second planar surfaces to the first planar surface can be application specific and can be acute or obtuse. In some embodiments, the substrates are printed circuit boards.

In an aspect, a lighting assembly includes a first substrate having a first planar surface and a first plurality of light emitting diodes coupled to the first planar surface, and a plurality of  
15 second substrates each second substrate having a second planar surface and a second plurality of light emitting diodes coupled to the second planar surface. Each second substrate is positioned at an angle to the first substrate such that each of the second planar surfaces are angled relative to the first planar surface. The first planar surface and the plurality of second planar surfaces are aligned to provide illumination from the first and second plurality of light emitting diodes directly onto an  
20 external illumination surface.

In some embodiments, the first planar surface and the plurality of second planar surfaces form a concave shape. In other embodiments, the first planar surface and the plurality of second planar surfaces form a convex shape. In some embodiments, directional light is output from the first and second plurality of light emitting diodes at converging angles. In other embodiments,  
25 directional light is output from the first and second plurality of light emitting diodes at diverging angles. In some embodiments, each second planar surface forms an acute angle with the first planar surface. In other embodiments, each second planar surface forms an obtuse angle with the first planar surface.

In some embodiments, the first planar surface is parallel to the external illumination  
30 surface. In some embodiments, the first planar surface and the plurality of second planar surfaces are angled to provide a determined lighting pattern on the external illumination surface. In some embodiments, each second substrate is rotatably coupled to the first substrate so as to enable change of the angle at which the second substrate is coupled to the first substrate. In some

embodiments, the angle that each second substrate is positioned relative to the first substrate is the same. In other embodiments, the angle that one or more of the second substrates is positioned relative to the first substrate is different. In some embodiments, the first substrate includes a plurality of first outer edges and each second substrate includes at least a second outer edge,  
5 further wherein the second outer edge of each second substrate is coupled to a corresponding one first outer edge of the first substrate. In some embodiments, a number of first outer edges equals a number of second substrates. In other embodiments, a number of first outer edges is not equal to a number of second substrates.

10 BRIEF DESCRIPTION OF THE DRAWINGS:

Several example embodiments are described with reference to the drawings, wherein like components are provided with like reference numerals. The example embodiments are intended to illustrate, but not to limit, the invention. The drawings include the following figures:

15 Figure 1 illustrates a perspective view of a lighting assembly according to an embodiment.

Figure 2 illustrates a side view of the lighting assembly of Figure 1.

Figure 3 illustrates a bottom perspective exploded view of the evaporator disassembled from an exemplary light source according to an embodiment.

20 Figure 4 illustrates a top down perspective view of an exemplary evaporator having a hemispherical configuration according to an embodiment.

Figure 5 illustrates a cut out side view of the evaporator of Figure 4.

Figure 6 illustrates a cut-out side view of a multi-facet LED light source according to an embodiment.

25 Figure 7 illustrates the substrates configured such that the planar surfaces are aligned having obtuse angles to form a convex shape.

Figure 8 illustrates a top down perspective view of an exemplary multi-facet LED light source having four side substrates coupled to a main substrate.

Figure 9 illustrates a top down view of the multi-facet LED light source of Figure 8.

30 Figure 10 illustrates a perspective view of a lighting assembly according to another embodiment.

Figure 11 illustrates a side view of the lighting assembly of Figure 10.

DETAILED DESCRIPTION OF THE EMBODIMENTS:

Embodiments of the present application are directed to a lighting assembly. Those of ordinary skill in the art will realize that the following detailed description of the lighting assembly is illustrative only and is not intended to be in any way limiting. Other embodiments of the lighting assembly will readily suggest themselves to such skilled persons having the benefit of this disclosure.

Reference will now be made in detail to implementations of the lighting assembly as illustrated in the accompanying drawings. The same reference indicators will be used throughout the drawings and the following detailed description to refer to the same or like parts. In the interest of clarity, not all of the routine features of the implementations described herein are shown and described. It will, of course, be appreciated that in the development of any such actual implementation, numerous implementation-specific decisions must be made in order to achieve the developer's specific goals, such as compliance with application and business related constraints, and that these specific goals will vary from one implementation to another and from one developer to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking of engineering for those of ordinary skill in the art having the benefit of this disclosure.

Figure 1 illustrates a perspective view of a lighting assembly according to an embodiment. The lighting assembly includes a light source, a cooling system, one or more power supply units, device electronics, and a mounting structure. The cooling system includes one or more cooling loops, each cooling loop including an evaporator, a vertically ascending pipe, a radiator and a return pipe. The exemplary cooling system shown in Figure 1 includes two cooling loops, each cooling loop shares a common evaporator 14. Figure 2 illustrates a side view of the lighting assembly 2 of Figure 1. A first cooling loop includes the evaporator 14, a vertically ascending pipe 16, a radiator 18, and a return pipe 20. A second cooling loop includes the evaporator 14, a vertically ascending pipe 26, a radiator 28 and a return pipe 30. Figures 1 and 2 also show an optional reflector 12. The light source is positioned within the reflector 12. The first cooling loop and the second cooling loop are each closed loop. Although two closed loop cooling systems are shown in the lighting assembly of Figures 1 and 2, it is understood that a lighting assembly can be configured to include a single closed loop cooling system or three or more closed loop cooling systems. The lighting assembly includes a mounting structure 10 coupled to the evaporator 14 and to device electronics 8. In this exemplary configuration, the lighting assembly includes two power supplies 6. The power supplies 6 can be mounted to the mounting structure 10, a housing

of the device electronics 8, the evaporator 14, the pipes 16 and 26 or some combination thereof. An external mounting base 7 is coupled to the housing of the device electronics 8. The external mounting base 7 is used to mount the lighting assembly. In some embodiments, the external mounting base 7 is configured to receive a conduit, which in turn is mounted to an external support, such as a ceiling.

The cooling system is configured to enable the dissipation of a large amount of energy in the form of heat without heating surrounding components, such as the one or more power supply units and device electronics. In some embodiments, the cooling loop is configured as a thermal siphon that uses a boiling fluid to transport heat between the evaporator and the radiators. In some embodiments, the evaporator also functions as a device chassis, which reduces the overall part count. In some embodiments, the light source is a plurality of LEDs. LEDs have a well defined thermal performance and therefore operate properly within a defined temperature range. The cooling system is designed to maintain the LED temperatures within the defined temperature range. The one or more power supply units are arranged such that heat generated by the one or more power supply units does not negatively impact the thermal performance of the LED light source.

The evaporator 14 is a fluid-based heat exchanger that conceptually functions as a boiling unit. In some embodiments, the evaporator 14 includes a fluid reservoir that is filled, or partially filled, with a fluid or fluid mixture, herein referred to collectively as a fluid. The evaporator 14 is thermally coupled to the light source such that heat generated by the light source is transferred to the fluid within the evaporator 14. The heat causes fluid in the evaporator 14 to evaporate. The resulting vapor rises through the vertically ascending pipes 16, 26 to the radiators 18, 28. In some embodiments, each pipe 16, 26 includes a first portion that extends straight up from the evaporator 14 and a second portion that bends at an angle from completely vertical, but not horizontal, which is coupled to the radiator 18, 28. In some embodiments, the angle of the second portion is 45 degrees relative to vertical. The portion of pipes 16, 26 shown in Figure 2 is the second, angled portion. It is understood that the pipes 16, 26 can be alternatively shaped so as to provide an upward path from the evaporator 14 to the radiator 18, 28. In some embodiments, the pipes 16, 20 are configured with fins, and the pipe with fins is made of thermally conductive materials. Heat from the rising vapor can be shed during transport through the pipes 16, 26. In some embodiments, the pipes 16, 26 are configured having an oval cross-section to accommodate the internal pressure.

The radiator 18 is aligned at a decline, or downward angle relative to horizontal, such that

one end is higher than the other end. The pipe 16 is coupled to a top portion of the radiator 18 and the return pipe 20 is coupled to a bottom portion of the radiator 18. In some embodiments, the pipe 16 is coupled to an end of the top portion of the radiator 18. In some embodiments, the return pipe 20 is coupled to an end of the bottom portion of the radiator 18. Vapor entering the radiator 18 from the pipe 16 condenses and the liquid flows downward through the radiator 18 to the return pipe 20. Due to the declining orientation of the radiator 18, liquid within the radiator is gravity fed toward the bottom end and to the return pipe 20. The return pipe 20 is aligned at a decline such that one end is higher than the other end such that liquid received from the radiator 18 is gravity fed to the evaporator 14.

The second cooling loop is configured similarly as the first cooling loop. The radiator 28 is aligned at a decline, or downward angle relative to horizontal, such that one end is higher than the other end. The pipe 26 is coupled to a top portion of the radiator 28 and the return pipe 30 is coupled to a bottom portion of the radiator 28. In some embodiments, the pipe 26 is coupled to an end of the top portion of the radiator 28. In some embodiments, the return pipe 30 is coupled to an end of the bottom portion of the radiator 28. Vapor entering the radiator 28 from the pipe 16 condenses and the liquid flows downward through the radiator 28 to the return pipe 30. Due to the declining orientation of the radiator 28, liquid within the radiator is gravity fed toward the bottom end and to the return pipe 30. The return pipe 30 is aligned at a decline such that one end is higher than the other end such that liquid received from the radiator 28 is gravity fed to the evaporator 14.

The cooling loops are described above as having separate pipes 16 and 26 that couple the evaporator to the radiators 18 and 28, respectively. Alternatively, the pipes 16 and 26 can include a common portion that splits for coupling to the radiators 18 and 28. For example, a single vertically ascending pipe can be coupled to the evaporator 14, and at a top portion of the pipe, the pipe branches, such as into two branches, each branch bends at an angle from completely vertical, but not horizontal. One or more branches are coupled to the radiator 18 and one or more branches are coupled to the radiator 28. Still alternatively, multiple separate pipes can be coupled between the evaporator 14 and a single radiator. For example, two or more pipes, each pipe similar to the pipe 16, can be coupled between the evaporator 14 and the radiator 18.

As shown in Figure 1, each radiator 18 and 28 includes an input header coupled to the pipe 16 and 26, respectively. The input header laterally distributes the vapor received from the pipe. The radiator can also include one or more fluid conduits coupled to the input header and fins coupled to the fluid conduits. The fluid conduits can be arranged laterally and/or layered to form

a vertical stack of fluid conduits, each layer separated by fins. The radiator can also include an output header coupled to the one or more fluid conduits. The output header is coupled to the return pipe. In general, the radiators are designed to dissipate the heat to the atmosphere using convection cooling without the need for fans blowing over the radiators.

5 In some embodiments, the fluid is a fluid mixture consisting of at least two different types of fluids that each evaporate at a different temperature. The thermal characteristics of the cooling system and fluid mixture are configured such that the heat supplied to the fluid within the evaporator is sufficient to evaporate one of the fluids, but insufficient to evaporate the second fluid. The evaporated fluid forms vapor bubbles within the remaining non-evaporated fluid  
10 mixture. In this manner, heat transferred to the fluid mixture results in a boiling fluid, a portion of which is a vapor and another portion of which is a liquid. The configuration of the fluid mixture and the vertically ascending pipes enables a pumping means whereby the boiling fluid, including the vapor and liquid forms of fluid mixture, rises from the evaporator 14, through the pipes 16 and 26, to the radiators 18 and 28. The vapor bubbles within the boiling fluid are used to siphon non-  
15 evaporated fluid up the pipes 16 and 26 and into the radiators 18 and 28. In this manner, a pumping means is integral to the cooling loop without including a discrete pumping component such as a powered pump. An example of such a pumping means is a bubble pump found in U.S. Patent Application Publication No. 2007/0273024, which is hereby incorporated in its entirety by reference. Although the boiling fluid includes a non-evaporated liquid component, this liquid  
20 component has been heated and as such the circulating liquid provides additional thermal transport from the evaporator to the radiator. In the case where the pipes 16 and 26 are finned pipes, heat from the rising boiling fluid can be shed during transport through the pipes 16 and 26.

Alternative configurations of the lighting assembly are also contemplated. Figure 10 illustrates a perspective view of a lighting assembly according to another embodiment. The  
25 lighting assembly includes a light source, a cooling system, one or more power supply units, and a mounting structure. The cooling system includes one or more cooling loops, each cooling loop including an evaporator, a vertically ascending pipe, a radiator and a return pipe. The lighting assembly of Figure 10 functions similarly as the lighting assembly of Figure 1 to provide cooling for the light source. The exemplary cooling system shown in Figure 10 includes two cooling  
30 loops, each cooling loop shares a common evaporator 114. Figure 11 illustrates a side view of the lighting assembly 102 of Figure 10. A first cooling loop includes the evaporator 114, a vertically ascending pipe 116, a radiator 118, and a return pipe 120. A second cooling loop includes the evaporator 114, a vertically ascending pipe 126, a radiator 128 and another return pipe (not

shown). Figures 10 and 11 also show an optional reflector 112. The light source is positioned within the reflector 112. The first cooling loop and the second cooling loop are each closed loop. Although two closed loop cooling systems are shown in the lighting assembly of Figures 10 and 11, it is understood that a lighting assembly can be configured to include a single closed loop cooling system or three or more closed loop cooling systems.

As shown in Figure 10, the radiator 118 and the radiator 128 are each coupled to an input header 119 and to an output header 121. In this manner, a single condensing unit is formed having two separate radiator portions coupled via common input and output headers. In the exemplary configuration shown in Figure 10, separation of the radiators 118 and 128 forms a pathway therebetween within which accessory elements can be positioned. The vertically ascending pipes 116 and 126 are each coupled at one end to the evaporator 114 and at the other end to the input header 119. The return pipe 120 and the other return pipe (not shown) are each coupled at one end to the output header 121 and at the other end to the evaporator 114. The input header 119 laterally distributes the vapor received from the vertically ascending pipes 116 and 126. The radiators 118 and 128 can also include one or more fluid conduits coupled to the input header 119 and to the output header 121, and fins coupled to the fluid conduits. The fluid conduits can be arranged laterally and/or layered to form a vertical stack of fluid conduits, each layer separated by fins. The output header 121 collects the condensed liquid from the radiators 118 and 128.

The lighting assembly includes a mounting structure 110 coupled to the evaporator 114 and positioned in the pathway between the radiators 118 and 128. The mounting structure 110 includes handles 111 for carrying the lighting assembly. In this exemplary configuration, the lighting assembly includes four power supplies 106. The power supplies 106 can be mounted to the mounting structure 110, as shown, the evaporator 114, the vertically ascending pipes 116 and 126 or some combination thereof. An external mounting base 107 is coupled to the mounting structure 110 and/or to the evaporator 114. Bracing elements 113 provide additional support and couple the radiators 118 and 128 to the mounting structure 110, the external mounting base 107, the evaporator 114 or some combination thereof. The external mounting base 107 is used to mount the lighting assembly. In some embodiments, the external mounting base 107 is configured to receive a conduit, which in turn is mounted to an external support, such as a ceiling.

In the configuration shown in Figures 10 and 11, a separate device electronics and housing, such as device electronics 8 in Figures 1 and 2, is not included. In the configuration shown in Figures 10 and 11, device electronics are included as part of a light source assembly,

such as the light source 36 shown in Figure 3 and described below. It is understood that device electronics and housing such as the device electronics 8 in Figures 1 and 2 can be added to the lighting assembly 102, such as mounted to the mounting structure 110 and/or to the external mounting base 107.

5 As described above, the evaporator is configured to transfer heat from a light source coupled to the evaporator to fluid within the evaporator. Figure 3 illustrates a bottom perspective exploded view of the evaporator 14 disassembled from an exemplary light source 36 according to an embodiment. The evaporator 14 includes a thermal exchange surface 32. As shown in Figure 3, the thermal exchange surface 32 is a rectangular, planar surface. Alternatively, the surface can  
10 be shaped other than a rectangle. Preferably, the shape of the thermal exchange surface matches that of a corresponding thermal exchange surface of the light source. The thermal exchange surface 32 is made of a thermally conductive material, which can be the same or different than the material used to make the remainder of the evaporator. The light source 36 is thermally coupled to the thermal exchange surface 32 via a thermal interface material 34. In some embodiments, the  
15 light source 36 is a plurality of LEDs mounted to a printed circuit board. In some embodiments, the printed circuit board is modified for enhanced rigidity. Such a modification is found in the co-pending U.S. Patent Application Serial No. (Attorney Docket Number FLEX-12303), filed \_\_\_\_\_, and entitled "Relampable LED structure", which is hereby incorporated in its entirety by reference. The light source 36 is mounted to the evaporator 14 using any conventional  
20 mounting means including, but not limited to, screws, clamps, and/or brackets.

As shown in Figures 1-3, the evaporator 14 has planar surfaces as in a rectangle or other trapezoidal configuration. Alternatively, the evaporator is configured as a hemispherical evaporator. A hemispherical design mimics the geometry of a pressure vessel with its spherical based shape. Such an evaporator configuration provides significantly improved hoop strength. In  
25 some embodiments, the bottom side of the evaporator remains planar in order to interface with a planar light source. In other embodiments, the bottom side is contoured to match some or all of a non-planar thermal exchange surface of the light source. Regardless of the bottom side configuration, at least an upper portion of the evaporator can have a hemispherical configuration. Figure 4 illustrates a top down perspective view of an exemplary evaporator 40 having a  
30 hemispherical configuration according to an embodiment. Figure 5 illustrates a cut out side view of the evaporator 40 of Figure 4. The evaporator 40 includes an upper spherical casing 42 coupled to a lower base 44. The upper spherical casing 42 includes one or more openings. In the exemplary configuration shown in Figure 4 there are two openings 48 and 50. Each opening is

coupled to a vertically ascending pipe. For example, the opening 48 is coupled to the vertically ascending pipe 26 (Figure 2) and the opening 50 is coupled to the vertically ascending pipe 16 (Figure 2). The lower base 44 includes a support portion 52 configured to receive the upper spherical casing 42. The lower base 44 also includes a thermal interface plate 54. The thermal interface plate 54 includes an outer surface 56 and an inner surface 58. The outer surface 56 is thermally coupled to the light source. In some embodiments, the outer surface 56 is planar, as shown in Figure 5. In other embodiments, the outer surface is non-planar and is configured to match some or all of a surface contour of the light source. In some embodiments, the lower base 44 has a circular configuration, as shown in Figure 4. The lower base 44 can also include additional threaded attachments for the light source, such as an external ring when the lower base has a circular shape. In other embodiments, the lower base is alternatively shaped. The inner surface 58 is configured to promote nucleate boiling of the fluid. In some embodiments, the inner surface 58 has an arrangement of fins and/or divots. In some embodiments, the inner surface 58 includes a specialized surface finish that promotes nucleate boiling.

In some embodiments, the upper spherical casing 42 and the lower base 44 are designed with an interface that allows them to be made with different processes to optimize costs. The separation of the upper spherical casing and the lower base allows the upper portion to be cast, for example, while the lower base is machined, for example, to achieve higher precise and more optimal heat transfer.

In some embodiments, the thermal exchanging surface of the evaporator is a non-planar surface. In this alternative configuration, a contour of the thermal exchanging surface is configured to match that of the corresponding thermal exchange surface of the light source. In some embodiments, the light source is configured with a plurality of planar surfaces angled relative to each other. In an exemplary configuration, the light source is a multi-facet LED light source where each facet is a planar surface having a plurality of LEDs. The facets are angled so as to provide a desired lighting pattern and backfilling. Configuring the light source as a multi-facet LED light source reduces shadowing and provides light directly to an external illumination surface without having to use additional secondary optical elements such as a reflector and/or lenses.

In contrast to the planar light source 36 in Figure 3, Figure 6 illustrates a cut-out side view of a multi-facet LED light source 60 according to an embodiment. The multi-facet LED light source 60 has a main, or first, substrate 62 including a first planar surface 68. One or more LEDs (not shown) are coupled to the first planar surface 68. In some embodiments, an array of LEDs is

coupled to the first planar surface 68. A second substrate 64 and a third substrate 66 are each coupled to the first substrate 62. The second substrate 64 includes a second planar surface 70 and the third substrate 66 includes a third planar surface 72. One or more LEDs (not shown) are coupled to the second planar surface 70 and one or more LEDs (not shown) are coupled to the third planar surface 72. In some embodiments, an array of LEDs is coupled to the second planar surface 70 and an array of LEDs is coupled to the third planar surface 72. In some embodiments, each of the substrates 62, 64 and 66 are printed circuit boards to which the LEDs are mechanically and electrically coupled. In some embodiments, each substrate 62, 64 and 66 is a discrete element, such as a discrete printed circuit board. In other embodiments, each substrate 62, 64 and 66 is part of a single substrate, such as an aluminum core printed circuit board that can be folded to form the substrates 62, 64 and 66.

In some embodiments, the second substrate 64 is rotatably coupled to the first substrate 62 so as to be able to change an angle between the first planar surface 68 and the second planar surface 70, and the third substrate 66 is rotatably coupled to the first substrate 62 so as to be able to change an angle between the first planar surface 68 and the third planar surface 72. These angles are set or changed to achieve a desired lighting pattern generated by the light source 60. In the exemplary configuration shown in Figure 6, the angles are acute and the first planar surface 68, the second planar surface 70 and the third planar surface 72 form a concave shape. Figure 7 illustrates the substrates configured such that the planar surfaces are aligned having obtuse angles to form a convex shape. As also shown in Figures 6 and 7, the angle between the first planar surface 68 and the second planar surface 70 is the same as the angle between the first planar surface 68 and the third planar surface 72. Alternatively, the angles can be different. As LEDs output substantially directional light, the LEDs on each planar surface outputs a corresponding directional light. In the case of a concave configuration, such as that shown in Figure 6, the directional light output from each planar surface converges and overlaps. In the case of a convex configuration, such as that shown in Figure 7, the directional light output from each planar surface diverges. In general, the overall non-planar configuration of the light emitting surfaces 68, 70, and 72 provides different illumination angles relative to the intended illumination surface. These different illumination angles essentially reproduce the effect of a reflector or other secondary optical elements without additional components and associated losses. Light output from the LEDs is provided directly from the LEDs on the planar surfaces to the illumination area, without the light being redirected through any secondary optical elements. The angles at which the light emitting surfaces are positioned relative to each other are determined according to the desired

lighting pattern. In the case where the side substrates are rotatably coupled to the main substrate, a given multi-facet LED light source can be adjusted to change the angles of the light emitting surfaces and therefore change the lighting pattern according to a specific application. Configuring the LED light source with LEDs providing illumination from multiple different angles enables backfilling of light and reduction of shadowing.

As shown in Figure 3, the light source is thermally coupled to the evaporator to provide heat transfer. In the case of the multi-facet LED light source, one or more of the substrates is thermally coupled to the evaporator. In some embodiments, the thermal exchange surface of the evaporator is configured to match a contour of the coupled light source substrates. For example, where the substrates form a concave shape as in Figure 6, the thermal exchange surface of the evaporator can be configured to match the concave shape of the light source substrates, which would result in a convex shaped thermal exchange surface. In other embodiments, the thermal exchange surface and the light source substrates can be configured such that the light source substrates are thermally coupled to each other, and the thermal exchange surface is mechanically coupled to only the main light source substrate.

Figures 6 and 7 show two-dimensional representations of the multi-facet LED light source, which in these cases include two side substrates 64 and 66 positioned on opposing sides of the main substrate 62. It is understood that the concept can be expanded to three dimensions such that, for example, an additional side substrate extending out of the page of Figure 6 is coupled to the main substrate and an additional side substrate extending into the page of Figure 6 is coupled to the opposing side of the main substrate. Figure 8 illustrates a top down perspective view of an exemplary multi-facet LED light source having four side substrates coupled to a main substrate. Figure 9 illustrates a top down view of the multi-facet LED light source of Figure 8. In this exemplary configuration, the multi-facet LED light source 80 includes a main substrate 82 having four side substrates 84, 86, 88, 90. Each side substrate has a planar surface and one or more LEDs coupled to the planar surface. The multi-facet LED light source 80 is configured symmetrically having side substrates 84 and 88 on opposing sides of the main substrate 82, and side substrates 86 and 90 on opposing sides. Asymmetrical configurations are also contemplated as well as configurations that have odd numbers of side substrates.

As shown in Figures 8 and 9, each of the side substrates is configured as a rectangle and none of the side substrates or their corresponding planar surfaces contact each other. Alternatively, the side substrates can be alternatively shaped, such as trapezoids, and can also be configured to contact adjacent side substrates at a common edge. In general, the multi-facet LED

engine can be configured to include one or more side substrates, each having a planar surface with one or more LEDs included thereon, coupled to the main substrate, aligned symmetrically or asymmetrically around the main substrate to achieve a desired lighting pattern. The angle between the main substrate planar surface and the planar surface of a any given side substrate can be concave or convex.

The LEDs can be positioned on a planar surface in any desired pattern. The spacing between LEDs is application specific, which when combined with the angles of the light emitting surfaces, is designed to achieve a specific light intensity per unit area. The size of the LEDs impacts this determination as smaller LEDs typically generate less illumination than larger LEDs.

In an exemplary application, the lighting assembly is designed for high bay lighting, such as 40-50 feet high ceilings. In such an application, the lighting assembly generates 100-400kW. In some applications, the lighting assembly generates more than 400kW. In general, the lighting assembly is useful for those applications requiring lighting solutions with higher wattages than those found in typical office environments having 8-10 feet high ceilings.

The present application has been described in terms of specific embodiments incorporating details to facilitate the understanding of the principles of construction and operation of the multi-facet LED device. Many of the components shown and described in the various figures can be interchanged to achieve the results necessary, and this description should be read to encompass such interchange as well. As such, references herein to specific embodiments and details thereof are not intended to limit the scope of the claims appended hereto. It will be apparent to those skilled in the art that modifications can be made to the embodiments chosen for illustration without departing from the spirit and scope of the application.

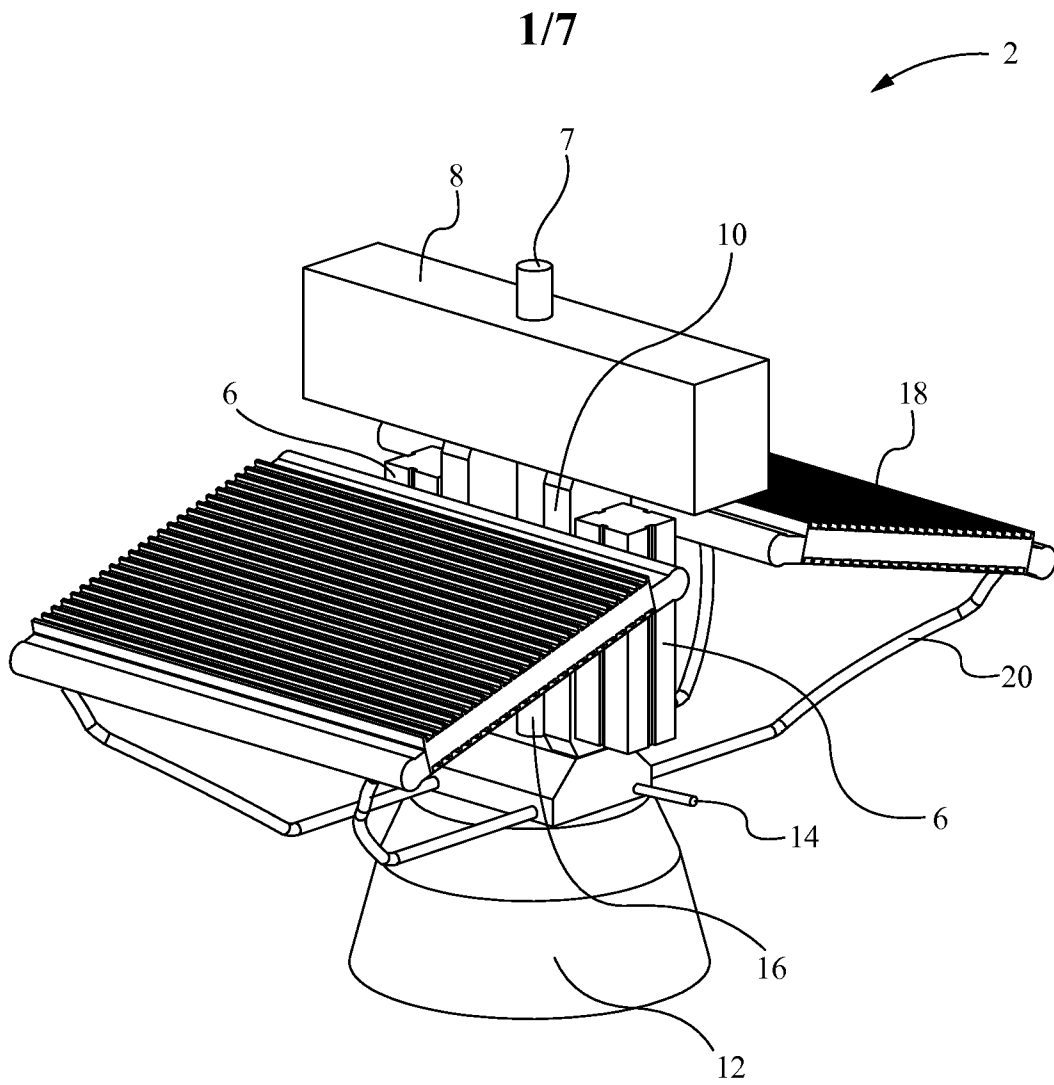
## C L A I M S

What is claimed is:

1. A lighting assembly comprising:
  - a. a first substrate having a first planar surface and a first plurality of light emitting diodes coupled to the first planar surface; and
  - b. a plurality of second substrates each second substrate having a second planar surface and a second plurality of light emitting diodes coupled to the second planar surface, wherein each second substrate is positioned at an angle to the first substrate such that each of the second planar surfaces are angled relative to the first planar surface, further wherein the first planar surface and the plurality of second planar surfaces are aligned to provide illumination from the first and second plurality of light emitting diodes directly onto an external illumination surface.
2. The lighting assembly of claim 1 wherein the first planar surface and the plurality of second planar surfaces form a concave shape.
3. The lighting assembly of claim 1 wherein the first planar surface and the plurality of second planar surfaces form a convex shape.
4. The lighting assembly of claim 1 wherein directional light is output from the first and second plurality of light emitting diodes at converging angles.
5. The lighting assembly of claim 1 wherein directional light is output from the first and second plurality of light emitting diodes at diverging angles.
6. The lighting assembly of claim 1 wherein each second planar surface forms an acute angle with the first planar surface.
7. The lighting assembly of claim 1 wherein each second planar surface forms an obtuse angle with the first planar surface.
8. The lighting assembly of claim 1 wherein the first planar surface is parallel to the external

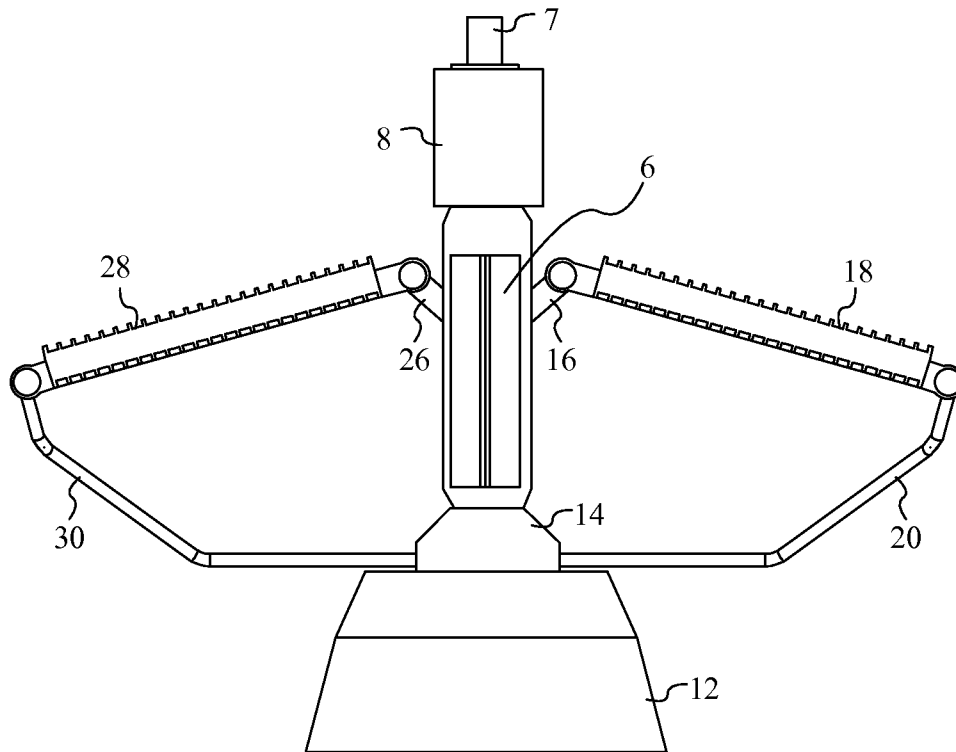
illumination surface.

9. The lighting assembly of claim 1 wherein the first planar surface and the plurality of second planar surfaces are angled to provide a determined lighting pattern on the external illumination surface.
10. The lighting assembly of claim 1 wherein each second substrate is rotatably coupled to the first substrate so as to enable change of the angle at which the second substrate is coupled to the first substrate.
11. The lighting assembly of claim 1 wherein the angle that each second substrate is positioned relative to the first substrate is the same.
12. The lighting assembly of claim 1 wherein the angle that one or more of the second substrates is positioned relative to the first substrate is different.
13. The lighting assembly of claim 1 wherein the first substrate comprises a plurality of first outer edges and each second substrate comprises at least a second outer edge, further wherein the second outer edge of each second substrate is coupled to a corresponding one first outer edge of the first substrate.
14. The lighting assembly of claim 13 wherein a number of first outer edges equals a number of second substrates.
15. The lighting assembly of claim 13 wherein a number of first outer edges is not equal to a number of second substrates.

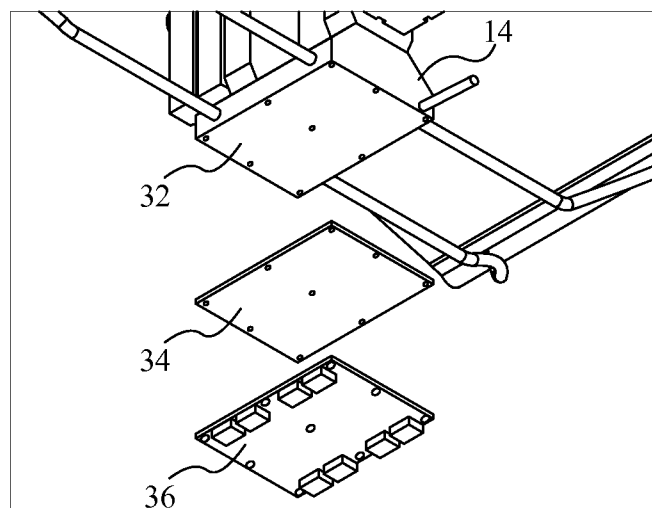


**Fig. 1**

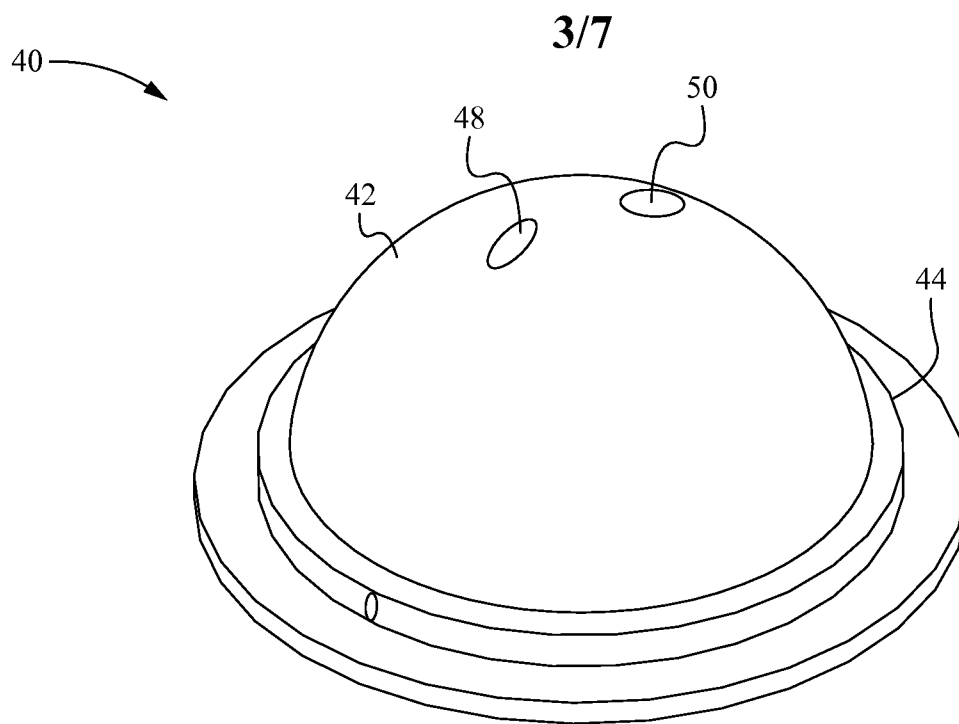
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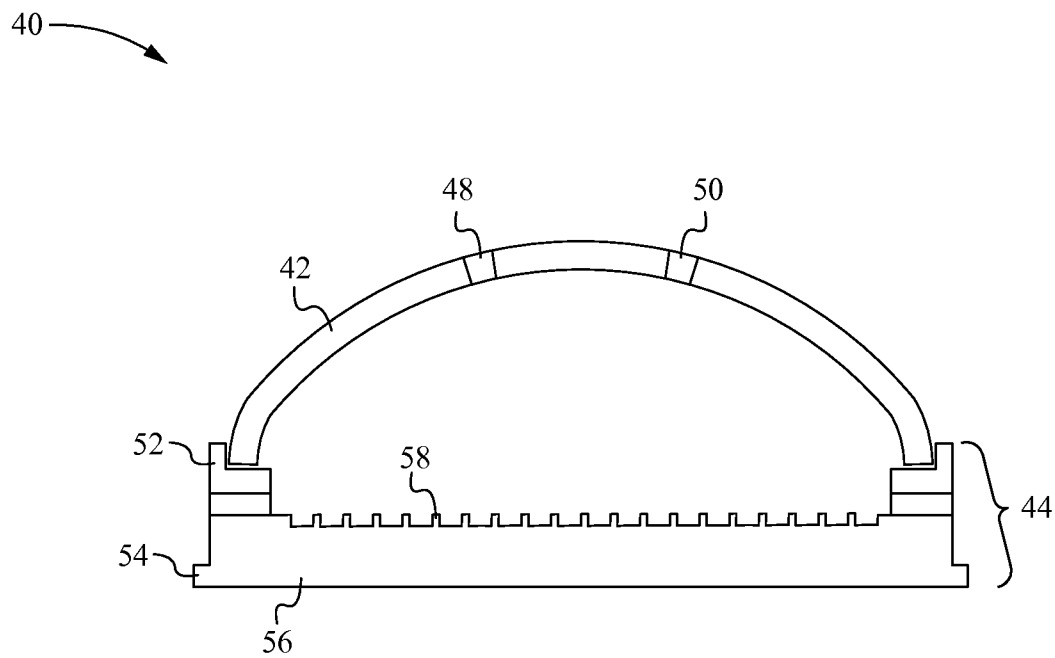
**Fig. 2**



**Fig. 3**



**Fig. 4**



**Fig. 5**

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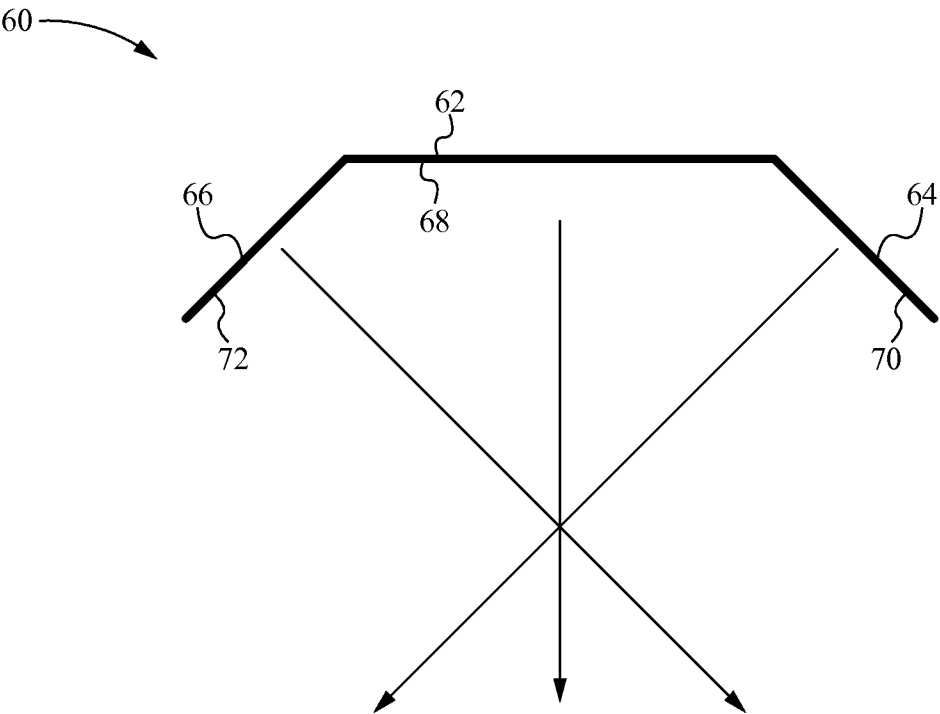


Fig. 6

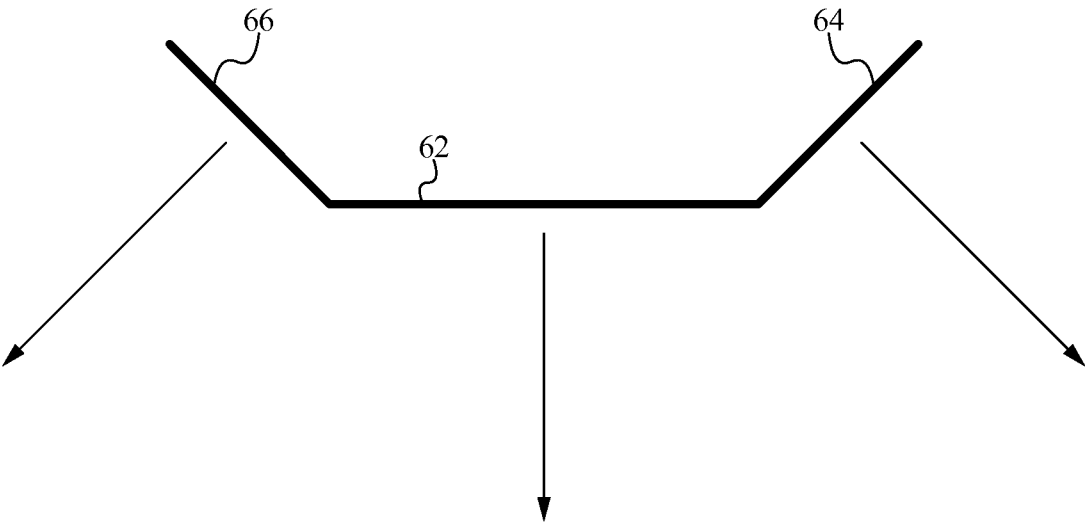
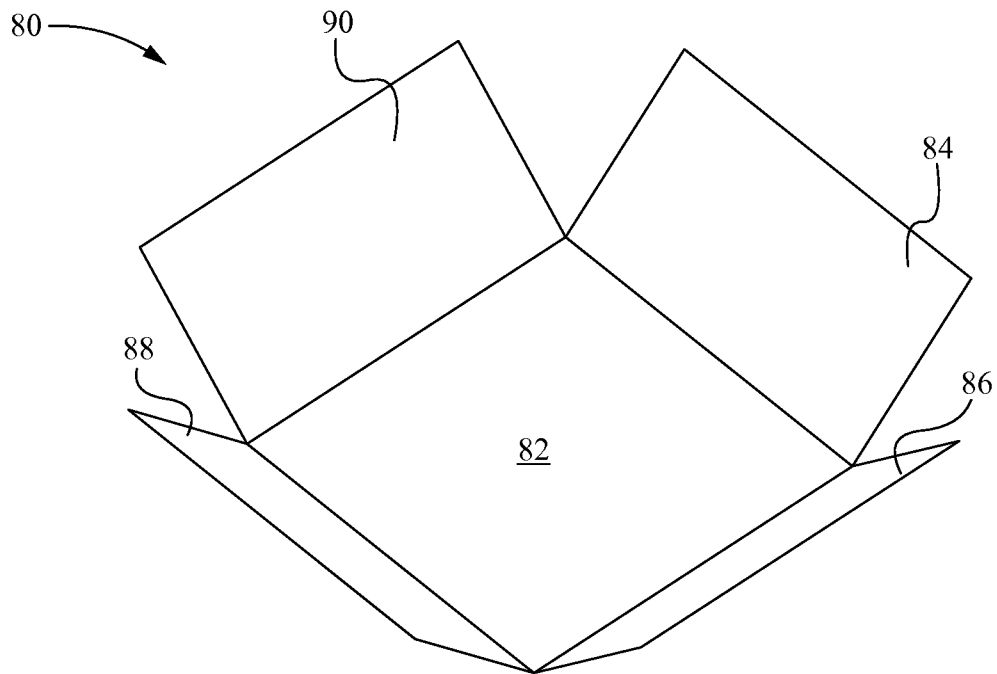
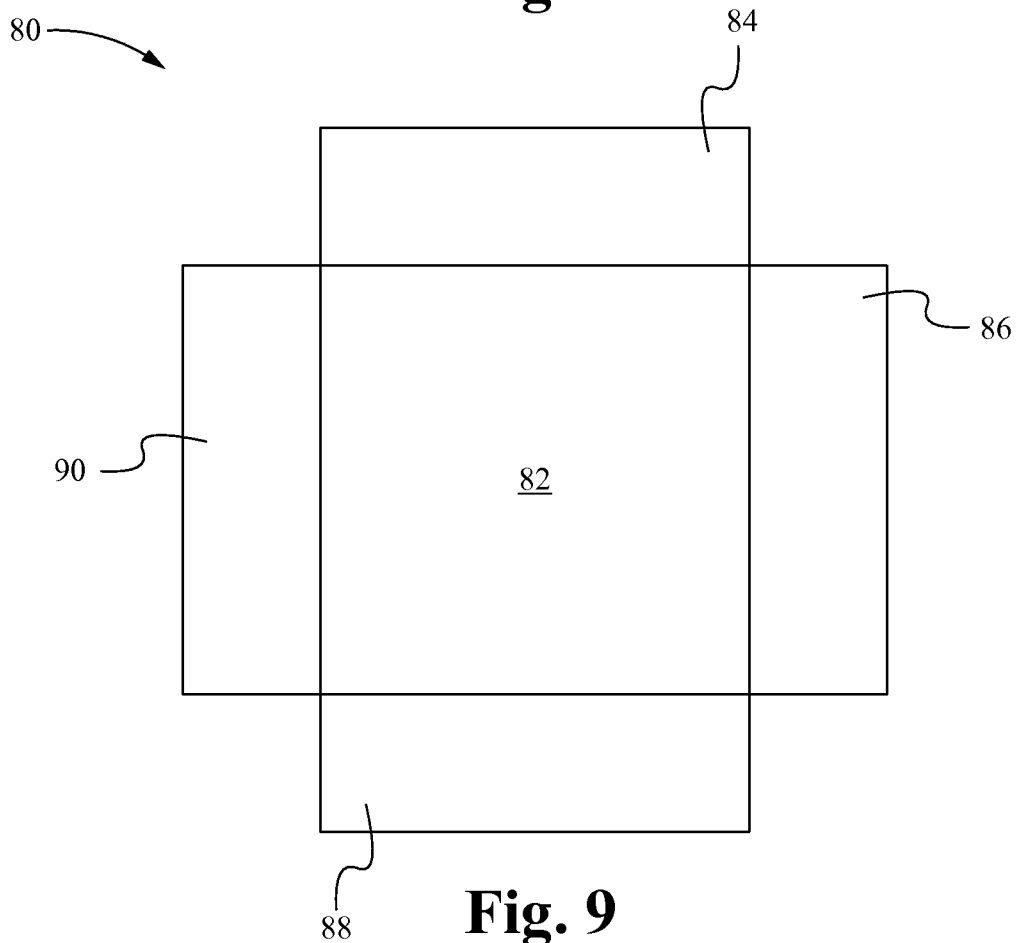


Fig. 7

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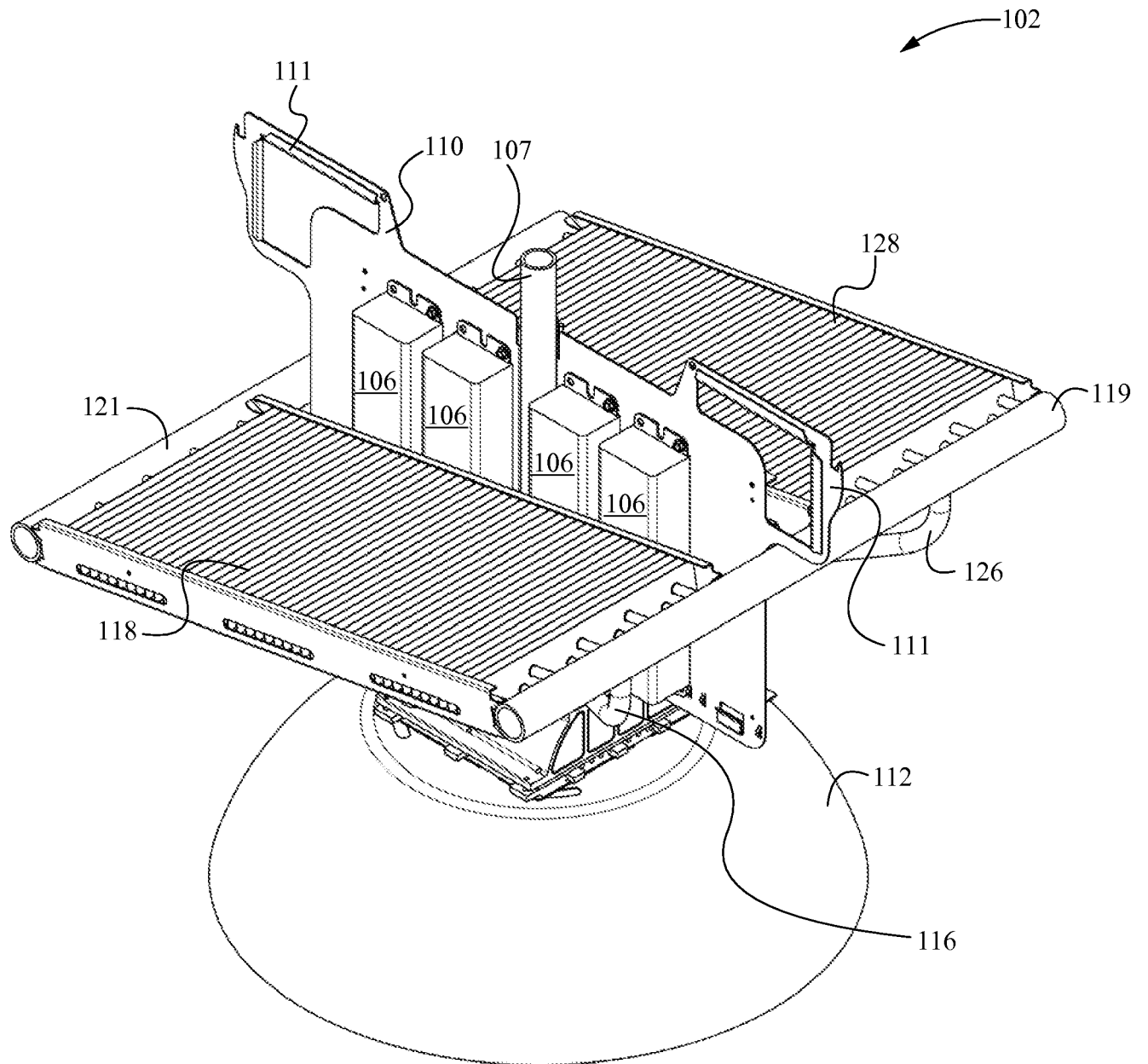


**Fig. 8**



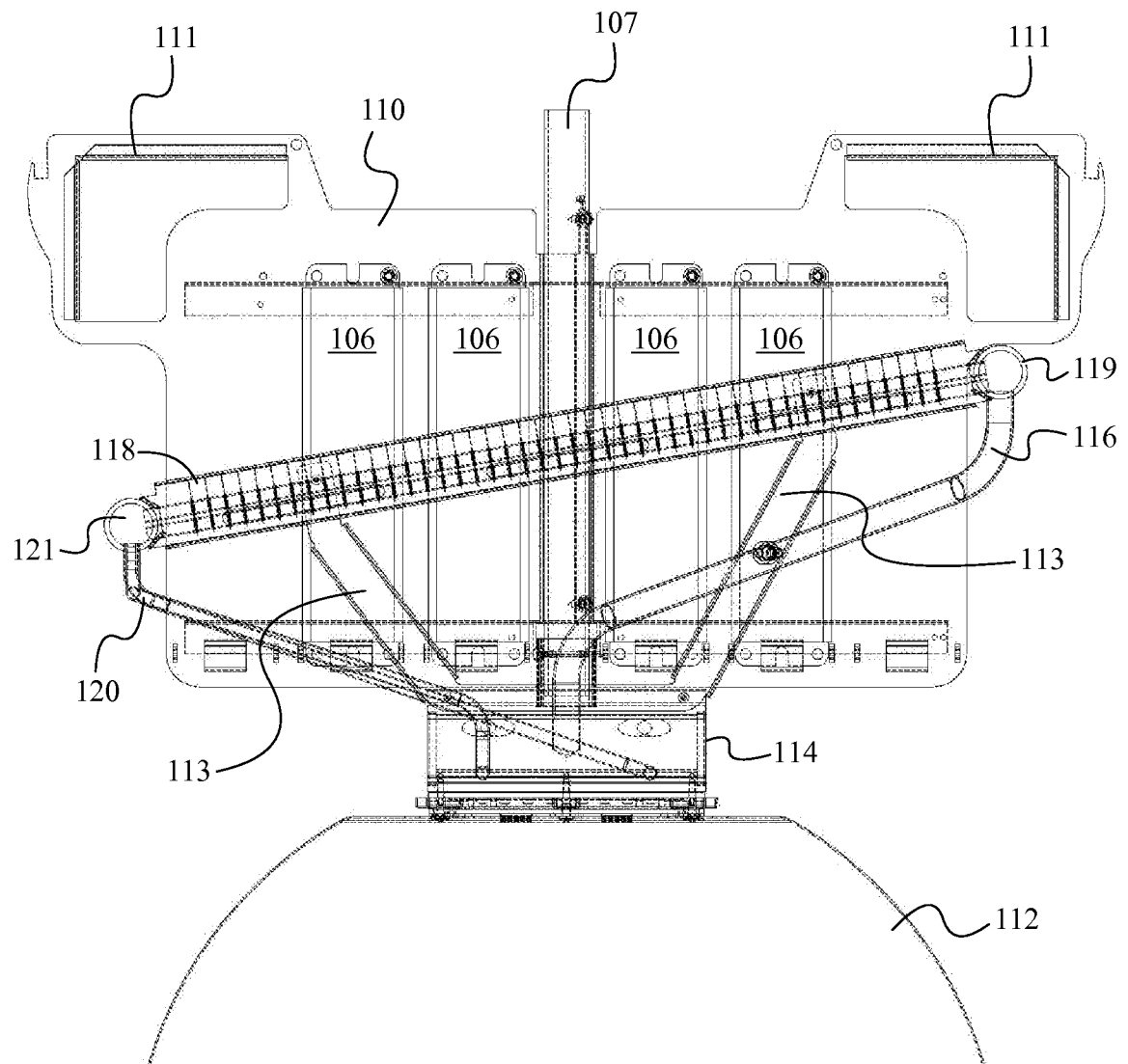
**Fig. 9**

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**Fig. 10**

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**Fig. 11**

**A. CLASSIFICATION OF SUBJECT MATTER****F21V 21/00(2006.01)i, F21V 14/02(2006.01)i, F21V 17/00(2006.01)i**

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)

F21V 21/00; H05B 33/00; F21S 4/00; H01J 61/94; F21S 810; F21V 2100; F21V 14/02; F21V 17/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &amp; Keywords:LED, multi-facet, angle, substrate

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | US 2010-0214780 A1 (RUSSEL GEORGE VILLARD) 26 August 2010<br>See abstract, paragraphs [0050]-[0053], [0064]-[0066], [0117]-[0119], claims 1-16 and figures 2A-12. | 1-15                  |
| A         | US 2009-0230833 A1 (HSUEH-CHUNG KAO et al.) 17 September 2009<br>See abstract, paragraphs [0020]-[0028], claims 1-11 and figures 1-10.                            | 1-15                  |
| A         | US 2010-0073941 A1 (YEN-WEI HO) 25 March 2010<br>See abstract, paragraphs [0014]-[0018], claims 1-7 and figures 1-6.                                              | 1-15                  |
| A         | US 6848819 B1 (KARLHEINZ ARNDT et al.) 01 February 2005<br>See abstract, column 3, line 56 - column 5, line 9, claim 1 and figures 1A-2D.                         | 1-15                  |
| A         | US 2006-0012286 A1 (BRIAN D. CULL et al.) 19 January 2006<br>See abstract, paragraphs [0028]-[0030], claims 1-4 and figures 7A-7B.                                | 1-15                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

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"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

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Date of the actual completion of the international search

26 September 2013 (26.09.2013)

Date of mailing of the international search report

**26 September 2013 (26.09.2013)**

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2013/048276**

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)                                                                                                                              | Publication<br>date                                                                                          |
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