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(71) Demandeur/Applicant:
ALTAIR ENGINEERING, INC., US

(72) Inventeurs/Inventors:
SIMON, DAVID L., US;
IVEY, JOHN, US;
LAVERING, GORDON R., US

(74) Agent: SIM & MCBURNEY

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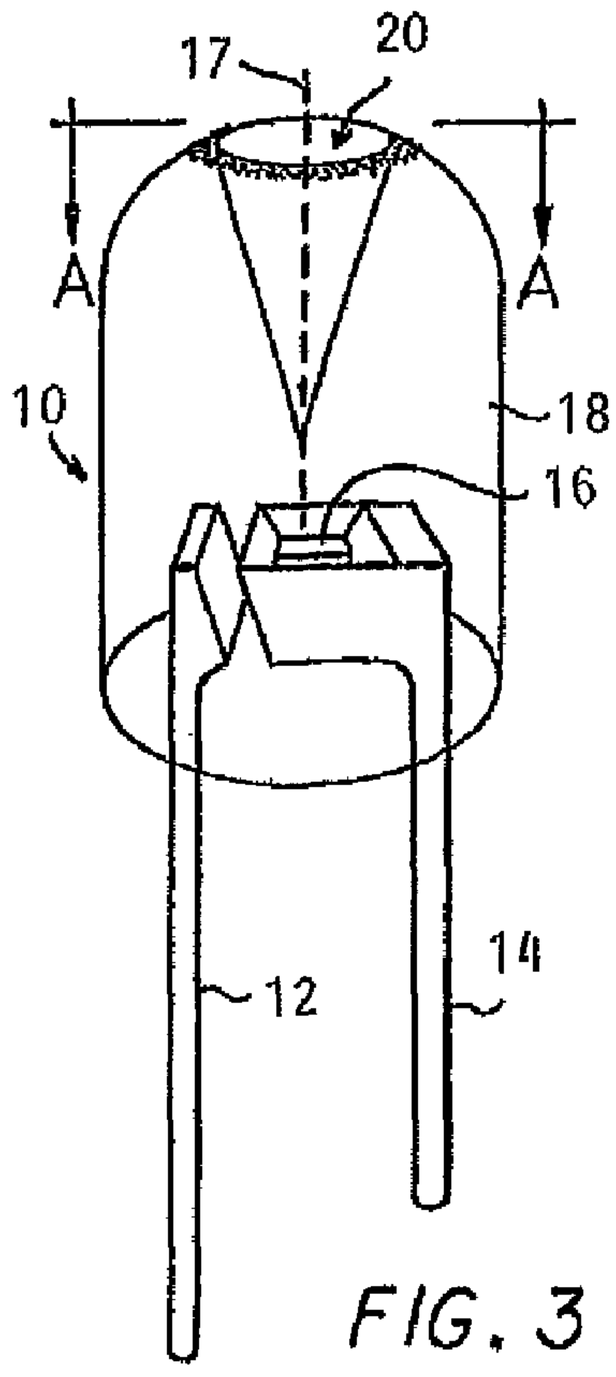


FIG. 3

(57) Abrégé/Abstract:
A light modifier for an LED producing light about a central axis is provided. The light modifier includes a lens defining an indentation. The indentation is angled relative to the central axis by an amount less than a complementary angle of a critical angle of the lens along the indentation. The lens can reduce the appearance of a bright spot created by the LED.

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(71) Applicant *(for all designated States except US)*: **ALTAIR ENGINEERING, INC.** [US/US]; 1820 East Big Beaver Road, Troy, Michigan 48083-2031 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **SIMON, David L.** [US/US]; c/o ALTAIR ENGINEERING, INC., 1820 East Big Beaver Road, Troy, Michigan 48083-2031 (US). **IVEY, John** [US/US]; c/o ALTAIR ENGINEERING, INC., 1820 East Big Beaver Road, Troy, Michigan 48083-2031 (US). **LAVERING, Gordon R.** [US/US]; c/o ALTAIR ENGINEERING, INC., 1820 East Big Beaver Road, Troy, Michigan 48083-2031 (US).

(74) Agents: **BASILE, SR., Andrew R.** et al.; Young Basile Hanlon & Macfarlane, PC, 3001 West Big Beaver Road, Suite 624, Troy, Michigan 48084 (US).

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[Continued on next page]

(54) Title: LED LENS

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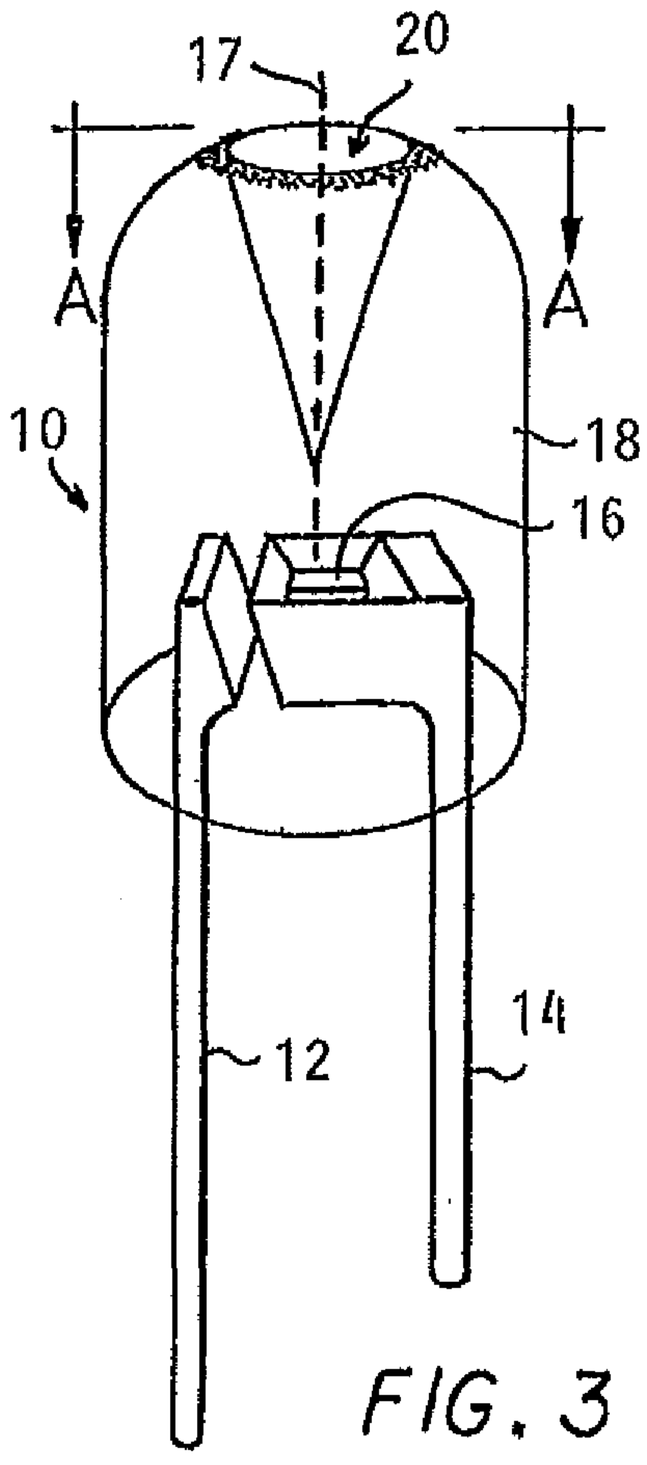


FIG. 3

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LED LENS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Patent Application No. 12/687,519 filed January 14, 2010 and to U.S. Provisional Patent Application No. 61/144,853, filed January 15, 2009, both of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

[0001] The present invention relates to a lens for an LED.

BACKGROUND

[0002] Light emitting diodes (LEDs) have many advantages over fluorescent tubes. LEDs are more efficient, last longer, and are less sensitive to vibrations and low temperatures. To take advantage of the benefits of LEDs, LEDs are being included in lights of various shapes, such as in the shape of fluorescent tubes. However, known LEDs are constrained by the directional light output of the LEDs in contrast to, for example, the uniform non-directional light output of fluorescent tubes. One way of spreading the directional light output from an LED is to direct the light through a diffuser.

BRIEF SUMMARY

[0003] Known LEDs provide directional light output that may result in the appearance of bright spots of light. Thus, known lights in the shape of fluorescent tubes including LEDs, for example, may appear different from fluorescent tubes, which are characterized by their uniform light distribution.

[0004] A light modifier for an LED which produces light about a central axis is described herein. The light modifier can reduce the appearance of bright spots resulting from the directional light output of the LED. In one example of such a light modifier, a lens defines an indentation. The indentation is angled relative to the central axis by an amount less than a complementary angle of a critical angle of the lens along the indentation.

[0005] In another embodiment, a replacement light for a fluorescent tube usable in a fluorescent fixture is provided. The replacement light includes a support structure having a longitudinal axis. At least one LED is connected to the support structure, and the at least one LED produces light about respective central axes. At least one lens is

positioned along the central axis of the at least one LED, and the lens defines an indentation angled relative to the central axis by an amount less than a complementary angle of a critical angle of the lens along the indentation. At least one electrical connector at a longitudinal end of the support structure is in electrical communication with the at least one LED.

[0006] In another embodiment, a method of forming a lens defining an indentation angled by an amount less than a complementary angle of a critical angle of the lens along the indentation relative to a central axis of light produced by an LED is provided. The method includes extruding material in an extrusion direction to form a sheet of greater width than the lens. The sheet has a same profile as the lens. The method also includes sectioning the sheet to form the lens.

[0007] In another embodiment, a replacement light for a fluorescent tube usable in a fluorescent fixture is provided. The replacement includes a support structure having a longitudinal axis. Multiple LEDs connected to the support structure, and the LEDs producing light about respective central axes. At least one light pipe is positioned along the central axis of one of the LEDs, and the light pipe has a reflector positioned over at least a portion of the LED such that the light initially emitted from the LED strikes the reflector. At least one electrical connector at a longitudinal end of the support structure is in electrical communication with the multiple LEDs.

[0008] These and other embodiments will be described in additional detail hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views, and wherein:

[0010] FIG. 1 is a graph showing light intensity distributions of multiple types of tube shaped lights;

[0011] FIG. 2 is a graph showing an efficiency of a diffuser;

[0012] FIG. 3 is a perspective view of an example of an LED including a lens according to the invention;

[0013] FIG. 4 is a cross section along line A-A of the LED in FIG. 3;

[0014] FIG. 5 is a graph showing a light intensity distribution of the LED of FIG. 3 compared to a known LED;

[0015] FIG. 6 is a perspective view of another LED according to the invention;

[0016] FIG. 7 is a cross section along line B-B of the LED in FIG. 6;

[0017] FIG. 8 is a partially exploded, perspective view of an example of a tube-shaped LED light according to the invention;

[0018] FIG. 9 is a cross section of the light of FIG. 8 along line C-C;

[0019] FIG. 10 is a graph showing a light intensity distribution of the light shown in FIG. 8 compared to a fluorescent tube;

[0020] FIG. 11 is a partial perspective view another tube shaped LED light according to the invention;

[0021] FIG. 12 is a cross section of the light shown in FIG. 11 along line D-D;

[0022] FIG. 13 is a cross section view taken along a longitudinal axis of another tube shaped light according to the invention;

[0023] FIG. 14 is a perspective view of an extruded sheet of lenses according to the invention;

[0024] FIG. 15 is a partial perspective view another tube shaped LED light according to the invention;

[0025] FIG. 16 is a cross section of the light shown in FIG. 15 along line E-E;

[0026] FIG. 17 is a cross section view of another tube shaped LED light according to the invention;

[0027] FIG. 18 is a cross section view of another tube shaped LED light according to the invention;

[0028] FIG. 19 is a cross section view of another tube shaped LED light according to the invention;

[0029] FIG. 20 is a partial perspective view another tube shaped LED light according to the invention;

[0030] FIG. 21 is a cross section of the light shown in FIG. 20 along line F-F;

[0031] FIG. 22 is a perspective view of another LED according to the invention;

[0032] FIG. 23 is a cross section along line G-G of the LED in FIG. 22;

[0033] FIG. 24 is a perspective view of another LED according to the invention;

[0034] FIG. 25 is a cross section along line H-H of the LED in FIG. 24;

[0035] FIG. 26 is a perspective view of another example of a tube-shaped LED light according to the invention;

[0036] FIG. 27 is a cross section of the light of FIG. 26 along line I-I;

[0037] FIG. 28 is a partially exploded, perspective view of another example of a tube-shaped LED light according to the invention; and

[0038] FIG. 29 is a cross section of the light of FIG. 28 along line J-J.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0039] Examples of lenses for use with LEDs are discussed below with reference to FIGS. 1-14. As shown in FIG. 1, a fluorescent tube produces a generally constant light intensity along its entire length, which is indicated by line 100. An LED, however, generally produces light in a Lambertian distribution, with a majority of the light within a few degrees of a central axis normal to the LED. The light concentrated around the central axis is referred to as a "bright spot." When LEDs are used in a fluorescent tube shaped light, the light can have the appearance of several bright spots. For example, line 102 in FIG. 1 includes four spikes, each of which represents the bright spot of light produced by an LED or a closely-spaced group of LEDs (e.g., a six-pack package of LEDs). A similar light distribution problem can exist when LEDs are used in other types of lights, such as LED-based flashlights and LED-based lights sized to replace incandescent bulbs.

[0040] A diffuser can be placed in the path of light produced by an LED to reduce the appearance of bright spots. However, as shown by line 104 in FIG. 1, merely diffusing the light does not result in a light distribution that is sufficiently similar to the light distribution of a fluorescent tube for many consumers. This is in part because, as shown in FIG. 2, the efficiency of a diffuser generally decreases as the angle of incidence of light striking the diffuser (i.e., the angle between a beam of light and a line normal to the diffuser) increases. As a result, if light does not strike a diffuser at a low angle of incidence, there is a high probability the light will be reflected instead of diffused. One goal of using a diffuser is to spread light to dark areas between two adjacent LEDs. However, light travelling toward these dark spots may have a high angle of incidence relative to a diffuser. As a result, diffusion can be least efficient (i.e., reflecting light instead of diffusing it) in the area between two adjacent LEDs. Therefore, diffusers alone do not provide a light distribution that is sufficiently similar to the light distribution of a fluorescent tube for many consumers.

[0041] FIG. 3 shows an example of an LED package 10 including electrical leads 12 and 14, an LED 16, and a lens 18. The LED 16 can be a single P-N junction, or the LED 16 can include multiple P-N junctions (e.g., a "six-pack" of P-N junctions).

Multiple P-N junctions can be sufficiently closely spaced to be approximated as a single point source of light and will therefore be considered the same as a single point source of light for the purposes of this description. Also, the LED package 10 can include additional structures not shown, such as a reflector between the LED 16 and the lead 14 to reflect errant light, or a heat sink (e.g., if the LED is high powered or otherwise generates enough heat to warrant the heat sink).

[0042] The LED 16 can produce light in a Lambertian distribution centered about a central axis 17, which can extend normally to the LED 16. However, the LED 16 may also exhibit a different distribution of light, in which case the axis 17 can still represent at least one of a center point of the distribution of light and an axis normal to the LED 16. The LED 16 can be an LED of any power rating, e.g. 0.05 W, 0.10 W, 0.25 W, or a high power LED, such as a surface-mount LED of the type available from Nichia. Electrical connectors other than the illustrated leads 12 and 14 can be included depending on the type of LED 16 used. The LED 16 can produce a variety of wavelengths of light, such as white light, red light, blue light, or ultra-violet light.

[0043] The lens 18 can encase the LED 16 and can also encase portions of the leads 12 and 14 as shown in FIG. 3. The lens 18 can protect the LED 16 from the external environment to reduce corrosion or other damage to the LED 16. The lens 18 can be translucent or transparent and can be made from a light transmitting material such as polycarbonate, acrylic, or glass.

[0044] As best shown in FIG. 4, the lens 18 can define a conical indentation 20. The conical indentation 20 can be centered over the axis 17 of the LED 16, and the indentation 20 can have a diameter large enough to cover the bright spot of light produced by the LED 16. (Given that the term "bright spot" is subjective, the bright spot does not necessarily have a definite diameter. However, the size of the bright spot can be determined based on, for example, consumer opinion or a standardized objective consideration, e.g., an area through which a certain percentage of the light produced by the LED 16 passes.) While the indentation 20 should be large enough to cover the bright spot produced by the LED 16, the indentation 20 can itself produce a dark spot since light can be totally internally reflected by a continuous sidewall 21 of the conical indentation 20. As a result, the indentation 20 should not be greatly larger than the bright spot. Thus, a trade-off can exist in determining the size of the indentation 20 between reflecting light that would otherwise produce the bright spot and not creating too large of a dark spot. A way of mitigating the dark spot created by the indentation 20 is discussed below.

[0045] The conical indentation 20 can include sidewalls 21 angled relative to the central axis 17 such that light produced by the LED 16 that contacts the sidewall 21 is

totally internally reflected. Since the critical angle for light contacting the sidewall 21 is measured from a line normal to the sidewall 21, the angle θ_1 between the axis 17 and the sidewall 21 should be less than a complementary angle of the critical angle of the sidewall 21. For example, if the lens 18 is made from polycarbonate and air surrounds the LED package 10, the critical angle for light striking the sidewall 21 is approximately forty degrees. That is, if light strikes the sidewall 21 at an angle greater than forty degrees from a line normal to the lens 18, then the light will be totally internally reflected. Since the angle θ_1 shown in FIG. 4 is measured from the sidewall 21, not normal to the sidewall 21, light is totally internally reflected if it strikes the sidewall 21 at an angle less than fifty degrees relative to the sidewall 21 (i.e., the complementary angle to the critical angle, forty degrees). Therefore, each sidewall 21 can be angled up to approximately fifty degrees relative to the axis 17 to achieve total internal reflection (TIR).

[0046] While the angle θ_1 can be up to, in the example above, fifty degrees, the specific angle θ_1 actually used can be selected based on the desired distribution of light. As the angle θ_1 increases, the indentation 20 distributes light over a greater area radial of the axis 17, which may reduce the amount of light directed to an area to be illuminated. However, as the angle θ_1 decreases, a greater amount of light is produced in the vicinity around the indentation 20, which can create the appearance of a bright halo of light around the indentation 20. Angling the sidewall 21 to produce a bright halo of light may allow a large amount of light to be directed toward a space to be illuminated while still reducing the appearance of bright spots.

[0047] Another consideration in selecting both the diameter of the indentation 20 and the angle θ_1 is the depth of the indentation 20, since the depth is a function of the diameter and angle θ_1. For example, the depth of the indentation 20 can be selected such that a tip of the indentation is near the LED 16 to reduce the distance light has to travel from the LED 16 before contacting the indentation 20, thereby reducing the likelihood that the light will be refracted by an imperfection in the lens 18 prior to contacting the indentation 20.

[0048] One way of determining an optimal indentation 20 diameter, sidewall 21 angle θ_1, and indentation 20 depth is objectively through experimentation or calculation, with the size, angle θ_1, and depth selected to obtain as even a distribution of light as possible (or some other distribution of light, if desired). For example, as shown in FIG. 4, the indentation 20 extends to adjacent the LED 16 and is angled approximately twenty degrees relative to the axis 17. Keeping the angle θ_1 relatively small (e.g., between approximately fifteen and twenty five degrees) can produce the bright halo of light around the indentation 20.

[0049] As discussed earlier, diffusion is generally inefficient when the angle of incidence is large. However, the halo of light that can be produced around the indentation 20 can have a small angle of incidence relative to an annular portion of the lens 18 circumscribing the indentation 20. As a result, providing the lens 18 with a diffusing surface 22 around the indentation 20 can efficiently diffuse the bright halo of light. The diffusing surface 22 as shown includes surface roughening, though other diffusers such as a diffusing film can be used to produce diffusion. Alternatively, other portions of the lens 18 can include a diffusing surface. For example, the entire lens 18 other than the indentation 20 can include a diffuser.

[0050] Diffusing the halo of light can reduce the appearance of a dark spot created by the indentation 20, and it can also lower the brightness of the halo to be more inline with the brightness of other portions of the lens 18. For example, as shown in FIG. 5, the LED package 10 can provide a distribution of light having two "peaks" with a "trough" between the peaks as indicated by line 108. The peaks can be created by the indentation 20, as it can direct light into the halo shape represented by the peaks. The indentation 20 can also cause the trough to appear between the peaks, since the indentation 20 can reflect light that would otherwise occupy the trough area. While TIR of light that contacts the sidewall 21 theoretically results in no light exiting the lens 18 through the indentation, the diffusing surface 22 can direct light that would otherwise add to the brightness of the halo to reduce the dark spot created by the indentation 20. That is, the diffusing surface 22 can decrease the difference between the height of the peaks and the depth of the trough. Further, the diffusing surface 22 can direct light that would otherwise add to the brightness of the halo radially away from the axis 17, increasing the light intensity of the areas outward of the peaks to further even out the distribution of light.

[0051] Thus, unlike many known LEDs which produce a bright spot represented by the spike shaped distribution indicated by line 102 in FIG. 5 for comparison, the LED package 10 can provide a relatively even distribution of light. The indentation 20 in the lens 18 can reduce the appearance of a bright spot by altering the distribution of light through the lens 18. The amount by which the bright spot of the known LED is reduced is illustrated as the distance between the top of the spiked shape distribution of the known LED and the top of one of the peaks of the light distribution of the LED package 10. Further, the distribution of the LED package 10 away from the LED 16 is more even than the distribution of light produced by the known LED, as the light distribution of the LED package 10 does not drop off when moving away from the LED 16 to the extent of the known LED.

[0052] Also, while the angle θ_1 of the sidewall 21 relative to the axis 17 is described above as designed to achieve TIR, this is not intended to mean that every photon of light that contacts the sidewall 21 is reflected. Current manufacturing limitations make achieving 100% TIR difficult, as the sidewall 21 may not be perfectly smooth. Instead, the angle θ_1 can be such that theoretically, without such imperfections, TIR is achieved. Also, the sidewall 21 can be made substantially smooth such that enough light is reflected that the light distribution of the light 10 meets consumer preferences. The sidewall 21 can be made substantially smooth by, as examples, forming the indentation 20 with higher tolerances than normal or polishing the indentation 20, while forming an uneven texture in the indentation 20 to diffuse light may prevent the sidewall 21 from being substantially smooth. Alternatively, a reflector can be placed in the indentation 20 to reflect light that refracts through the sidewall 21. However, since reflectors can be less efficient than TIR, the lens 18 can be designed such that a large portion of light is reflected by TIR when contacting the sidewall 21.

[0053] While the indentation 20 described above is conically shaped, an indentation can have an alternative shape and still provide TIR. For example, FIGS. 6 and 7 show another LED package 30 including leads 12 and 14, another LED 16 defining an axis 17, and a lens 38. The lens 38 can be the same as the lens 18 described above, except the lens 38 can include a V-shaped indentation 40 having two angled sidewalls 41 and 42 in place of the conical indentation 20. The indentation 40 can have a width sufficient to block a bright spot produce by the LED 16 shown in FIGS. 6 and 7. The sidewalls 41 and 42 can be angled to produce TIR, with the angles θ_2 between the sidewalls 41 and 42 and the axis 17 less than a complementary angle of a critical angle of the sidewalls 41 and 42. The geometry of the indentation 40 (i.e., the width and depth of the indentation 40 and the angle θ_2) can be determined with the same considerations as used to determine the geometry of the indentation 20 described above. As illustrated in FIGS. 6 and 7, the angle θ_2 is approximately twenty degrees, and the depth of the indentation 40 is such that a tip of the indentation is adjacent the LED 16.

[0054] The lens 38 can provide a more even distribution of light than a known LED, though the distribution of light provided by the lens 38 can differ from the distribution of light provided by the lens 18. For example, when the angle θ_2 is slightly greater or smaller than twenty degrees (e.g., between approximately fifteen and twenty five degrees), the indentation 40 produces two bright lines of light, one along each of its edges. Thus, the V-shaped indentation 40 can tend to create two bright lines separated by a dark line instead of the bright halo circumscribing a dark spot created by the conical indentation 20. However, to reduce the appearance of the dark line, the lens 38 can

include a diffusing surface 44 on each side of the indentation 40 to diffuse some of the light that would otherwise contribute to the brightness of the bright lines. The diffusing surface 44 can direct light into the area above the indentation 40, which can reduce the appearance of the dark line. Also, other indentations can have other shapes not illustrated, such as an inverted pyramid shape or an asymmetrical shape.

[0055] While the above described lenses 18 and 38 are parts of stand-alone LED packages 10 and 30, respectively, lights can include LEDs having lenses to reduce the appearance of bright spots. For example, FIG. 8 illustrates a light tube 50 shaped like a fluorescent tube and including bi-pin end caps 52, a circuit board 54, a housing 56, and multiple LEDs 58 covered by a lens 60.

[0056] One of the bi-pin end caps 52 can be disposed at each longitudinal end of the housing 56 for physically and electrically connecting the light 50 to a fluorescent fixture. The end caps 52 can be electrically connected to the circuit board 54 to provide power to the LEDs 58. Each end cap 52 can include two pins, though two of the total four pins can be "dummy pins" that do not provide an electrical connection. Alternatively, other types of end caps can be used, such as single pin end caps. Also, while the end caps 52 are shown as including cup-shaped bodies, the end caps 52 can have a different configuration (e.g., the end caps 52 can be shaped to be press fit into the housing 56).

[0057] The circuit board 54 as illustrated in FIG. 8 is an elongate printed circuit board. Multiple circuit board sections can be joined by bridge connectors to create the circuit board 54. The circuit board 54 can be slidably engaged with the housing 56, though the circuit board 54 can alternatively be clipped, adhered, snap- or friction-fit, screwed or otherwise connected to the housing 56. For example, the circuit board 54 can be mounted on a heat sink that is attached to the housing 56. Also, other types of circuit boards may be used, such as a metal core circuit board. Or, instead of a circuit board 54, other types of electrical connections (e.g., wires) can be used to electrically connect the LEDs 58 to the end caps 52.

[0058] The housing 56 as shown in FIG. 8 is a light transmitting cylindrical tube. The housing 56 can be made from polycarbonate, acrylic, glass or another light transmitting material (i.e., the housing 56 can be transparent or translucent). For example, a translucent housing 56 can be made from a composite, such as polycarbonate with particles of a light refracting material interspersed in the polycarbonate. While the illustrated housing 56 is cylindrical, the housing 56 can alternatively have a square, triangular, polygonal, or other cross sectional shape. Similarly, while the illustrated housing 56 is linear, the housing 56 can have an alternative shape, e.g., a U-shape or a

circular shape. Additionally, the housing 56 need not be a single piece as shown in FIG. 8. Instead, the housing 56 can be formed by attaching multiple individual parts, not all of which need be light transmitting. For example, the housing 56 can include a lower portion and a lens attached to the lower portion to cover the LEDs 58. The housing 56 can be manufactured to include light diffusing or refracting properties, such as by surface roughening or applying a diffusing film to the housing 56. The housing 56 can have a length such that the light 50 is approximately 48" long, and the housing 12 can have a 0.625", 1.0", or 1.5" diameter for engagement with common fluorescent fixtures.

[0059] The LEDs 58 can each produce light in a Lambertian distribution centered on a central axis 59, which can extend normally to its respective LED 58 as shown in FIG. 9. However, the LEDs 58 may also exhibit a different distribution of light, in which case the axes 59 can still represent at least one of a center point of the distribution of light of each LED 58 and axes normal to the respective LEDs 58. The LEDs 58 can be LEDs of any power rating, e.g. 0.05 W, 0.10 W, 0.25 W, or high power LEDs, such as surface-mount LEDs of the type available from Nichia. The LEDs 58 can produce any wavelength of light, such as white light, red light, blue light, or ultra-violet light.

[0060] The lens 60 can extend over multiple LEDs 58 as shown in FIG. 9, encasing the LEDs 58 and providing protection from the external environment to reduce corrosion or other damage to the LEDs 60. The lens 60 can be translucent or transparent and can be made from a material such as polycarbonate, acrylic, or glass. The lens 60 can include semispherical portions 61 over each LED 58, and connecting portions 63 extending between adjacent hemispherical portions 61. Alternatively, discrete lenses consisting of only the semispherical portions 61 can be used for each LED 58.

[0061] Each hemispherical portion 61 can define an indentation 62 and a diffusing surface 64. The indentation 62 can be conical with a continuous sidewall 66 angled at an angle θ_3 relative to the respective axis 59. Each indentation 62 can be centered over one of the axes 59, and the indentation 62 can have a diameter sufficient in diameter to reduce a bright spot of light produced by its respective LED 58. The specific geometry of the indentation 62 can be based on the same considerations discussed above in reference to the indentation 20.

[0062] Further, as shown in FIGS. 8 and 9, the angle θ_3 can be approximately twenty degrees, and the indentation 62 can extend to adjacent its respective LED 58. An annular diffusing surface 64 can circumscribe the indentation 62. Thus, the indentation 62 can reduce a bright spot of light produced by the LED 58, directing the light to form a bright halo circumscribing the indentation 62. The diffusing surface 64 can diffuse the halo of light to reduce the appearance of a dark spot created by the indentation 62 and to

more evenly distribute the light radially relative to the axis 59.

[0063] The lens 60 additionally includes connecting portions 63. Each connecting portion 63 can include a Fresnel type lens 68 approximately midway between adjacent hemispherical portions 61. A portion of light produced by the LEDs 58 may not enter the hemispherical portions 61 of the lens 60. Instead, this light may enter one of the connecting portions 63. The connecting portion 63 can act as a light pipe, directing light to the Fresnel lens 68. The Fresnel lens 68 can direct the light outward, away from the circuit board 54. However, depending on the design of the connecting portion 63, some of the light may refract out of the connecting portion prior to reaching the Frensel lens 68. As a result, the lens 60 can reduce the appearance of dark spots between hemispherical portions 61.

[0064] FIG. 10 illustrates the distribution of light from the light 50 as indicated by line 110 compared to a fluorescent tube as indicated by the line 100 and a known LED light shaped as a tube as indicated by the line 102. The distribution of light from the lens 60 around each LED 58 can include two peaks on opposing sides of a trough, similar to the distribution of light described with reference to FIG. 5. The peaks can be of lower intensity than the peak of the spiked light distribution of the known LED light shaped as a tube. Further, due to diffusion of the bright halo of light and the placement of Frensel lenses 68 between hemispherical portions 61, the lens 60 can provide a more even distribution of light between LEDs 58 compared to the known LED light shaped as a tube. Thus, while the light 50 can avoid the spiked peaks of the known LED light, the light 50 can also have a more even distribution between LEDs 58 compared to the known LED light.

[0065] Additionally, while the above described embodiments describe lenses that are integral with an LED package (i.e., the lenses function as casings for LEDs), this need not be the case. For example, FIG. 11 illustrates an LED light 70 shaped to replace a fluorescent tube including a heat sink 72, a circuit board 74, a lower cover 76, LEDs 78, and an upper cover 80 that functions as a lens. The heat sink 72 can be made from a highly thermally conductive material such as aluminum, copper, or another material, and it can be shaped to have a large surface area. However, the heat sink 72 may not be necessary depending on the amount of heat produced by the LEDs 78. The circuit board 74 can be a printed circuit board or another type of circuit board, and the LEDs 78 can be physically and electrically connected to the circuit board 74. The circuit board 74 can be mounted on the heat sink 72. Alternatively, the LEDs 78 can be electrically connected with a structure other than a circuit board 74, such as wires.

[0066] The lower cover 76 can be made from a polymer such as polycarbonate or

ABS, and lower cover 76 can be generally U-shaped and engaged with the heat sink 74. For example, the lower cover 76 can be sized to slidably receive the heat sink 74, though the cover 76 can alternatively be bonded or otherwise adhered to the heat sink 74. Further, the lower cover 76 can be configured to secure the upper cover 80 in place. For example, the lower cover 76 can define grooves for slidably receiving the upper cover 80. Since little light is directed toward the lower cover 76 as shown in FIGS. 11 and 12, the lower cover 76 need not be light transmitting. For example, the lower cover 76 can be a dark body with a high thermal emissivity. Alternatively, the lower body 76 and upper body 80 can be integral, e.g., the two bodies 76 and 80 can form a generally cylindrical housing.

[0067] The LEDs 78 can be similar to the LEDs 58, with each LED 78 producing light in a Lambertian distribution about a central axis 79 as shown in FIG. 12. The upper cover 80 can define a V-shaped indentation 82 extending longitudinally the length of the cover 80, and the indentation 82 can be centered above the axes 79 of the LEDs 78. The indentation 40 can have a width sufficient to block multiple bright spots produce by the LEDs 78. The sidewalls 83a and 83b can be angled to produce TIR, with the angles θ_4 between the sidewalls 83a and 83b and the axis 79 less than a complementary angle of a critical angle of the sidewalls 83a and 83b. The geometry of the indentation 82 (i.e., the width and depth of the indentation 82 and the angle θ_4) can be determined with the same considerations as used to determine the geometry of the indentation 20 described above. As illustrated in FIGS. 11 and 12, the angle θ_4 is approximately twenty degrees, and the depth of the indentation 82 is such that a tip of the indentation 82 is adjacent the LED 78.

[0068] The upper cover 80 can function as a lens to provide a more even distribution of light than known LED lights shaped as fluorescent tubes, though the distribution of light provided by the cover 80 can differ from the distribution of light provided by the lens 60 described above in reference to FIGS. 8 and 9. For example, when the angle θ_4 is slightly greater or smaller than twenty degrees (e.g., between approximately fifteen and twenty five degrees), the indentation 82 results in two bright lines of light along each of its edges when the LEDs 78 produce light. Thus, the V-shaped indentation 82 can tend to create two bright lines separated by a dark line instead of the bright halos circumscribing dark spots created by the hemispherical portions 61 of the lens 60.

[0069] Also as shown in FIGS. 11 and 12, a reflector 84 can be positioned to cover the sidewalls 83 of the indentation 82. The reflector 84 can be a reflective film applied to the indentation 82, a reflective material deposited in the indentation 82, or another light reflecting structure. While the sidewalls 83 are angled to produce TIR,

manufacturing a perfectly smooth surface is difficult. As a result, the sidewalls 83 may include some imperfections that can allow light to be refracted through the sidewalls 83 instead of reflected. The reflector 84 can reflect light that refracts through one of the sidewalls 83 back through the sidewall 83, in effect acting as a back-up reflector for any light that is not reflecting by the sidewall 83. However, a reflector 84 may not be necessary if the amount of light that refracts through the sidewalls 83 is sufficiently small that the light distribution is acceptable to consumers.

[0070] FIG. 13 illustrates another light 90 shaped to replace a fluorescent tube. The light 90 can include the heat sink 72, the circuit board 74, the lower cover 75, and the LEDs 78 defining the central axis 79 as described above in reference to FIGS. 11 and 12. However, the light 90 includes an upper cover 92 having V-shaped indentations 94 extending perpendicular to a longitudinal axis of the light 90. The geometry of the indentations 94 can be determined based on the same considerations as used to determine the geometry of the indentation 82 in FIGS. 11 and 12.

[0071] However, the orientation of the indentations 94 causes the light 90 to have a different appearance compared to the light 70. While the light 70 can result in two bright lines extending longitudinally the length of the light 70, the light 90 can result in a series of bright lines extending perpendicular to the longitudinal axis of the light 90. More specifically, each indentation 94 can result in two bright lines extending perpendicularly to the longitudinal axis of the light 90 due to the orientation of the indentations 94. A dark line created by the indentation 94 can separate the two lines. The darkness of this line can be mitigated by, for example, including a diffusing surface on each side of the indentation 94. An additional dark line can exist between adjacent indentations 92, though the exact distribution of light between the indentations 92 can vary depending on the spacing of the LEDs 78 and the geometries of the indentations 92. Alternatively, a cover can be formed to include conical indentations, pyramid shaped indentations, or other indentation shapes.

[0072] The cover 92 shown in FIG. 13 can be formed by extrusion. As shown in FIG. 14, a sheet 112 of material such as polycarbonate or acrylic can be extruded in an extrusion direction 114 to produce the cover 92. Once extruded, the sheet 112 can have the same profile (i.e., shape when viewed from the extrusion direction 92) as the cover 92. However, the sheet 112 can have a width greater than a width of the cover 92. The sheet 112 can be cut or otherwise sectioned perpendicularly to the extrusion direction 114 as indicated by lines 116 to produce multiple covers 92. Alternatively, the sheet 112 can be extruded to have a different shape, such as the cover 80 shown in FIG. 11. However, in that case, the sheet can be cut parallel to the extrusion direction to produce the covers 80.

[0073] While the above described lights 50, 70, and 90 are shaped to replace fluorescent tubes, a lens as described herein can also be used in other types of lights, such as flashlights and lights shaped to replace incandescent bulbs.

[0074] FIGS. 15 and 16 illustrate another embodiment of a light tube 120 shaped like a fluorescent tube and similar to that shown in FIG. 8 in that it includes bi-pin end caps (not shown), a circuit board 124, a housing 126, and multiple LEDs 128 covered by light pipes 131 functioning as lenses therefore. The bi-pin end caps, the circuit board 124, the housing 126, and the multiple LEDs 128 can be similar to the bi-pin end caps 52, the circuit board 54, the housing 56, and multiple LEDs 58, respectively, of FIG. 8. Alternatively, other components may be used as desired or required.

[0075] Each light pipe 131 can be adjacent to another light pipe 131 so that a space 129 exists between adjacent light tubes. The light pipe 131 can be made of any suitable light transmitting material such as acrylic. The light pipe 131 can have a generally rectangular cross section and a level surface although other suitably shaped light pipes are also available. Further, the light pipe 131 may be of any sufficient size to provide an even distribution of light in the light tube 120, as discussed in more detail below, across the length and width thereof.

[0076] The space 129 can be of any suitable dimension as desired or required. Alternatively, in other embodiments, no space can exist between adjacent light pipes 131 (i.e. light pipes are physically touching), a single light pipe can extend over all or most of the LEDs 128 or a single light pipe can be positioned over more than one LED 128.

[0077] Each light pipe 131 can define a conical indentation 132 with a continuous sidewall 136 angled at an angle θ_5 relative to a central axis 135. The indentation 132 can be shaped to provide TIR and reflect light down the light pipe 131. Each indentation 132 can be centered over one of the axes 135, and the indentation 132 can have a diameter sufficient in size to reduce a bright spot of light produced by its respective LED 128. The specific geometry of the indentation 132 can be determined using the same considerations (i.e., the width and depth of the indentation 132 and the angle θ_5) described above in reference to the indentation 20. For example, the angle θ_5 can be approximately twenty degrees, and the indentation 132 can extend to adjacent its respective LED 128. Further, the conical indentation 132 is illustrated as having a planar surface, in other embodiments the conical indentation can have a curved surface.

[0078] The light pipe 131 permits the light L to be transported across the surface thereof through TIR. The light is extracted at multiple points P1-P4, as discussed in more detail below by a diffusing surface 134. Further, the light L diminishes at, for example, points P1 and P4 (i.e. points that are further from the light source LED 128) as

the light is transported down the length of the pipe. The indication of points P1-P4 and illustration of the light L are provided in order to allow easy understanding of the invention and do not limit the scope of embodiments of the invention. Other embodiments may have more or less points where the light is emanated and reflected and may have a different distribution of light L.

[0079] The diffusing surface 134 disrupts the TIR to permit light to emanate at points P1-P4. The diffusing surface 134 can be, for example, grooves, pits, bumps or any other type of extraction elements and be any combination thereof. Each extraction element of diffusing surface 134 may be of varying size and at the same or different distances from other extraction elements. The diffusing surface may be printed, formed as a part of or otherwise adhered to a top surface 131c of the light pipe 131. Alternatively the diffusing surface maybe printed, formed as a part of or otherwise adhered on a bottom surface 131d of the light pipe 131. The light L emanating at points P1-P4 may strike diffusing surface 134 and be diffused thereby. The emitted light may emanate from the light pipe 131 in a variety of directions. The light L may also be emanated in a direction back within the light pipe 131.

[0080] The pattern of the diffusing surface 134 can be, for example, selected to provide a substantially uniform distribution of light across the length and width of the light pipe 131. The diffusing surface 134 can be evenly spread across each light pipe 131 or, as illustrated in FIG. 15, be more densely disbursed at the distal ends 131a and 131b. The selection of a pattern for the diffusing surface 134 can include, for example, selecting the size of the elements or the spatial density of the elements in diffusing surface 134. By controlling the pattern of the diffusing surface 134, the distribution of light may be controlled along the length and width of the light pipe 131. Thus, for example, because of the increased distance from the LED 128, a reduced amount of light may be emitted at the distal ends 131a and 131b. To compensate for this reduced amount of light, the pattern of diffusing surface 134 can be selected such that, for example, the light L, can be diffused more at points P1 and P4 than at points P2 and P3 in order to provide a more even distribution of light. Of course, other patterns of diffusing surfaces are also available.

[0081] While the indentation 132 is conically shaped, an indentation can have an alternative shape and still provide TIR. For example, FIG. 17 shows another cross section of a light tube including, similar to the light tube illustrated in FIGS. 15 and 16, a circuit board 154, with light pipes 161 over each LED 158 with light emanating at points P5-P8. Each light pipe 161 can be adjacent to another light pipe 161 so that a space 159 exists between adjacent light pipes. Additionally, the light pipe 131 can also include a

diffusing surface (not shown) that is similar to diffusing surface 134. However, light pipes 161 in this embodiment include a V-shaped indentation 152 (similar to that shown in FIGS. 6 and 7). Each V-shaped indentation has two angled sidewalls 166a and 166b and can have a width sufficient to block a bright spot produce by the LED 158. The sidewalls 166a and 166b can be angled to produce TIR, with the angles θ_6 between the sidewalls 166a and 166b and the axis 165 less than a complementary angle of a critical angle of the sidewalls 166a and 166b. The geometry of the indentation 132 (i.e., the width and depth of the indentation 132 and the angle θ_6) can be determined with the same considerations as used to determine the geometry of the indentation 20 described above.

[0082] While the light pipes 131 and 161 have a generally rectangular cross section and a level top surface, a light pipe can have an alternative shape. For example, FIG. 18 shows another cross section of a light tube including, similar to the light tube illustrated in FIGS. 15 and 16, a circuit board 184, with light pipes 181 over each LED 188. Each light pipe 181 can be adjacent to another light pipe 181 so that a space 189 exists between adjacent light pipes. Each light pipe 181 includes a conical indentation 182 (similar to that shown in FIGS. 15 and 16). Additionally, the light pipe 161 can also include a diffusing surface (not shown) that is similar to diffusing surface 134. However, the top surface 181c of the light pipes 181 in this embodiment include can taper from the conical indentation 182 toward the distal end 181a and from the conical indentation 182 toward the distal end 181b. The tapered surface permits TIR failure to occur, which can assist in providing a more even distribution of light across the light emitted at points P9-P12. As the light L propagates down the light guide toward both the distal ends 181a and 181b, its angle of incidence constantly decreases due to the tapered surface 181c. As the angle of incidence nears a line normal to the tapered surface 181c, some of the light L is no longer totally internally reflected and eventually is emitted from the light pipe 181 after a sufficient number of internal reflections. Further, the tapered surface 181c permits an increased number of internal reflections as compared to a level surface (e.g. FIGS. 15 and 16) which can permit additional opportunities to intercept an extraction element of the diffusing surface on light pipe 181.

[0083] FIG. 19 illustrates another cross section of a light tube. Similar to the light tube illustrated in FIGS. 15 and 16, the light tube of this embodiment includes a circuit board 214, with light pipes 211 over each LED 218. However, in this embodiment the light pipe does not include an indentation but rather a reflector 212. The reflector 218 can be a reflective film applied to a top surface 211c of the light pipe 211, a reflective material deposited on a top surface 211c of the light pipe 211, or another light reflecting structure. As one non-limiting example, in one embodiment, the

reflector 84 is a polymer film reflector deposited on the top surface 211c of the light pipe 211.

[0084] The reflector 218 can cover the LED 218. Specifically, the reflector 218 can be positioned such that the light L emitted directly from the LED 128 would strike the reflector 218 and experience TIR. As such, the reflector can additionally cover an area slightly surrounding the LED 218 as desired or required.

[0085] After the light L strikes the reflector 218, the light can be transported through the light pipe 211 similar to the manner described in FIGS. 15 and 16. Additionally, the light pipe 211 can also include a diffusing surface (not shown) that is similar to diffusing surface 134 for disrupting TIR from the reflector 218 and to permit light to emanate at, for example, points P13-P16. The diffusing surface can be, as discussed previously, uniformly distributed or exhibit a particular pattern on the top surface 211c or the bottom surface 211d of light pipe 211. More specifically, for example, the diffusing surface can be located on any portion of the top surface 211c excluding the portion covered by reflector 218. A diffusing reflecting layer 232 may also be added under a bottom surface 211d of the light pipe. The diffusing reflecting layer 232 can assist in transporting the light L through light pipe 211 and can assist in disrupting TIR from reflector 218. Alternatively, the diffusing reflecting layer 232 can be a diffusing layer similar to diffusing surface 134 (or any other suitable diffusing layer) or a reflecting layer similar to reflector 218 (or any other suitable reflecting layer).

[0086] Although the light pipes 131, 161, 181 and 211 illustrate light L emitted through the top surface thereof, in other embodiments, light may be extracted and emitted in any direction such the top, bottom, sides or ends of the light pipes. For example, in one embodiment, a light tube can include light pipes that extract and emit light in all directions (i.e. 360°). Further, as discussed previously, the LEDs 128, 158, 188 and 218 may be any suitable LED white or colored LED. If the LEDs 128, 158, 188 and 218 are colored LEDs, a wavelength-converting material may be included in, on or outside the light pipes 131, 161, 181 and 211, respectively. Alternatively, a wavelength-converting layer can be included between LEDs 128, 158, 188 and 218 and the light pipes 131, 161, 181 and 211, respectively.

[0087] As discussed previously, LED packages containing conical indentation 20 and V-shaped indentation 40 can create the appearance of a bright halo of light circumscribing a dark spot. A way of mitigating the dark spot is to provide, for example a diffusing surface around the indentations such that the bright halo of light is diffused. Other light tubes are available having a double-coned LED package and or a double-coned lens to obfuscate the bright spot created by the LED while also mitigating the dark

spot by further spreading the light rays.

[0088] For example, FIGS. 20 and 21 describe a light tube 300, which can include, similar to the light tube 70 of FIGS. 11 and 12, a heat sink 302, a circuit board 304, a lower cover 306, LEDs 308, and an upper cover 310 and a double-coned linear lens 311 extending over the LEDs 308. The heat sink 302, circuit board 304, lower cover 306 and LEDs 308 can be similar to heat sink 72, circuit board 74, lower cover 76 and LEDs 78, respectively. The upper cover 310 can be U-shaped and can snap onto the lower cover 306. Alternatively, other components may be used as desired or required or other components may be eliminated (e.g. heat sink 302).

[0089] Each LED 308 produces light in a Lambertian distribution about a central axis 309 as shown in FIG. 21. The double-coned linear lens 311 extends substantially the entire length of the light tube 300 and includes a V-shaped indentation 312 formed by sidewalls 311a and 311b. The V-shaped indentation 312 also extends substantially the entire length of the light tube 300. The indentation 312 can have a width sufficient to block multiple bright spots produce by the LEDs 308. The sidewalls 311a and 311b can be angled to produce TIR, with the angles θ_7 between the sidewalls 311a and 311b and the axis 309 less than a complementary angle of a critical angle of the sidewalls 311a and 311b. The geometry of the indentation 312 (i.e., the width and depth of the indentation 312 and the angle θ_7) can be determined with the same considerations as used to determine the geometry of the indentation 20 described above. As illustrated in FIGS. 20 and 21, the angle θ_7 is approximately twenty degrees.

[0090] The linear lens 311 also includes two flared outer walls 311c and 311d extending from edges 311e and 311f, respectively. Edge 311e is formed by an intersection of sidewall 311a and outer wall 311c and edge 311f is formed by an intersection of sidewall 311b and outer wall 311d. Two base walls 311g and 311h vertically extend to the circuit board 304 from edges 311i and 311k. Edge 311i is formed by an intersection of outer wall 311c and base wall 311g and edge 311k is formed by an intersection of outer wall 311d and base wall 311h.

[0091] Outer walls 311c and 311d can be angled relative to a horizontal axis 320 to receive the totally internally reflected light from sidewalls 311a and 311b and to redirect the light into an external path parallel and/or substantially parallel to a central axis 309. In other words, the primary light rays L1 are redirected to produce light rays L2 in this manner by, for example, angling outer walls 311c and 311d at suitable angles θ_8. Angle θ_8 is the angled between outer walls 311c and 311d and horizontal axis 320. As illustrated in FIGS. 20 and 21, angle θ_8 is approximately seventy-four degrees. Accordingly, the outer walls 311c and 311d of linear lens 310 can reduce or eliminate the

dark spot created by indentation 320 by spreading light rays L2 thereto.

[0092] Additionally, linear lens 311 can also include an optional reflector 315 on end surfaces 311k (only one end surface shown in FIG. 20) of linear lens 311 to provide, for example, maximum internal reflection. Reflector 315 can reflect any wasted and/or uncontrolled light from exiting through the end surfaces 311k back through the linear lens 311. Accordingly, reflector 315 can be, for example a mirrored surface. In other embodiments, the reflector 315 can be a reflective film applied to the end surfaces 311k, a reflective material deposited on the end surfaces 311k, or another light reflector. Reflector 315 can be optional because, for example, the amount of light that exits the linear lens 311 through end surfaces 311k may be minimal and the light distribution provided by the light tube 300 may be suitable.

[0093] While the double-coned concept is implemented within a linear lens and is described above as extending through the light tube, other embodiments may include the double-coned concept as part of an LED package. For example, FIGS. 22 and 23 show another LED package 400 including leads 412 and 414, another LED 416 centered about a central axis 417 and a lens 408. Leads 412 and 414, LED 416 and axis 417 can be similar to leads 12 and 14, LED 16 and axis 17, respectively, of FIGS. 3, 4, 6 and 7.

[0094] Lens 408 includes a V-shaped indentation 440 having two angled sidewalls 441 and 442. The indentation 440 can have a width sufficient to block a bright spot produce by the LED 416. The sidewalls 441 and 442 can be angled to produce TIR, with the angles θ_9 between the sidewalls 441 and 442 and the axis 417 less than a complementary angle of a critical angle of the sidewalls 41 and 42. The geometry of the indentation 440 (i.e., the width and depth of the indentation 440 and the angle θ_9) can be determined with the same considerations as used to determine the geometry of the indentation 20 described above. As illustrated in FIGS. 22 and 23, the angle θ_9 is approximately twenty degrees.

[0095] The lens 408 also includes a circumferentially flared outer wall 450 extending from points (or edges) 452 and 454, respectively. Point 452 is formed by an intersection of sidewall 441 and outer wall 450 and point 454 is formed by an intersection of side wall 442 and outer wall 450. A circumferentially extending base wall 456 vertically extends from an edge 458. Edge 458 is formed by an intersection of outer wall 450 and base wall 456.

[0096] Outer wall 450 can be angled relative to a horizontal axis 467 to receive the totally internally reflected light from sidewalls 441 and 442 and, similar to the linear lens 311 of FIGS. 20 and 21, to redirect the light into an external path parallel and/or substantially parallel to the central axis 417. Outer walls can be angled at angle θ_{10} to

produce the redirected light to reduce or eliminate the dark spot created by indentation 440. As illustrated in FIGS. 22 and 23, angle θ_{10} approximately seventy-four degrees.

[0097] In another example, FIGS. 24 and 25 show another LED package 500 including leads 512 and 514, another LED 516 centered about a central axis 517 and a lens 508. Leads 512 and 514, LED 516 and axis 517 can be similar to leads 12 and 14, LED 16 and axis 17, respectively, of FIGS. 3, 4, 6 and 7.

[0098] Rather than a V-shaped indentation as described in lens 408, lens 508 includes a conical indentation 540 having an angled sidewall. The indentation 440 can have a width sufficient to block a bright spot produce by the LED 416. Sidewall 541 can be angled to produce TIR, with the angles θ_{11} between the sidewall 541 and the axis 517 less than a complementary angle of a critical angle of the sidewall 541. The geometry of the indentation 540 (i.e., the width and depth of the indentation 540 and the angle θ_{11}) can be determined with the same considerations as used to determine the geometry of the indentation 20 described above. As illustrated in FIGS. 24 and 25, the angle θ_{11} is approximately twenty degrees.

[0099] The lens 508 also includes a circumferentially flared outer wall 550 extending from an annular edge 542. Annular edge 542 is formed by an intersection of sidewall 541 and outer wall 550. A circumferentially extending base wall 556 vertically extends from an edge 558. Edge 558 is formed by an intersection of outer wall 550 and base wall 556.

[00100] Outer wall 550, similar to outer wall 450 of FIGS. 22 and 23, can be angled relative to a horizontal axis 567 to receive the totally internally reflected light from sidewall 541. Outer wall 550 can then, as discussed previously, redirect the light into an external path parallel and/or substantially parallel to the central axis 517. Outer walls can be angled at angle θ_{12} to produce the redirected light to reduce or eliminate the dark spot created by indentation 540. As illustrated in FIGS. 24 and 25, angle θ_{11} approximately seventy-four degrees.

[00101] While the above described lenses 408 and 508 are parts of stand-alone LED packages 400 and 500, respectively, lights can include LEDs having lenses incorporating the double-coned structure . For example, FIGS. 26 and 27 illustrate a light tube 600, which can include a heat sink 602, a circuit board 604, a lower cover 606, LEDs 608, an upper cover 610 and double-coned lens portions 611 extending over the LEDs 608. The heat sink 602, circuit board 604, lower cover 606 and LEDs 608 can be similar to heat sink 72, circuit board 74, lower cover 76 and LEDs 78, respectively, of the light tube 70 illustrated in FIGS. 11 and 12. The upper cover 610 can be U-shaped and can snap onto the lower cover 606. Alternatively, other components may be used as desired

or required or other components may be eliminated (e.g. heat sink 602).

[00102] Additionally, light tube 600 can include connecting portions 663 extending between adjacent double-coned portions 611. Connecting portions 663 can be similar to connecting portions 63 illustrated in FIGS. 8 and 9. Alternatively, in other embodiments, light tube 600 may include the double-coned lens portions 711 without the connecting portions 663

[00103] Each double-coned portion 611 can define a V-shaped indentation 612 having two angled sidewalls 611a and 611b. The indentation 612 can have a width sufficient to block a bright spot produce by the LED 608. The sidewalls 611a and 611b can be angled to produce TIR, with the angles θ_{13} between the sidewalls 611a and 611b and the axis 609 less than a complementary angle of a critical angle of the sidewalls 611a and 611b. The geometry of the indentation 612 (i.e., the width and depth of the indentation 612 and the angle θ_{13}) can be determined with the same considerations as used to determine the geometry of the indentation 20 described above. As illustrated in FIGS. 26 and 27, the angle θ_{13} is approximately twenty degrees.

[00104] The double coned portion 611 also includes a circumferentially flared outer wall 650 extending from points (or edges) 652 and 654, respectively. Point 652 is formed by an intersection of sidewall 611a and outer wall 650 and point 654 is formed by an intersection of side wall 611b and outer wall 650. A circumferentially extending base wall 656 vertically extends from an edge 658. Edge 658 is formed by an intersection of outer wall 650 and base wall 656.

[00105] Outer wall 650 can be angled relative to a horizontal axis 620 to receive the totally internally reflected light from sidewalls 611a and 611b, similar to the linear lens 311 of FIGS. 20 and 21, to redirect the light into an external path parallel and/or substantially parallel to the central axis 609. Outer walls can be angled at angle θ_{14} to produce the redirected light to reduce or eliminate the dark spot created by indentation 612. As illustrated in FIGS. 26 and 27, angle θ_{14} approximately seventy-four degrees.

[00106] In another example, FIGS. 28 and 29 show another light tube 700 shaped like a fluorescent tube and including bi-pin end caps 772, a circuit board 704, a housing 756, multiple LEDs 708 and conical lens portions 711 over the LEDs 708. Bi-pin end caps 772, circuit board 704, housing 756 and LEDs 708 can be similar to bi-pin end caps 52, circuit board 54, housing 56 and LEDs 58 of FIGS. 8 and 9.

[00107] Conical lens portions 711 extend over each LED 708 similar to double-coned portions 611. However, rather than a V-shaped indentation, each portion 711 includes a conical indentation 740 having an angled sidewall 711a. The indentation 740 can have a width sufficient to block a bright spot produce by the LED 708. Sidewall

711a can be angled to produce TIR, with the angles θ_{15} between the sidewall 711a and the axis 709 less than a complementary angle of a critical angle of the sidewall 711a. The geometry of the indentation 740 (i.e., the width and depth of the indentation 740 and the angle θ_{15}) can be determined with the same considerations as used to determine the geometry of the indentation 20 described above. As illustrated in FIGS. 28 and 29, the angle θ_{15} is approximately twenty degrees.

[00108] Each portion 711 also includes a circumferentially flared outer wall 750 extending from an annular edge 742. Annular edge is 742 formed by an intersection of sidewall 711a and outer wall 750. A circumferentially extending base wall 756 vertically extends from an edge 758. Edge 758 is formed by an intersection of outer wall 750 and base wall 756.

[00109] Outer wall 750, similar to outer wall 450 of FIGS. 22 and 23 and outer wall 550 of FIGS. 24 and 25, can be angled relative to a horizontal axis 720 to receive the totally internally reflected light from sidewall 741. Outer wall 750 can then, as discussed previously, redirect the light into an external path parallel and/or substantially parallel to the central axis 709. Outer walls can be angled at angle θ_{16} to produce the redirected light to reduce or eliminate the dark spot created by indentation 712. As illustrated in FIGS. 28 and 29, angle θ_{16} approximately seventy-four degrees.

[00110] The above-described embodiments have been described in order to allow easy understanding of the invention and do not limit the invention. On the contrary, the invention is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structure as is permitted under the law.

What is claimed:

1. A replacement light for a fluorescent tube usable in a fluorescent fixture comprising:

a support structure having a longitudinal axis;

at least one LED connected to the support structure, the LED producing light about respective central axes;

at least one lens positioned along the central axis of the at least one LED, the lens defining an indentation angled relative to the central axis less than a complementary angle of a critical angle of the lens along the indentation; and

at least one electrical connector at a longitudinal end of the support structure in electrical communication with the at least one LED.

2. The replacement light of claim 1, wherein the lens includes multiple indentations, each indentation positioned along the central axis of one of the at least one LEDs.

3. The replacement light of claim 2, wherein the lens is hemispherically shaped around each indentation.

4. The replacement light of claim 2, wherein the indentations are conically shaped.

5. The replacement light of claim 2, wherein the lens includes integral Fresnel lenses between indentations.

6. The replacement light of claim 1, wherein the lens includes a single V-shaped indentation extending longitudinally a length of the lens.

7. The replacement light of claim 1, wherein the indentation is angled between approximately 15 and 25 degrees relative to the central axis.

8. The replacement light of claim 7, wherein the entire indentation is angled approximately 20 degrees relative to the axis.

9. The replacement light of claim 1, wherein a width of the indentation is greater than a diameter of a bright spot produced by the at least one LED.

10. The replacement light of claim 1, wherein the lens includes a light pipe around each indentation.

11. The replacement light of claim 10, wherein the light pipe includes a light diffuser on at least one of a top surface and a bottom surface thereof.

12. The replacement light of claim 10, wherein the light diffuser is more densely disbursed on at least one of the distal ends of the light pipe.

13. The replacement light of claim 10, wherein the at least one LED includes multiple LEDs and the light pipe is positioned over substantially all of the multiple LEDs.

14. The replacement light of claim 10, wherein the light pipe tapers from the indentation toward at least one of the distal ends of the light pipe.

15. The replacement light of claim 1, wherein the lens includes a double-coned shaped outer wall surface.

16. The replacement light of claim 1, wherein an outer surface of the lens outwardly extends from an edge of the indentation to a base wall.

17. The light modifier of claim 1, wherein the outer surface is angled relative to a horizontal axis approximately between 70 and 80 degrees.

18. A light modifier for an LED producing light about a central axis, the light modifier comprising:

a lens defining an indentation, the indentation angled relative to the central axis by an amount less than a complementary angle of a critical angle of the lens along the indentation.

19. The light modifier of claim 18, wherein the indentation is angled between approximately 15 and 25 degrees relative to the central axis.

20. The light modifier of claim 19, wherein the indentation is angled approximately 20 degrees relative to the central axis.

21. The light modifier of claim 19, wherein the entire indentation is angled a same degree relative to the central axis.

22. The light modifier of claim 18, wherein a width of the indentation is at least as large as a diameter of a bright spot produced by the LED.

23. The light modifier of claim 18, wherein a surface of the indentation is substantially smooth.

24. The light modifier of claim 18, wherein the indentation is one of conical and V-shaped.

25. The light modifier of claim 18, wherein the lens includes a light diffuser around the indentation.

26. The light modifier of claim 18, wherein a portion of the lens circumscribing the indentation is hemispherical.

27. The light modifier of claim 18, further comprising a reflector within the indentation.

28. The light modifier of claim 18, wherein an outer surface of the lens outwardly extends from an edge of the indentation to a base wall.

29. The light modifier of claim 18, wherein the outer surface is angled relative to a horizontal axis approximately between 70 and 80 degrees.

30. A method of forming a lens for an LED producing light about a central axis, the lens defining an indentation angled relative to the central axis less than a complementary angle of a critical angle of the lens along the indentation, the method comprising:

extruding material in an extrusion direction to form a sheet of greater width than the lens, the sheet having a same profile as the lens; and

sectioning the sheet to form the lens.

31. The method of claim 30, wherein sectioning the sheet including cutting the sheet perpendicular to the extruding direction.

32. A replacement light for a fluorescent tube usable in a fluorescent fixture comprising:

a support structure having a longitudinal axis;

multiple LEDs connected to the support structure, the LEDs producing light about respective central axes;

at least one light pipe positioned along the central axis of one of the LEDs, the light pipe having a reflector positioned over at least a portion of the LED such that the light initially emitted from the LED strikes the reflector; and

at least one electrical connector at a longitudinal end of the support structure in electrical communication with the multiple LEDs.

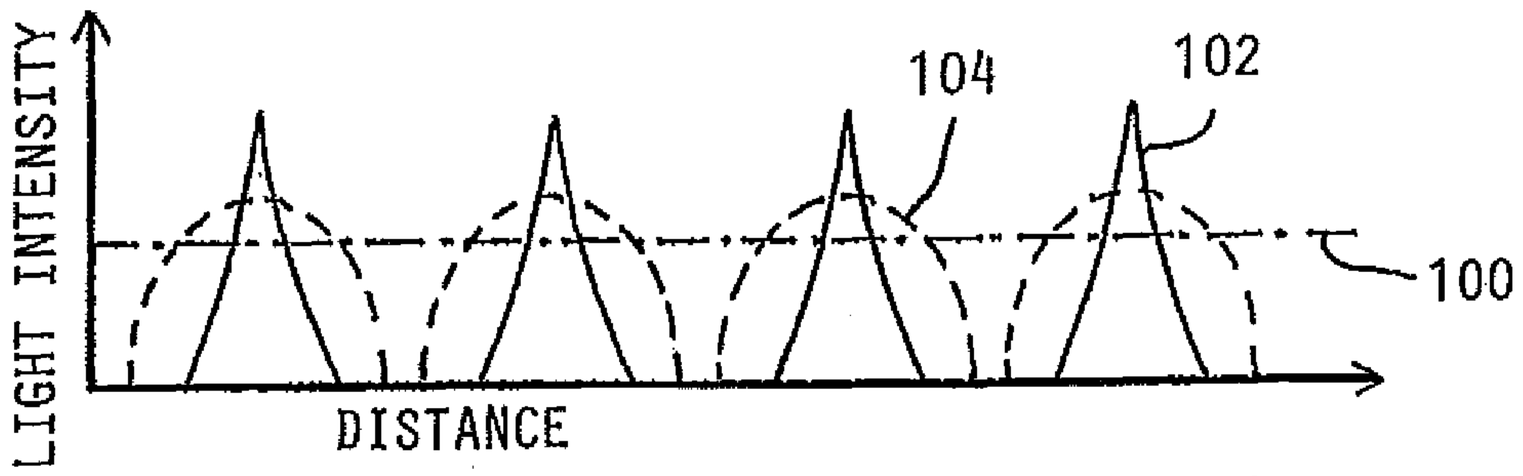


FIG. 1

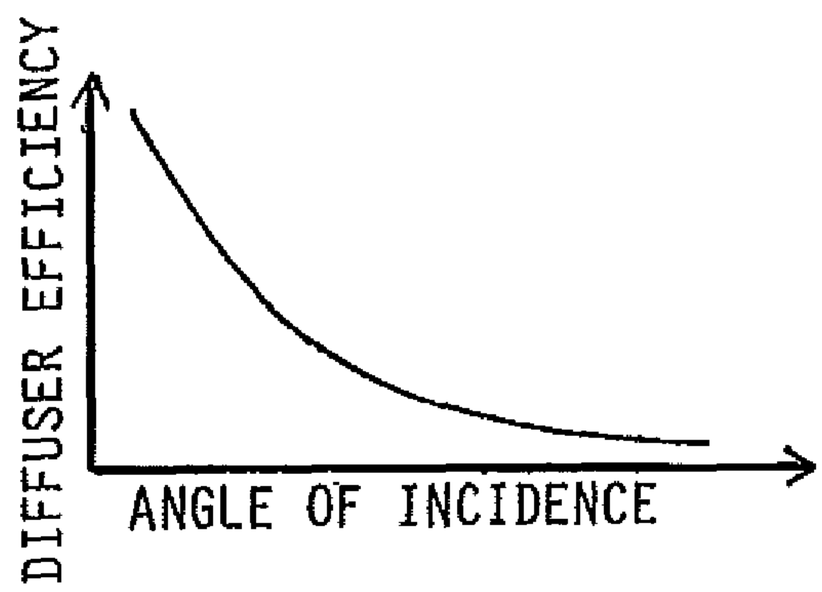


FIG. 2

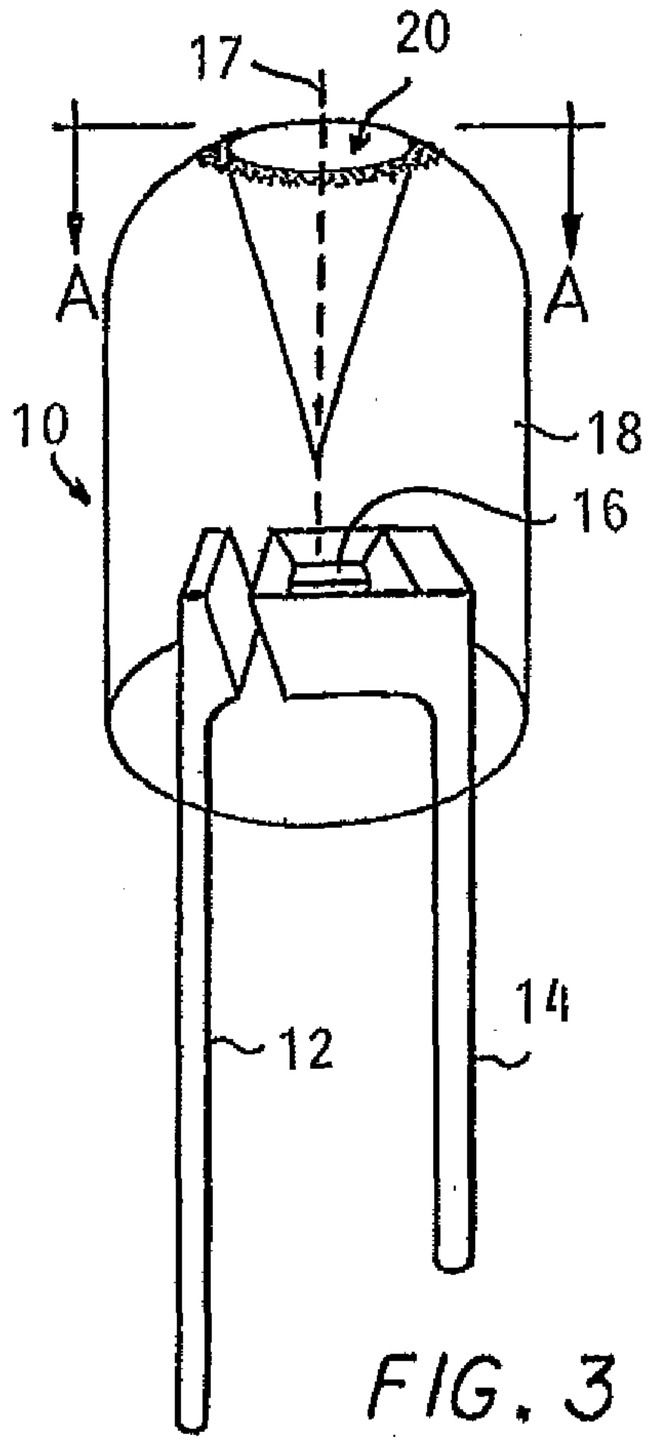


FIG. 3

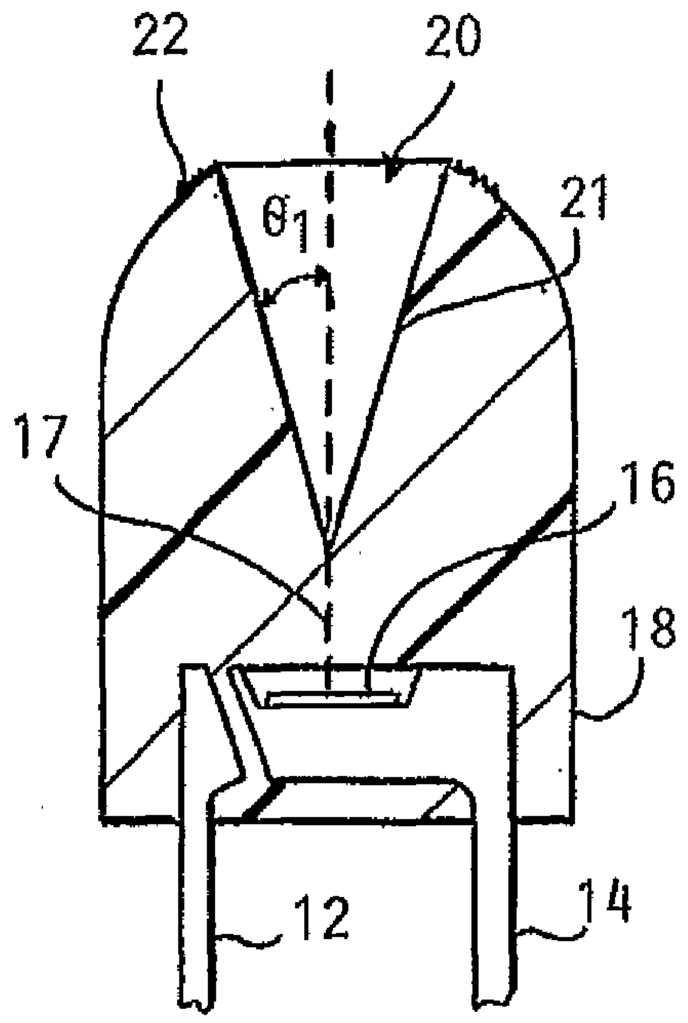


FIG. 4

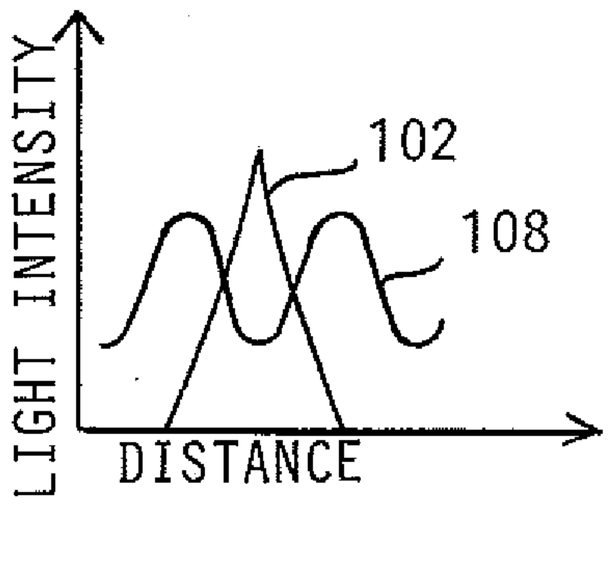


FIG. 5

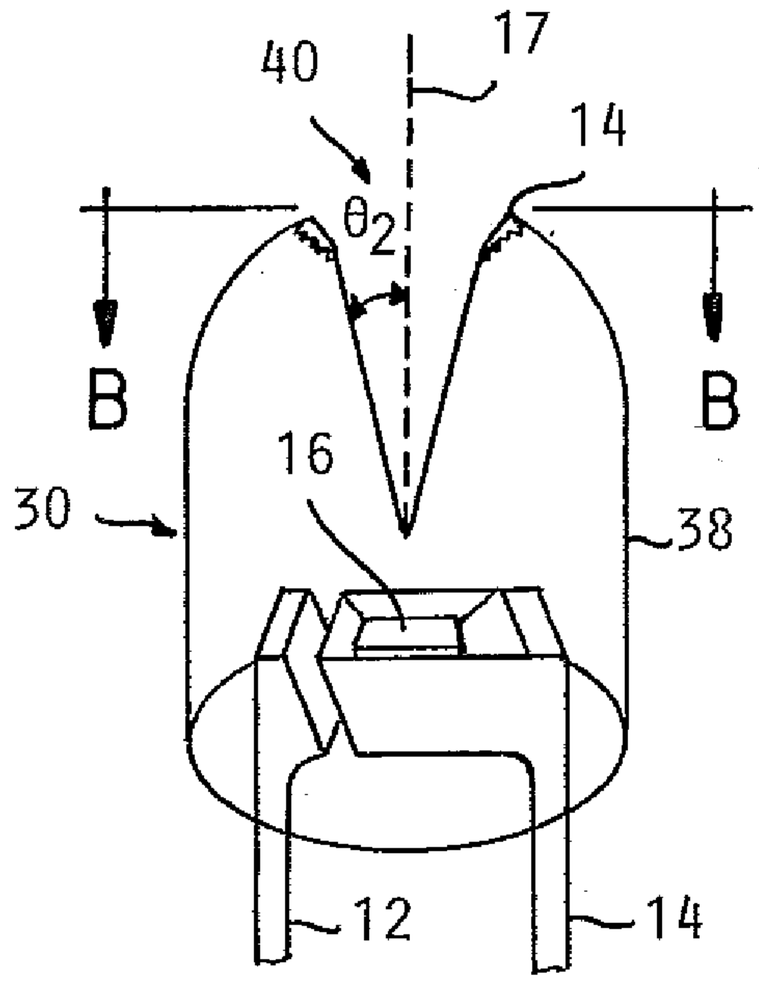


FIG. 6

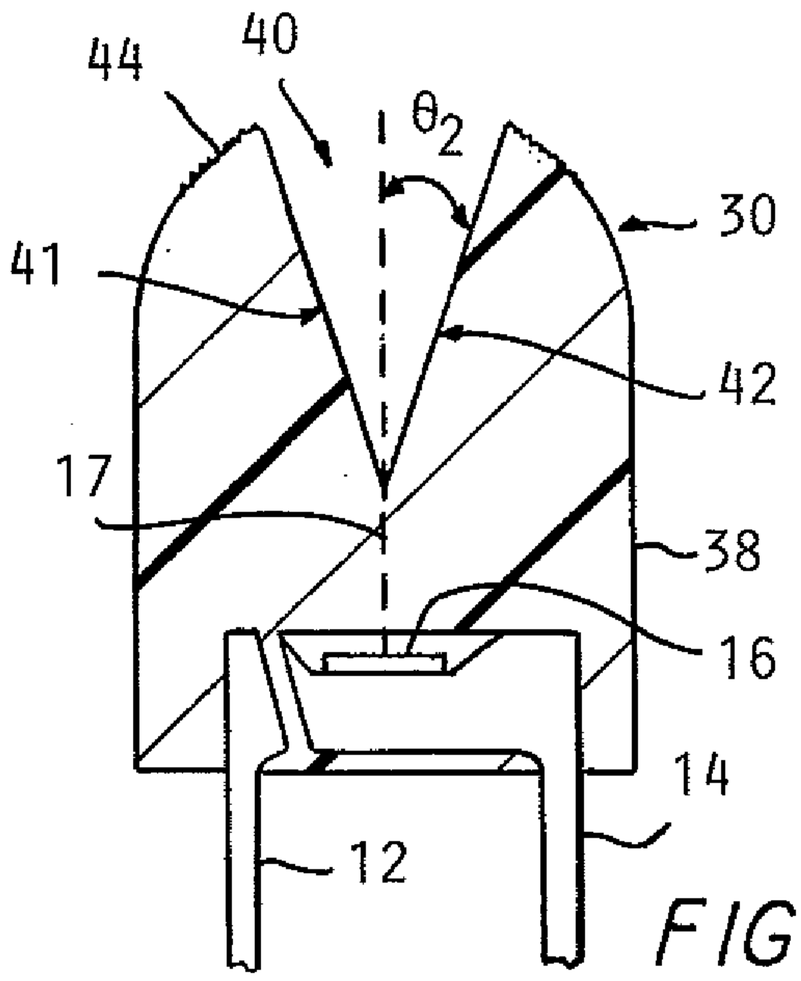


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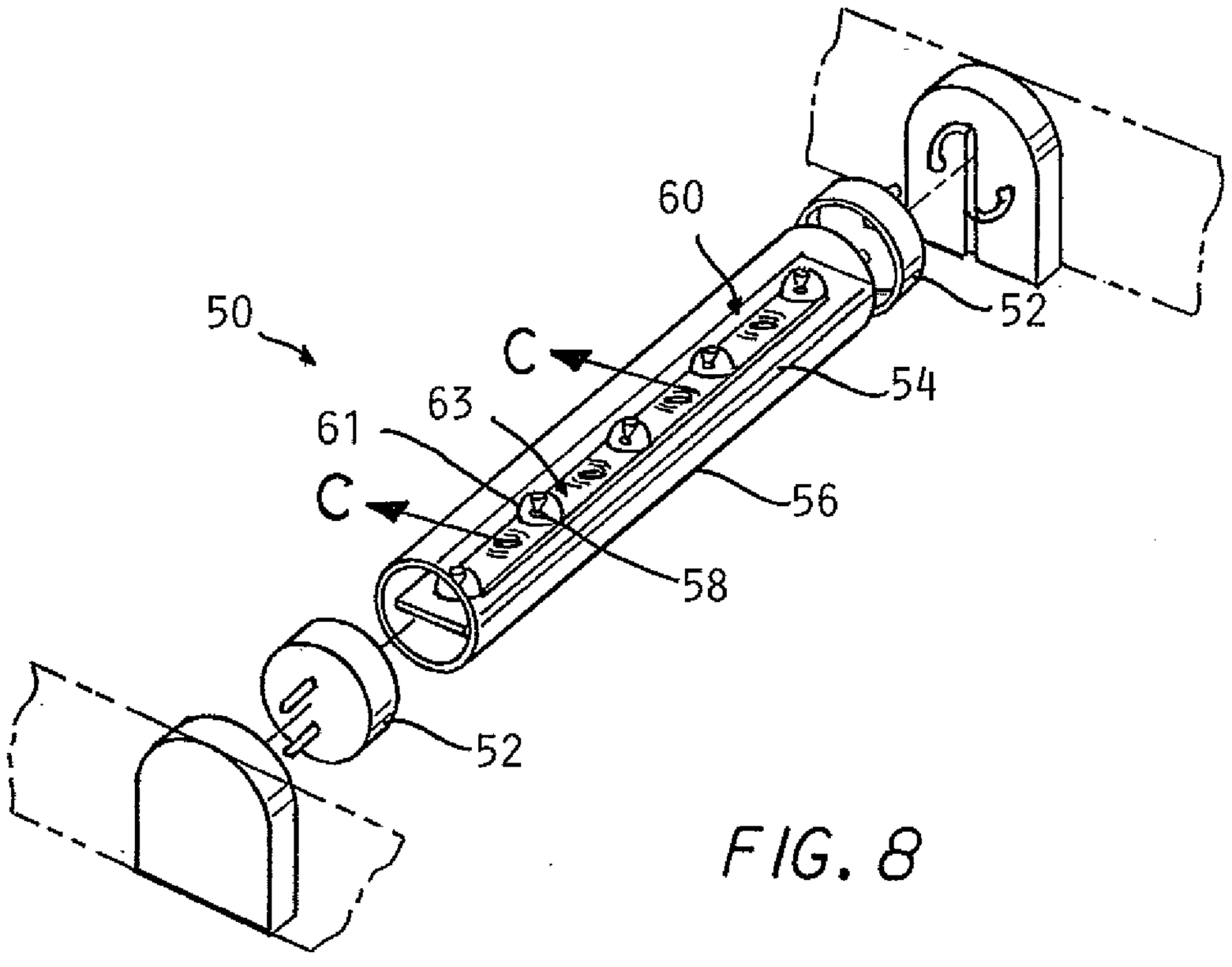


FIG. 8

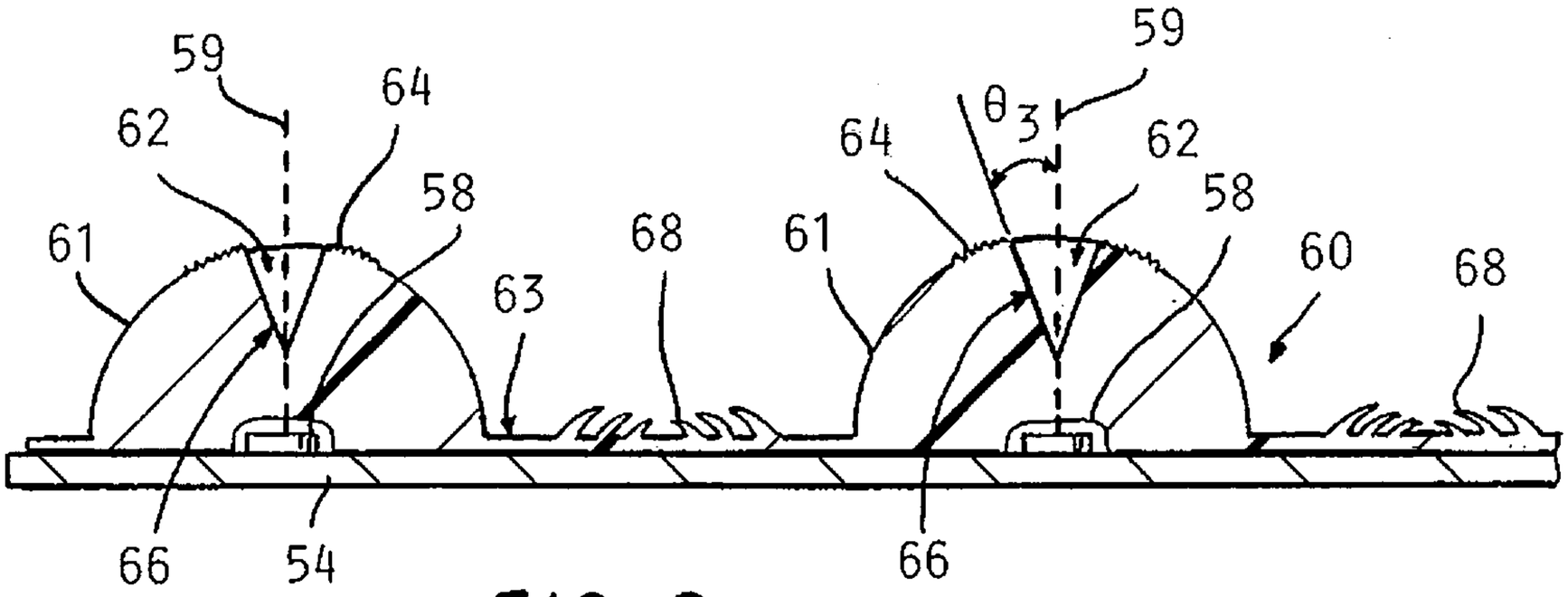


FIG. 9

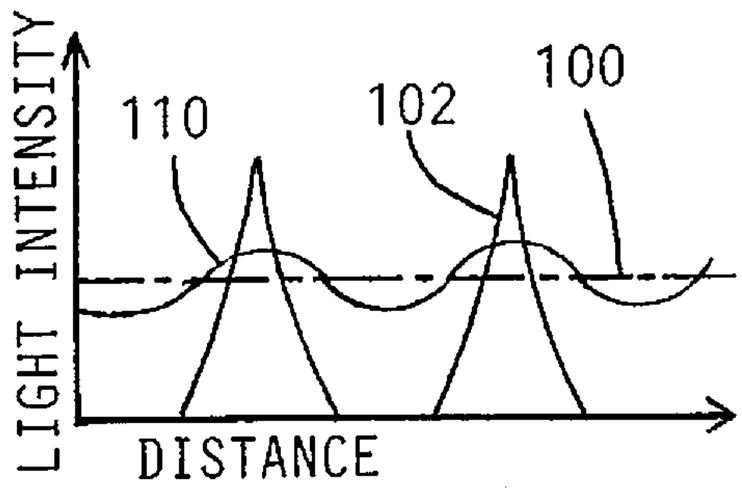


FIG. 10

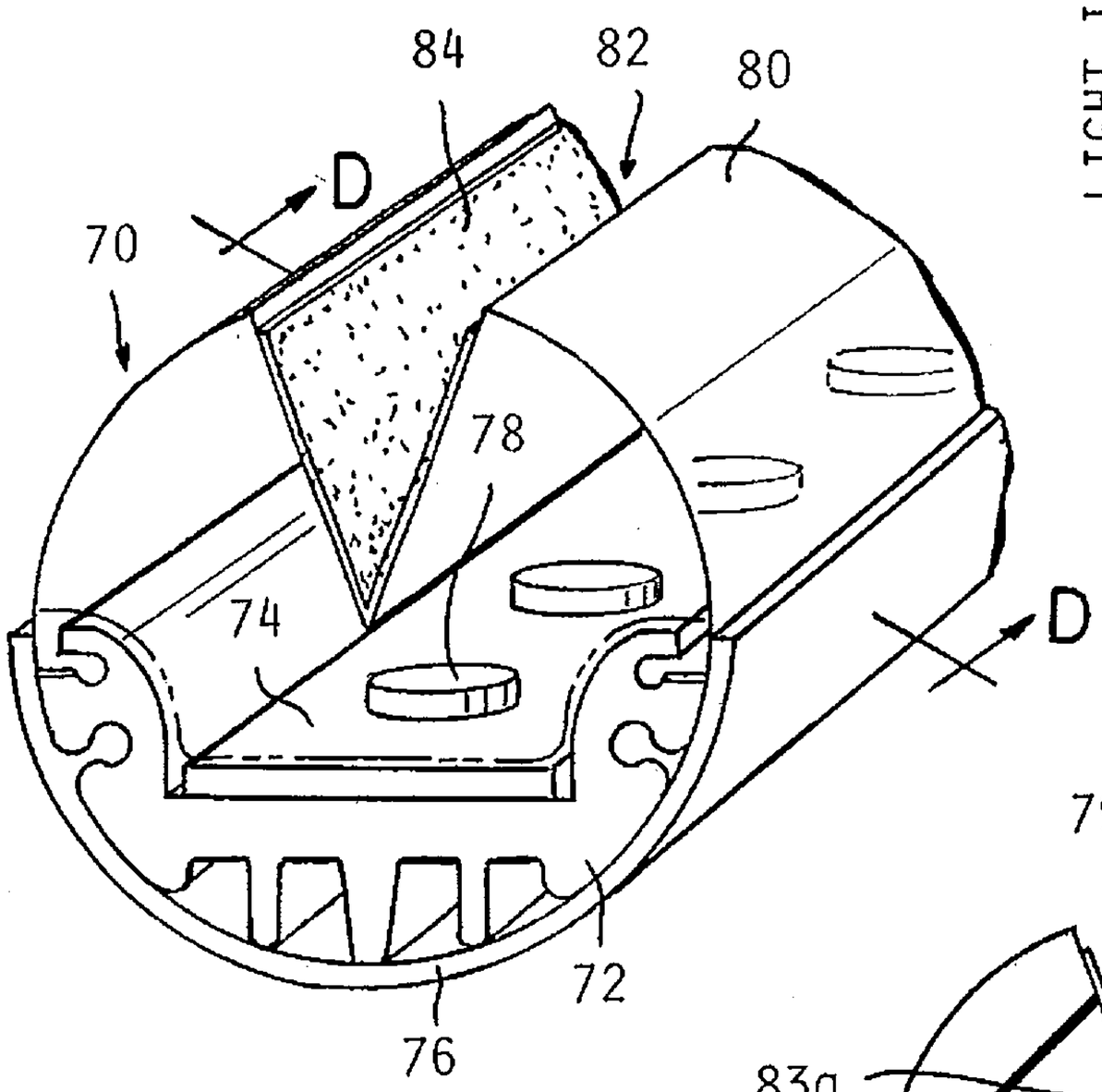


FIG. 11

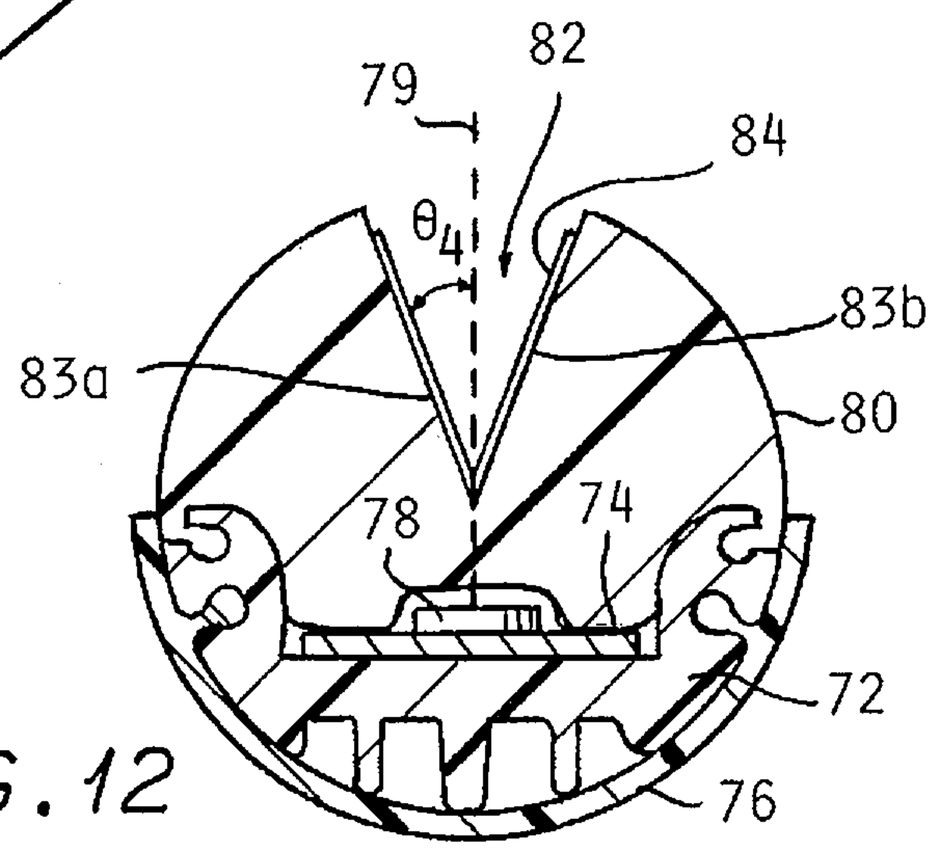


FIG. 12

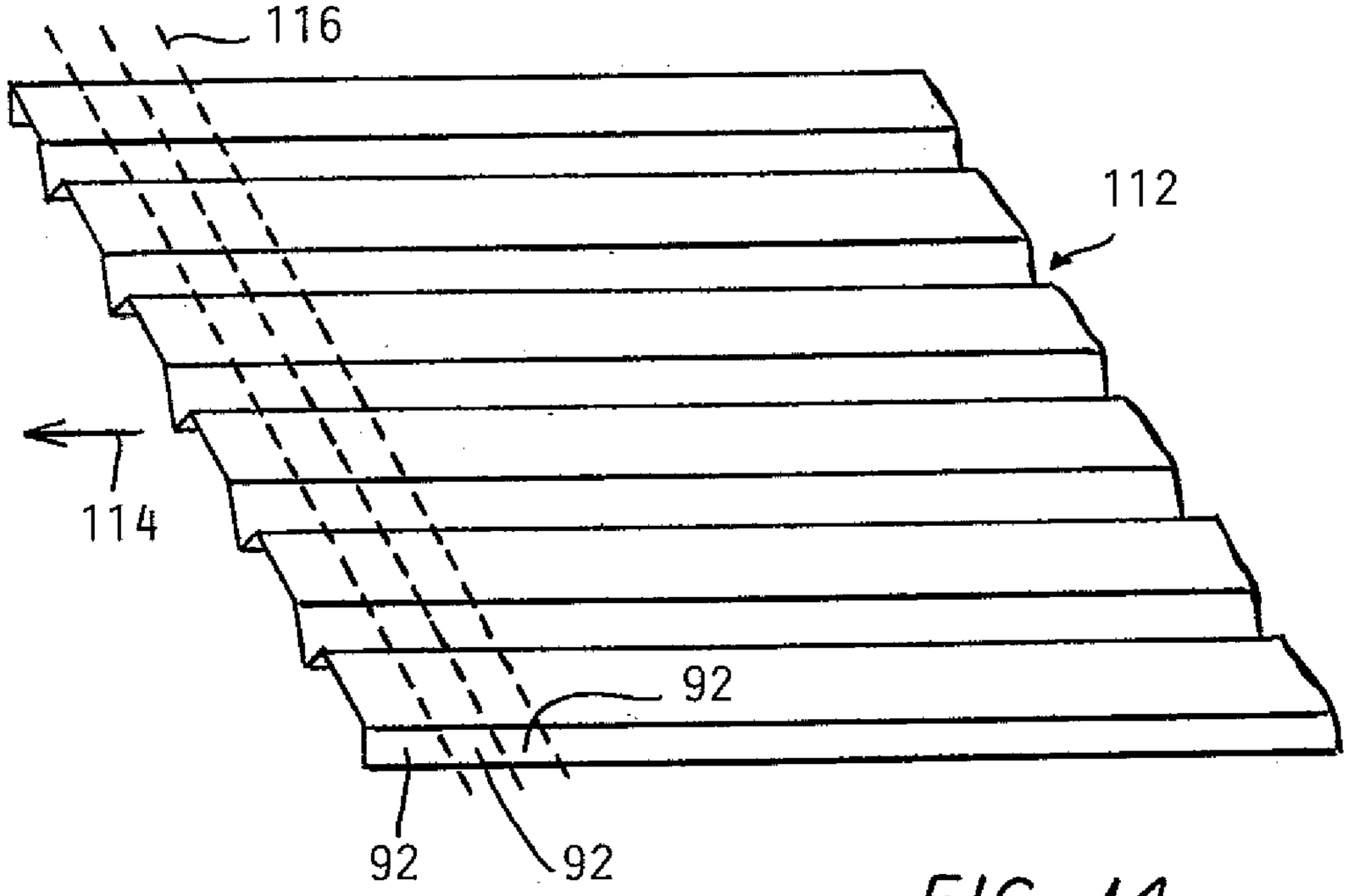


FIG. 14

FIG. 13

FIG. 15

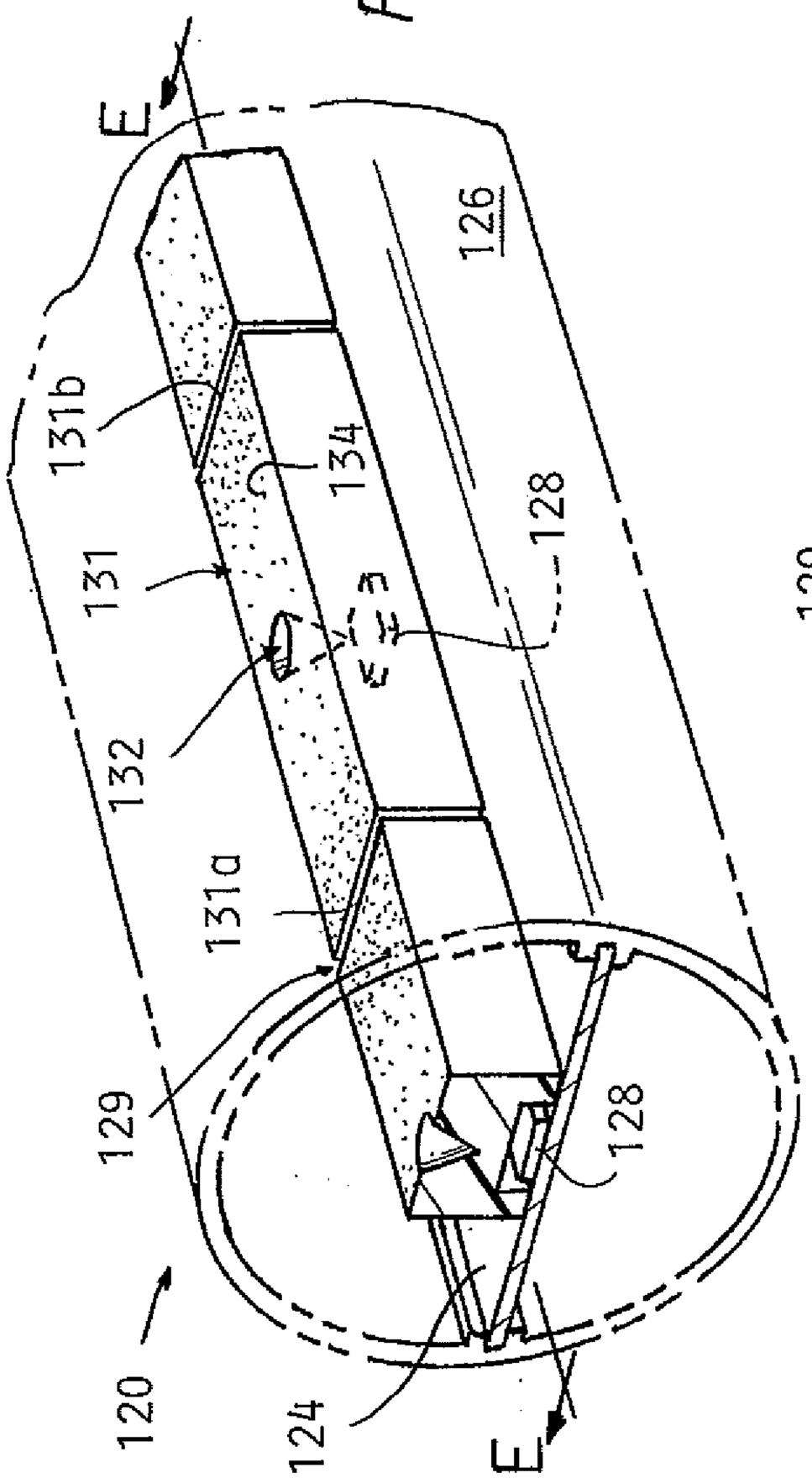

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FIG. 16

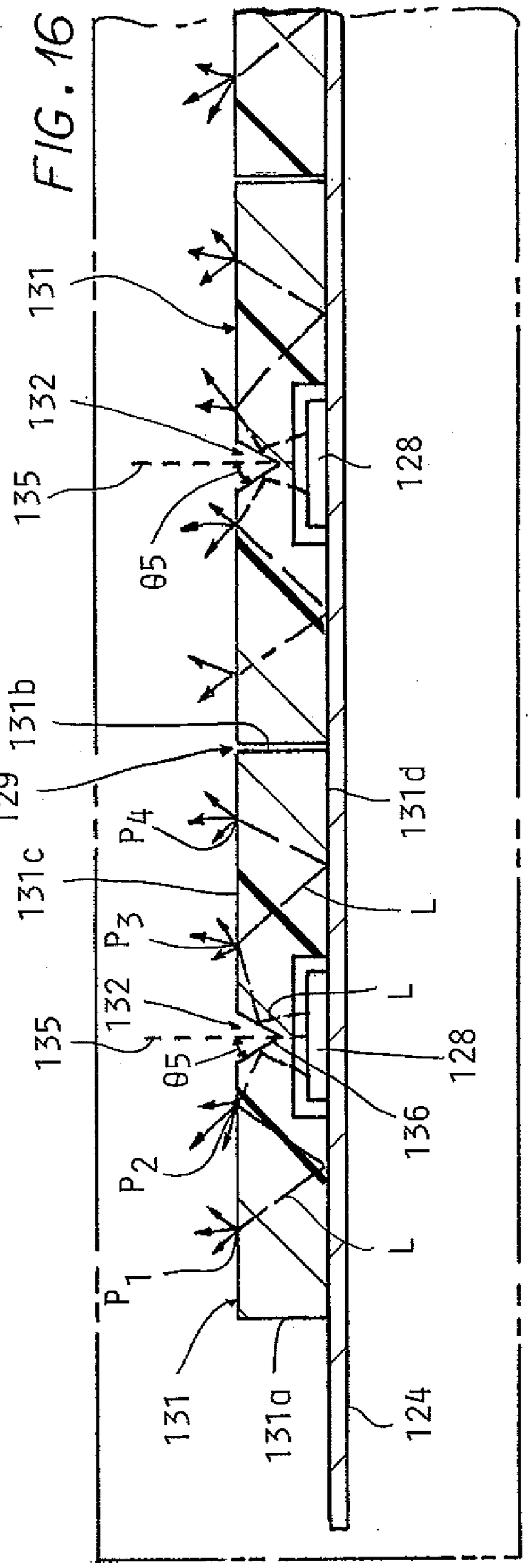

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FIG. 17

FIG. 18

FIG. 19

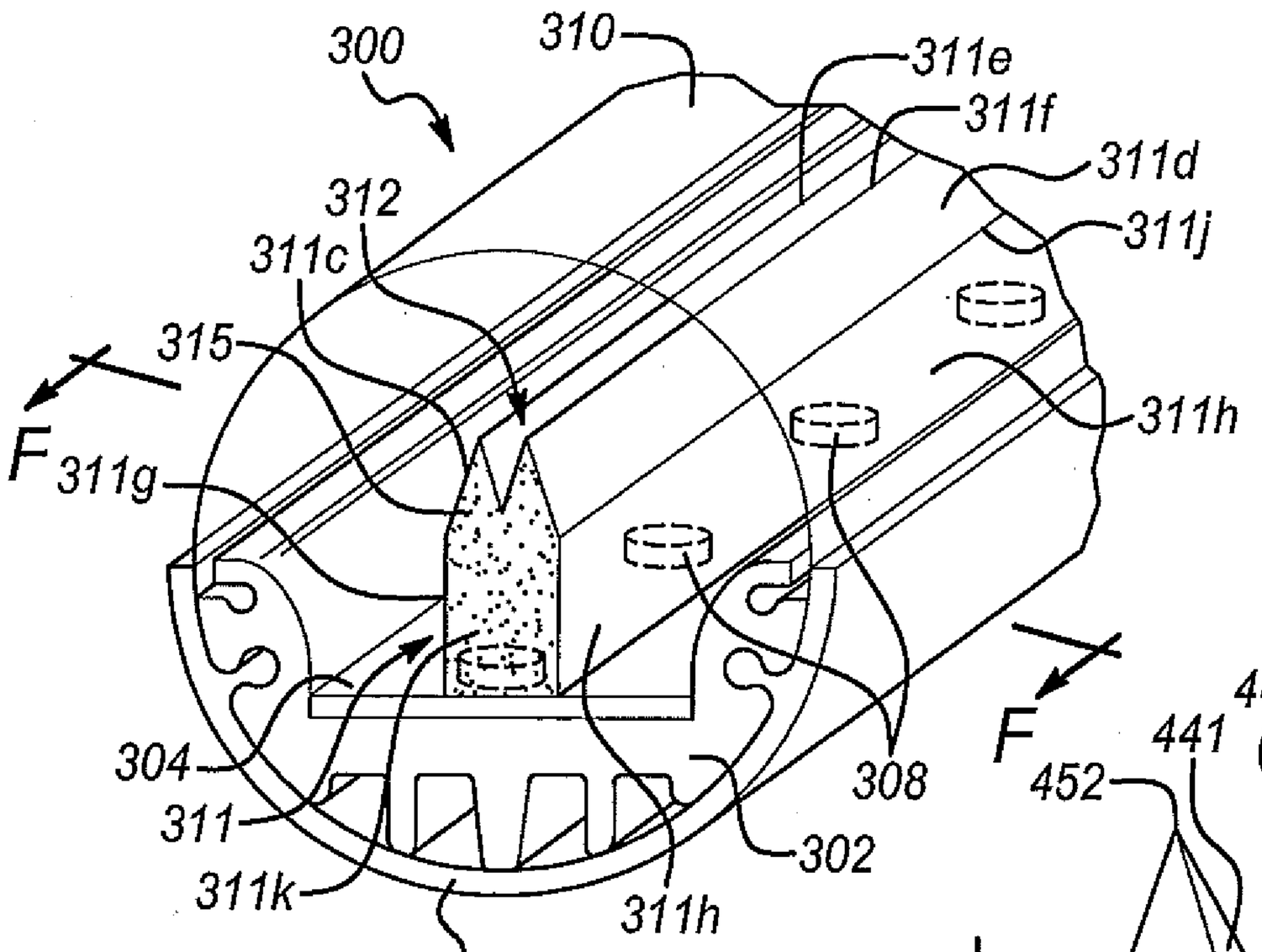


FIG . 20

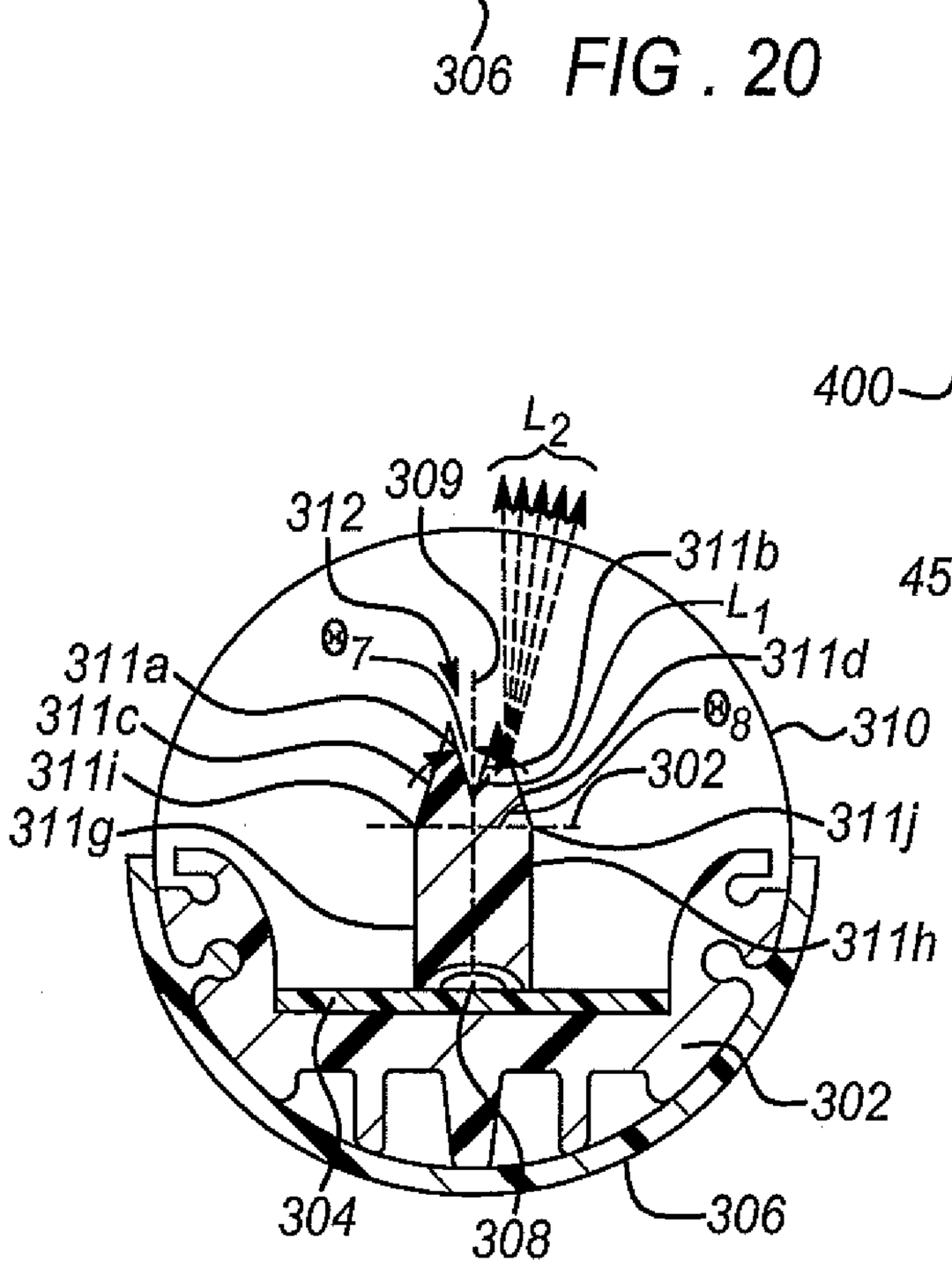


FIG . 21

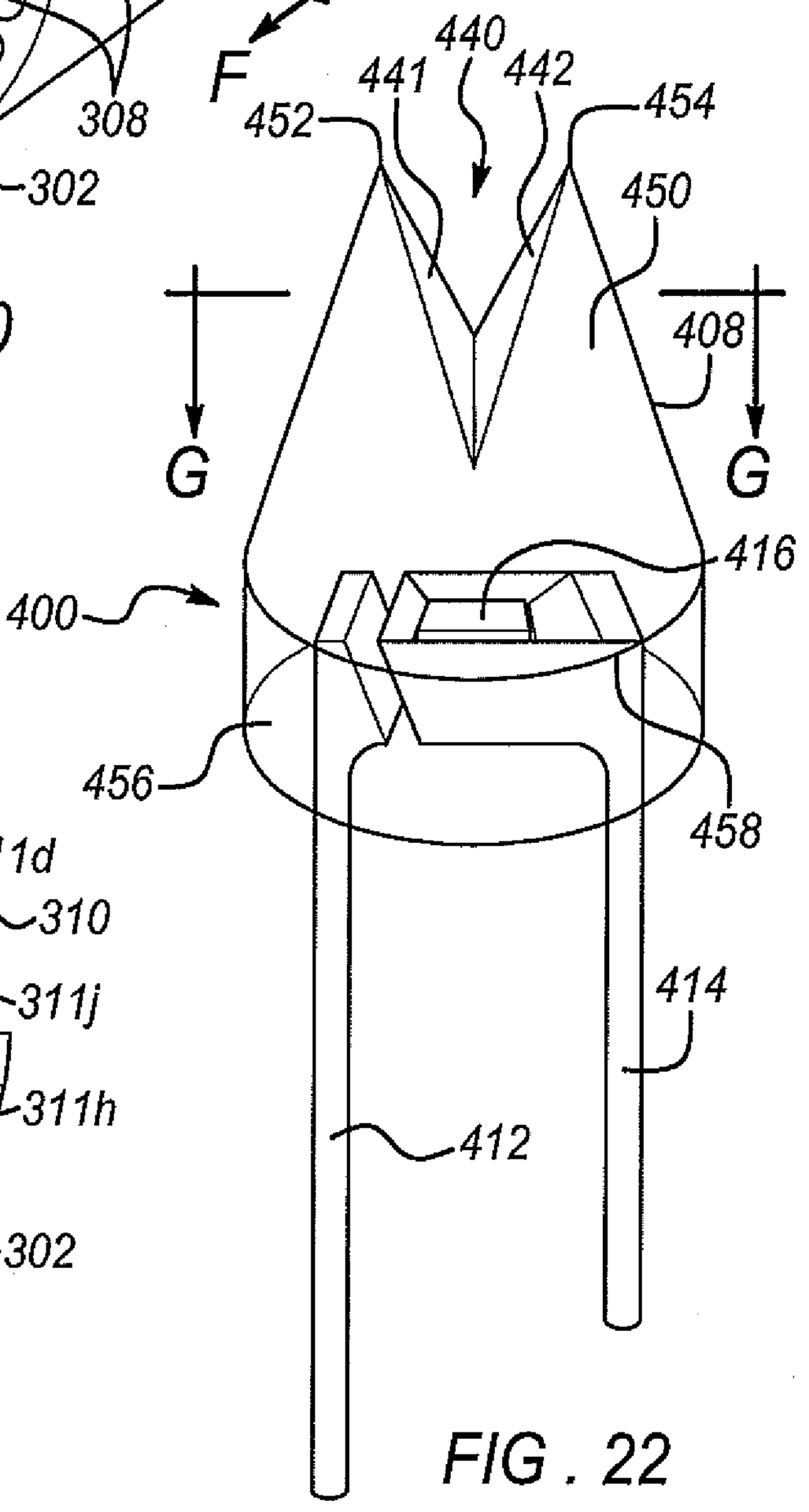


FIG . 22

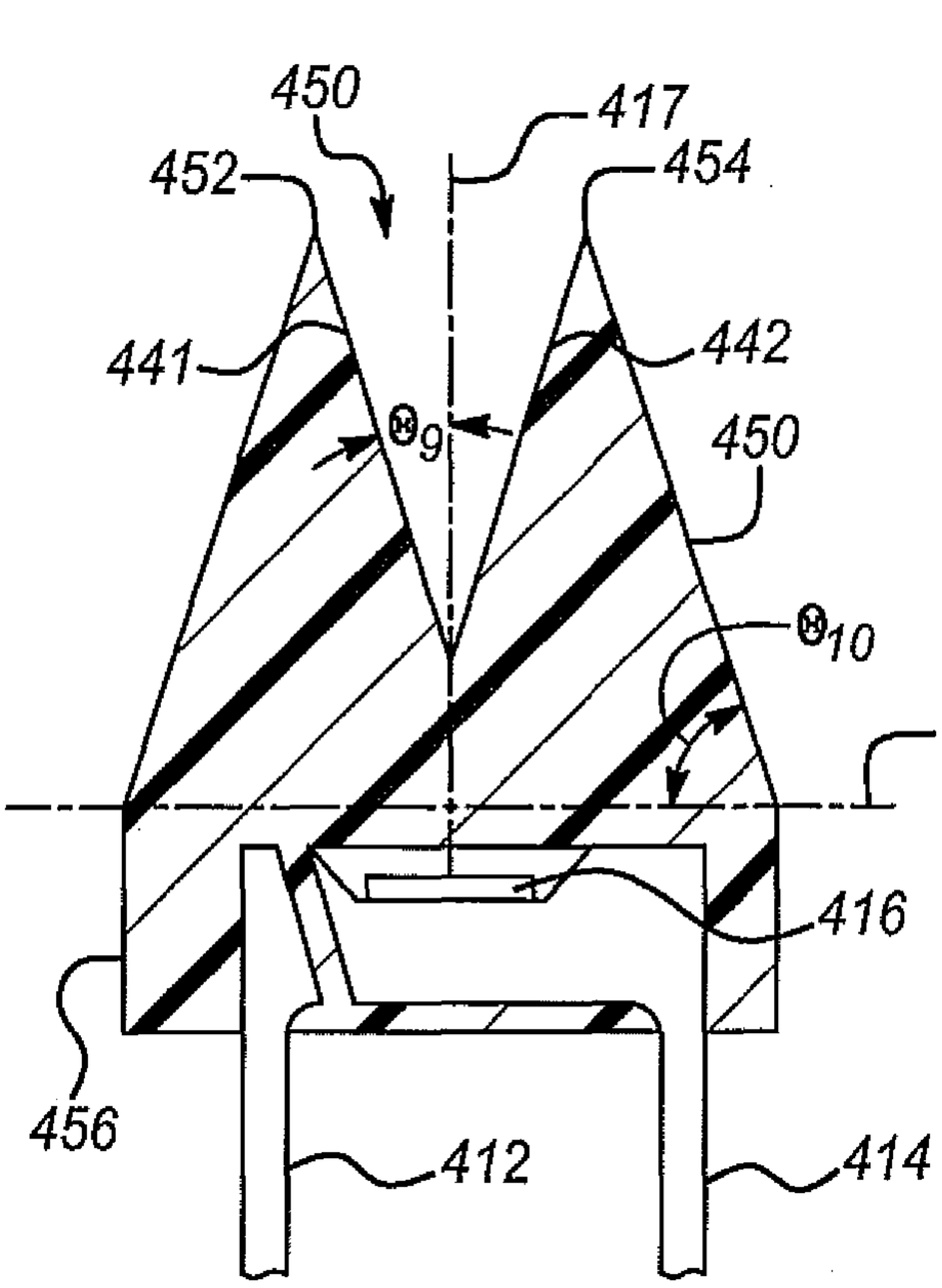


FIG . 23

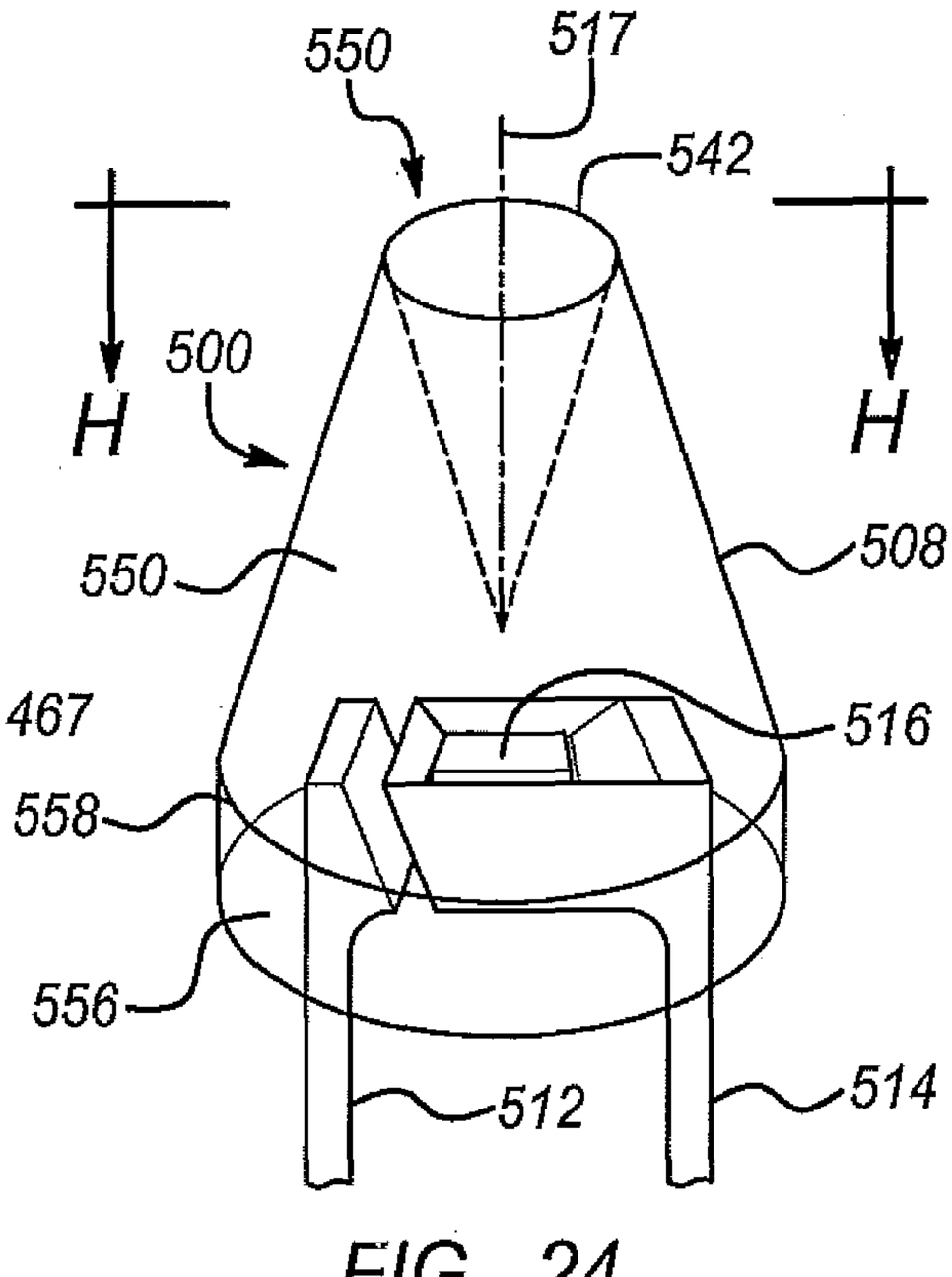


FIG . 24

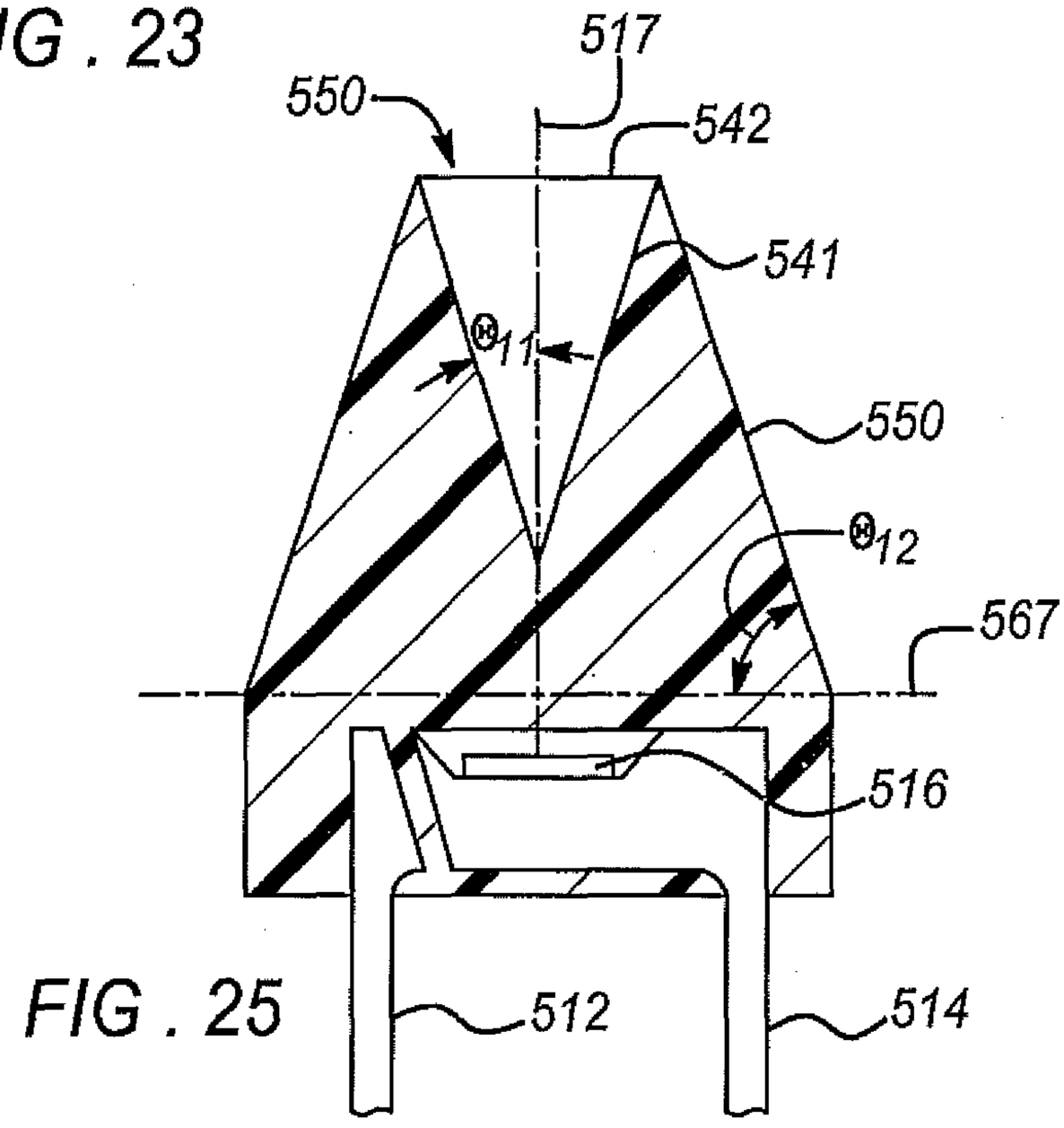


FIG . 25

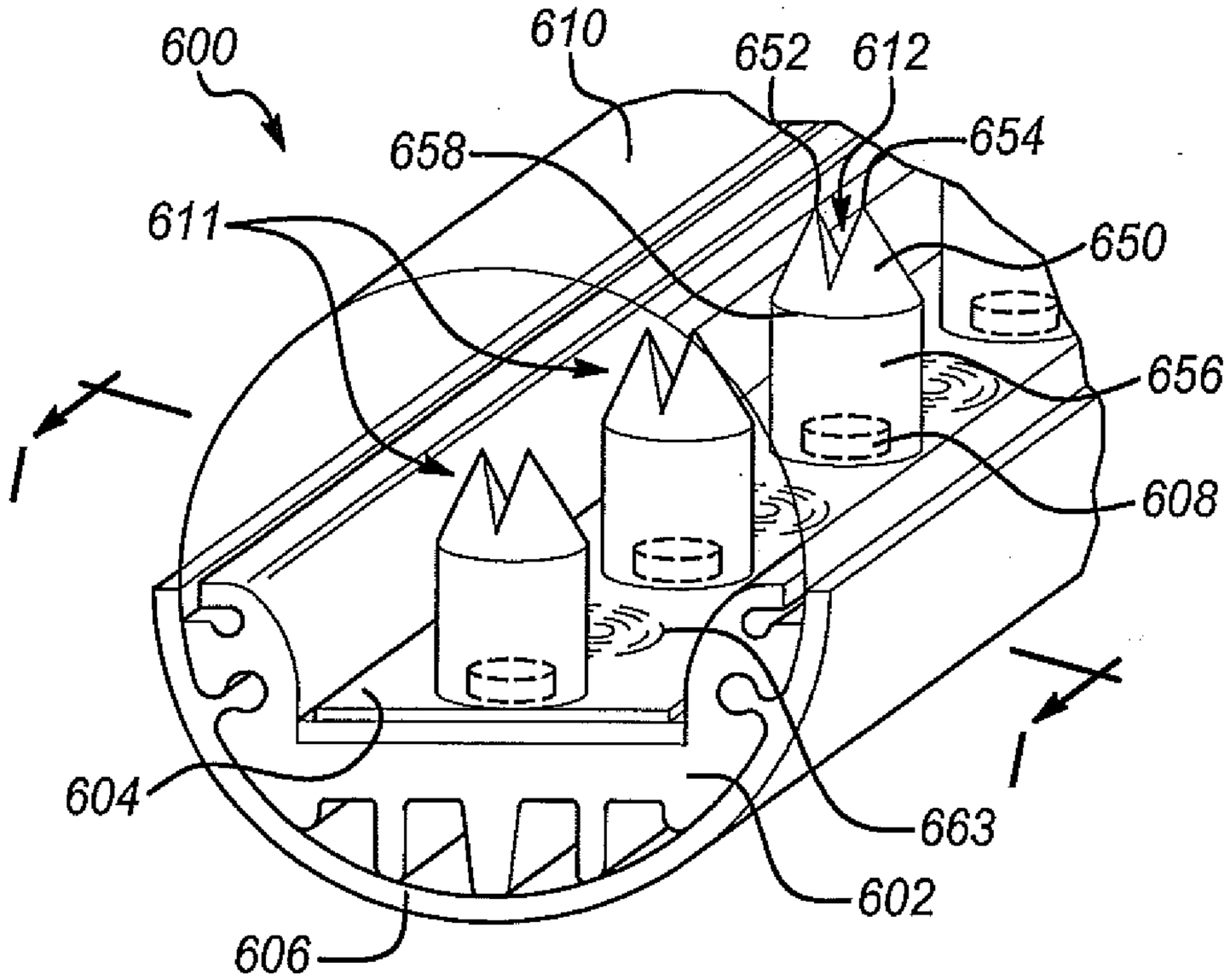

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FIG . 26

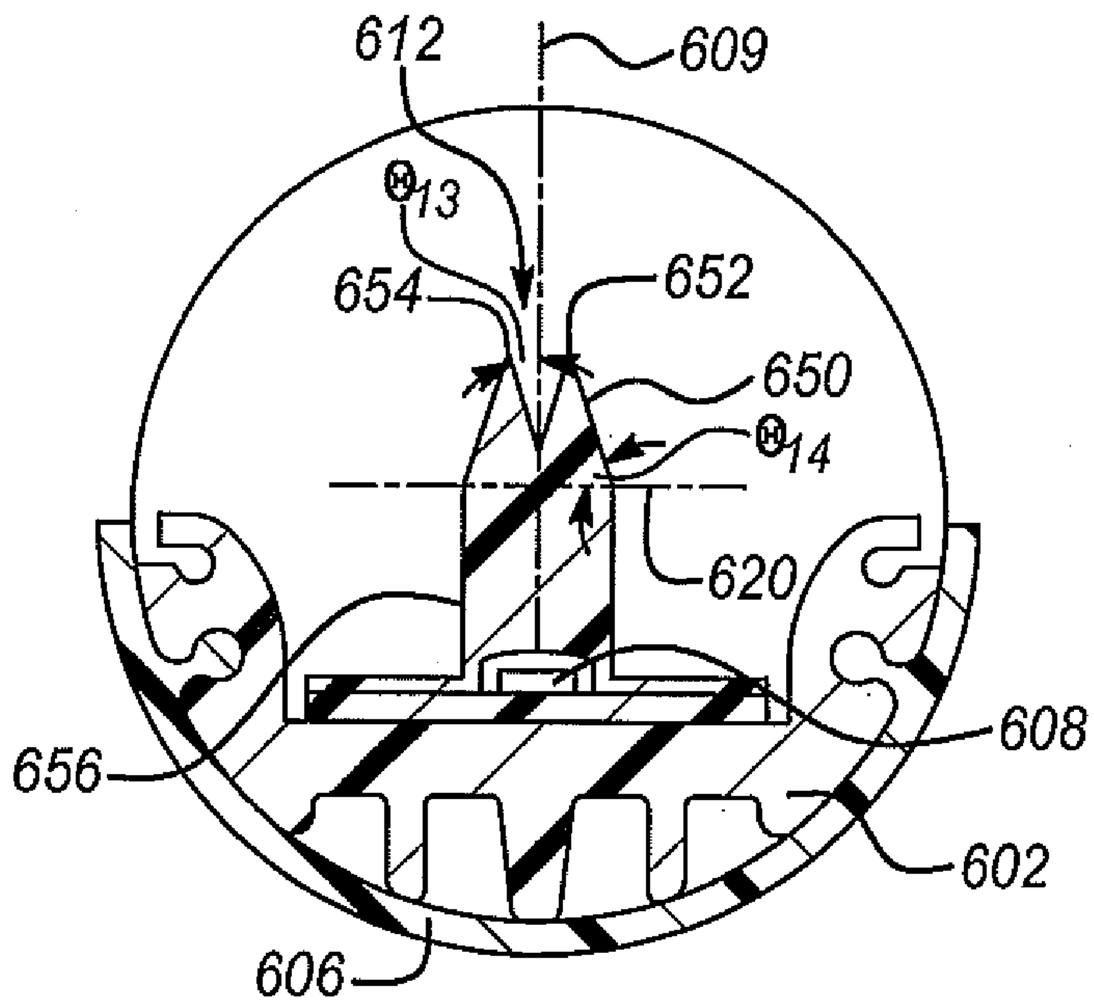

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FIG . 27

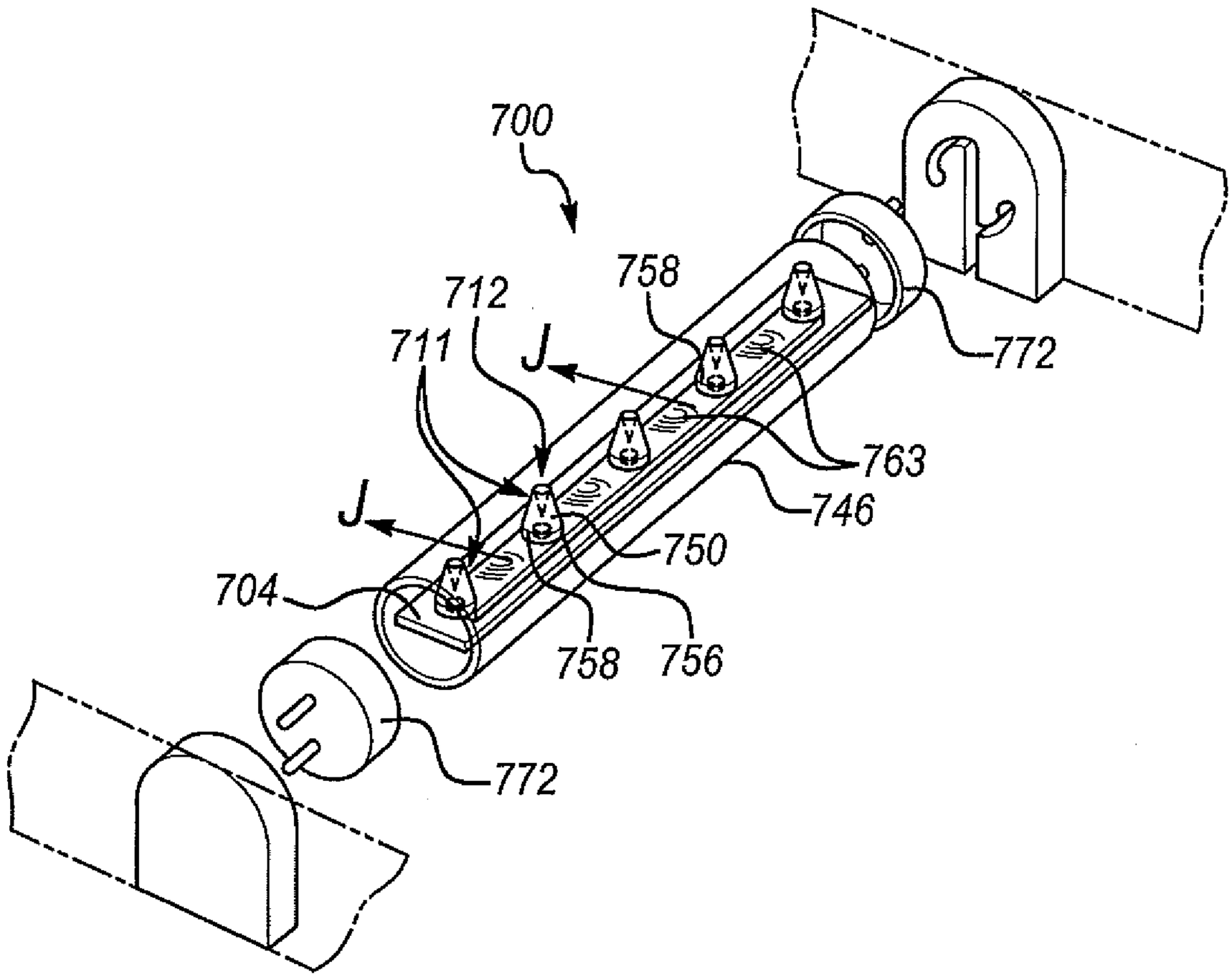

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FIG . 28

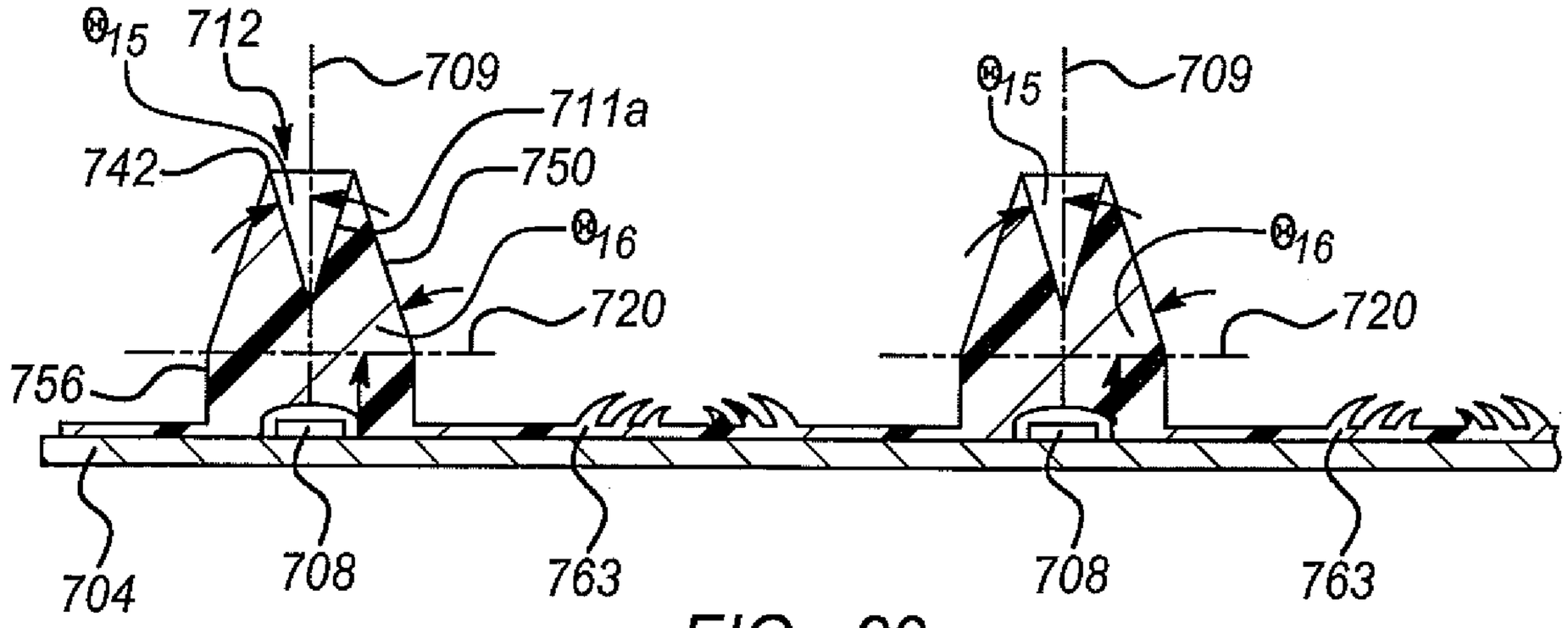

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FIG . 29

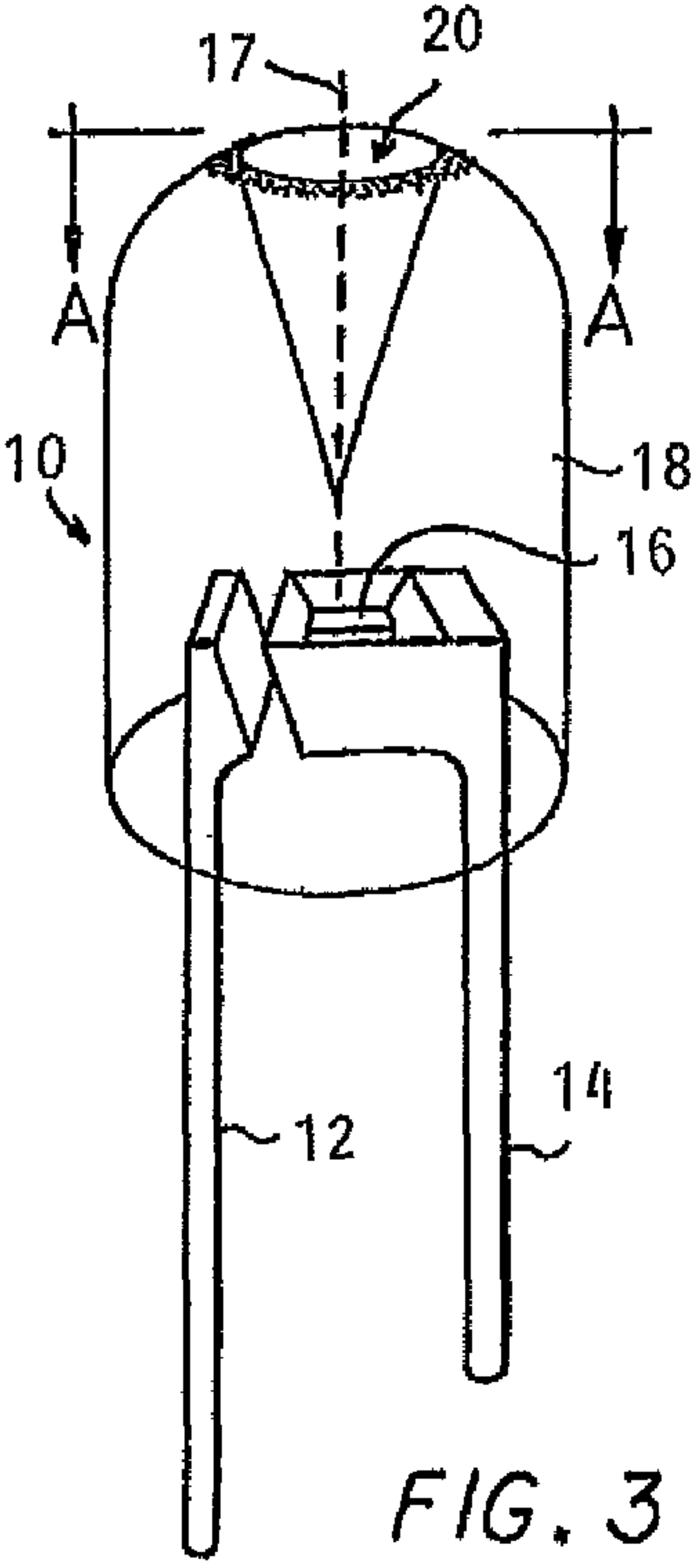


FIG. 3