(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 April 2013 (25.04.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/058971 A1

(51) International Patent Classification:
*F21V 3/00* (2006.01) *F21V 9/00* (2006.01)
*F21V 7/04* (2006.01)

(21) International Application Number:
PCT/US2012/058250

(22) International Filing Date:
1 October 2012 (01.10.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/547,845 17 October 2011 (17.10.2011) US
61/691,591 21 August 2012 (21.08.2012) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ,

*[Continued on next page]*

(54) Title: LIGHTING ASSEMBLY

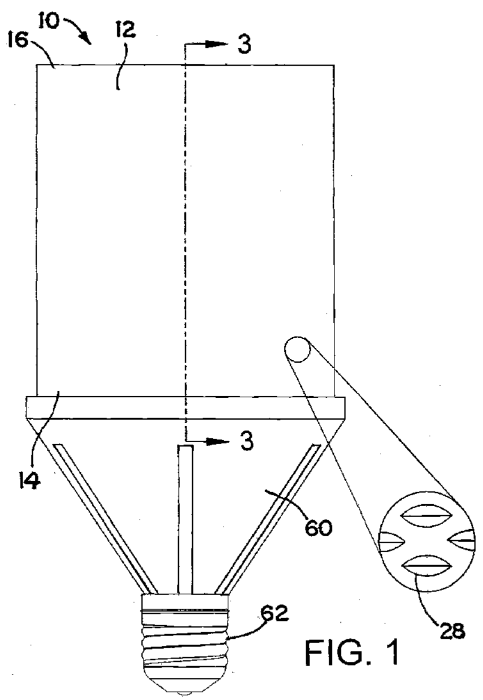


FIG. 1

(57) **Abstract**: A lighting assembly includes a light guide in which light propagates by total internal reflection between opposed major surfaces. The light guide is edge lit by a light source the inputs light of a first spectrum to the light guide. Light of a second spectrum is mixed with the light of the first spectrum so that light output by the lighting assembly has a spectrum that is a combination of the first spectrum and the second spectrum.

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UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Published**:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

# TITLE: LIGHTING ASSEMBLY

## RELATED APPLICATION DATA

[0001] This application claims the benefit of U.S. Patent Application No. 61/547,845 filed October 17, 2011 and U.S. Patent Application No. 61/691,591 filed August 21, 2012, the disclosures of which are herein incorporated by reference in their entireties.

## BACKGROUND

[0002] Energy efficiency has become an area of interest for energy consuming devices. One class of energy consuming devices is lighting devices. Solid-state light sources, such as light emitting diodes (LEDs), show promise as energy efficient light sources for lighting devices. Different LEDs have different efficiencies. But the higher efficiency LEDs may not output light with a color temperature that is appropriate for a desired application.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. 1 is a schematic side view of an exemplary lighting assembly in the form of a light bulb;

[0004] FIG. 2 is a perspective view of the lighting assembly of FIG. 1;

[0005] FIG. 3 is a cross-sectional view taken along the line 3--3 in FIG. 1;

[0006] FIG. 4 is a representative light source for a lighting assembly;

[0007] FIG. 5 is a perspective view of another exemplary lighting assembly;

[0008] FIG. 6 is a top view of the lighting assembly of FIG. 5;

[0009] FIG. 7 is a perspective view of another exemplary lighting assembly;

[0010] FIG. 8 is a top view of the lighting assembly of FIG. 7;

[0011] FIG. 9 is a perspective view of another exemplary lighting assembly;

[0012] FIG. 10 is a top view of the lighting assembly of FIG. 9;

[0013] FIG. 11 is a perspective view of another exemplary lighting assembly;

[0014] FIG. 12 is a top view of the lighting assembly of FIG. 11;

[0015] FIG. 13 is a cross-sectional view of a portion of an exemplary lighting assembly;

[0016] FIG. 14 is a cross-sectional view of a portion of an exemplary lighting assembly;

[0017] FIG. 15 is a schematic diagram of an exemplary lighting assembly;

[0018] FIG. 16 is an enlarged end view of the lighting assembly of FIG. 15 taken along the line 16--16 in FIG. 15;

[0019] FIG. 17 is a schematic diagram of an exemplary lighting assembly;

[0020] FIG. 18 is an enlarged end view of the lighting assembly of FIG. 17 taken along the line 18--18 in FIG. 17;

[0021] FIG. 19 is a top view of another exemplary lighting assembly;

[0022] FIG. 20 is a cross-sectional view taken along the line 20--20 in FIG. 19;

[0023] FIG. 21 is a cross-sectional view of a portion of another exemplary lighting assembly; and

[0024] FIG. 22 is a perspective view of another representative light bulb, in which a portion of the light bulb is broken away to show internal components.

## DETAILED DESCRIPTION

[0025] Embodiments will now be described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. The figures are not necessarily to scale. Features that are described and/or illustrated with respect to one embodiment may be used in the same way or in a similar way in one or more other embodiments and/or in combination with or instead of the features of the other embodiments.

[0026] With initial reference to FIGs. 1-3, an exemplary embodiment of a lighting assembly 10 is shown. The lighting assembly 10 of this embodiment is configured as a light bulb. References in this disclosure to a "light bulb" are meant to broadly encompass light-producing devices that fit into and engage any of various fixtures used for mechanically mounting the light-producing device and for providing electrical power thereto. Examples of such fixtures include, without limitation, screw-in fixtures for engaging an Edison light bulb base, a bayonet fixture for engaging a bayonet light bulb base, and a bi-pin fixture for engaging a bi-pin light bulb base. Thus the term "light bulb," by itself, does not provide any limitation on the shape of the light-producing device, or the mechanism by which light is produced from electric power. In one embodiment, however, the light bulb conforms to an outer envelope of an A19 light bulb. Also, the light bulb need not have an enclosed envelope forming an environment for light generation. The light bulb may conform to American National Standards Institute (ANSI) or other standards for electric lamps, but the light bulb does not necessarily have to have this conformance.

[0027] The lighting assembly 10 includes a non-planar, optically-conductive light guide 12 that is open at opposite ends, referred to as a proximal end 14 and a distal end 16. In the example shown, the light guide 12 is cylindrical in shape. An edge surface at the proximal end 14 provides a light input edge 18 through which light from a light source 20 is input to the light guide 12. In the example shown, the light source 20 includes solid-state light emitters mounted on a printed circuit board 22. The printed circuit board 22 is typically heat conducting. An exemplary solid-state light emitter constructed as a single light-emitting device (e.g., a single LED die) is shown using reference numeral 21. Reference numeral 21 also may be used to refer to more than one solid-state light emitting device collectively.

[0028] The light source 20 is arranged such that light from the light source 20 enters the light input edge 18 at the proximal end 14 of the light guide 12 and travels in the light guide 12 by total internal reflection at an inner major surface 24 of the light guide and at an outer major surface 26 of the light guide 12. In one embodiment, the solid-state light emitters 21 constituting the light source 20 are arranged in a ring or another suitable pattern depending on the shape of the light input edge 18 of the light guide 12 to which the light source 20 supplies light.

[0029] The light guide 12 includes light extracting elements 28 at one or both of the major surfaces 24, 26 for extracting light from the light guide 12 through at least the outer major surface 26. The extracted light is represented by arrows identified by reference numeral 30. Typically, additional light 31 is extracted through the inner major surface 24.

[0030] To reduce power consumption, the light source 20 is a relatively efficient light source. A relatively efficient light source 20 has an efficacy of greater than about 80 lumens/watt (lm/W). In one embodiment, the solid state light emitters 21 constituting light source 20 are LEDs. Other types of solid-state light emitters 21 include organic LEDs (OLEDs).

[0031] A simplified example of a solid state light emitter 21 embodied as an LED is illustrated in FIG. 4. The solid-state light emitter 21 includes an LED die 32 having a light emitting surface 34 from which most of the light is emitted. The LED die is covered by a layer 36 that contains a wavelength shifting material, such as a phosphor material. The wavelength shifting material converts at least some of the light emitted by the LED die 32 to light of a longer wavelength. The light output by the wavelength shifting material and any unconverted light collectively constitute light of a first spectrum. The light of the first spectrum propagates through the light guide by total internal reflection and is the light 30, 31 that is extracted from the light guide 12 by the light extracting elements 28 through the outer major surface 26 and the inner major surface 24, respectively. The light source 20 can be a top-fire LED or a side-fire LED. The solid-state light emitters 21 are broad-spectrum LEDs that emit white light.

[0032] In an exemplary embodiment, the light of the first spectrum emitted by the solid state light emitters 21 is what is referred to in the art as "cool white" light (e.g., solid state light emitters 21 that generate light having a color temperature in the range from about 5,000 K to about 7,000 K). Solid-state emitters that emit cool white light typically have an efficacy greater than about 120 lm/W. However, for many applications, it is preferred to have light that is warmer than cool white light. Cool white light is unacceptable in such applications despite the relatively high efficacy of its production. In contrast, "warm white" light, which has a color temperature in the range from about 2,500 K to about 3,500 K, is more acceptable for certain lighting applications. However, LEDs that generate warm white light have an efficacy substantially lower than that of LEDs that generate cool white light, so the use of LEDs that generate cool white light is preferable to reduce energy consumption.

[0033] To make the light 30, 31 of the first spectrum generated by LEDs that generate cool white light warmer, the lighting assembly 10 includes a color adjuster 38 disposed at least partially in the internal volume 40 of the light guide 12. The color adjuster 38 is configured to direct light of a second spectrum (represented by arrow 42), different from the first spectrum, toward the inner major surface 24. The light of the second spectrum is narrower in spectrum than the light of the first spectrum. The light 42 of the second spectrum passes through the light guide 12 and mixes with the light 30 of the first spectrum so that output light 44 output by the lighting assembly 10 has a spectrum that is a combination of the first spectrum and the second spectrum. The color adjuster 38 is also configured to direct light of the second spectrum, represented by arrow 43 and having a different light ray angle distribution than light 42, to mix with the light 31 of the first spectrum so that additional output light 45 output by the lighting assembly 10 has a spectrum that is a combination of the first spectrum and the second spectrum. Typically, the light 45 is output through the open distal end 16 of the light guide 12.

[0034] The spectrum of the output light 44 and 45 is measured by placing the lighting assembly 10 in an integrating sphere and measuring the spectrum using a sensor located on the internal surface of the integrating sphere. In the practical examples of the lighting assembly 10 described herein with reference to the figures, small variations in the spectrum of output light 44 and 45 depending on the observer's location relative to lighting assembly can occur as a result of the different source locations of the light of the first spectrum and the light of the second spectrum, and the possibly different directional properties of the light of the first spectrum and the light of the second spectrum.

[0035] In exemplary embodiments, the light 42, 43 of the second spectrum is red light or, more broadly, is narrow-band light having a wavelength peak in the range from about 550 nanometers (nm) to about 750 nm. In an embodiment where the light of the first spectrum is cool white light and light of the second spectrum is red light, the resulting mixed output light 44, 45 has a spectrum that is warmer than the first spectrum. Also, in one embodiment, the intensity of the light 42, 43 of the second spectrum is less than the intensity of the light 30, 31 of the first spectrum. Light intensity is measured in lumens, candela per square meter ($cd/m^2$), or another appropriate unit of measure. In one embodiment, a ratio of the intensity of the light 42, 43 of the second spectrum to the intensity of the light 30, 31 of the first spectrum is in the range from about one to two to about one to twenty. In one embodiment, the ratio is in the range from about one to six to about one to twelve.

[0036] The color adjuster 38 includes a light source 46 and a light director 48 that directs at least a portion of the light from the light source 46 toward the inner major surface 24. In one embodiment, the light source 46 is composed of one or more solid state light emitters, such as LEDs. An exemplary solid state light emitter is shown at 47. Reference numeral 47 is also used to indicate the solid state light emitters that constitute light source 46 collectively. Other solid state light source types that can be used as light source 46 include laser diodes and organic LEDs (OLEDs). Typically, the solid state light emitters 47 are monochromatic LEDs. Such LEDs do not employ a phosphor and typically have a greater efficacy (e.g., greater than 150 lm/W) than LEDs that employ a phosphor.

[0037] In the embodiment of FIGs. 1-3, the light director 48 is a light guide 50 having a light input edge 52 through which light from the light source 46 is received and an output surface 54 through which the light 42 is extracted. Light propagates in the light guide 50 by total internal reflection at the output surface 54 and is extracted from the light guide 50 with light extracting elements 56 that are at the light output surface 54. In the illustrated embodiment, the light guide 50 is a solid cylinder. In one embodiment, the light director 48 has a length that is comparable in length to the light guide 12 (e.g., within the range of about 80 percent to about 120 percent of the length of the light guide 12). Additionally, the output surface 54 is smaller in area than either of the major surfaces 24, 26. In one embodiment, the output surface 54 is substantially smaller in area (e.g., less than about 25 percent of the area of one of the major surfaces 24, 26).

[0038] Once output from the light output surface 54, the light 42 travels in the internal volume 40 of the light guide 12 and is incident on the inner major surface 24. The light 42 enters the light guide 12 through the inner major surface 24 and exits the light guide 12 through the outer major surface 26.

[0039] In one embodiment, the solid state light emitters 47 that constitute light source 46 are mounted to a thermally conductive printed circuit board 58 that is separate from the printed circuit board 22 to which the solid state light emitters 21 that constitute light source 20 are mounted. In another embodiment, the light source 20 and the light source 46 are mounted to the same printed circuit board 22.

[0040] The lighting assembly 10 further includes a housing 60 at the proximal end 14 of the light guide 12. The housing 60 retains the printed circuit board 22 and light source 20, the light guide 12, and the color adjuster 38. The housing 60 also includes a base 62 configured to mechanically mount the lighting assembly 10 and receive electrical power.

[0041] With continuing reference to FIGs. 1-3, the light guide 12 is a solid article made from, for example, acrylic, polycarbonate, glass, or another appropriate material. The light guide 12 also may be a multi-layer light guide having two or more layers.

[0042] Dimensions of each of the major surfaces 24, 26 are much greater than, typically ten or more times greater than, the thickness of the light guide 12. The thickness is the dimension of the light guide 12 in a direction orthogonal to the major surfaces 24, 26. The thickness of the light guide 12 may be, for example, about 0.1 millimeters (mm) to about 10 mm. The light guide 12 may be rigid or flexible.

[0043] As indicated, the light guide 12 includes the light-extracting elements 28 in, on or beneath at least one of the major surfaces 56, 58 and the light guide 50 includes the light-extracting elements 56 in, on or beneath the light output surface 54. Light-extracting elements 28, 56 that are in, on or beneath a respective surface will be referred to as being "at" that surface. Each light-extracting element 28, 56 functions to disrupt the total internal reflection of the propagating light that is incident on the light-extracting element 28, 56. In one embodiment, the light-extracting elements 28 reflect light toward the opposed major surface so that the light exits the light guide 12 through the opposed major surface. Alternatively, the light-extracting elements 28, 56 transmit light through the light-extracting elements and out of the surface 24, 26, 54 having the light-extracting elements 28, 56. In another embodiment, both of these types of light-extracting elements are present. In yet another embodiment, the light-extracting elements 28, 56 reflect some of the light and refract the remainder of the light incident thereon. Therefore, the light-extracting elements 28 of the light guide 12 are configured to extract light from the light guide 12 through one or both of the major surfaces 24, 26 and the light-extracting elements 56 of the light guide 50 are configured to extract light from the light guide 50 through the light output surface 54. The light-extracting elements 28 may be arranged to extract light through part or all of one or both of the major surfaces 24, 26 and the light-extracting elements 56 may be arranged to extract light through part or all of the light output surface 54.

[0044] Light guides having such light-extracting elements are typically formed by a process such as stamping, molding, embossing, extruding, laser etching, chemical etching, or another suitable process. Light-extracting elements may also be produced by depositing curable material on the light guide and curing the deposited material using heat, UV-light or other radiation. The curable material can be deposited by a process such as printing, ink jet printing, screen printing, or another suitable process. Alternatively, the light-extracting elements may be inside the light guide (e.g., the light-extracting elements may be light redirecting particles and/or voids disposed in the light guide).

[0045] In one embodiment, the light-extracting elements are configured to extract light in a defined intensity profile, such as a uniform intensity profile, over the relevant surface and/or to extract light in a defined light ray angle distribution. Using variations in the light-extracting elements, the relevant surface, or portion thereof, can have different intensity profiles and/or light ray angle distributions. Intensity profile refers to the variation of intensity with position within a light-emitting region (such as the area of the major surface 24, 26 through which light is extracted). Light ray angle distribution refers to the variation of intensity with ray angle (typically a solid angle) of light extracted through a light-emitting surface (such as the area of the major surface 24, 26 through which light is extracted).

[0046] Exemplary light-extracting elements 28, 56 include light-scattering elements, which are typically features of indistinct shape or surface texture, such as printed features, ink-jet printed features, selectively-deposited features, chemically etched features, laser etched features, and so forth. Other exemplary light-extracting elements 28, 56 include features of well-defined shape, such as V-grooves, lenticular grooves, and features of well-defined shape that are small relative to the linear dimensions of the surfaces 24, 26, 54, which are referred to herein as micro-optical elements. The smaller of the length and width of a micro-optical element is less than one-tenth of the larger of the length and width of the respective light guide, and the larger of the length and width of the micro-optical element is less than one-half of the smaller of the length and width of the respective light guide. The length and width of the micro-optical element are measured in a plane parallel to the surface 24, 26, 54 of the light guide in the case of a flat light guide or along a surface contour in the case of a non-flat light guide.

[0047] Micro-optical elements are shaped to predictably reflect light or predictably refract light. However, one or more of the surfaces of the micro-optical elements may be modified, such as roughened, to produce a secondary effect on light output. Exemplary micro-optical elements are described in U.S. Patent No. 6,752,505 and, for the sake of brevity, will not be described in detail in this disclosure. The micro-optical elements may vary in one or more of size, shape, depth or height, density, orientation, slope angle, or index of refraction such that a desired light output from the light guide is achieved over the corresponding surface through which light is output.

[0048] Other embodiments of the lighting assembly 10 with a color adjuster 38 are possible. With additional reference to FIGs. 5 and 6, another such embodiment is illustrated. In this embodiment, the lighting assembly 10 includes a heat sink 64 disposed in the internal volume 40 of the light guide 12. The heat sink 64 includes branches 66 that extend from a common node 68 toward the inner major surface of the 24 of the light guide 12. In this manner, the heat sink 64 has a branched cross section, and each branch 66 extends outward from the common node 68 to segment the light guide 12 into regions 70 and segment the internal volume 40 into respective regions 72.

[0049] The light director 48 in the illustrated embodiment is a light guide 50 having a segment 74 in each region 72 and interleaved with the branches 66 of the heat sink 64. Each segment 74 receives light from a respective solid state light emitter 47 of light source 46 that outputs light of the second spectrum. Each segment 74 of the light director 48 directs light of the second spectrum through a respective region 70 of the light guide 12 to mix with light of the first spectrum from the light source 20. In this embodiment, each segment 74 of the light director 48 is physically independent and independently supplied with light. In the illustrated embodiment, each segment 74 is a solid cylinder having light extracting elements 56 (FIG. 2) at its surface to extract light of the second spectrum therefrom and to direct at least a portion of the extracted light toward the inner surface 24 of the light guide 12.

[0050] In one embodiment, the branches 66 of the heat sink 64 have spaced walls 76 that define an air flow channel 77 through which cooling air may flow. The air flow channel

77 of each branch 66 terminates in a through-slot 78 between adjacent regions 70 of the light guide through which cooling air can pass between the air flow channel 77 and the environment surrounding the outer major surface 26 of the light guide 12. Additionally, vents 80 may be present in the housing 60 to allow for additional airflow.

[0051] Another embodiment is shown in FIGs. 7 and 8. In this embodiment, the segments 74 of the light director 48 each extend from an unsegmented portion 82 of the light director 48. The unsegmented portion 82 is not segmented by the heat sink 64. The unsegmented portion 82 receives light of the second spectrum from the light source 46 and the light passes through the unsegmented portion 82 to each segment 74. Each segment 74 of the light director 48 directs light of the second spectrum through a respective region 70 of the light guide 12 to mix with light of the first spectrum from the light source 20. Light of the second spectrum also may be directed toward the inner surface 24 of the light guide 12 from the base 82 of the light director 48. In the illustrated embodiment, each of the unsegmented portion 82 and the segments 74 is a respective solid cylinder having light extracting elements 56 (FIG. 1) at its surface to extract light of the second spectrum therefrom and to direct the extracted light toward the inner surface 24 of the light guide 12.

[0052] With additional reference to FIGs. 9 and 10, the segments 74 of the light director 48 are each solid and shaped as a sector of a circle when taken in cross-section in a plane orthogonal to the longitudinal axis of each segment 74. Each segment 74 has flat surfaces 84 that conform to the walls 76 of a pair of adjacent branches 66 of the heat sink 64. Each segment 74 also includes a curved outward-facing surface 86 at which are located light extracting elements 56 (FIG. 1) to extract light of the second spectrum from the segment 74 and to direct the extracted light toward a respective segment 70 of the light guide 12. The segments 74 are located in respective regions 72 of the internal volume 40 and are interleaved with the branches 66 of the heat sink 64. Each segment 74 receives light from a respective solid-state light emitter 47 of light source 46 that outputs light of the second spectrum. Each segment 74 of the light director 48 directs light of the second spectrum through a respective region 70 of the light guide 12 to mix with light of the first spectrum from the light source 20. In this embodiment, each segment 74 of the light director 48 is physically independent and independently supplied with light.

[0053] Another embodiment is shown in FIGs. 11 and 12. In this embodiment, the segments 74 of the light director 48 each extend from an unsegmented portion 82 of the light director 48. The unsegmented portion 82 is not segmented by the heat sink 64. The unsegmented portion 82 receives light of the second spectrum from one or more solid-state light emitters 47 of light source 46 and the light passes through the unsegmented portion 82 to each segment 74. Each segment 74 of the light director 48 directs light of the second spectrum through a respective region 70 of the light guide 12 to mix with light of the first spectrum from the light source 20. The unsegmented portion 82 may also have light extracting elements 56 (FIG. 1) at its surface to extract light of the second spectrum from the unsegmented portion 82 and to direct the extracted light toward the inner surface 24 of the light guide 12.

[0054] In the illustrated embodiment, the unsegmented portion 82 is a solid cylinder and each segment 74 is shaped as a sector of a circle when taken in cross-section taken in a plane orthogonal to a longitudinal axis of the segment 74. Each segment 74 has flat surfaces 84 that conform to the walls 76 of a pair of adjacent branches 66 of the heat sink 64. Each segment 74 also includes a curved outward-facing surface 86 having light extracting elements 56 (FIG. 1) that extract light of the second spectrum from the segment and direct the extracted light toward a respective segment 70 of the light guide 12. The segments 74 are located in respective regions 72 of the internal volume 40 and are interleaved with the branches 66 of the heat sink 64. Each segment 74 of the light director 48 directs light of the second spectrum through a respective region 70 of the light guide 12 to mix with light of the first spectrum from the light sources 20.

[0055] Another embodiment is shown in FIG. 13. In this embodiment, the color adjuster 38 includes a light source 46 and a diffuser 88 disposed between the light source 46 and the inner surface 24 of the light guide 12. In an example, the diffuser is hollow and light source 46 is located within the diffuser. The light source 46 emits light 42 of the second spectrum. This light 42 travels through the diffuser 88, which scatters at least a portion of the light of the second spectrum (light 42) towards the inner major surface 24 of light guide 12 and at least a portion of the light of the second spectrum (light 43) toward the open distal end 16 of the light guide 12. The diffuser 88 is shaped to diffuse the light of the second spectrum with a light ray angle distribution that approximates the light ray angle distribution of the light of the first spectrum. In the example shown, the diffuser 88 is substantially hemispherical in shape. Other shapes are possible and may be used. The light 42 of the second spectrum passes through the light guide 12 and mixes with the light 30 of the first spectrum so that output light 44 output by the lighting assembly 10 has a spectrum that is a combination of the first spectrum and the second spectrum. The light 43 mixes with the light 31 of the first spectrum so that output light 45 output by the lighting assembly 10 has a spectrum that is a combination of the first spectrum and the second spectrum.

[0056] In another embodiment, the diffuser 88 has color changing properties to change spectrum of the light emitted by the light source 46 to the second spectrum. The color changing may be in the form of wavelength shifting and/or selective color attenuating. Wavelength shifting is used herein to refer to a process in which a material absorbs light at certain wavelengths, and reemits the light at one or more different wavelengths. Wavelength shifting may be achieved using a phosphor material, a luminescent material, a luminescent nanomaterial such as a quantum dot material, a conjugated polymer material, an organic fluorescent dye, an organic phosphorescent dye, lanthanide-doped garnet, or the like. The wavelength shifting material is located in the interior volume 40 of the light guide 12. This reduces the visibility of the wavelength shifting material and provides light bulb 10 with a more attractive appearance when the light bulb is not emitting light. Selective color attenuating may be achieved using color filtering material.

[0057] Another embodiment is shown in FIG. 14. In this embodiment, the color adjuster 38 does not include a light source separate from the light source 20. Rather, the color adjuster 38 includes a reflector 90 adjacent the inner major surface 24 of the light guide 12 and a wavelength-shifting element 92 disposed between the reflector 90 and the inner major surface 24. A portion of the light 30 of the first spectrum generated by the light source 20 is extracted from the light guide 12 through the inner major surface 24 and is changed in spectrum by the wavelength-shifting element 92 to produce the light 42 of the second spectrum. The light 42 of the second spectrum is reflected by the reflector 90 back toward the inner major surface 24 where it enters the light guide 12 and exits through the outer major surface 26 with the light 30 of the first spectrum to produce the mixed output light 44 that is output from the lighting assembly 10. The output light 44 has a spectrum that is a combination of the first spectrum and the second spectrum.

[0058] In one embodiment, and as explained above in connection with FIG. 4, light source 20 includes LED dies 32 each having a layer 36 of a phosphor that contributes respective spectral portions of the light 30 of the first spectrum. Some of the light produced by each LED die 32 is not converted. This unconverted portion is converted by the wavelength-shifting element 92 (e.g., wavelength-shifting element 92 converts at least part of the portion of the light of the first spectrum contributed by the LED die 32) to contribute respective spectral portions of the light 42 of the second spectrum.

[0059] In one embodiment, the wavelength-shifting element 92 is spaced apart from the inner major surface 24 of light guide 12 by an air gap. In an example, the wavelength-shifting element 92 is coated onto the reflector 90. In one embodiment, the reflector 90 is provided by the reflective outer surface of a heat sink 64. In the illustrated embodiment, the heat sink 64 has a reflective, cylindrical outer surface that is concentric and coaxial with the light guide 12. The heat sink 64 may include other structural members (not illustrated) for dissipating heat and guiding cooling airflow.

[0060] Turning now to FIGs. 15 and 16, another type of lighting assembly 10 is illustrated. In this embodiment, the light guide 12 is planar. It is possible, however, that the light guide 12 is non-planar (e.g., curved about one or more axes), such as a portion of a cylinder. The lighting assembly 10 includes a light source 20 that emits light of the first spectrum and a light source 46 that emits light of the second spectrum, which as explained above is different than the first spectrum.

[0061] The light guide 12 includes a light input edge 18 and first and second opposed major surfaces 94, 96 between which light propagates by total internal reflection. The light guide 12 further includes a dispersing region 98 at an edge of the light guide. In the embodiment of FIGs. 15 and 16, the dispersing region 98 is adjacent the light input edge 18 through which light from the light source 20 edge lights the light guide 12. The light guide 12 also includes one or more secondary light input edges 100 adjacent the dispersing region 98 through which light from the light source 46 edge lights the light guide 12. In the embodiment of FIGs. 15 and 16, the light input edge(s) 100 are non-parallel to the light input edge 18. In the illustrated embodiment, the light input edge 18 is along one of the edges of the light guide 12 and the light input edge(s) 100 are along parts of respective opposed edges of the light guide 12 orthogonal to light input edge 18.

[0062] The dispersing region 98 includes dispersing features 102 that disperse light from the light source 46 among the light from the light source 20 to mix the light from the respective light sources 20 and 46 to produce mixed light that enters a light output region 104 of the light guide 12. The mixed light has a spectrum that is a combination of the first spectrum and the second spectrum. The light output region 104 includes light extracting elements 28 at one or both of the major surfaces 94, 96 of the light guide 12 to extract the mixed light from the light guide 12 through one or both of the major surfaces 94, 96.

[0063] The dispersing features 102 of one embodiment include apertures in the light guide 12 having walls 106 that are nominally orthogonal to the major surfaces 94, 96 of the light guide 12. In the embodiment of FIGs. 15 and 16, the dispersing features 102 extend through the light guide 12 between the first major surface 94 and the second major surface 96, as shown in FIG. 16. In one embodiment, the dispersing features 102 are open to the surrounding environment and are, therefore, filled with air. In other embodiments, the dispersing features 12 are filled with a material differing in index of refraction from the light guide 12. This material may be a gas or a liquid (in which case, the dispersing features 12 are closed to the surrounding environment at the major surfaces 94 and 96), or a may be a solid material inserted into the light guide 12 or formed in situ in the light guide 12.

[0064] With additional reference to FIGs. 17 and 18, a variation of the lighting assembly 10 of FIGs. 15 and 16 is illustrated. In this variation, the dispersing features 102 extend part-way through the light guide 12 from at least one of the major surfaces 94, 96. In the illustrated embodiment, some of the dispersing features 102 extend part-way through the light guide 12 from the first major surface 94 and some of the dispersing features 102 extend part-way through the light guide 12 from the second major surface 96. In other embodiments, the dispersing features 102 extend part-way through the light guide 12 from only one of the major surfaces 94, 96.

[0065] In the embodiments of FIGs. 15-18, the light input edge 100 that is edge lit by the light source 46 includes portions 108-1 and 108-2 that are separated from one another by the light input edge 18 that is edge lit by the light source 20.

[0066] The lighting assembly 10 embodiments of FIGs. 15-18 may have application as a backlight for a display. The lighting assembly 10 embodiments of FIGs. 15-18 may also have application in a lighting fixture to supply light in various general lighting contexts.

[0067] With additional reference to FIGs. 19 and 20, another lighting assembly 110 in the form of a light bulb is shown. In this embodiment, the lighting assembly 110 includes one or more of the lighting assemblies 10 described in connection with FIGs. 15-18. In this embodiment, each light guide 12 forms a curved region 70 of a light output region 104 of the lighting assembly 110. In the illustrated embodiment, the light guides 12 collectively approximate a hollow cylinder that is open at both the proximal and distal ends 14, 16. Other geometries are possible, such as a light output region 104 that is polygonal in cross-section in a plane orthogonal to the longitudinal axis of the light emission portion 112. Although not fully illustrated, the lighting assembly may include the housing 60 and base 62 (e.g., FIG. 1) and/or a heat sink, such as the heat sink of FIGs. 5 and 6 where the branches 66 are aligned with gaps between the light guides 12 that form slots 79 in the light output region 104 of the lighting assembly 110.

[0068] In one embodiment, the light source 46 for one of the light guides 12 is disposed between respective side edges 114, 116 of the light guide 12 and an adjacent light guide 12. In the illustrated embodiment, the light sources 46 for adjacent light guides 12 are located in the same slot 79 and face in opposite directions toward the respective light input edges 100 of the light guides 12.

[0069] For purposes of illustration in FIGs. 15, 17 and 20, a line is shown to represent a boundary between the dispersing region 98 and the light output region 104. In one embodiment, the dispersing region 98 and the light output region 104 are integrally formed. Therefore, the illustrated line is merely representative of the boundary and visible or light-affecting demarcations between the regions 98 and 104 may not exist.

[0070] With additional reference to FIG. 21, a portion of a lighting assembly 10 in the form of a light bulb is shown in cross section. In this embodiment, the color adjuster 38 includes an organic light emitting diode (OLED) 118 adjacent the inner major surface 26 of the light guide 12. The OLED is configured to generate the light of the second spectrum (e.g., arrow 42) and direct the light of the second spectrum toward the inner surface 26 of the light guide 12. The OLED 118 is spaced apart from the inner major surface 26 of the light guide 12.

[0071] In the illustrated embodiment, the OLED 118 is mounted to or is formed on a flanged substrate 120. OLEDs are susceptible to environmental conditions, such as humidity. To counteract the effects of environmental conditions, the flanged substrate 120 defines a cavity for the OLED 118 and the light guide 12 covers the cavity. In one embodiment, a seal between the light guide 12 and the flanges of the substrate 120 encapsulates the OLED 118. In one embodiment, the flanged substrate 120 is secured to the light guide 12 with adhesive that also provides the seal. In one embodiment, the flanged substrate 120 physically supports the light guide 12 and/or the OLED 118. Also, the surface of the substrate 120 facing the light guide 12 may be reflective. In some embodiments, the substrate 120 is part of a heat sink, such as a cylindrical outer surface of a heat sink.

[0072] With additional reference to FIG. 22, another exemplary embodiment of a light bulb 200 is shown. The light bulb 200 of FIG. 22 has features that are similar to features of the above-described lighting assemblies 10, but will be described using a new series of reference numerals. Features that are described and/or illustrated with respect to the lighting assemblies 10 may be used in the same way or in a similar way in the light bulb 200 and/or in combination with or instead of the features of the light bulb 200, or vice versa.

[0073] The light bulb 200 includes a non-planar, optically-conductive light guide 202 that is open at opposite ends, referred to as a proximal end 204 and a distal end 206. In the example shown, the light guide 202 is a hollow body. More specifically, the illustrated light guide 202 example is an open-ended hollow body that is cylindrical in shape. Other shapes are possible, such as a frustoconical light guide or a planar light guide. Slots 208 are present in the light guide 202 to allow air to flow into fluid communication with an internal heat sink 210 that is located in an internal volume 212 defined by the light guide 202.

[0074] An edge surface at the proximal end 204 provides a light input edge 214 through which light from a light source 216 is input to the light guide 202. In the example shown, the light source 216 includes solid-state light emitters mounted on a printed circuit board 218. The printed circuit board (PCB) 218 is typically heat conducting. An exemplary solid-state light emitter constructed as a single light-emitting device (e.g., a single LED die) is shown using reference numeral 220. Reference numeral 220 also may be used to refer to more than one solid-state light emitting device collectively. The internal heat sink

210 is thermally coupled to the solid state light emitters 220 by way of the PCB 218 to dissipate heat generated by the solid state light emitters 220. The solid state light emitters 220 also are thermally coupled to an external heat sink 222 to dissipate heat generated by the solid state light emitters 220.

[0075] The light source 216 is arranged such that light from the light source 216 enters the light input edge 214 at the proximal end 204 of the light guide 202 and travels in the light guide 202 by total internal reflection at an inner major surface 224 of the light guide and at an outer major surface 226 of the light guide 202. In one embodiment, the solid-state light emitters 220 of the light source 216 are arranged in a ring or another suitable pattern depending on the shape of the light input edge 214 of the light guide 202 to which the light source 216 supplies light.

[0076] The light guide 202 includes light extracting elements 228 (shown in the enlarged inset of FIG. 22) at one or both of the major surfaces 224, 226 for extracting light from the light guide 202 through at least the outer major surface 226. In some embodiments, light is also extracted through the inner major surface 224.

[0077] In the exemplary embodiment of FIG. 22, the external heat sink 222 also functions as a housing that retains the light guide 202, the internal heat sink 210, the light source 216, the PCB 218, drive electronics (not shown) for the light source 216, and a base 230. The base 230 is configured to mechanically mount the light bulb 200 and receive electrical power. In another embodiment, the external heat sink 210 is separate from a housing (not shown) that retains the external heat sink 222, the light guide 202, the internal heat sink 210, the light source 216, the PCB 218, drive electronics (not shown) for the light source 216, and the base 230. In the exemplary embodiment of FIG. 22, the base 230 is an Edison screw base and the light bulb 200 conforms to an outer envelope of an A19 light bulb. In other embodiments, the light bulb 200 may have a different type of base (e.g., a bi-pin base) or may conform to a different shape.

[0078] The external heat sink 222 includes fins 232 at various locations around the circumference of the light guide 202 and that extend parallel to the light guide 202 from the proximal end 204 toward the distal end 206. The fins 232 are spaced apart from the light guide 202 by an air gap that allows cooling air to flow between the fins 232 and the light guide 202. Each fin 232 includes side surfaces 234 that have a radial component relative to a longitudinal axis 235 of the light bulb 200. The side surfaces 234 of this embodiment serve as color adjusting surfaces 236 of a color adjuster 238, the purpose of which will be described below. In one embodiment, portions 240 of external heat sink 222 connecting the side surfaces 234 of adjacent fins 232 also serve as color adjusting surfaces 236. In other embodiments, additional or different portions of the external heat sink 222 radially outward of the light guide 202 serve as the color adjuster 238. In still other embodiments, the color adjuster 238 is located on one or more structures other than the external heat sink 222 radially outward of the light guide 202. For example, such structures could be supported by the internal heat sink 210 radially outward of the light guide 202 or could be supported by the fins 232 radially outward of the light guide 202.

[0079] To reduce power consumption, the light source 216 is a relatively efficient light source. A relatively efficient light source 216 has an efficacy of greater than about 80 lumens/watt (lm/W). In one embodiment, the solid state light emitters 220 constituting light source 216 are LEDs. Other types of solid-state light emitters 220 include organic LEDs (OLEDs).

[0080] As is typical for a solid state light emitter 220 embodied as an LED, the solid-state light emitter 220 includes an LED die having a light emitting surface from which most of the light is emitted. The LED die is covered by a layer that contains a wavelength shifting material, such as a phosphor material. The wavelength shifting material converts at least some of the light emitted by the LED die to light of a longer wavelength. The light from the solid-state light emitter propagates through the light guide 202 by total internal reflection and is extracted from the light guide 202 by the light extracting elements 228 through the outer major surface 226. The light 242 extracted from the light guide 202 through the outer major surface 226 will be referred to as light of a first spectrum. Each solid state light emitter 220 can be a top-fire LED or a side-fire LED. Typically, the solid-state light emitters 220 are broad-spectrum LEDs that emit white light.

[0081] In an exemplary embodiment, the light emitted by the solid state light emitters 220 is what is referred to in the art as "cool white" light (e.g., solid state light emitters 220 that generate light having a color temperature in the range from about 5,000 K to about 7,000 K). Solid-state emitters that emit cool white light typically have an efficacy greater than about 120 lm/W. However, for many applications, it is preferred that the light bulb

10 emit light that is warmer than cool white light. Cool white light is unacceptable in such applications despite the relatively high efficacy of its production. In contrast, "warm white" light, which has a color temperature in the range from about 2,500 K to about 3,500 K, is more acceptable for certain lighting applications. However, LEDs that generate warm white light have an efficacy substantially lower than that of LEDs that generate cool white light, so the use of LEDs that generate cool white light is preferable to reduce energy consumption.

[0082] The color adjuster 238 makes the light output by the light bulb 200 warmer. A portion 244 of the light of the first spectrum extracted from the light guide 202 is incident on the color adjuster 238. The color adjuster 238 has color adjusting surfaces 236 adjacent and radially outward from the outer major surface 226 of the light guide 202. The portion 244 of the light propagates from the light guide 202 in a direction having a radially outward component so as to be incident on the color adjusting surfaces 236 of the color adjuster 238. The portion 244 of light is less than half of the light 242 of the first spectrum extracted from the light guide 202, and is typically less than 30 percent of the light 30 of the first spectrum.

[0083] The color adjuster 238 changes the spectrum of the portion 244 of the light incident on the color changing surfaces 236 from the first spectrum to light 246 having a second spectrum. The light 246 of the second spectrum is different (e.g., warmer) than the light 242, 244 of the first spectrum. The changed light 246 (light of the second spectrum) and the unchanged light 242 (light of the first spectrum) mix outside the light guide 202 so that the overall light output by the light bulb 200 is a combination of the first spectrum and the second spectrum.

[0084] In light bulb designs that have fins radially outward of the light guide, light from the light guide is going to interact with the surfaces of the fins, and this will change the color of the light by locating a color changing surface on the fins. A desired change in the color of the light can be attained without any additional interaction between the light and the fins. Interaction between the light and the fins may be used to obtain a desired change in the color of the light. Light from the light guide 202 is incident on and interacts with the fins 232 that are radially outward of the light guide 202 regardless of the color changing properties of their surfaces.

[0085] In one embodiment, the color adjusting surface 236 includes a color attenuating material. Exemplary color attenuating materials include, but are not limited to, paint, coatings (e.g., a powder coating), and one or more narrow band absorbers, e.g., absorbers that absorb light in a narrow range of the visible spectrum such as a range having a full width half maximum of less than 100 nm. The color attenuating material may be applied to an adhesive tape for application to the fin 232.

[0086] In another embodiment, the color adjusting surface 236 includes a wavelength shifting material. Exemplary wavelength shifting materials include, but are not limited, to a phosphor material, a luminescent material, a luminescent nanomaterial, a quantum dot material, a conjugated polymer material, an organic fluorescent dye, an organic phosphorescent dye, and lanthanide-doped garnet. In some cases, the color adjusting surface 236 includes more than one wavelength shifting material.

[0087] As indicated, the light 246 of the second spectrum changes the color of the light output by the light bulb 200. In one embodiment, the output light from the light bulb 200 has a spectrum lower in color temperature than the first spectrum by more than 100 K. In another embodiment, the output light from the light bulb 200 has a spectrum lower in color temperature than the first spectrum by more than 1,000 K. The change in the color of the light output by the light bulb 200 can be characterized in ways other than the color temperature: such ways include color rendering index, chromaticity, correlated color temperature, spectral power distribution, and spectral balance.

[0088] The spectrum of the light output by the light bulb 200, which is a mix of the light 242 and the light 246, is measured by placing the light bulb 200 in an integrating sphere and measuring the spectrum using a sensor located on the internal surface of the integrating sphere. In the practical examples of the light bulbs described herein, small variations in the spectrum of output light depending on the observer's location relative to light bulb can occur as a result of the different source locations of the light of the first spectrum and the light of the second spectrum, and the possibly different directional properties of the light of the first spectrum and the light of the second spectrum.

[0089] The light guide 202 is a solid article made from, for example, acrylic, polycarbonate, glass, or another appropriate material. The light guide 202 also may be a multi-layer light guide having two or more layers.

[0090] Dimensions of each of the major surfaces 224, 226 are much greater than, typically ten or more times greater than, the thickness of the light guide 202. The thickness is the dimension of the light guide 202 in a direction orthogonal to the major surfaces 224, 226. The thickness of the light guide 202 may be, for example, about 0.1 millimeters (mm) to about 10 mm. The light guide 202 may be rigid or flexible.

[0091] As indicated, the light guide 202 includes the light-extracting elements 228 in, on or beneath at least one of the major surfaces 224, 226. Light-extracting elements 228 that are in, on or beneath a respective surface will be referred to as being "at" that surface. Each light-extracting element 228 functions to disrupt the total internal reflection of the propagating light that is incident on the light-extracting element 228. In one embodiment, the light-extracting elements 228 reflect light toward the opposed major surface so that the light exits the light guide 202 through the opposed major surface. Alternatively, the light-extracting elements 228 transmit light through the light-extracting elements and out of the surface 224, 226 having the light-extracting elements 228. In another embodiment, both of these types of light-extracting elements are present. In yet another embodiment, the light-extracting elements 228 reflect some of the light and refract the remainder of the light incident thereon. Therefore, the light-extracting elements 228 of the light guide 202 are configured to extract light from the light guide 202 through one or both of the major surfaces 224, 226. The light-extracting elements 228 may be arranged to extract light through part or all of one or both of the major surfaces 224, 226.

[0092] Light guides having light extracting elements are typically formed by a process such as molding. The light extracting elements are typically defined in a shim or insert used for molding light guides by a process such as diamond machining, laser etching, laser micromachining, chemical etching, or photolithography. Alternatively, any of the above-mentioned processes may be used to define the light extracting elements in a master that is used to make the shim or insert. The light guide may alternatively be initially formed without light extracting elements by a process such as molding, and the light extracting elements subsequently formed on one or both of the major surfaces by a process such as stamping, embossing, laser etching, or another suitable process. Light extracting elements may also be produced by depositing elements of curable material on one or both of the major surfaces of the light guide and curing the deposited material using heat, UV-light, or other radiation. The curable material can be deposited by a process such as printing, ink jet printing, screen printing, or another suitable process. Alternatively, the light extracting elements may be inside the light guide between the major surfaces (e.g., the light extracting elements may be light redirecting particles and/or voids disposed in the light guide).

[0093] In one embodiment, the light-extracting elements are configured to extract light in a defined intensity profile, such as a uniform intensity profile, over the relevant surface and/or to extract light in a defined light ray angle distribution. Using variations in the light-extracting elements, the relevant surface, or portion thereof, can have different intensity profiles and/or light ray angle distributions. Intensity profile refers to the variation of intensity with position within a light-emitting region (such as the area of the major surface 224, 226 through which light is extracted). Light ray angle distribution refers to the variation of intensity with ray angle (typically a solid angle) of light extracted through a light-emitting surface (such as the area of the major surface 224, 226 through which light is extracted).

[0094] Exemplary light-extracting elements 228 include light-scattering elements, which are typically features of indistinct shape or surface texture, such as printed features, ink-jet printed features, selectively-deposited features, chemically etched features, laser etched features, and so forth. Other exemplary light-extracting elements 228 include features of well-defined shape, such as V-grooves, lenticular grooves, and features of well-defined shape that are small relative to the linear dimensions of the surfaces 224, 226, which are referred to herein as micro-optical elements. The smaller of the length and width of a micro-optical element is less than one-tenth of the larger of the length and width of the respective light guide, and the larger of the length and width of the micro-optical element is less than one-half of the smaller of the length and width of the respective light guide. The length and width of the micro-optical element are measured in a plane parallel to the surface 224, 226 of the light guide in the case of a flat light guide or along a surface contour in the case of a non-flat light guide.

[0095] Micro-optical elements are shaped to predictably reflect light or predictably refract light. However, one or more of the surfaces of the micro-optical elements may be modified, such as roughened, to produce a secondary effect on light output. Exemplary micro-optical elements are described in U.S. Patent No. 6,752,505 and, for the sake of brevity, will not be described in detail in this disclosure. The micro-optical elements may vary in one or more of size, shape, depth or height, density, orientation, slope angle, or index of refraction such that a desired light output from the light guide is achieved over the corresponding surface through which light is output.

[0096] References in this disclosure to a "light bulb" are meant to broadly encompass light-producing devices that fit into and engage any of various fixtures used for mechanically mounting the light-producing device and for providing electrical power thereto. Examples of such fixtures include, without limitation, screw-in fixtures for engaging an Edison light bulb base, a bayonet fixture for engaging a bayonet light bulb base, and a bi-pin fixture for engaging a bi-pin light bulb base. Thus the term "light bulb," by itself, does not provide any limitation on the shape of the light-producing device, or the mechanism by which light is produced from electric power. In one embodiment, however, the light bulb conforms to an outer envelope of an A19 light bulb. In another embodiment, the light bulb conforms to an outer envelope of a PAR light bulb. Also, the light bulb need not have an enclosed envelope forming an environment for light generation. The light bulb may conform to one or more American National Standards Institute (ANSI) standards, one or more ENERGY STAR® standards, or one or more other standards for electric lamps, but the light bulb does not necessarily have to have this conformance.

[0097] In this disclosure, the phrase "one of" followed by a list is intended to mean the elements of the list in the alterative. For example, "one of A, B and C" means A or B or C. The phrase "at least one of" followed by a list is intended to mean one or more of the elements of the list in the alterative. For example, "at least one of A, B and C" means A or B or C or (A and B) or (A and C) or (B and C) or (A and B and C).

## CLAIMS

What is claimed is:

1. A light bulb, comprising:

a light guide configured as a hollow body surrounding an internal volume, the light guide comprising an inner major surface, an outer major surface, a proximal end, a distal end, a light input edge at the proximal end, and light extracting elements at at least one of the major surfaces;

a light source to edge light the light guide with white light of a first spectrum such that the light of the first spectrum propagates in the light guide by total internal reflection and at least a portion of the light of the first spectrum is extracted from the light guide by the light extracting elements through the outer major surface; and

a color adjuster disposed at least partially in the internal volume and configured to direct light of a second spectrum, narrower than the first spectrum, toward the inner major surface, at least a portion of the light of the second spectrum passing through the light guide and mixing with the light of the first spectrum so that output light output by the light bulb has a spectrum that is a combination of the first spectrum and the second spectrum.

2. The light bulb of claim 1, wherein the light guide is cylindrical.

3. The light bulb of claim 1, wherein the light guide is an open-ended hollow body.

4. The light bulb of claim 1, wherein the light of the first spectrum has a cool white spectrum, and the output light has a spectrum that is warmer than the first spectrum.

5. The light bulb of claim 4, wherein the light of the second spectrum is red light.

6. The light bulb of claim 4, wherein the light of the second spectrum is narrow-band light having a peak wavelength within a range from 550 nm to 750 nm.

7. The light bulb of claim 1, wherein the light source comprises a light emitting diode.

8. The light bulb of claim 1, wherein:

the light source is a primary light source; and

the color adjuster comprises:

a secondary light source; and

a light director that directs the portion of the light from the secondary light source toward the inner surface.

9. The light bulb of claim 8, wherein the light director comprises a diffuser.

10. The light bulb of claim 8, wherein:

the light guide is a primary light guide; and

the light director comprises an elongate secondary light guide end lit by the secondary light source, the secondary light guide comparable in length with the primary light guide in the direction in which light propagates and comprising a light output surface smaller in area than the major surfaces of the primary light guide and comprising optical elements to extract light from the secondary light source.

11. The light bulb of claim 10, wherein the primary light source and the secondary light source are adjacent one another.

12. The light bulb of claim 10, additionally comprising a printed circuit board to which the primary light source and the secondary light source are mounted.

13. The light bulb of claim 8, wherein:

the light guide is a primary light guide and the light extracting elements are primary light extracting elements;

the light director comprises a secondary light guide comprising a light output surface and secondary light extracting elements at the light output surface; and the light of the second spectrum from the secondary light source edge lights the secondary light guide and is extracted by the secondary light extracting elements through the light output surface of the secondary light guide toward the inner major surface of the primary light guide.

14. The light bulb of claim 13, additionally comprising a heat sink having a branched cross section, each branch extending outward from a common node and segmenting the primary light guide into regions, and wherein the light director is segmented, the segments interleaved with the branches of the heat sink and each segment of the light director directing light through a respective region of the primary light guide.

15. The light bulb of claim 14, additionally comprising a respective secondary light source to illuminate each segment of the light director.

16. The light bulb of claim 14, wherein the segments of the light director are cylindrical.

17. The light bulb of claim 16, wherein the segments of the light director extend from an unsegmented portion of the light director through which light passes from the secondary light source to the segments of the light director.

18. The light bulb of claim 14, wherein the segments of the light director each comprise surfaces that conform to surfaces of adjacent branches of the heat sink and an outward-facing surface through which the light of the second spectrum is output.

19. The light bulb of claim 18, wherein the outward-facing surface is curved.

20. The light bulb of claim 18, wherein the segments of the light director extend from an unsegmented portion of the light director through which light passes from the secondary light source to the segments of the light director.

21. The light bulb of claim 1, wherein the color adjuster comprises:

a reflector adjacent the inner major surface; and

a wavelength-shifting element disposed between the reflector and the inner major surface;

wherein the light extracting elements are additionally configured to extract a portion of the light of the first spectrum from the light guide through the inner major surface, and the wavelength-shifting element changes a spectral component of the light of the first spectrum extracted through the inner major surface to produce the light of the second spectrum, and the light of the second spectrum is reflected by the reflector back toward the inner major surface.

22. The light bulb of claim 21, wherein the wavelength-shifting element is spaced apart from the inner major surface by an air gap.

23. The light bulb of claim 21, additionally comprising a heat sink within the internal volume, the heat sink comprising a reflective outer surface and wherein the reflector is the reflective outer surface of the heat sink.

24. The light bulb of claim 21, wherein:

the light source comprises a light emitting diode and a phosphor that contributes respective spectral portions of the light of the first spectrum; and

the wavelength-shifting element converts part of the spectral portion contributed by the light emitting diode.

25. The light bulb of claim 1, wherein the color adjuster comprises an organic light emitting diode (OLED) adjacent the inner major surface, the OLED configured to direct light of the second spectrum toward the inner surface of the light guide.

26. The light bulb of claim 25, wherein the light bulb further comprises a flanged substrate adjacent the OLED and configured to protect the OLED from environmental conditions, the OLED between the substrate and the light guide.

27. The light bulb of claim 26, wherein the OLED is sealed by the substrate and the light guide.

28. The light bulb of claim 1, further comprising a housing at the proximal end of the light guide, the housing retaining the light source, the light guide and the color adjuster.

29. The light bulb of claim 28, wherein the housing comprises a base configured to mechanically mount the light bulb and receive electrical power.

30. The light bulb of claim 29, wherein the base comprises an Edison screw base.

31. The light bulb of claim 1, wherein the light bulb conforms to an outer envelope of an A19 light bulb.

32. The light bulb of claim 1, wherein:

the light extracting elements are configured to extract another portion of the light of the first spectrum through the inner major surface; and

the color adjuster is additionally configured to direct light of the second spectrum to mix with the light of the first spectrum extracted through the inner major surface.

33. A lighting assembly, comprising:

a first light source that emits white light of a first spectrum;

a second light source that emits light of a second spectrum narrower than the first spectrum; and

a light guide comprising:

first and second opposed major surfaces between which light propagates by total internal reflection;

a dispersing region at an edge of the light guide and comprising dispersing features, a first light input edge at which the light guide is edge lit by the light from the first light source, and a second light input edge at which the light guide is edge lit by the light from the second light source, wherein the dispersing features are configured to disperse the light of the second spectrum among the light of the first spectrum to produce mixed light having a spectrum that is a combination of the first spectrum and the second spectrum; and

light extracting elements at one or both of the major surfaces of the light guide to extract the mixed light from the light guide through one or both of the major surfaces.

34. The lighting assembly of claim 33, wherein the first light input edge is non-parallel to the second light input edge.

35. The lighting assembly of claim 33, wherein the first light input edge is along one of the edges of the light guide and the second light input edge is along part of an orthogonal edge of the light guide.

36. The lighting assembly of claim 33, wherein the second light input edge comprises portions separated from one another by the first light input edge.

37. The lighting assembly of claim 33, wherein the light extracting elements are disposed at a light output region of the light guide and the mixed light propagates from the dispersing region into the light output region.

38. The lighting assembly of claim 33, wherein the dispersing features have walls nominally orthogonal to the major surfaces of the light guide.

39. The lighting assembly of claim 38, wherein the dispersing features extend through the light guide between the first major surface and the second major surface.

40. The lighting assembly of claim 38, wherein the dispersing features extend part-way through the light guide from at least one of the major surfaces.

41. The lighting assembly of claim 40, wherein some of the dispersing features extend part-way through the light guide from the first major surface and some of the dispersing features extend part-way through the light guide from the second major surface.

42. The lighting assembly of claim 38, wherein the dispersing features are open.

43. The lighting assembly of claim 38, wherein the dispersing features are filled with a material differing in index of refraction from the light guide.

44. A light bulb, comprising:

the lighting assembly of claim 33, the light guide further comprising a proximal end and a distal end; and

a housing at the proximal end of the light guide and that retains the light guide, the first light source, and the second light source.

45. The light bulb of claim 44, wherein the first light input edge is adjacent the housing.

46. The light bulb of claim 45, wherein the first light input edge is along the proximal edge of the light guide and the second light input edge is along part of an edge orthogonal to the proximal edge.

47. The light bulb of claim 46, wherein the second light input edge comprises portions separated from one another by the first light input edge.

48. The light bulb of claim 44, wherein the housing comprises a base configured to mechanically mount the light bulb and receive electrical power.

49. The light bulb of claim 48, wherein the base comprises an Edison screw base.

50. The light bulb of claim 44, wherein the light bulb conforms to an outer envelope of an A19 light bulb.

51. A light bulb, comprising:

a first lighting assembly of claim 33;

a second lighting assembly of claim 33, the light guides of the first and second lighting assemblies each comprising a proximal end and a distal end; and

a housing at the proximal ends of the light guides and that retains the light guides and the first and second light sources of the lighting assemblies; and

wherein the second light source of the first lighting assembly is disposed between respective side edges of the light guide of the first lighting assembly and the light guide of the second lighting assembly.

52. A lighting assembly, comprising:

a first light guide comprising a first major surface, a second major surface, a proximal end, a distal end, a light input edge at the proximal end, and light extracting elements at at least one of the major surfaces;

a first light source to edge light the first light guide with white light having a first spectrum such that the white light propagates in the first light guide by total internal reflection and at least a portion of the white light is extracted from the first light guide by the light extracting elements through the first major surface;

a second light source to provide auxiliary light having a second spectrum, narrower than the first spectrum; and

a second, elongate light guide comprising a light output surface, a proximal end, a distal end, a light input edge at the proximal end, and light extracting elements, the light output surface of the second light guide smaller in area than the major surfaces of the first light guide, and comparable in length thereto from the proximal end to the distal end thereof, the second light guide disposed with the light output surface opposite the second major surface of the first light guide to direct the auxiliary light extracted from the second light guide through the light output surface toward the second major surface of the first light guide, at least a portion of the auxiliary light passing through the first light guide and mixing with the white light so that output light output by the lighting assembly has a spectrum that is a combination of the first spectrum and the second spectrum.

53. The lighting assembly of claim 52, wherein the light input edges of the first light guide and the second light guide are adjacent.

54. A light bulb, comprising:

a light guide having a longitudinal axis, the light guide comprising opposed major surfaces, a proximal end, a distal end, a light input edge at the proximal end, and light extracting elements at at least one of the major surfaces;

a solid-state light emitter adjacent the light input edge to edge light the light guide through the light input edge, the light propagating in the light guide by total internal reflection and being extracted from the light guide by the light extracting elements to provide light of a first spectrum; and

a heat sink thermally coupled to the light emitter, the heat sink comprising a color adjusting surface adjacent and radially outward from the light guide to adjust the color of light output by the light bulb, the color adjusting surface providing light of a second spectrum when a portion of the light of the first spectrum is incident thereon such that the color of the light output by the light bulb is a combination of the first spectrum and the second spectrum.

55. The light bulb of claim 54, wherein the heat sink comprises a fin, and the fin comprises the color adjusting surface and extends parallel to the light guide.

56. The light bulb of claim 55, wherein the light guide is configured as a hollow body surrounding an internal volume, one of the major surfaces is an outer major surface, and the fin is located adjacent the outer major surface.

57. The light bulb of claim 55, wherein the fin is separated from the outer major surface of the light guide by an air gap to allow cooling air to flow between the fin and the outer major surface of the light guide.

58. The light bulb of claim 54, wherein the color adjusting surface comprises color attenuating material.

59. The light bulb of claim 58, wherein the color attenuating material comprises a paint or a coating.

60. The light bulb of claim 58, wherein the color attenuating material comprises a narrow band absorber.

61. The light bulb of claim 54, wherein the color adjusting surface comprises a wavelength shifting material.

62. The light bulb of claim 61, wherein the wavelength shifting material comprises one of a phosphor material, a luminescent material, a luminescent nanomaterial, a quantum dot material, a conjugated polymer material, an organic fluorescent dye, an organic phosphorescent dye, or lanthanide-doped garnet.

63. The light bulb of claim 54, wherein the light guide is cylindrical.

64. The light bulb of claim 54, wherein the light guide is frustoconical.

65. The light bulb of claim 54, wherein the light guide is an open-ended hollow body.

66. The light bulb of claim 54, wherein the light guide is planar.

67. The light bulb of claim 54, wherein the output light is lower in color temperature than the light of the first spectrum by more than 100 K.

68. The light bulb of claim 54, wherein the output light is lower in color temperature than the light of the first spectrum by more than 1,000 K.

69. The light bulb of claim 54, additionally comprising a housing at the proximal end of the light guide, the housing retaining the solid-state light emitter, the light guide and the color adjusting surface.

70. The light bulb of claim 69, additionally comprising a base configured to mechanically mount the light bulb and receive electrical power.

71. The light bulb of claim 54, wherein the output light is lower in correlated color temperature than the light of the first spectrum by more than 100 K.

72. The light bulb of claim 54, wherein the output light is lower in correlated color temperature than the light of the first spectrum by more than 1,000 K.

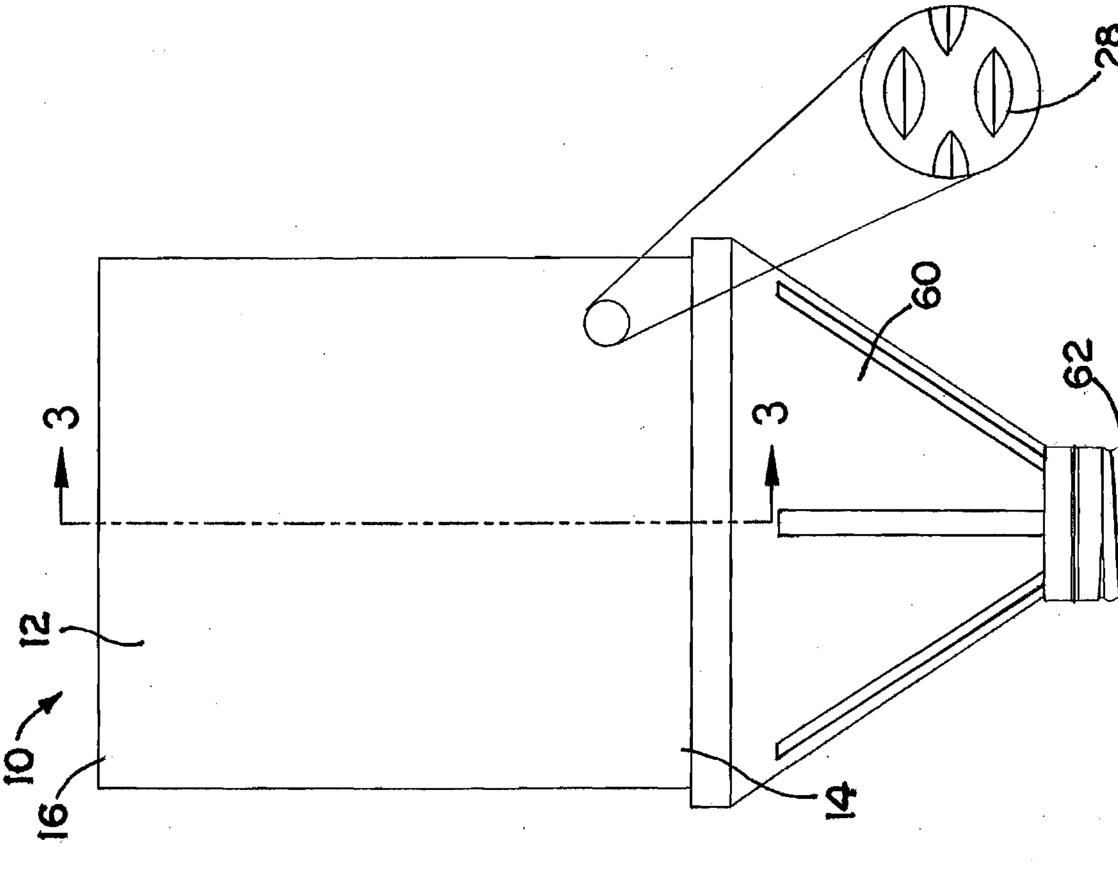
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FIG. 1

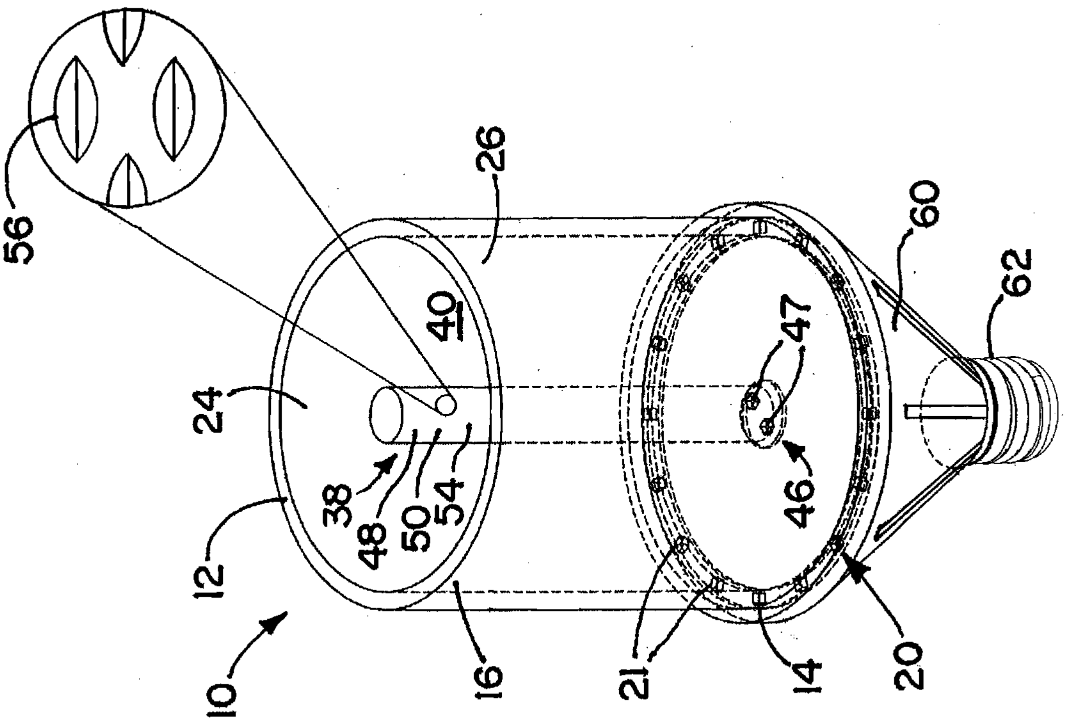
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FIG. 2

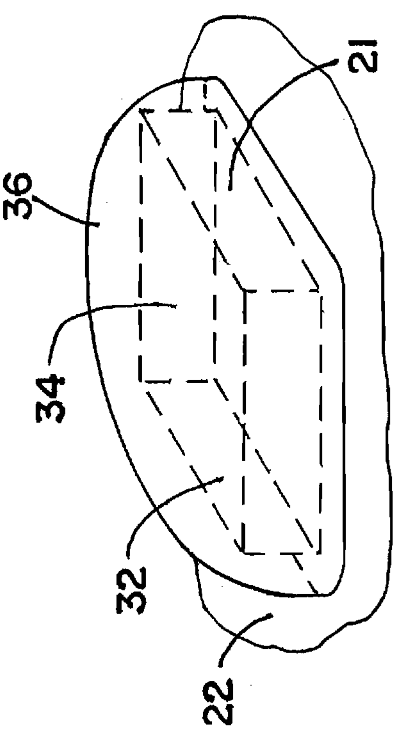
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FIG. 4

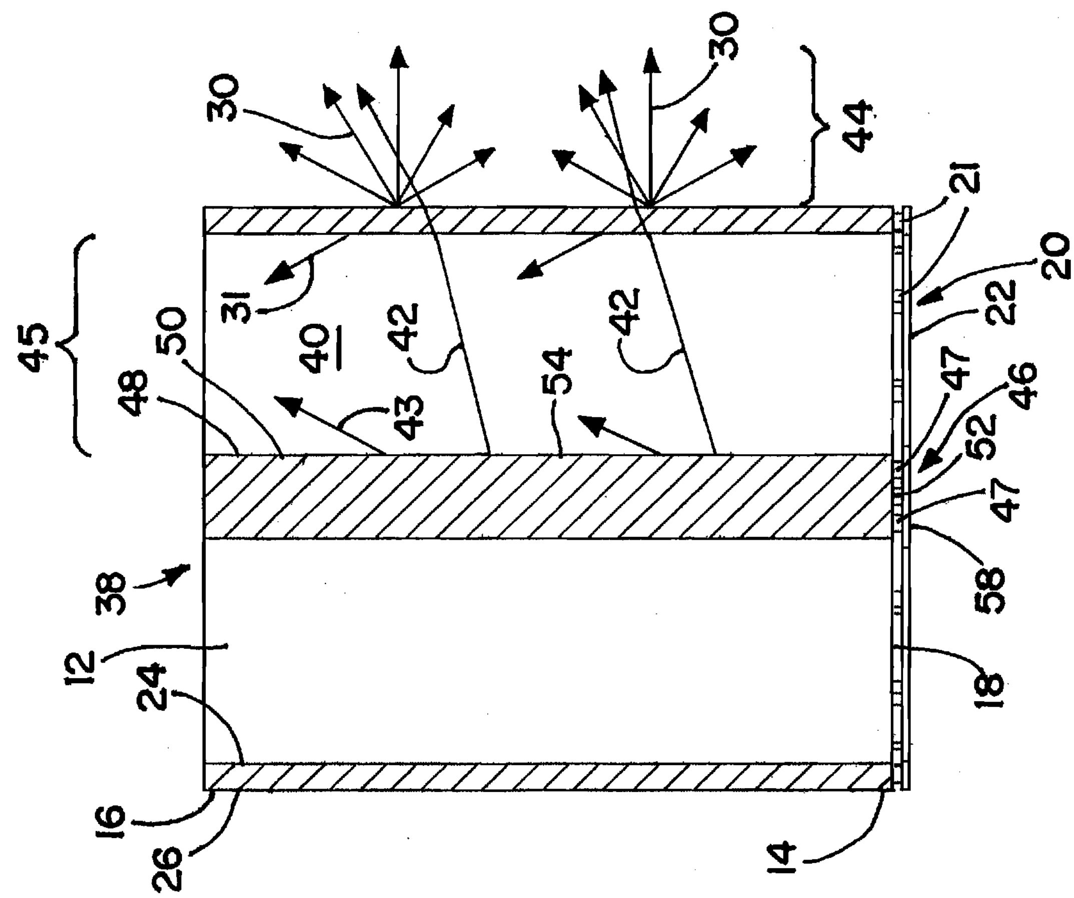
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FIG. 3

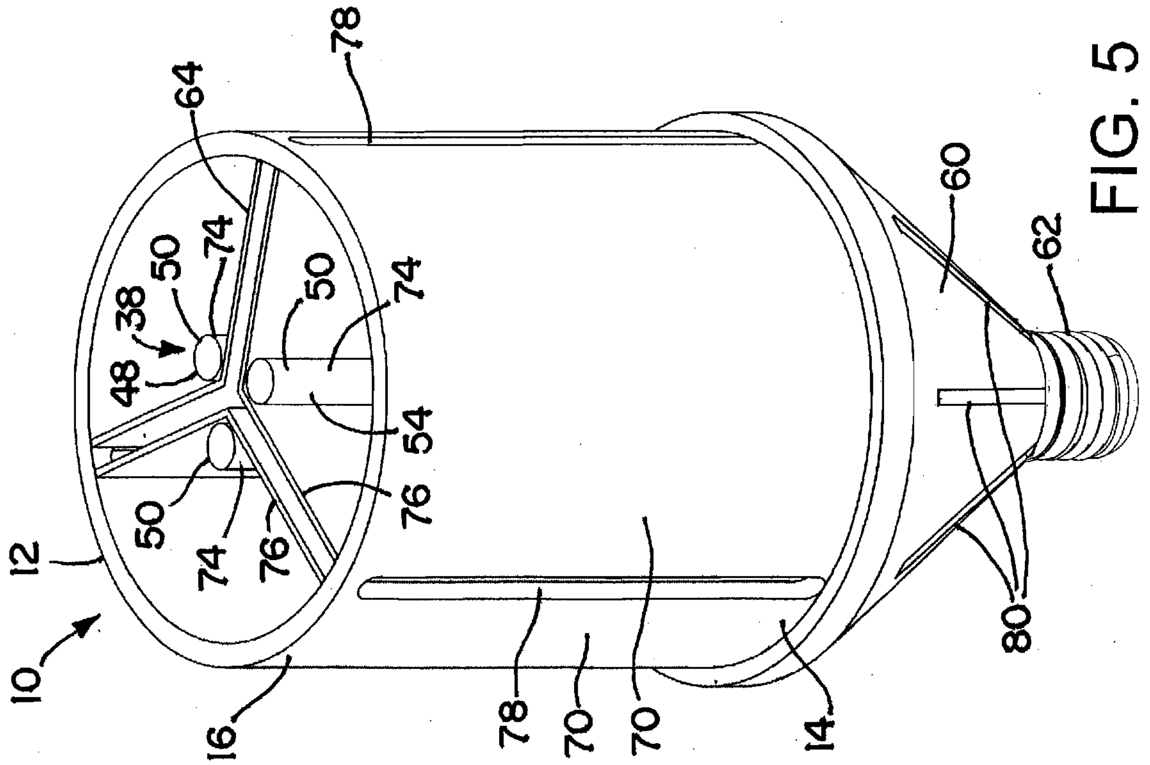
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FIG. 5

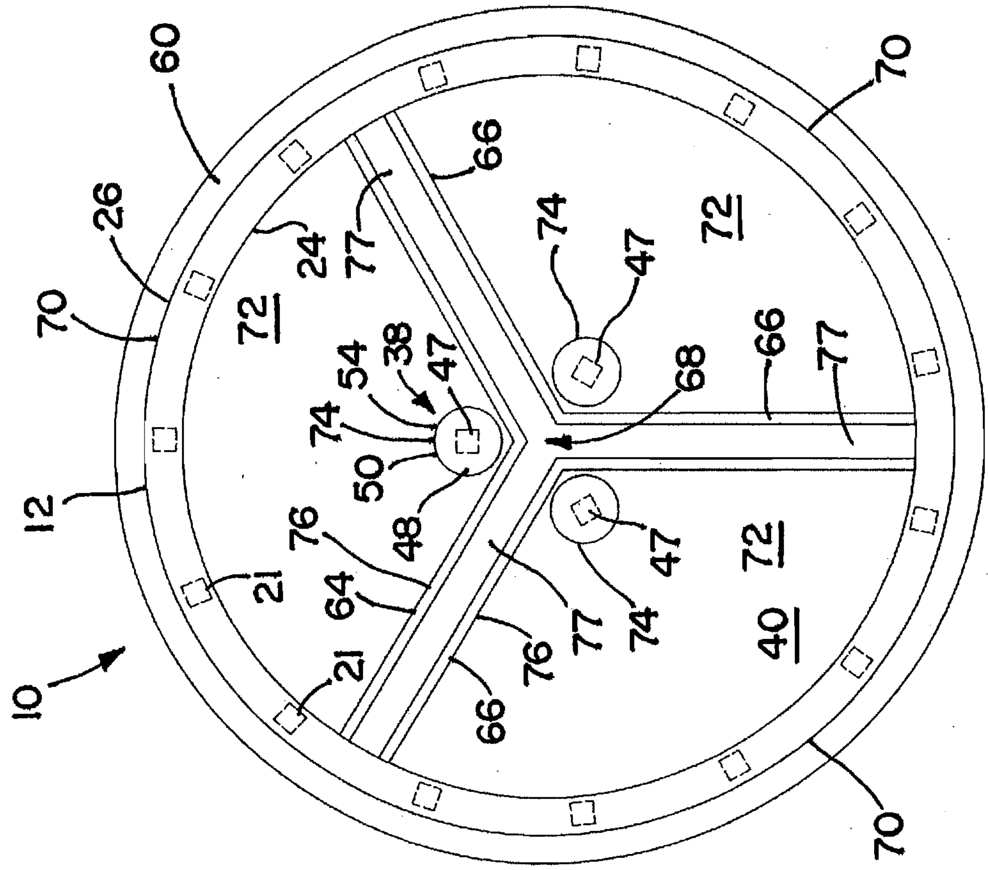
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FIG. 6

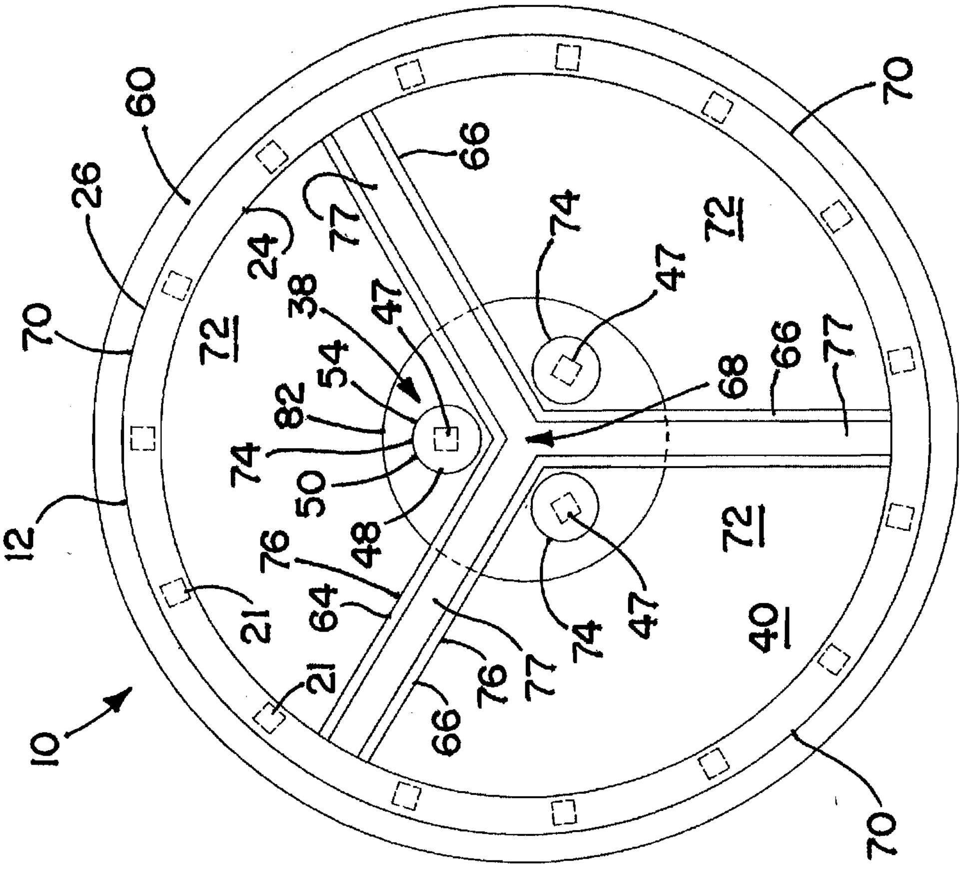
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FIG. 8

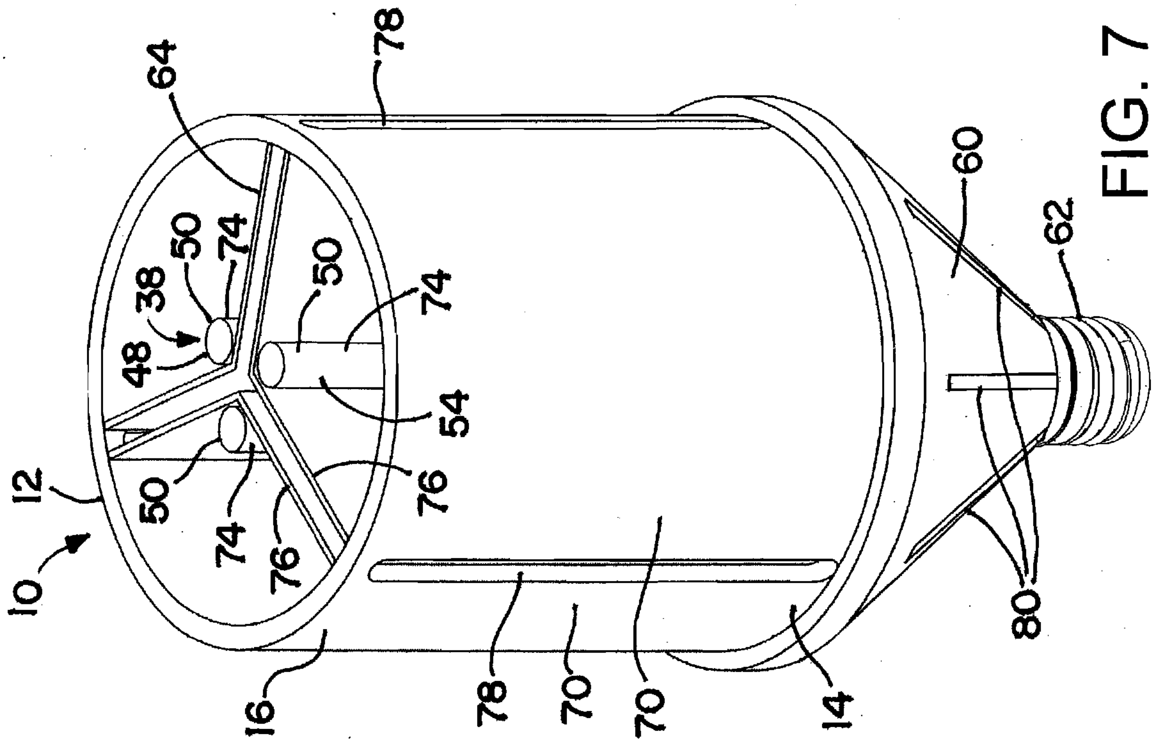
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FIG. 7

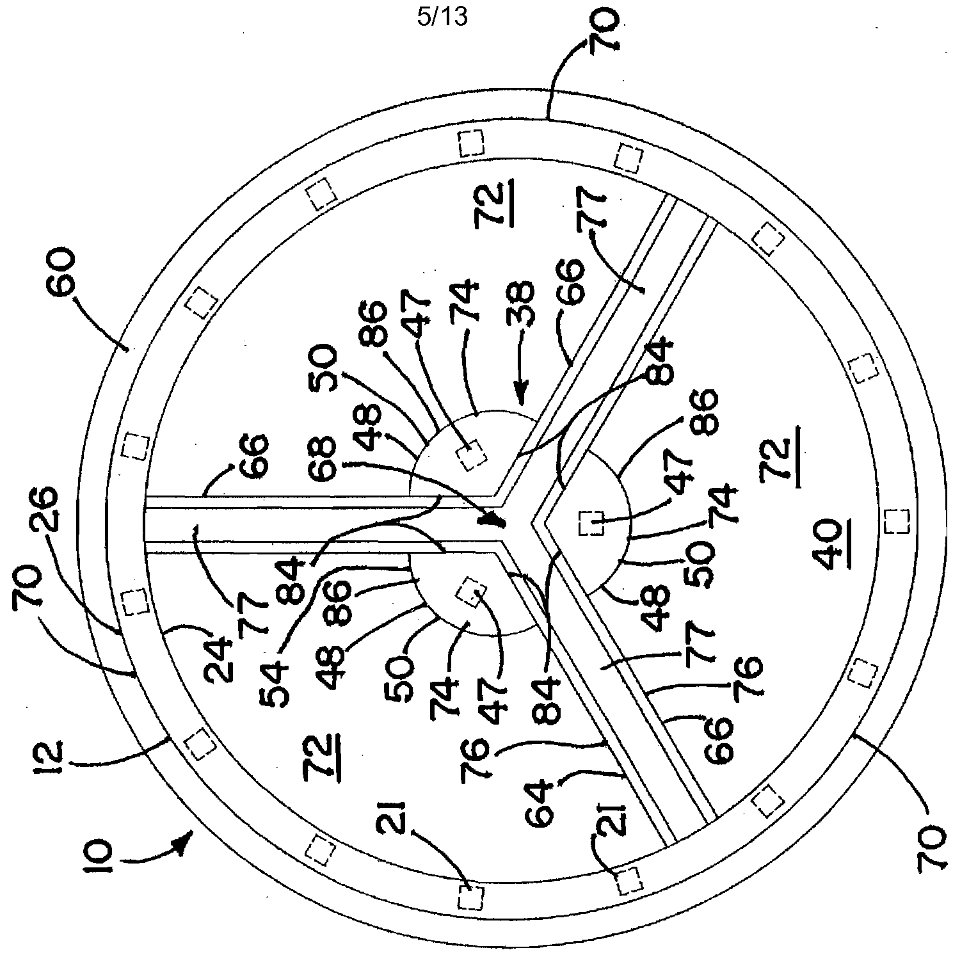
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FIG. 10

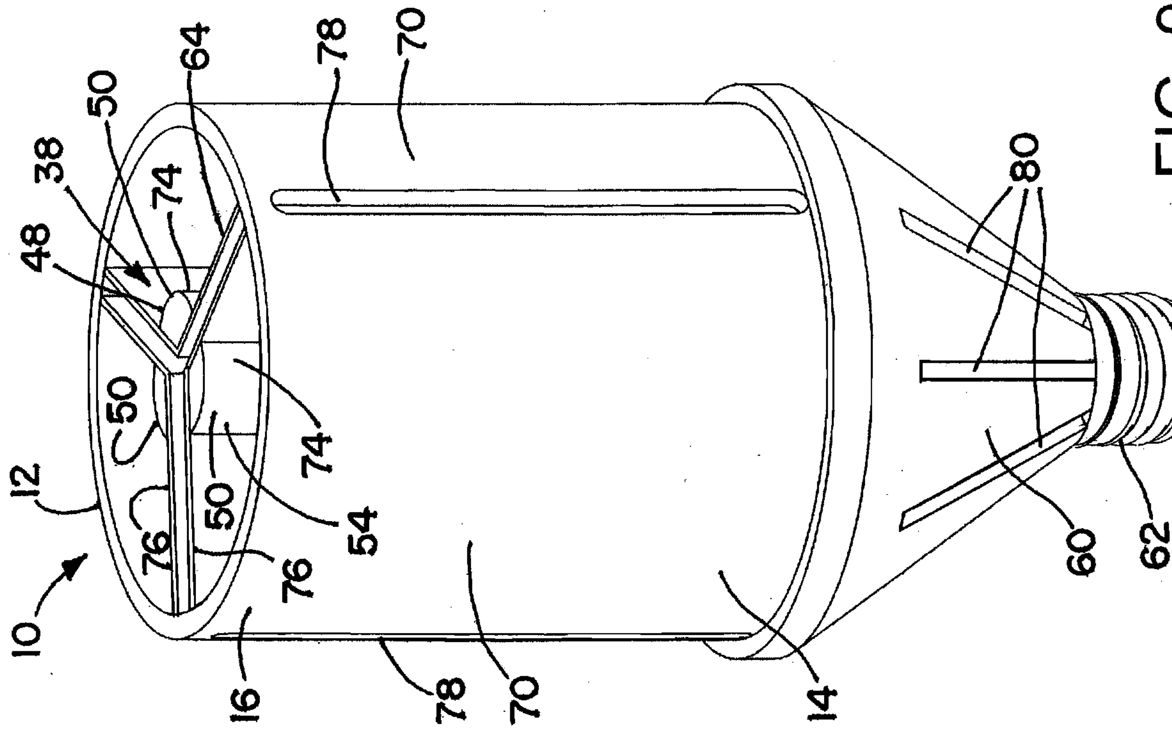
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FIG. 9

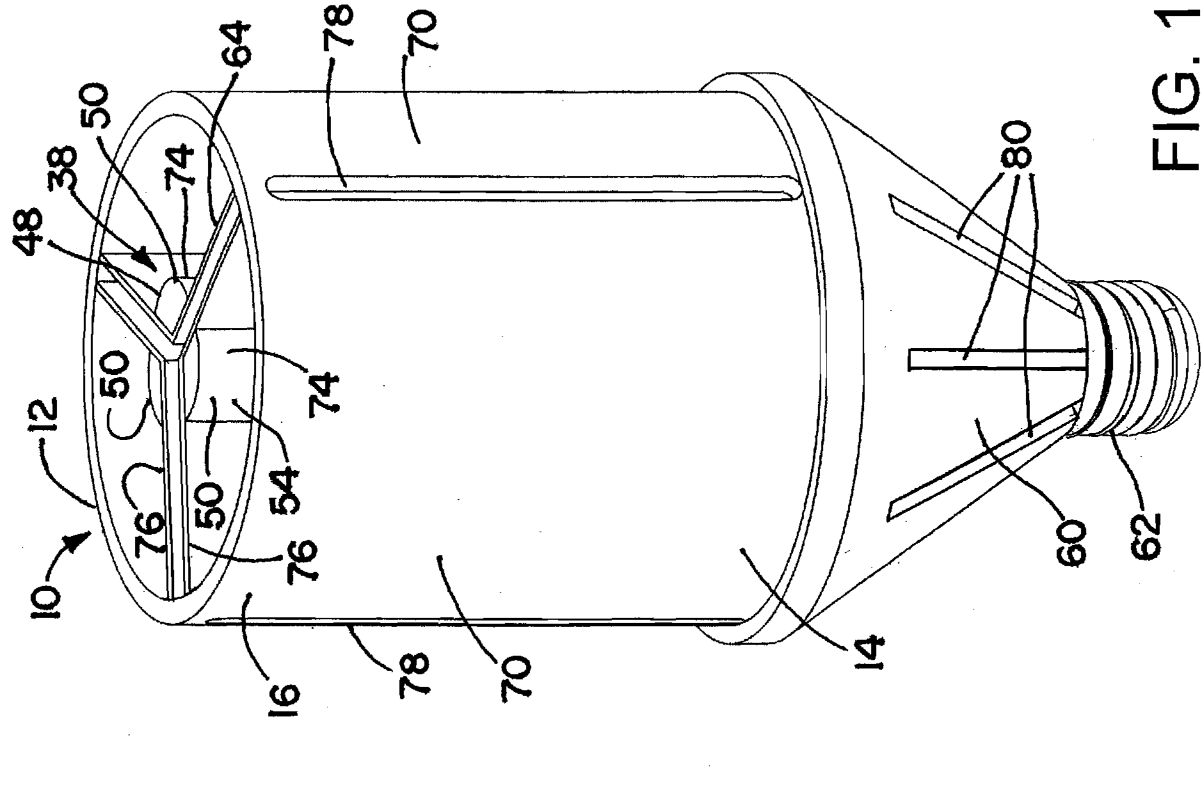
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FIG. 11

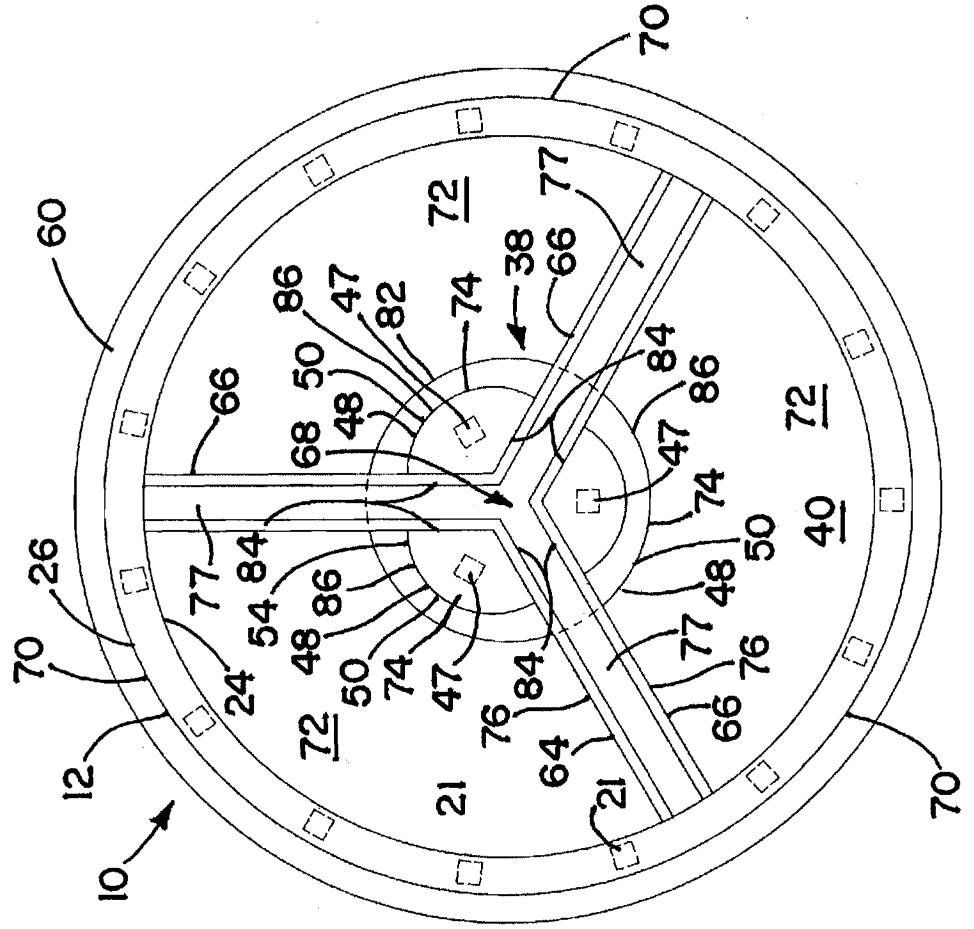
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FIG. 12

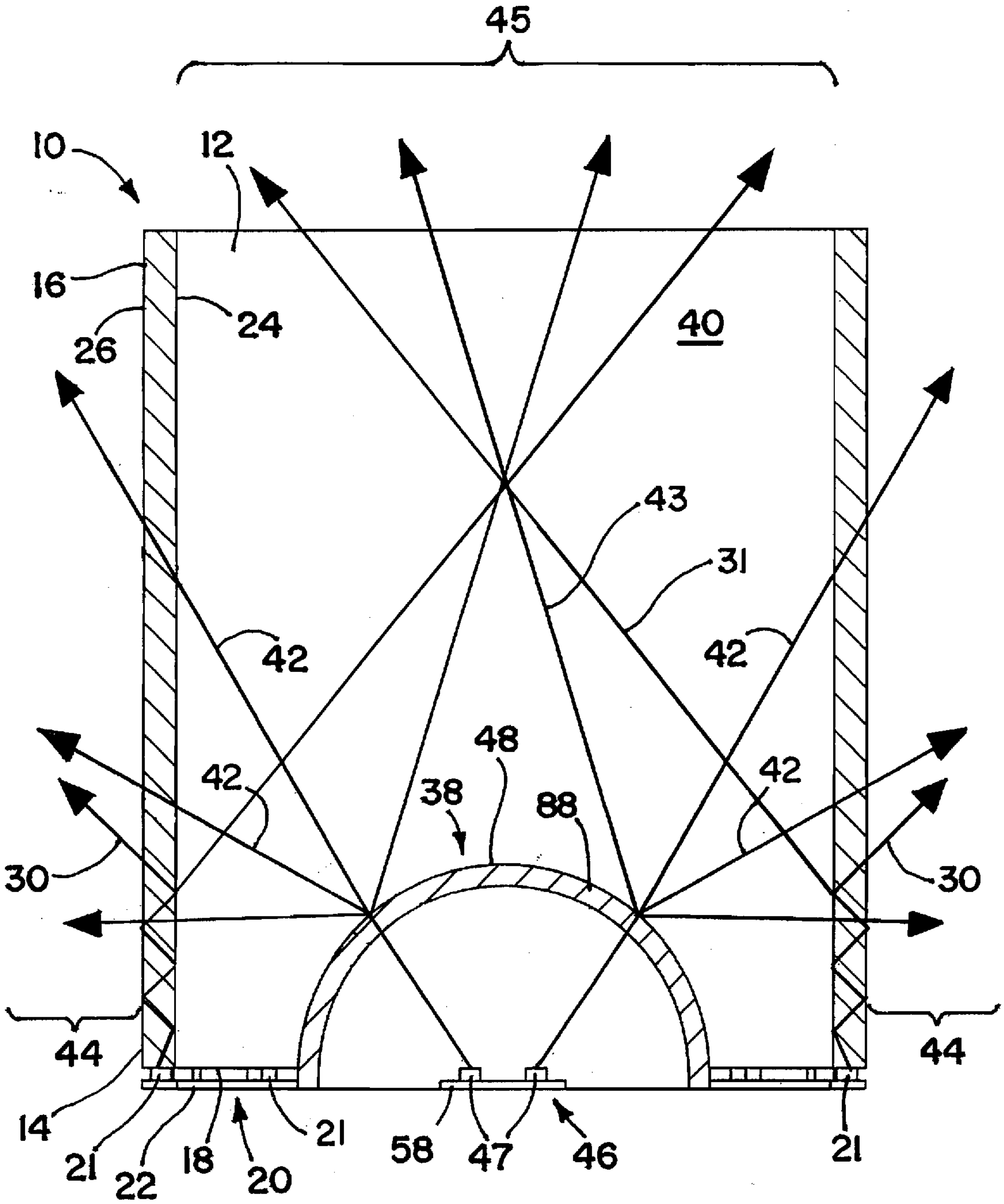
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FIG. 13

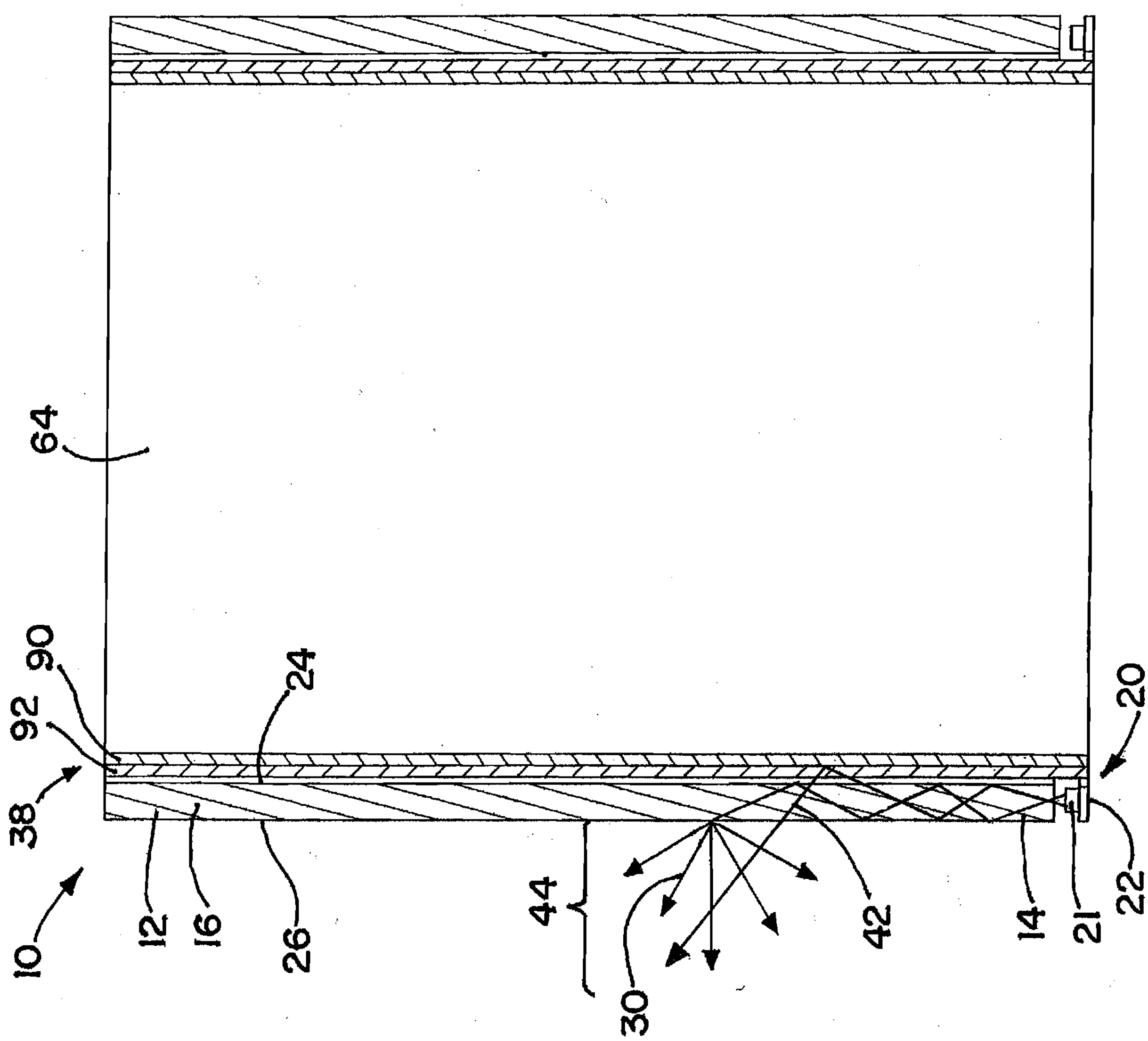


FIG. 14

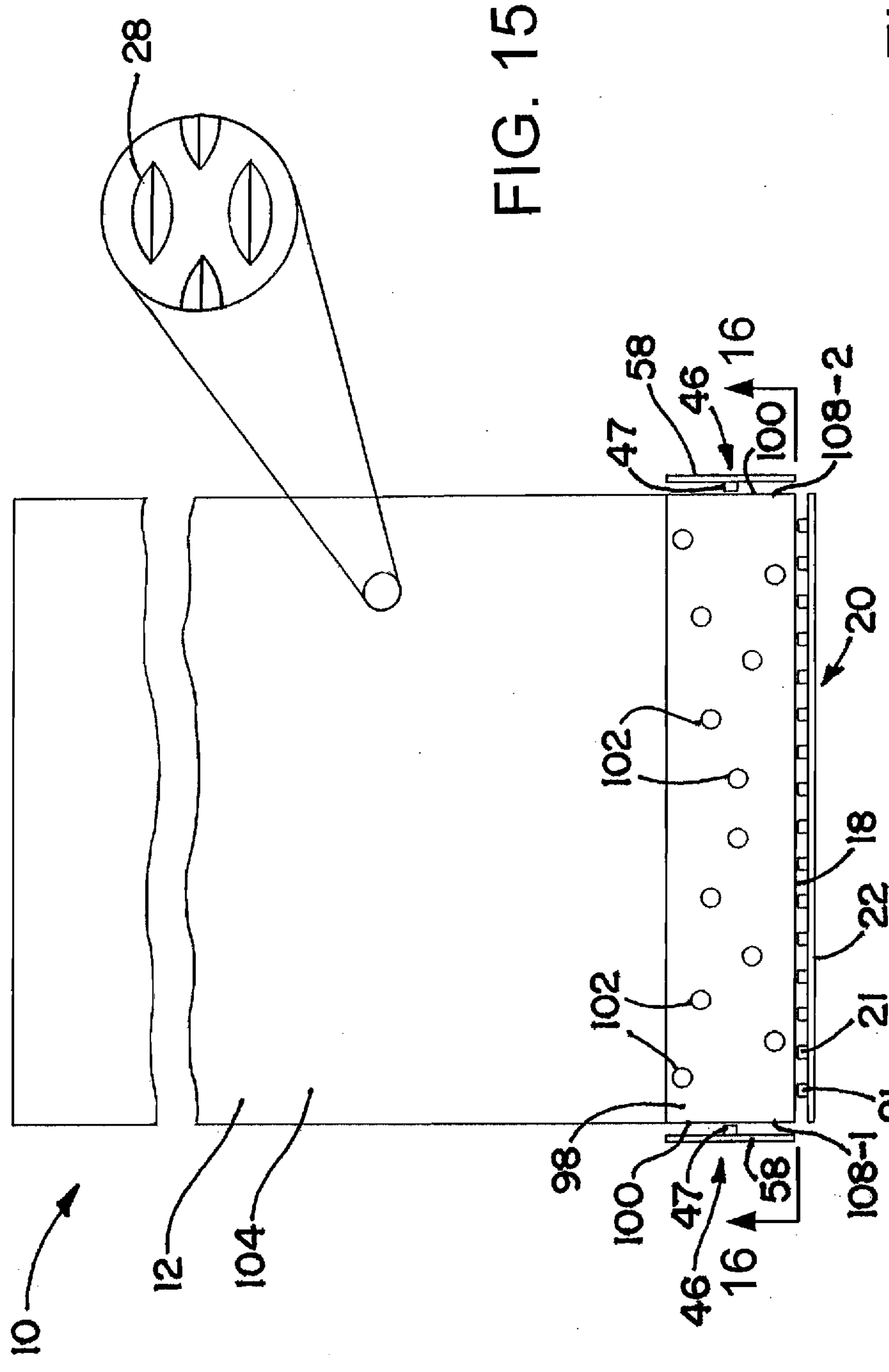
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FIG. 15

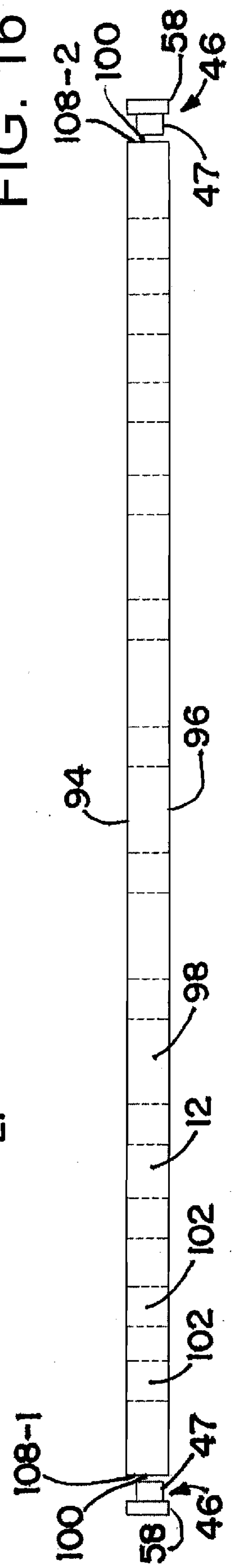
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FIG. 16

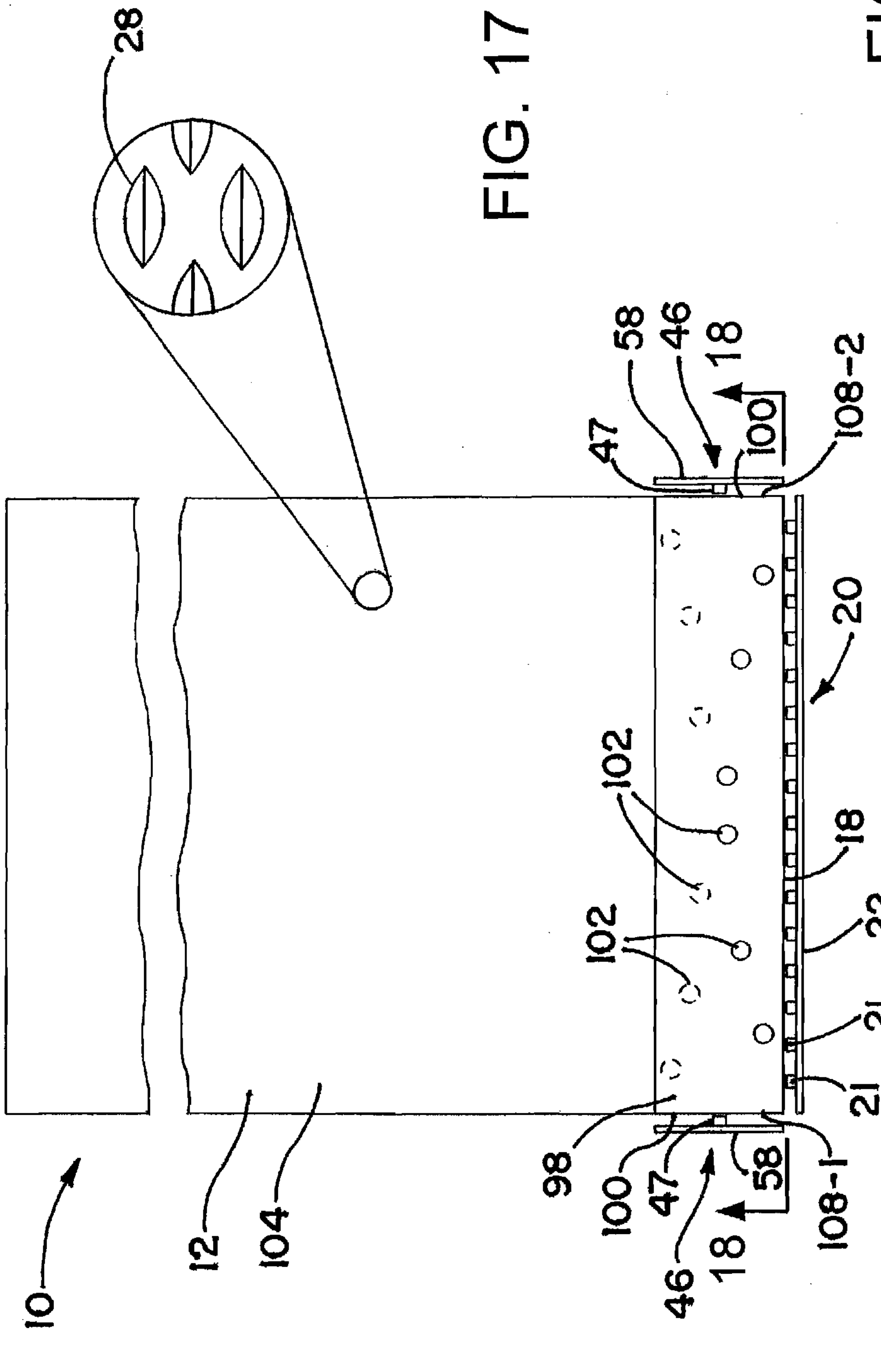
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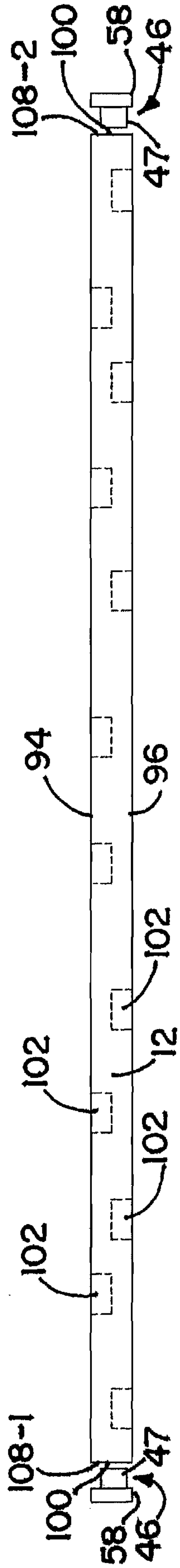
FIG. 17

FIG. 18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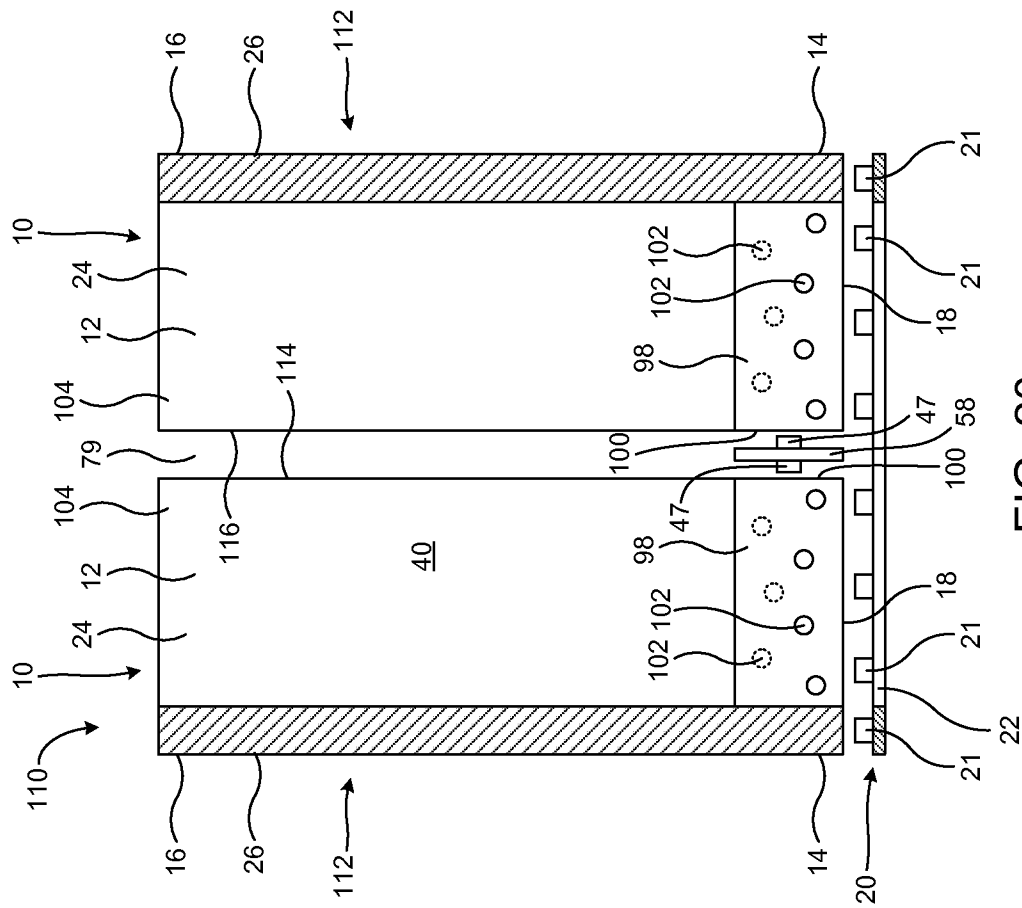
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FIG. 20

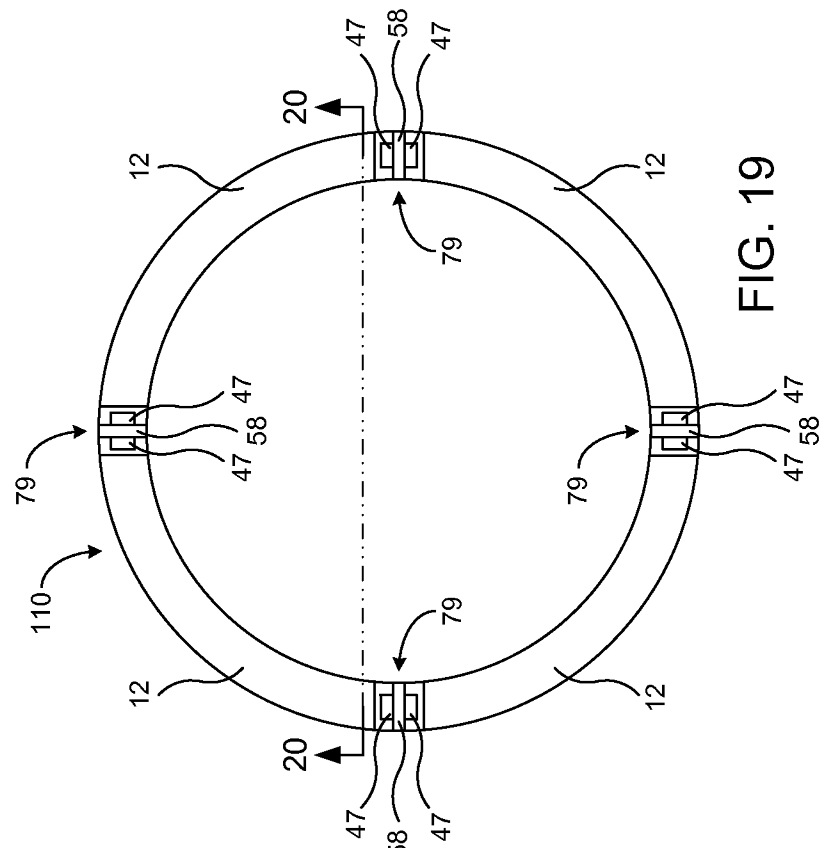
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FIG. 19

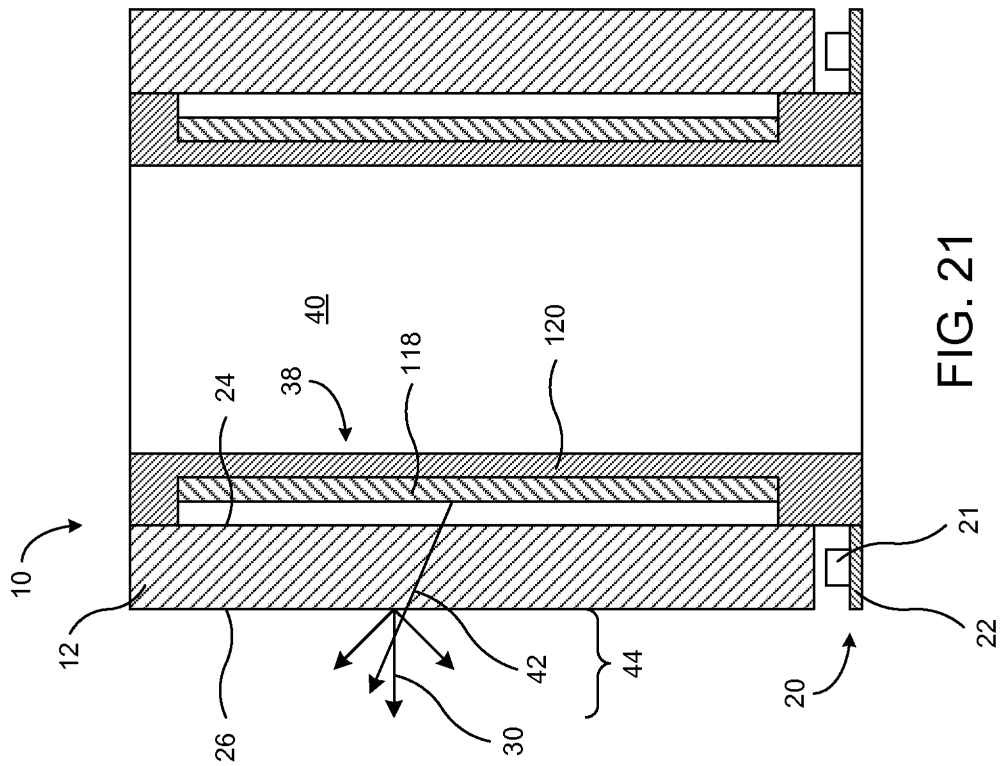


FIG. 21

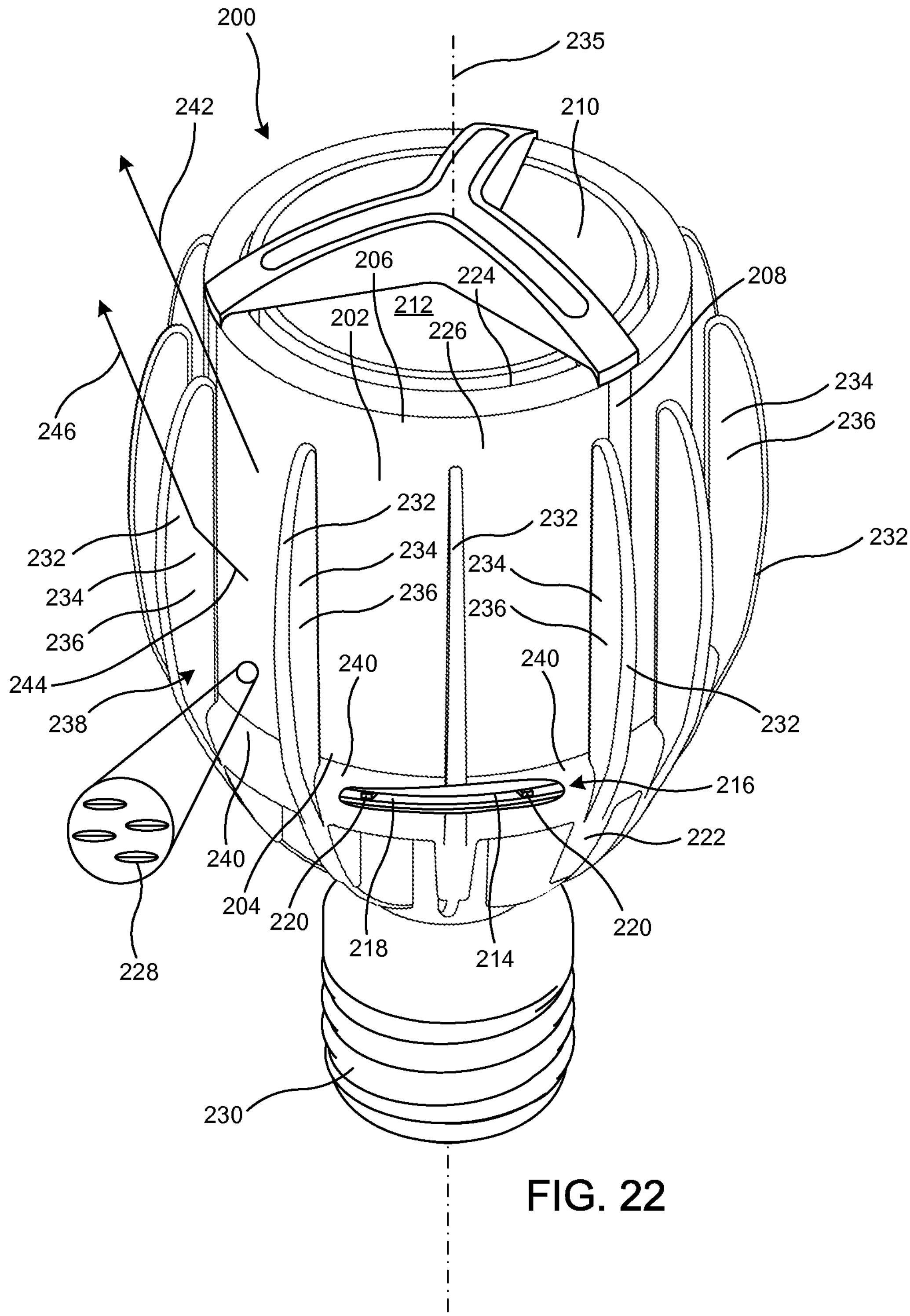
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FIG. 22

## INTERNATIONAL SEARCH REPORT

International application No.
**PCT/US2012/058250**

### A. CLASSIFICATION OF SUBJECT MATTER

***F21V 3/00(2006.01)i, F21V 7/04(2006.01)i, F21V 9/00(2006.01)i***

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F21V 3/00; F21V 9/10; F21V 29/00; F21S 2/00; F21V 17/00; F21V 7/00; F21V 29/02; F21Y 101/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: light bulb, light guide, light source, color adjuster

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 2010-0027270 A1 (HUANG, Y. H. et al.) 04 February 2010<br>See paragraphs [0013], [0015], [0021], figures 2, 4, and claim 1. | 1-72 |
| A | US 2010-0103666 A1 (CHANG, K. J. et al.) 29 April 2010<br>See paragraphs [0015], [0016], figure 4, and claim 1. | 1-72 |
| A | JP 2010-086709 A (TOSHIBA LIGHTING & TECHNOLOHY CORP.) 15 April 2010<br>See paragraph [0019], figures 1-3, and claim 1. | 1-72 |
| A | WO 2010-144572 A2 (RESSELASER POLYTECHNIC INSTITUTE) 16 December 2010<br>See p.10, lines 11-19, p.11, lines 3-9, figures 2, 3, and claims 1, 16. | 1-72 |

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 25 March 2013 (25.03.2013) | **27 March 2013 (27.03.2013)** |

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YANG, In Su
Telephone No. 82-42-481-8131

**INTERNATIONAL SEARCH REPORT**
Information on patent family members

International application No.
**PCT/US2012/058250**

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| US 2010-0027270 A1 | 04.02.2010 | None | |
| US 2010-0103666 A1 | 29.04.2010 | None | |
| JP 2010-086709 A | 15.04.2010 | CN 101639171 A | 03.02.2010 |
| | | CN 101639171 B | 18.05.2011 |
| | | EP 2154419 A2 | 17.02.2010 |
| | | JP 05-062433 B2 | 17.08.2012 |
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| | | JP 2010-108774 A | 13.05.2010 |
| | | US 2010-0026185 A1 | 04.02.2010 |
| WO 2010-144572 A2 | 16.12.2010 | CA 2765106 A1 | 16.12.2010 |
| | | CN 102460005 A | 16.05.2012 |
| | | EP 2440841 A2 | 18.04.2012 |
| | | US 2012-081880 A1 | 05.04.2012 |
| | | WO 2010-144572 A3 | 03.03.2011 |