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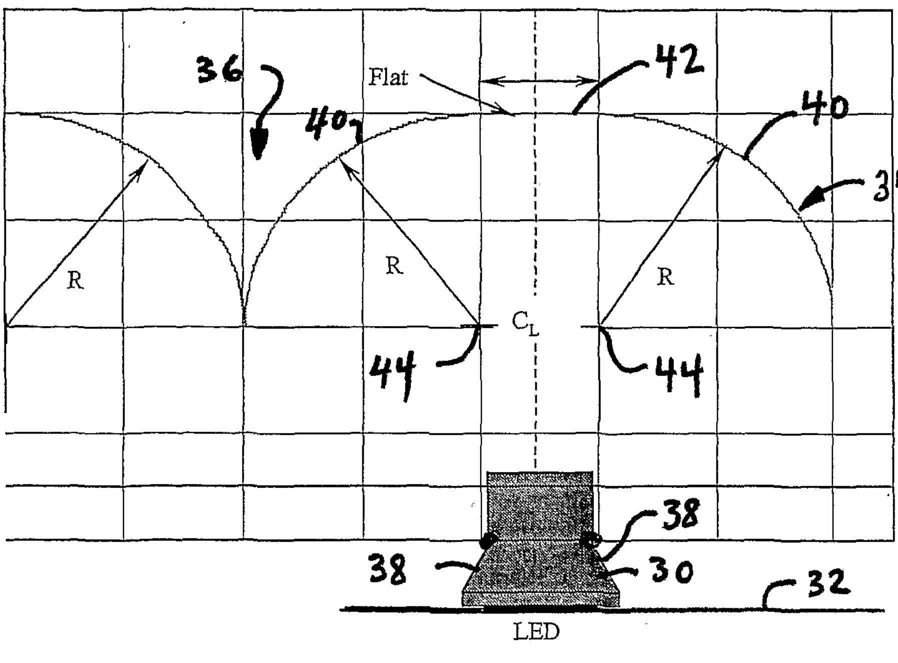
(54) **Title:** COLLECTION OPTICS FOR LED ARRAY WITH OFFSET HEMISPHERICAL OR FACETED SURFACES



(57) **Abstract:** An array of LEDs is provided having a lens array for collecting divergent light from each LED. Each lens in the array is associated with a respective LED and has a compound shape including a curved surface that may be spherical or may have an offset aspherical shape. The curved surfaces are centered about each side of its associated LED. The lens may alternatively include faceted surfaces that approximate the curved lens surface.

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COLLECTION OPTICS FOR LED ARRAY WITH OFFSET HEMISPHERICAL OR FACETED SURFACES

Inventors: Duwayne R. Anderson and Roland Jasmin, Jr.

This invention claims the benefit of co-pending U.S. Provisional Application No. 60/516,382, entitled "Collection Optics for Led Array with Offset Hemispherical or Faceted Surfaces", filed October 31, 2003, the entire disclosure of which is hereby incorporated by reference as if set forth in its entirety for all purposes.

Background of the Invention

Solid state lighting devices such as, for example, light emitting diodes (LEDs) are used for a number of applications. One type of such solid state lighting device is disclosed in International Patent Application No. PCT/US03/14625, filed May 28, 2003, entitled High Efficiency Solid-State Light Source And Methods Of Use And Manufacture, the details of which are hereby incorporated by reference.

Arrays of light-emitting diodes (LEDs) are used for many purposes. For example, arrays of LEDs are sometimes used in conjunction with arrays of lenses. The lens arrays are used to collect and collimate the light from the array of LEDs. However, since the light from LEDs emits into a wide range of angles, there is often a need to collect the light and project it more usefully. For example, as seen in Fig. 1, an array 10 of such light sources 12, such as, for example, LEDs are sometimes used with an array of lenses 14. Such lens arrays 14 are typically mounted above the LED array 10 and are used to collect and collimate the light from the LED array 10. The simplest and most common lens shape has a spherical surface to it, as shown in Fig. 1. The problem with the configuration in Fig. 1 is that the spherical design of each lens

16 assumes that the LED 12 is a point source of light. However, in reality LEDs are not point sources of light. Rather, LEDs project distributed light in a wide range of angles.

Figure 2 shows a more accurate depiction of light emitted from an LED array 18. Figure 2 shows that LEDs 20 often emit light from their sides, in which case the light is distributed and each LED 20 actually looks more like two closely spaced sources of light, rather than a single point source. Therefore, for some types of light sources, a single spherical lens 22 is an inadequate optic because it does not adequately gather or collect the disparate light so that it is more usefully projected. This makes the simple plano-convex lens an inappropriate shape for efficiently collecting and directing the light from such LED sources. In order to adequately collect such disparate light, two or more lenses would be required for each light source or LED.

In order to overcome the above-described problems, some light sources include a focusing optic that has an aspherical surface to collect disparate light from a source. The configuration of the aspherical surface for any given application may be determined, for example, by using typical lens makers equations know to those skilled in the art. Thus, the optimal aspheric shape for a collimating optic used with a highly divergent source such as an LED may be calculated. Aspherical surfaces are a well-established means of collimating the light from highly divergent sources. However, aspherical optics are complex and often too expensive and/or require expensive tooling to be practical. Even spherical lens arrays can be too expensive to manufacture for some low-cost, high-volume applications.

Examples of these various means of collimating the light from and LED are found in the following U.S. Patents to Marshall et al (U.S. Pat. No. 6,547,423), Wu

(U.S. Pat. No. 6,502,956), and Suzuki (U.S. Pat. No. 6,330,017), the details of which are herein incorporated by reference.

What is needed is a low-cost optic for a highly distributed and divergent light source that collects the light so that it is projected in a concentrated beam.

Additionally, what is needed is a low-cost solution for approximating complex optical surfaces to give adequate collection efficiency for arrays of light sources for lighting (non-imaging) applications.

Summary of the Invention

In one aspect of the present invention, a lens array for use with an array of LEDs is provided in which each lens has a compound shape, but is still constructed of curved surfaces. Since each side of the LED emits primarily into the curved hemisphere on that side, each side of the LED emits light that primarily transmits through what looks like a plano-convex lens centered over that side. This means that the geometry of the curved surfaces is optimized for each portion of the LED from which it collects light. Therefore, only one lens may be used for each light source or LED.

Another aspect of this invention uses cut facets to approximate the shape of either a spherical or an aspheric surface. These facets may be machined into a tool that works like a drill bit, or they may be machined by a router or grinder. When used in conjunction with a custom drill bit, the faceted angles will lie on a circularly symmetric surface. When used in conjunction with a router or grinder, the facets can be used to build tiered structures, such as micro-pyramids, in, for example, a square tile pattern that fully fills the surface. The faceted approach can accommodate flattened shapes necessitated in this case by the fact that the LED has two facets on either side of its extended width.

While not intended for imaging applications, this approach is an inexpensive way of improving the collection efficiency of the optic.

A lens array is provided for collecting light from a light source in which the light source emits divergent light. At least one lens is provided having a compound shape including curved surfaces that are centered about each side of the light source. The curved surface may be spherical or may have an offset aspheric shape. The lens may include a flat top portion separating the curved surfaces with the curved surfaces being equidistant from a center line extending through the light source. The lens includes geometry that is optimized for each portion of the light source from which that section of the lens collects light.

The lens may include an approximated aspheric shape that includes faceted surfaces that approximates an aspheric shape. The faceted surfaces may be formed to have a symmetrically circular shape by a tool, such as, for example, a drill bit. Alternatively, the faceted surface may be formed of micro-pyramids forming a square tile pattern by a tool, such as, for example, a surface lathe or grinder.

These and other embodiments are described in more detail in the following detailed descriptions and the figures.

The foregoing is not intended to be an exhaustive list of embodiments and features of the present invention. Persons skilled in the art are capable of appreciating other embodiments and features from the following detailed description in conjunction with the drawings.

Brief Description of the Drawings

Figure 1 is a view of a typical point source light array with simple plano-convex lenses having spherical surface profiles a point source of light.

Figure 2 is a view of a typical LED array emitting widely disparate light with simple plano-convex lenses.

Figure 3 is a view of a single LED and associated lens in an array with a spherical lens having a compound shape.

Figure 4 is a plot showing faceted surfaces approximating an aspheric shape.

Figure 5 is a partial cross-section of an LED array having a faceted lens in which the faceted surfaces are circularly symmetrical.

Figure 6 is a top view of a lens array in which the faceted surfaces are in the form of micro-pyramids forming a square tile pattern.

Detailed Description of the Invention

Representative embodiments of the present invention are shown in Figs. 3-7, wherein similar features share common reference numerals.

More specifically, Fig. 3 shows an LED 30 mounted on a circuit board 32 with an associated lens 34 from an array that may comprise, for example, one thousand (1,000) LED's. Each LED 30 typically emits disparate light from the sides 38 so that the light is widely dispersed. In order to more effectively collect the light, lens 34 is formed of a compound shape that includes a curved surfaces 40 separated by a flat surface 42. Curved surfaces 40 may have a spherical or offset aspheric shape, although in Fig. 3 a spherical surface is shown. Lens 34 is centered about center line C_L extending through LED 30 so that light from each side 38 of LED 30 is projected into the respective curved surface 40 on that side. Each curved surface 40 is centered about a radius R extending from a center point 44. Each radius R extends from center point 44 that lies directly above an imaginary light point source on each side of the

LED 30. The location of center point 44 and length of radius R are determined by standard rules for finding a radius of curvature and center point distance for a plano-convex lens. Even though light is emitted along the sides 38 of LED, center point 44 is determined by assuming a point source of light at each side of LED 30. Thus, each side 38 of LED 30 emits light that primarily transmits through what is effectively a plano-convex lens centered over that side 38. The geometry of each spherical surface 40 is optimized for each portion of the LED 30 from which it collects light. In other words, the dimensions of the lens 34 is determined by finding the preferred plano-convex shape for collimating light on one side of the LED (assuming a point source of light) by standard rules known to those skilled in the art. However, each plano-convex shape (curved surface 40) is incorporated into a single lens separated by flat surface 42. This configuration effectively provides half of a lens on one side of the LED 30 and another half of a lens on another side of the LED 30.

Another aspect of this invention uses cut facets 46 to approximate the shape of a curved surface aspheric surface 48 as seen in Fig. 4. Curved or aspheric surface 48 may be determined according to standard lens makers formulas. For example, these formulas calculate the optimal aspheric shape for a collimating optic used with a highly divergent light source, such as an LED. However, for the purposes of collecting light from an LED in non-imaging applications, a precisely and expansively manufactured aspheric lens surface is not needed. Light from an LED may be collected adequately by faceted surfaces 46 that approximate the aspheric surface 48.

As seen in Fig. 5, faceted surfaces 50 on lens 52 may be formed by a tool or mold into which faceted surfaces 50 are machined by a tool that works like a drill bit, for example. For instance, the facet surfaces may be formed on a drill bit, which is then used to form the mold. The resulting lens may include faceted surfaces 50 that are circularly symmetric as seen in Fig. 5. Faceted surfaces 50 are separated by a flat surface 51. Lens 52 of Fig. 5 includes dimensions that are merely illustrative and are not intended to be limiting.

Alternatively, as seen in Fig. 6, faceted surfaces 54 may be machined in a tool or mold for the lens 56 with, for example, a router or grinder. As seen in Fig. 6, the resulting lens 56 may include faceted surfaces 54 that form micro-pyramids in a square tile pattern that fully fills the surface of each lens 56. Faceted surfaces 54 are formed centrally along perpendicular axes of symmetry. Each square lens 56, for example, may have equal sides having a dimension in the range of about 1mm to about 1.9mm. In all the embodiments, the lens encapsulates the LED, which may have a width dimension of, for example, about 0.25 mm. Often tools for material removal might also apply, such as water-jet or laser cutting tools.

As seen in Figs. 5 and 6, the faceted surfaces can accommodate flattened shapes necessitated in this case by the fact that the LED's 30, as seen most clearly in Fig. 6, has faceted sides 58 on either side of its extended width.

The lens array may be formed of a potting gel that is cured within a tool or mold to have the desired configuration. The mold may be metal such as, for example, stainless steel. Alternatively, the lens array may be formed of glass or other material that may be machined to the desired configuration. Furthermore, the number of faceted surfaces may vary according to the desired precision. Additionally, the width of the lens in all embodiments may vary according to a number of factors such as, for example, the grid spacing of the LED's.

Persons skilled in the art will recognize that many modifications and variations are possible in the details, materials, and arrangements of the parts and actions which have been described and illustrated in order to explain the nature of this invention and that such modifications and variations do not depart from the spirit and scope of the teachings and claims contained therein.

WHAT IS CLAIMED:

1. A lens for collecting light from a light source having plural sides, wherein the light source emits divergent light, comprising;

at least one lens having a compound shape including curved surfaces that are distributed around of the light source, wherein the curved surfaces may have an offset spherical or an offset aspheric shape.

2. The lens of claim 1, wherein the lens includes a flat top portion separating the curved surfaces.

3. The lens of claim 1, wherein the spherical surfaces are equidistance from a center line extending through the light source.

4. The lens of claim 1, wherein the lens is symmetric about a center line extending through the light source.

5. The lens of claim 1, wherein the lens includes sections that collect light from respective portions of the light source.

6. The lens of claim 5, wherein each curved section of the lens includes geometry that is optimized for each portion of the light source from which that section of the lens collects light.

7. The lens of claim 1, wherein the lens includes an offset aspheric shape.

8. The lens of claim 7, wherein the lens includes a faceted surface that approximates the aspheric shape.

9. The lens of claim 8, wherein the faceted surfaces have a symmetrically circular shape.

10. The lens of claim 8, wherein the faceted surfaces have a square tile pattern.

11. The lens of claim 10, wherein the square tile pattern fully fills a surface of the lens.

12. The lens of claim 10, wherein the square tile pattern is formed from micro-pyramids.

13. The lens of claim 1, wherein the lens is an array of lenses.

14. An LED module that emits light from plural sides, comprising;

at least one lens having a compound shape including curved surfaces that are distributed around the light source, wherein the curved surfaces may have an offset spherical or an offset aspherical shape.

15. The LED module of claim 14, wherein the module comprises an array of LEDs.

16. The LED module of claim 15, wherein each LED is associated with a lens having a compound shape including curved surfaces that are centered about each side of the LED.

17. The LED module of claim 16, wherein the lens comprises an array of lens with each LED having an associated lens.

18. The LED module of claim 14, wherein the lens includes a flat top portion separating the curved surfaces.

19. The LED module of claim 14, wherein the spherical surfaces are equidistance from a center line extending through the light source.

20. The LED module of claim 18, wherein the lens is symmetric about a center line extending through the light source.

21. The LED module of claim 14, wherein the lens includes sections that collect light from respective portions of the light source.

22 The LED module of claim 14, wherein each section of the lens includes geometry that is optimized for each portion of the light source from which that section of the lens collects light.

23. The LED module of claim 14, wherein the lens includes an aspheric shape.

24. The LED module of claim 23, wherein the lens includes a faceted surface that approximates the aspheric shape.

25. The LED module of claim 24, wherein the faceted surface has a symmetrically circular shape.

26. The LED module of claim 24, wherein the faceted surface has a square tile pattern.

27. The LED module of claim 26, wherein the square tile pattern fully fills a surface of the lens.

28. The LED module of claim 26, wherein the square tile pattern is formed from micro-pyramids.

29. The LED module of claim 14, further comprising an array of LED's and an array of lenses, wherein each LED is associated with a respective lens.

30. A method of manufacturing a lens for a light source, the light source emitting divergent light, comprising;

providing at least one lens having a compound shape including curved surfaces that are distributed around the light source, wherein the curved surfaces may have an offset spherical or an offset aspherical shape.

31. The method of claim 30, wherein the lens comprises a lens array.

32. The method of claim 31, wherein the lens array is formed in a mold.

33. The method of claim 31, wherein each lens in the lens array includes faceted surfaces.

34. The method of claim 33, wherein the shape of the lens array is formed in the mold by a drill bit-type tool.

35. The method of claim 34, wherein each lens in the lens array is circularly symmetric.

36. The method of claim 33, wherein the shape of the lens array is formed in the mold by a surface lathe, router, or grinder.

37. The method of claim 36, wherein each lens in the lens array is formed of micro-pyramids in a square tile pattern.

38. The method of claim 32, wherein the lens array is formed of a potting gel.

39. The method of claim 31, wherein the lens array is formed of glass.

40. The method of claim 39, wherein each lens in the lens array is circularly symmetric.

41. The method of claim 39, wherein each lens in the lens array is formed of micro-pyramids in a square tile pattern.

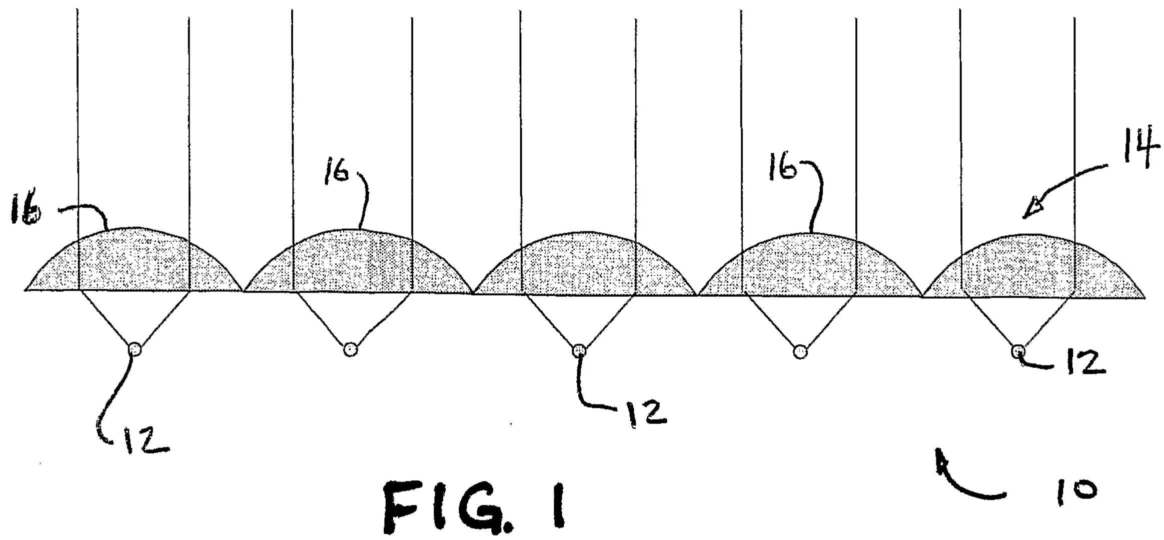


FIG. 1
(PRIOR ART)

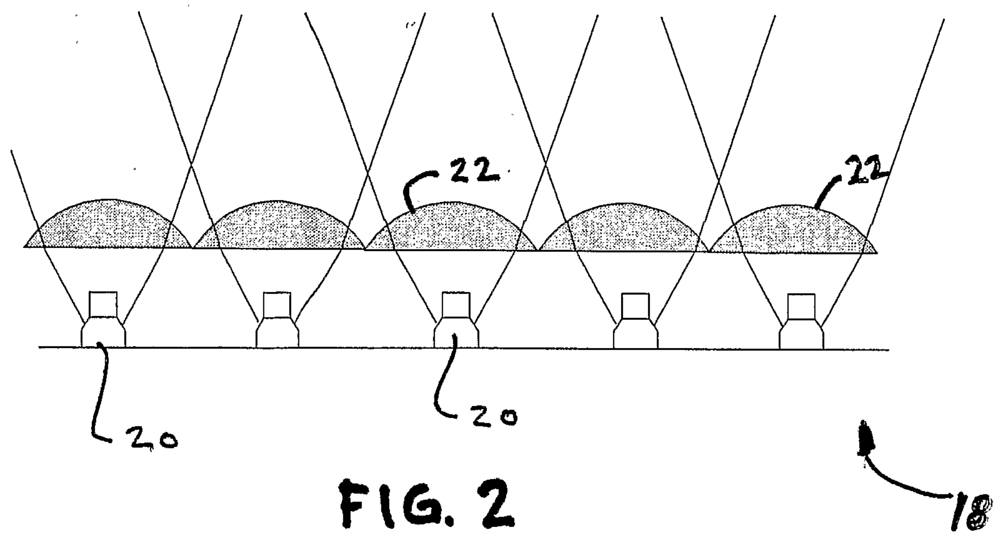


FIG. 2
(PRIOR ART)

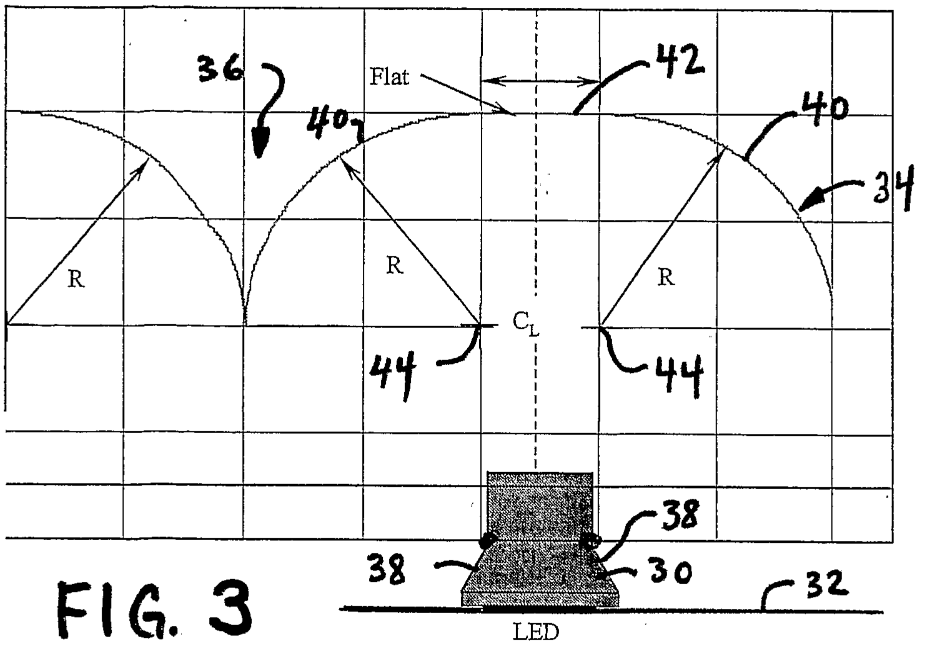

36
Flat
42
40
40
34
R
R
R
C_L
44
44
38
38
30
32
LED

FIG. 3

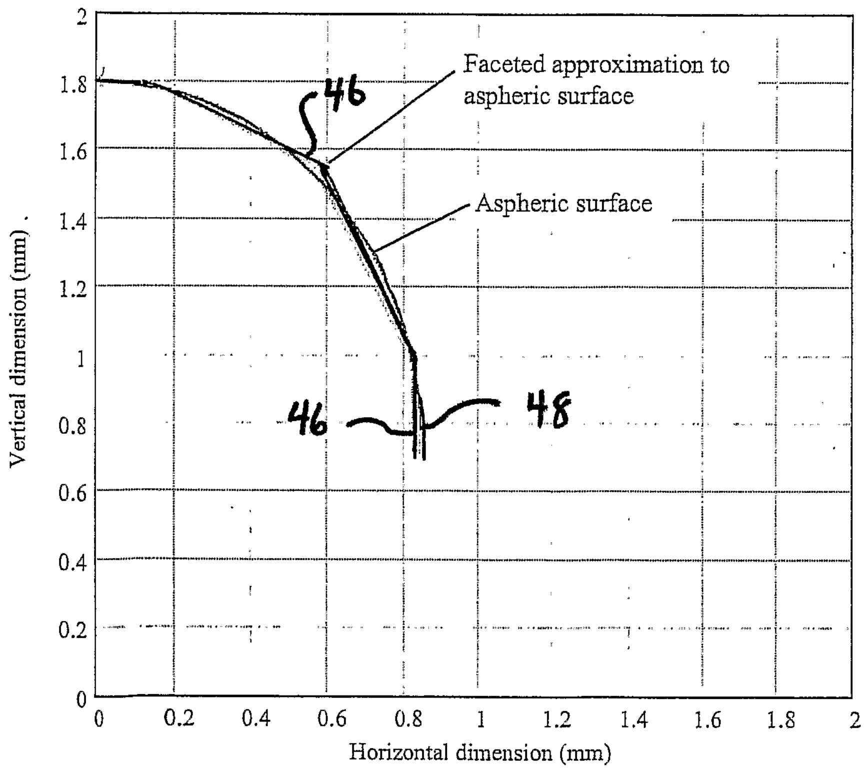
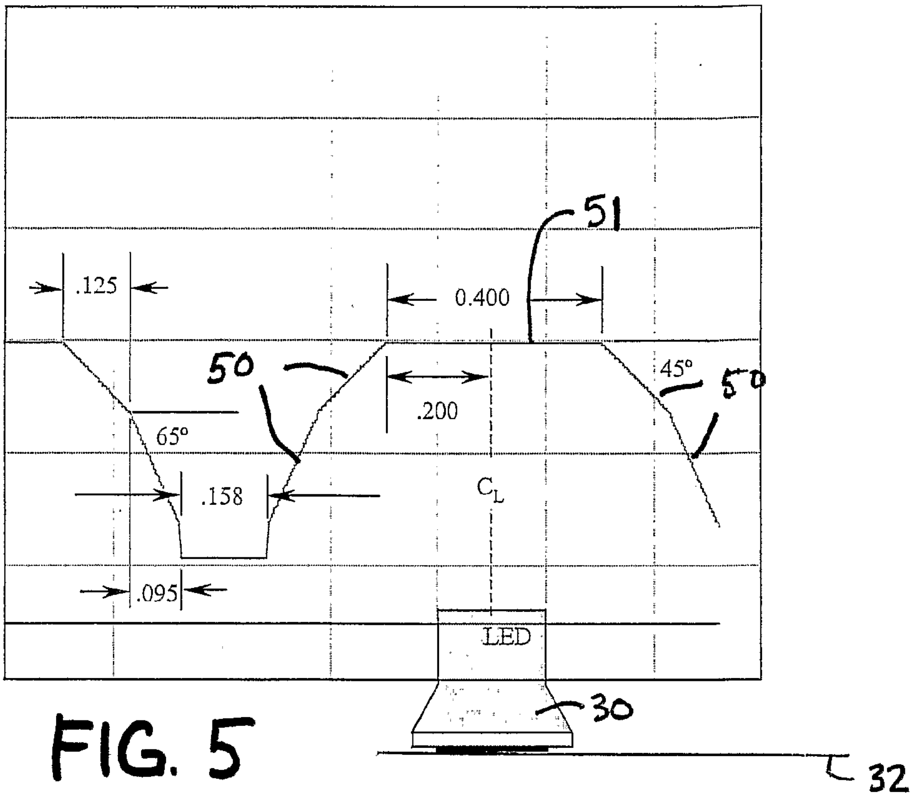

Faceted approximation to aspheric surface
46
Aspheric surface
46
48
Vertical dimension (mm)
Horizontal dimension (mm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

FIG. 4


51
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50
45°
50
.200
65°
.158
C_L
.095
LED
30
32

FIG. 5

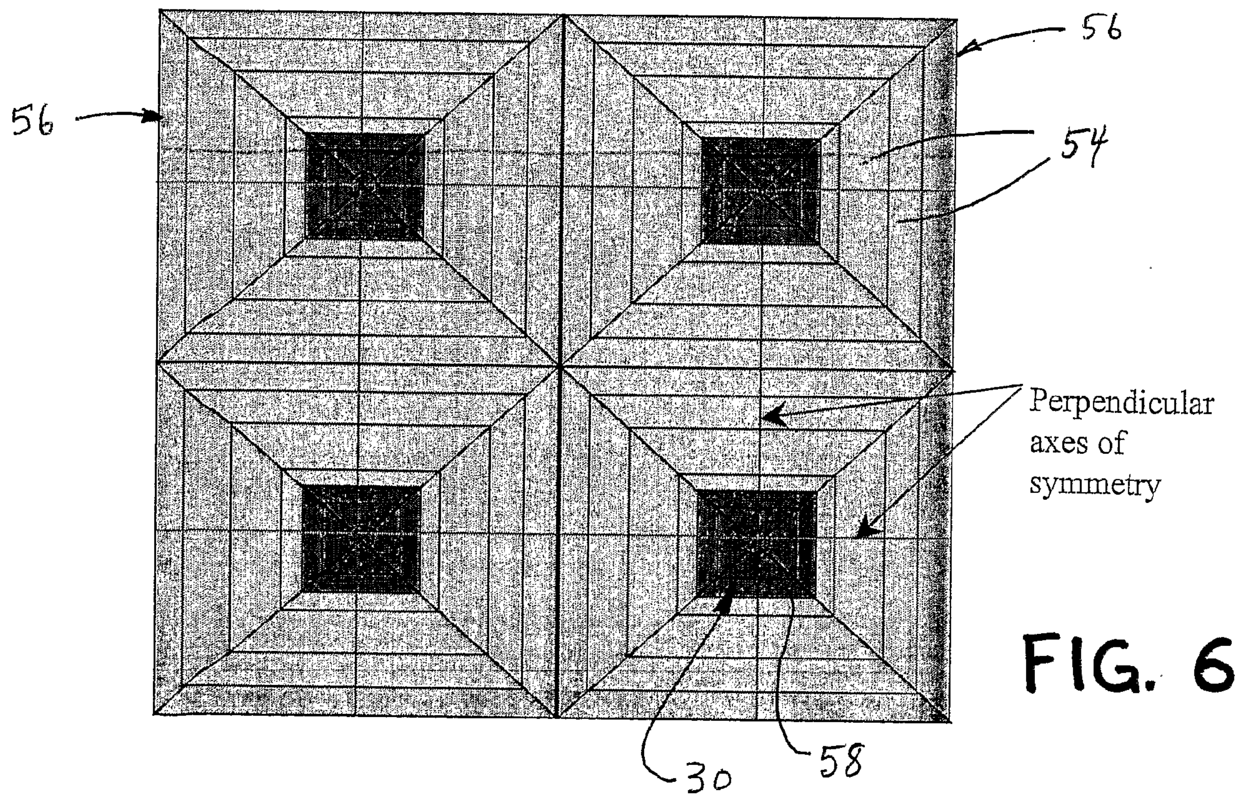
56
56
54
Perpendicular
axes of
symmetry
30
58

FIG. 6