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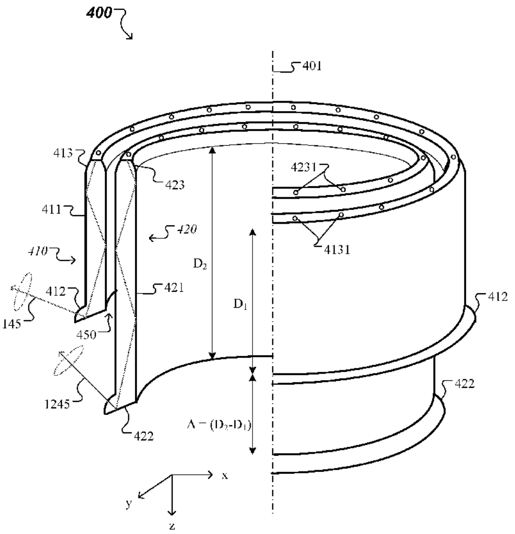

FIG. 4A

(57) **Abstract:** A luminaire includes (i) a first optical system to output light having a first output light distribution and a second optical system arranged adjacent the first optical system and to output light having a second different output light distribution; and (ii) a first light engine optically coupled to an input aperture of the first optical system and a second light engine optically coupled to an input aperture or the second optical system, the first and second light engine to allow independent control of amounts of light provided to the first and second optical systems. Each of the first and second optical systems has an output aperture displaced by a predetermined distance along a forward direction from the corresponding input aperture to direct light received at the input aperture to the output aperture. The first and second optical systems have elongate extensions extending sideways from the forward direction.

[Continued on next page]

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LUMINAIRES FOR SPATIAL DIMMING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit under 35 U.S.C. § 119(e)(1) of U.S. Provisional Application No. 62/629,674, filed on February 12, 2018, and of U.S. Provisional Application No. 62/680,491, filed on June 4, 2018, all of which being incorporated by reference herein.

FIELD OF TECHNOLOGY

The present technology relates to lighting devices that are configured to allow control of the amount of light emitted in different directions.

BACKGROUND

Spatial dimming, also referred to as spatial tuning or dynamic beam shaping, refers to control of the amounts of light output by a luminaire during operation into the ambient environment in different directions and traditionally requires moving parts, multiple luminaires or complex luminaire architectures. There has been a long-felt need to mitigate this situation.

SUMMARY

In one aspect, a luminaire includes (i) a first optical system configured to output light having a first output light distribution and a second optical system arranged adjacent the first optical system and configured to output light having a second output light distribution different from the first output light distribution; and (ii) a first light engine optically coupled to an input aperture of the first optical system and a second light engine optically coupled to an input aperture or the second optical system. The first and second light engines are configured to allow independent control of amounts of light provided to the first and second optical systems. Each of the first and second optical systems has an output aperture displaced by a predetermined distance along a forward direction from the corresponding input aperture, and is configured to direct light received at the input aperture to the output aperture. The first and second optical systems have elongate extensions extending sideways from the forward direction.

The foregoing and other embodiments can each optionally include one or more of the following features, alone or in combination. In some implementations, the forward direction can be perpendicular to the elongate extension. Here, the first and second optical systems can have concentric annular shapes. In some cases, the annular shapes are circles. In some cases, the annular shapes are polygons.

In some implementations, first and second light distributions can include obtuse angles relative to the forward direction. In some implementations, first and second light distributions can include acute angles relative to the forward direction.

In some implementations, the first optical system can include a first light guide extending along a forward direction and the second optical system can include a second light guide extending along the forward direction. Here, the forward direction is perpendicular to the elongate extension. Additionally, the first and second light guide include a solid transparent material. Further, the first and second light guide can be spaced apart. Moreover, the first and second light guide can be separated by a transparent material having a first refractive index smaller than a second refractive index of the solid transparent material of the first and second light guides.

In some implementations, the first and second optical systems can have linear elongate extensions and are arranged in parallel. In some implementations, the first and second optical systems can have elongate curvilinear extensions perpendicular to the forward direction. In some cases, the luminaire can undulate multiple times along the elongate curvilinear extension.

In some implementations, the first optical system can include multiple first segments. In some cases, adjacent ones of the multiple first segments can be displaced relative to each other. In some cases, the second optical system can include multiple second segments and the first and second segments are interlaced.

In some implementations, the optical systems can be formed as solid transparent bodies.

In some implementations, the first and second light engines can include light-emitting diodes. In some implementations, the first and second light engines can include exit apertures of optical fibers.

In some implementations, the luminaire can include a socket and is configured in a light bulb format.

In some implementations, a lighting system can include any one of the forgoing luminaires; and a controller operatively coupled with the luminaire and configured to independently control the first and second light engines. In some cases, the controller is configured to vary the amounts of light provided by each of the first and second light engines substantially continuously between a fully OFF and fully ON state.

The details of one or more implementations of the technologies described herein are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the disclosed technologies will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF FIGURES

FIGs. 1A-1B show different schematic views of an example of a luminaire according to the present technology.

FIG. 1C shows a schematic view of a polygonal arrangement of luminaires according to the present technology.

FIG. 2 shows a perspective schematic view of another example of a luminaire according to the present technology.

FIG. 3 shows a polar plot of example output light distributions of the luminaire of FIGs. 1A-1B or the luminaire of FIG. 2.

FIGs. 4A-4B show different schematic views of another example of a luminaire according to the present technology.

FIGs. 5-9 show examples of luminaires similar to the one shown in FIG. 4.

FIGs. 10A-10F show aspects of example luminaire modules that include ccomponents similar to the components used in the light engines and the optical systems of the luminaire modules of the luminaires described herein.

FIG. 11A is a cross sectional view of a portion of a luminaire similar to the luminaires described herein, the luminaire having multiple independently controllable sets of LEEs and corresponding light guides and an electronically controllable fluid between the light guides.

FIG. 11B is a cross sectional view of a portion of a luminaire similar to the luminaires described herein, the luminaire having multiple independently controllable sets of LEEs and corresponding light guides and a liquid crystal sheet between the light guides.

Reference numbers and designations in the various drawings indicate example aspects of implementations of particular features of the present disclosure.

DETAILED DESCRIPTION OF THE TECHNOLOGY

This disclosure includes technologies directed to improvements of luminaires which use edge-coupled virtual filament (ECVF) technologies. Some embodiments that show how ECVF technology can collect and manipulate light from an array of light emitting elements (LEEs) such as light emitting diodes are described below in connection with FIGs. 10A-10F and 11A-11B. Other embodiments of ECVF-based luminaires are disclosed in previous commonly owned applications, such as U.S. Patent Nos. 8,506,112 and 9,335,462, and U.S. Patent Application Publications Nos. US2013/0208495, US2013/0039050 and US2016/0025300. The contents of these applications are incorporated herein by reference.

The following improvements to ECVF designs describe possibilities for alternative embodiments that take advantage of the core technology and detail innovative ways to control the amount of light emitted in different directions during operation of respective luminaires.

FIG. 1A shows an exploded view of a portion of an example luminaire 100 that is configured to allow control of illumination of portions of a surrounding ceiling. Generally, luminaires according to the present technology can be configured to illuminate various target surfaces, for example a ceiling, a wall, a floor or other surface or combinations of two or more of such surfaces. The illumination by portion is accomplished via a combination of multiple luminaire modules that are integrated into one luminaire that are configured to provide light to different portions of a target surface and allow independent activation/dimming during operation.

The example luminaire 100 includes two luminaire modules 110 and 120 – other examples may include more. In this example, the first luminaire module 110 is formed from a first light engine 115 and a first optical system including a first light guide 111 of a first depth D_1, along the z-axis, and a first extractor 112. Here, the second luminaire module 120 is formed from a second light engine 125 and a second optical system including a second light guide 121 of a second depth D_2, along the z-axis, and a second extractor 122. Since, in this example, (i) input apertures of the first and second light guides 111, 121 are arranged in the same plane, here parallel to the (x,y)-plane, and (ii) first and second depths of the first and second light guides 111, 121 are different, $D_2 \neq D_1$, output apertures of the first and second light guides 111, 121 are staggered in depth (along the z-direction) by a predetermined offset $\Delta = D_2 - D_1$, as illustrated. Note that the predetermined offset Δ is a fraction of the depth D_2 of the deeper light guide 121, e.g., Δ can be 80%, 50%, 20%, 10% or less of D_2. Staggering of the output apertures can provide unobstructed light output from the respective extractors 112 and 122. Luminaire modules in other example luminaires may have light guides with relative depths that allow deliberate obstruction of light output from different extractors, as the predetermined offset $\Delta \rightarrow 0$, for instance. Other example extractors may output light on both sides, as shown for example in FIG. 2.

In this example light in the luminaire modules 110 and 120 propagates through the respective light guides 111, 121 in generally forward directions, here parallel to within acute angles relative to the (positive) z-direction, while light is output through respective extractors 112, 122 in generally backward directions including obtuse angles relative to the forward direction. Other example luminaires may have other output light distributions. For example, the first extractor 112, the second extractor 122 or both may be configured to output light in backward and forward directions or forward directions only, here in directions with parallel components relative to the (positive) z-direction.

As noted above, the luminaire modules 110 and 120 include their own light engines 115 and 125. Each light engine 115, 125 includes a substrate with light-emitting elements (LEEs) 116 and 126, respectively that are configured to allow operative connection to a controller190. In this case the LEEs provide multiple discrete light sources. In other examples, the LEEs may be displaced from and optically coupled with the luminaire modules 110 and 120 via optical fibers (e.g., as shown below in FIGs. 10C and 10E). In such cases one or more LEEs may be coupled to one or more fibers with one end of each of the one or more optical fibers receiving light from the one or more LEEs and the opposite ends being optically coupled with a respective luminaire module.

Referring again to FIG. 1A, the example luminaire 100 is configured to allow independent control of the overall amount of light provided by the light engines 115 and 125 via the controller190. Other example luminaires can be configured to allow more granular control of LEEs 116 and/or 126, for example, vary amounts of light provided along the elongate extension (here the y-direction) independently per light engine or in other ways.

In the present examples, the optical systems of the luminaire modules 110 and 120 further include respective coupling portions 113 and 123 with pockets 1131 and 1231 providing an input aperture for receiving light from the LEEs 116 and 126. In some implementations the pockets 1131 and 1231 are spaced apart from each other along the y-axis. In other implementations, the pockets 1131 and 1231 are arranged in a contiguous manner to form respective grooves extending along the y-axis. In either implementation, the pockets 1131 and 1231 and/or the grooves are sized to accommodate the LEEs 116 and 126 when the light engines 115 and 125 are operatively combined with their respective optical systems. In the example illustrated in FIG. 1A, the coupling portions 113 and 123 are tapered to collimate light before it propagates to respective light guides 111 and 121.

The light guides 111 and 121 of this example are configured to aid in mixing light from respective light engines 115/125 to provide a more uniform light distribution along the exit aperture of the light guides 111 and 121 near their respective extractors 112 and 122.

In general, the light guides 111 and 121 are spaced apart with a medium 150. FIG. 1B shows a top view of portions of the luminaire modules 110 and 120 of the luminaire 100. In the example shown in FIG. 1B, the medium 150, which separates the light guides 111 and 121 by a predetermined spacing δ along the x-axis in the assembled configuration, is an air gap. Other examples, may include a solid intermediary layer of transparent material having a refractive index lower than the light guides abutting them on both sides. Such an intermediary layer may allow for some light to pass from one luminaire module to another and/or vice versa. Furthermore, an intermediary layer may be employed that allows control of optical properties during operation, for example an electrochromic or liquid crystal system that allows transmission of varying amounts of light depending on an applied voltage, as described below in connection with FIGs. 11A-11B. Other intermediary layers are possible.

Referring again to FIGs. 1A-1B, the extractors 112 and 122 are configured to output light within different solid angles in order to provide light to different portions of a target surface. Depending on the embodiment, the extractors may be configured to provide light distributions that allow for uniform illuminance or other distribution on the target surface. Details regarding the extractors 112 and 122 as well as other components of the luminaire modules 110 and 120 are described in detail in connection with FIGs. 10A-10F, and in the incorporated references noted above.

The example luminaire 100 has a generally planar elongate profile extending along the y-axis. Other example luminaires may have elongate curvilinear, for example ellipsoidal, undulating, polygonal with N sides, where N = 4, 6, 8, etc., or other regular or irregular profiles. Such profiles can be open or closed.

FIG. 1C shows an N-side polygonal arrangement 105 of luminaires similar to the luminaire 100, where N = 4. Here, a first arm of the arrangement 105 is formed from a first luminaire which includes luminaire modules 110a, 120a having light guides elongated along the y-axis and separated from each other along the x-direction by a predetermined spacing δ, a second arm is formed from a second luminaire which includes luminaire modules 110b, 120b having light guides elongated along the x-axis and separated from each other along the y-direction by a predetermined spacing δ (or a different spacing), a third arm is formed from a third luminaire which includes luminaire modules 110c, 120c having light guides elongated along the y-axis and separated from each other along the x-direction by a predetermined spacing δ (or a different spacing), and a fourth arm is formed from a fourth luminaire which includes luminaire modules 110d, 120d having light guides elongated along the x-axis and separated from each other along the y-direction by a predetermined spacing δ (or a different spacing).

The medium 150 separating each of the pairs of luminaire modules can be the same for each arm, or different for different arms. Luminaires of adjacent arms are connected together with connectors in the following manner.

The first luminaire module 110a of the first luminaire is connected using a first outer connector 180ab to the first luminaire module 110b of the second luminaire, and the second luminaire module 120a of the first luminaire is connected using a first inner connector 182ab to the second luminaire module 120b of the second luminaire. The first luminaire module 110b of the second luminaire is connected using a second outer connector 180bc to the first luminaire module 110c of the third luminaire, and the second luminaire module 120b of the second luminaire is connected using a second inner connector 182bc to the second luminaire module 120c of the third luminaire. The first luminaire module 110c of the third luminaire is connected using a third outer connector 180cd to the first luminaire module 110d of the fourth luminaire, and the second luminaire module 120c of the third luminaire is connected using a third inner connector 182cd to the second luminaire module 120d of the fourth luminaire. The first luminaire module 110d of the fourth luminaire is connected using a fourth outer connector 180ad to the first luminaire module 110a of the first luminaire, and the second luminaire module 120d of the fourth luminaire is connected using a fourth inner connector 182ad to the second luminaire module 120a of the first luminaire.

Generally, in further example implementations, the number of luminaire modules along an elongate extension of a luminaire may vary. For example, sections with two and three luminaire modules may be interlaced. Furthermore, even without change in the number of luminaire modules, aspects of extractors, light guides, light engines or other components may vary along an extension of the luminaire. Such variation may be continuous or discrete. This may apply for luminaires with straight, polygonal, curvilinear or other geometries.

In the example luminaire 100, the luminaire modules have like configuration. It is noted that in other implementations, different luminaire modules may have different configurations. FIG. 2 shows such a schematic view of an example luminaire 200. Here, luminaire 200 can include the same first luminaire module 110 described above in connection with luminaire 100. As such, the extractor 112 of the luminaire module 110 of both luminaire 100 and 200 is configured to output light in a first backward angular range 1145. The second luminaire module 220, however, is different from the second luminaire module 120 of luminaire 100 described above. The luminaire module 220 can include the same components as the luminaire module 120 of luminaire 100, except they have different extractors 122 and 222. In this manner, while the extractor 122 of the luminaire module 120 is configured to output light in a second backward angular range 1245, and optionally in a forward angular range 1245", the extractor 222 of the luminaire module 220 can be configured to output light in the same second backward angular range 1245 and in a different, third backward angular range 1245'.

It is noted that the angular ranges 1145 and 1245 can be oriented in ways other than as shown so far. For example, the angular range of light output from the extractor that is closest to the z=0 plane can be oriented at steeper angles relative to the angular range of light output from the extractor that is further away from the z=0 plane. Both orientations can provide unique functions for space illumination. For example, some luminaires according to the present technology can be deliberately configured to enhance or de-emphasize aspects of ceilings, plenums, walls, reflector dishes, or other surfaces and/or additional optical elements by way of providing more or less amounts of light at shallow/gracing incidence angles.

FIG. 3 shows a polar plot 399 of example output light distributions of the luminaires 100 and 200 based on the example angular ranges indicated in FIGs. 1A and 2. Here, lobe 1145a corresponds to light output by the first luminaire module 110 of either of the luminaires 100, 200 in the first backward angular range 1145. Lobe 1245a corresponds to light output by either the second luminaire module 120 of luminaire 100, or the second luminaire module 220 of luminaire 200 in the second backward angular range 1245. Further, lobe 1245c corresponds to light output optionally by the second luminaire module 120 of the luminaire 100 in the forward angular range 1245". Furthermore, lobe 1245b corresponds to light output by the second luminaire module 220 of the luminaire 200 in the third backward angular range 1245'.

As noted above, in other implementations the distribution of light output from luminaire module 220 may follow the orientation of lobe 1145a instead of that of lobe 1245a and the distribution of light output from luminaire module 110 may follow the orientation of lobe 1245a instead of that of lobe 1145a. Note that the illustrated shapes of the lobes are schematic only and may be different in different implementations. Note also that the relative orientation of lobes provided by different luminaire modules may further depend on whether or not a luminaire includes additional optical elements for transforming the distribution of light output from the extractors. For example, an additional reflector dish may be employed in the luminaire to alter all or a portion of the light distribution for indirect illumination of a space via a ceiling or be arranged to provide direct illumination.

The present technology achieves spatial dimming as a superposition of individually weighted light distributions 1145a and 1245a by selectively activating and/or dimming the corresponding light sources – in this case the respective LEEs 116 and 126. In this example, the output light distribution 1145a is provided by luminaire module 110 and has a shorter range on a target surface perpendicularly intersecting the z-axis at positive z coordinates. As noted output light distributions at shallower angles relative to the target surface similar to 1145a can be provided by luminaire module 120 or 220 and has a longer range on such a target surface. In this case, the longer range refers to potentially wider portions and/or greater distances of a target surface that can be illuminated by the luminaire.

As noted, to provide suitable lighting for various lighting applications, example luminaires can be configured with curvilinear profiles in the z-plane with open or closed polygonal or toroidal/annular shapes, for example. Closed configurations of such shapes can provide symmetrical illumination about the z-axis even when using luminaire modules with profiles that otherwise have asymmetrical output light distributions.

FIG. 4A shows a perspective schematic view of a portion of another example luminaire 400 with two nested luminaire modules 410 and 420, each of which having contiguous toroidal shape – a quadrant portion of the example luminaire 400 is broken away for better illustration. The luminaire modules 410 and 420 and the luminaire modules 110 and 120 of example luminaire 100 have similar profiles in sectional planes through the z-axis, however, luminaire modules 410 and 420 are wrapped in a circular manner about axis 401 of the luminaire 400.

In the example, the light guides 411, 421, extractors 412, 422, and couplers 413, 423 of the nested luminaire modules 410, 420 have continuous axial symmetry. Other components may have like or different symmetry. For example, light engines (e.g., similar to 115, 125) may have discrete rotational symmetry about axis 401, which may be determined by the spacing of the discrete light sources in the light engine and/or the coupling system. Other implementations may have light guides, extractors, couplers and/or other components with discrete rotational symmetry, e.g., as shown in FIG. 1C.

In this example, the first luminaire module 410 is formed from a first light engine (not shown in FIG. 4A) and a first optical system including the first light guide 411 having a first depth D_1, along the z-axis, and the first extractor 412. Here, the second luminaire module 420 is formed from a second light engine (not shown in FIG. 4A) and a second optical system including a second light guide 421 of a second depth D_2, along the z-axis, and the second extractor 422. Since, in this example, (i) input apertures of the first and second light guides 411, 421 are arranged in the same plane, here parallel to the (x,y)-plane, and (ii) first and second depths of the first and second light guides 411, 421 are different, $D_2 \neq D_1$, output apertures of the first and second light guides 411, 421 are staggered in depth (along the z-direction) by a predetermined offset $\Delta = D_2 - D_1$, as illustrated. As noted above, the predetermined offset Δ is a fraction of the depth D_2 of the deeper light guide 421, and Δ can be, e.g., 80%, 50%, 20%, 10% or less of D_2.

In this example light in the luminaire modules 410 and 420 propagates through the respective light guides 411, 421 in generally forward directions, here parallel to the (positive) z-direction, while light is output through respective extractors 412, 422 in generally backward directions including obtuse angles relative to the forward direction. As such, the first extractor 412 of the first luminaire module 410 can output light in a first backward angular range 1145, and the second extractor 422 of the second luminaire module 420 can output light in a second backward angular range 1245.

The couplers 413 and 423 have pockets 4131 and 4231 providing an input aperture for receiving light from the LEEs of the respective light engines of the luminaire modules 410 and 420. In some implementations the pockets 4131 and 4231 are spaced apart from each other along an azimuthal direction, e.g., in the (x,y)-plane. In other implementations, the pockets 4131 and 4231 are arranged in a contiguous manner to form respective grooves extending along the azimuthal direction, e.g., in the (x,y)-plane. In either implementation, the pockets 4131 and 4231 and/or the grooves are sized to accommodate the LEEs when the respective light engines are operatively combined with their respective optical systems. In the example illustrated in FIG. 4A, the couplers 413 and 423 are tapered to collimate light before it propagates to respective light guides 411 and 421.

The light guides 411 and 421 of this example are configured to aid in mixing light from the respective light engines to provide a more uniform light distribution along the exit aperture of the light guides 411 and 421 near their respective extractors 412 and 422.

In general, the light guides 411 and 421 are spaced apart with a medium 450. FIG. 4B shows a top view of the luminaire modules 410 and 420 of the luminaire 400. In the example shown in FIG. 4B, the medium 450, which separates the light guides 411 and 421 by a predetermined spacing δ along the radial direction in the assembled configuration, is an air gap. Other examples, may include a solid intermediary layer of transparent material having a refractive index lower than the light guides abutting them on both sides. Such an intermediary layer may allow for some light to pass from one side to another and/or vice versa. Furthermore, an intermediary layer may be employed that allows control of optical properties during operation, for example an electrochromic or liquid crystal system that allows transmission of varying amounts of light depending on an applied voltage, as described below in connection with FIGs. 11A-11B.

Note that the predetermined spacing δ between the light guides 411 and 421 can cover a broad range of values. The lower bound of the range corresponds to the case when the light guides 411, 421 are substantially in contact with each other or when they are separated by a very thin film. Here, the spacing δ is smallest, $\delta \rightarrow 0$. The upper bound of the range corresponds to the case when the inner light guide 421 is a pipe of thickness T. Here, the spacing δ is largest, $\frac{ID_1 - T}{2} \rightarrow 0$, where the toroidal outer light guide 411 has inner diameter ID_1.

It is noted again that in the example luminaire 400, the luminaire modules 410 and 420 have like configuration, however, in other implementations, different luminaire modules may have different configurations. For example, in other implementations, the luminaire module 420 from example luminaire 400 may be replaced with either a bulb-like-shaped luminaire module, a planar diskshaped luminaire module, or other-shaped luminaire module to provide another example luminaire.

FIGs. 5-9 show further example luminaires according to the present technology.

FIG. 5 shows an example luminaire 500 configured as a pendant for suspension from a ceiling, plenum or other support structure. The luminaire 500 includes two nested luminaire modules 510, 520 arranged in like directions. Here, the luminaire modules 510, 520 are arranged in a concentric manner like the luminaire modules 410, 420 described above. The luminaire 500 further includes a housing 580 which encapsulates at least a portion of the respective light engines of the luminaire modules 510, 520, and provides support for the respective optical systems of the luminaire modules 510, 520. In this manner, input apertures of the optical systems of the luminaire modules 510, 520 are arranged in the same plane, here parallel to the (x,y)-plane, while output apertures of the optical systems of the luminaire modules 510, 520 are staggered along the z-axis by a predetermined offset Δ. Further in this manner, the light guides of the luminaire modules 510, 520 are spaced apart in the radial direction by a predetermined spacing δ. In this example, a medium between the light guides of the luminaire modules 510, 520 is either an air gap, or a dielectric film having a refractive index smaller than a refractive index of the light guides, or an electrochromic or liquid crystal system, as described below in connection with FIGs. 11A-11B.

Referring again to FIG. 5, the luminaire 500 also includes a reflector 555 supported by the housing 580 and arranged to surround the nested luminaire modules 510, 520. The reflector 555 is shaped to receive light output by each of the nested luminaire modules 510, 520 in a backward direction, and to redirect the received light in a forward direction.

In the example illustrated in FIG. 5, the entire luminaire 500 can be suspended, e.g., from a ceiling, using a rod / cable 582 attached to the housing 580.

FIG. 6 shows another example luminaire 600 configured as a pendant. The luminaire 600 includes two nested luminaire modules 610, 620 arranged in like directions. Here, the luminaire modules 610, 620 are arranged in a concentric manner like the luminaire modules 410, 420 or 510, 520 described above. The luminaire 600 further includes a housing 680 which encapsulates at least a portion of the respective light engines of the luminaire modules 610, 620, and provides support for the respective optical systems of the luminaire modules 610, 620. In this manner, input apertures of the optical systems of the luminaire modules 610, 620 are arranged in the same plane, here parallel to the (x,y)-plane, while output apertures of the optical systems of the luminaire modules 610, 620 are staggered along the z-axis by a predetermined offset Δ. Further in this manner, the light guides of the luminaire modules 610, 620 are spaced apart in the radial direction by a predetermined spacing δ. In this example, a medium between the light guides of the luminaire modules 610, 620 is either an air gap, or a dielectric film having a refractive index smaller than a refractive index of the light guides, or an electrochromic or liquid crystal system, as described below in connection with FIGs. 11A-11B.

Referring again to FIG. 6, the luminaire 600 also includes a reflector 655 arranged to surround the nested luminaire modules 610, 620. The reflector 655 is shaped to receive light output by each of the nested luminaire modules 610, 620 in a backward direction, and to redirect the received light in a forward direction.

In the example illustrated in FIG. 6, the entire luminaire 600 can be suspended, e.g., from a ceiling, by attaching the housing 680 using a first rod / cable 682, and the reflector 655 using additional rods / cables 684.

FIG. 7 shows an example luminaire 700 configured that can be partially recessed or flush mounted on a support surface. The luminaire 700 includes two nested luminaire modules 710, 720 arranged in like directions. Here, the luminaire modules 710, 720 are arranged in a concentric manner like the luminaire modules 410, 420 or 510, 520, or 610, 620 described above. The luminaire 700 further includes a housing 780 which encapsulates at least a portion of the respective light engines of the luminaire modules 710, 720, and provides support for the respective optical systems of the luminaire modules 710, 720. In this manner, input apertures of the optical systems of the luminaire modules 710, 720 are arranged in the same plane, here parallel to the (x,y)-plane, while output apertures of the optical systems of the luminaire modules 710, 720 are staggered along the z-axis by a predetermined offset Δ. Further in this manner, the light guides of the luminaire modules 710, 720 are spaced apart in the radial direction by a predetermined spacing δ. In this example, a medium between the light guides of the luminaire modules 710, 720 is either an air gap, or a dielectric film having a refractive index smaller than a refractive index of the light guides.

The luminaire 700 also includes a reflector 755, e.g., of a ceiling 709, and arranged to surround the nested luminaire modules 710, 720. The reflector 755 can be shaped to receive light output by luminaire module 710, luminaire module 720, or both luminaire modules 710 and 720, and to redirect the received light in a forward direction. Any remaining light that is output from the luminaire modules 710 and 720 can be used for indirect illumination, for example to provide diffuse lighting to a space under the luminaire 700 from the surrounding ceiling 709.

FIG. 8 shows yet another example luminaire 800 configured as a pendant. The luminaire 800 includes two nested luminaire modules 810, 820 arranged in like directions. Here, the luminaire modules 810, 820 are arranged in a concentric manner like the luminaire modules 410, 420 or 510, 520, or 610, 620 or 710, 720 described above. The luminaire 800 further includes a housing 880 which encapsulates at least a portion of the respective light engines of the luminaire modules 810, 820, and provides support for the respective optical systems of the luminaire modules 810, 820. In this manner, input apertures of the optical systems of the luminaire modules 810, 820 are arranged in the same plane, here parallel to the (x,y)-plane, while output apertures of the optical systems of the luminaire modules 810, 820 are staggered along the z-axis by a predetermined offset Δ. Further in this manner, the light guides of the luminaire modules 810, 820 are spaced apart in the radial direction by a predetermined spacing δ. In this example, the light guides of the luminaire modules 810, 820 are separated by an air gap.

The luminaire 800 also includes a reflector 855 supported by the housing 880 and arranged to surround the nested luminaire modules 810, 820. The reflector 855 is shaped to receive light output by each of the nested luminaire modules 810, 820 in a backward direction, and to redirect the received light in a forward direction.

In the example illustrated in FIG. 8, the entire luminaire 800 can be suspended, e.g., from a ceiling, using a rod / cable 882 attached to the housing 880.

FIG. 9 shows yet another example luminaire 900 configured as a pendant. The luminaire 900 includes two nested luminaire modules 910, 920 arranged in like directions. Here, the luminaire modules 910, 920 are arranged in a concentric manner like the luminaire modules 410, 420 or 510, 520, or 610, 620 or 710, 720 or 810, 820 described above. The luminaire 900 further includes a housing 980 which encapsulates at least a portion of the respective light engines of the luminaire modules 910, 920, and provides support for the respective optical systems of the luminaire modules 910, 920. In this manner, input apertures of the optical systems of the luminaire modules 910, 920 are arranged in the same plane, here parallel to the (x,y)-plane, while output apertures of the optical systems of the luminaire modules 910, 920 are staggered along the z-axis by a predetermined offset Δ. Further in this manner, the light guides of the luminaire modules 910, 920 are spaced apart in the radial direction by a predetermined spacing δ. In this example, the light guides of the luminaire modules 910, 920 are separated by an air gap.

The luminaire 900 also includes a pair of reflectors 955, 957. The first reflector 955 is supported by the housing 980 and is arranged to surround the first luminaire module 910. The first reflector 955 is shaped to receive light output by the first luminaire module 910 in a backward direction, and to redirect the received light in a forward direction. The second reflector 957 is supported by the housing 980 and is arranged to surround the second luminaire module 920. As shown in FIG. 9, the second reflector 957 is disposed above the output apertures of the optical system of the second luminaire module 920, but below the output apertures of the optical system of the first luminaire module 910. Also, the second reflector 957 is shaped to receive light output by the second luminaire module 920 in a backward direction, and to redirect the received light in a forward direction.

In the example illustrated in FIG. 9, the entire luminaire 900 can be suspended, e.g., from a ceiling, using a rod / cable 982 attached to the housing 980.

Furthermore, some implementations of luminaire modules can be sized and configured to replace various traditional light bulb formats and be provided with suitable sockets for use in respective luminaires.

Depending on the implementation, luminaire modules can include multiple curvilinear or straight linear segments of light guides, extractors, couplers or other components or combinations thereof. In some implementations, whole luminaire modules may be segmented, in other implementations some but not all components may be segmented. For example, a luminaire module may include multiple light guide segments coupled with one contiguous extractor.

Luminaire modules can include curvilinear segments, straight linear segments or both. Such segments can be arranged abutting or with interspersed gaps between them in open shapes or in loops. Different gaps can have different widths. Gaps between adjacent segments can have constant or varying width depending on radius or position along an axis of symmetry of the respective luminaire.

Segments can have curvilinear, polygonal or other cross sections with parallel or oblique extensions relative to an axis of the luminaire to provide general cylindrical shapes. Such shapes can be straight or undulating along their extension. For example, luminaire module segments can include generalized cylindrical shapes (prismatic bodies) with trapezoidal or curvilinear arced sections perpendicular to the z-direction, straight circular cylinders, oblique undulating cylinders (prisms) with polygonal cross sections or other segments of other shapes. Segments can be arranged in symmetrical or asymmetrical manners and/or at like or different distances from a reference axis. Multiple segments may be optically coupled with one and the same light engine or they may have their own individual light engines. Corresponding luminaires may have up to as many light engines as there are luminaire module segments.

The luminaire modules used in the luminaires 100, 200, 400, 500, 600, 700, 800, 900 can be implemented in manners similar to the following luminaire modules.

Referring to FIG. 10A, in which a Cartesian coordinate system is shown for reference, a luminaire module 1000 includes a mount 1005 (also referred to as a substrate) having a plurality of LEEs 1010 distributed along a first surface of the mount. The mount 1005 with the LEEs 1010 is disposed at a first (e.g., upper) edge 1031a of a light guide 1030. Once again, the positive z-direction is referred to as the "forward" direction and the negative z-direction is the "backward" direction. Sections through the luminaire module 1000 parallel to the x-z plane are referred to as the "cross-section" or "cross-sectional plane" of the luminaire module. Also, luminaire module 1000 extends along the y-direction, so this direction is referred to as the "longitudinal" direction of the luminaire module. Implementations of luminaire modules can have a plane of symmetry parallel to the y-z plane, be curved or otherwise shaped. This is referred to as the "symmetry plane" of the luminaire module. Referring now to both FIGs. 10A and 10B, multiple LEEs 1010 are disposed on the first surface of the mount 1005. For example, the plurality of LEEs 1010 can include multiple white

LEDs. The LEEs 1010 are optically coupled with one or more optical couplers 1020. An optical extractor 1040 is disposed at second (e.g., lower) edge 1031b of light guide 1030.

Mount 1005, light guide 1030, and optical extractor 1040 extend a length L along the y-direction, so that the luminaire module is an elongated luminaire module with an elongation of L that may be about parallel to a wall of a room (e.g., a ceiling of the room). Generally, L can vary as desired. Typically, L is in a range from about 1 cm to about 200 cm (e.g., 20 cm or more, 30 cm or more, 40 cm or more, 50 cm or more, 60 cm or more, 70 cm or more, 80 cm or more, 100 cm or more, 125 cm or more, or, 150 cm or more).

The number of LEEs 1010 on the mount 1005 will generally depend, *inter alia*, on the length L, where more LEEs are used for longer luminaire modules. In some implementations, the plurality of LEEs 1010 can include between 10 and 1,000 LEEs (e.g., about 50 LEEs, about 100 LEEs, about 200 LEEs, about 500 LEEs). Generally, the density of LEEs (e.g., number of LEEs per unit length) will also depend on the nominal power of the LEEs and illuminance desired from the luminaire module. For example, a relatively high density of LEEs can be used in applications where high illuminance is desired or where low power LEEs are used. In some implementations, the luminaire module 1000 has LEE density along its length of 0.1 LEE per centimeter or more (e.g., 0.2 per centimeter or more, 0.5 per centimeter or more, 1 per centimeter or more, 2 per centimeter or more). The density of LEEs may also be based on a desired amount of mixing of light emitted by the multiple LEEs. In implementations, LEEs can be evenly spaced along the length, L, of the luminaire module. In some implementations, a heat-sink 1012 can be attached to the mount 1005 to extract heat emitted by the plurality of LEEs 1010, e.g., as illustrated in FIG. 10A. The heat-sink 1012 can be disposed on a surface of the mount 1005 opposing the side of the mount 1005 on which the LEEs 1010 are disposed. The luminaire module 1000 can include one or multiple types of LEEs, for example one or more subsets of LEEs in which each subset can have different color or color temperature.

Referring again to both FIGs. 10A and 10B, in some implementations, optical coupler 1020 includes one or more solid pieces of transparent optical material (e.g., a glass material or a transparent organic plastic, such as polycarbonate or acrylic). Here, the LEEs 1010 are optically coupled with the optical coupler 1020 through respective input apertures such as multiple discrete indentations 1024 of the one or more solid pieces of transparent optical material, the indentations 1024 being distributed along the y-axis. In other implementations, optical coupler 1020 includes one or more hollow reflectors. Here, the LEEs 1010 are optically coupled with the optical coupler 1020 through respective openings 1024 the one or more hollow reflectors, the openings 1024 being distributed along the y-axis. In the example implementation illustrated in FIG. 10C, the LEEs 1010 are spaced apart from the optical coupler 1020, such that the light emitted by the LEEs 1010 is provided to the optical coupler 1020 through multiple optical fibers 1028. Here, a respective output tip of each of the optical fibers 1028 delivers light emitted by the LEEs 1010 to a respective indentation 1024 of each of the solid pieces of transparent optical material of the optical coupler 1020 or a respective opening 1024 of each of the hollow reflectors of the optical coupler 1020. In some implementations, the multiple discrete indentations 1024 may be replaced with one contiguous indentation extending along the y-direction.

Referring now to all of FIGs. 10A-10C, each of the pieces of transparent optical material of the optical coupler 1020 or each of the hollow reflectors of the optical coupler 1020 has surfaces 1021 and 1022 positioned to reflect light from the LEEs 1010 towards the light guide 1030. In general, surfaces 1021 and 1022 are shaped to collect and at least partially collimate light emitted from the LEEs. In the x-z cross-sectional plane, surfaces 1021 and 1022 can be straight or curved. Examples of curved surfaces include surfaces having a constant radius of curvature, parabolic or hyperbolic shapes. In some implementations, surfaces 1021 and 1022 are coated with a highly reflective material (e.g., a reflective metal, such as aluminum or silver), to provide a highly reflective optical interface. The cross-sectional profile of optical coupler 1020 can be uniform along the length L of luminaire module 1000. Alternatively, the cross-sectional profile can vary. For example, surfaces 1021 and/or 1022 can be curved out of the x-z plane.

The exit aperture of the optical coupler 1020 adjacent upper edge of light guide 1031a is optically coupled to edge 1031a to facilitate efficient coupling of light from the optical coupler 1020 into light guide 1030. For example, the surfaces of a solid coupler and a solid light guide can be attached using a material that substantially matches the refractive index of the material forming the optical coupler 1020 or light guide 1030 or both (e.g., refractive indices across the interface are different by 2% or less.) The optical coupler 1020 can be affixed to light guide 1030 using an index matching fluid, grease, or adhesive. In some implementations, optical coupler 1020 is fused to light guide

1030 or they are integrally formed from a single piece of material (e.g., coupler and light guide may be monolithic and may be made of a solid transparent optical material).

FIGs. 10D and 10E show portions of a luminaire module, like the luminaire module 1000, in which the LEEs 1010 are optically coupled directly to the light guide 1030, i.e., without using an optical coupler like the optical coupler(s) 1020. Here, the receiving end 1031a of the light guide 1030 has multiple indentations 1034 distributed along the y-axis. For example, in the implementation shown in FIG. 10D, the mount 1005 is mechanically coupled with the receiving end 1031a of the light guide 1030. In this manner, the LEEs 1010 are optically coupled with the light guide 1030 through respective indentations 1034 of the receiving end 1031a of the light guide 1030. As another example, in the implementation shown in FIG. 10E, the LEEs 1010 are spaced apart from the light guide 1030, such that the light emitted by the LEEs 1010 is provided to the receiving end 1031a of the light guide 1030 through multiple optical fibers 1028. Here, a respective output tip of each of the optical fibers 1028 delivers light emitted by the LEEs 1010 to a respective indentation 1034 of the receiving end 1031a of the light guide 1030.

Referring again to FIG. 10A, light guide 1030 is formed from a piece of transparent material (e.g., glass material such as BK7, fused silica or quartz glass, or a transparent organic plastic, such as polycarbonate or acrylic) that can be the same or different from the material forming optical couplers 1020.

The example light guide 1030 of FIG. 10A extends over a length L in the y-direction, has a uniform thickness T in the x-direction, and a uniform depth D in the z-direction. The dimensions D and T are generally selected based on the desired optical properties of the light guide (e.g., which spatial modes are supported) and/or the direct/indirect intensity distribution. During operation, light coupled into the light guide 1030 from optical coupler 1020 (with an angular range 135) reflects off the planar surfaces of the light guide by TIR and spatially mixes within the light guide. The mixing can help achieve illuminance and/or color uniformity, along the y-axis, at the distal portion 1031b of the light guide at optical extractor 1040. The depth, D, of light guide 1030 can be selected to achieve adequate uniformity at the exit aperture (i.e., at end 1031b) of the light guide. In some implementations, D is in a range from about 1 cm to about 20 cm (e.g., 2 cm or more, 4 cm or more, 6 cm or more, 8 cm or more, 10 cm or more, 12 cm or more).

In general, optical couplers 1020 are designed to restrict the angular range of light entering the light guide 1030 (e.g., to within +/-40 degrees) so that at least a substantial amount of the light (e.g., 95% or more of the light) is optically coupled into spatial modes in the light guide 1030 that undergoes TIR at the planar surfaces. Light guide 1030 can have a uniform thickness T, which is the distance separating two planar opposing surfaces 1032a, 1032b of the light guide. Generally, T is sufficiently large so the light guide has an aperture at first (e.g., upper) surface 1031a sufficiently large to approximately match (or exceed) the exit aperture of optical coupler 1020. In some implementations, T is in a range from about 0.05 cm to about 2 cm (e.g., about 0.1 cm or more, about 0.2 cm or more, about 0.5 cm or more, about 0.8 cm or more, about 1 cm or more, about 1.5 cm or more). Depending on the implementation, the narrower the light guide the better it may spatially mix light. A narrow light guide also provides a narrow exit aperture. As such light emitted from the light guide can be considered to resemble the light emitted from a one-dimensional linear light source, also referred to as an elongate virtual filament.

Optical extractor 1040 is also composed of a solid piece of transparent optical material (e.g., a glass material or a transparent organic plastic, such as polycarbonate or acrylic) that can be the same as or different from the material forming light guide 1030. In the example implementation shown in FIG. 10A, the optical extractor 1040 includes redirecting (e.g., flat) surfaces 1042 and 1044 and curved surfaces 1046 and 1048. The flat surfaces 1042 and 1044 represent first and second portions of a redirecting surface 1043, while the curved surfaces 1046 and 1048 represent first and second output surfaces of the luminaire module 1000.

Surfaces 1042 and 1044 are coated with a reflective material (e.g., a highly reflective metal such as aluminum or silver) over which a protective coating may be disposed. For example, the material forming such a coating may reflect about 95% or more of light incident thereon at appropriate (e.g., visible) wavelengths. Here, surfaces 1042 and 1044 provide a highly reflective optical interface for light having the angular range 135 entering an input end of the optical extractor 1032' from light guide 1030. As another example, the surfaces 1042 and 1044 include portions that are transparent to the light entering at the input end 1032' of the optical extractor 1040. Here, these portions can be uncoated regions (e.g., partially silvered regions) or discontinuities (e.g., slots, slits, apertures) of the surfaces 1042 and 1044. As such, some light is transmitted in the forward direction (along the z-axis) through surfaces 1042 and 1044 of the optical extractor 1040 in an output angular range 145'''. In some cases, the light transmitted in the output angular range is refracted. In this way, the redirecting surface 1043 acts as a beam splitter rather than a mirror, and transmits in the output angular range 145''' a desired portion of incident light, while reflecting the remaining light in angular ranges 138 and 138'.

In the x-z cross-sectional plane, the lines corresponding to surfaces 1042 and 1044 have the same length and form an apex or vertex 1041, e.g. a v-shape that meets at the apex 1041. In general, an included angle (e.g., the smallest included angle between the surfaces 1044 and 1042) of the redirecting surfaces 1042, 1044 can vary as desired. For example, in some implementations, the included angle can be relatively small (e.g., from 30° to 60°). In certain implementations, the included angle is in a range from 60° to 120° (e.g., about 90°). The included angle can also be relatively large (e.g., in a range from 120° to 150° or more). In the example implementation shown in FIG. 10A, the output surfaces 1046, 1048 of the optical extractor 1040 are curved with a constant radius of curvature that is the same for both. In an aspect, the output surfaces 1046, 1048 may have optical power (e.g., may focus or defocus light.) Accordingly, luminaire module 1000 has a plane of symmetry intersecting apex 1041 parallel to the y-z plane.

The surface of optical extractor 1040 adjacent to the lower edge 1031b of light guide 1030 is optically coupled to the input end 1032' of the optical extractor. For example, optical extractor 1040 can be affixed to light guide 1030 using an index matching fluid, grease, or adhesive. In some implementations, optical extractor 1040 is fused to light guide 1030 or they are integrally formed from a single piece of material.

The emission spectrum of the luminaire module 1000 corresponds to the emission spectrum of the LEEs 1010. However, in some implementations, a wavelength-conversion material may be positioned in the luminaire module, for example remote from the LEEs, so that the wavelength spectrum of the luminaire module is dependent both on the emission spectrum of the LEEs and the composition of the wavelength-conversion material. In general, a wavelength-conversion material can be placed in a variety of different locations in luminaire module 1000. For example, a wavelength-conversion material may be disposed proximate the LEEs 1010, on the input aperture of couplers 1020 or on the input aperture of the light guide 1031a, adjacent to the redirecting surfaces 1042 and 1044 of optical extractor 1040, on the exit surfaces 1046 and 1048 of optical extractor 1040, and/or at other locations.

The layer of wavelength-conversion material (e.g., phosphor) may be attached to light guide 1030 held in place via a suitable support structure (not illustrated), disposed within the extractor (also not illustrated) or otherwise arranged, for example. Wavelength-conversion material that is disposed within the extractor may be configured as a shell or other object and disposed within a notional area that is circumscribed between R/n and $R^*(1+n^2)^{(-1/2)}$, where R is the radius of curvature of the light-exit surfaces (1046 and 1048 in FIG. 10A) of the extractor 1040 and n is the index of refraction of the portion of the extractor that is opposite of the wavelength-conversion material as viewed from the reflective surfaces (1042 and 1044 in FIG. 10A). The support structure may be a transparent self-supporting structure. The wavelength-conversion material diffuses light as it converts the wavelengths, provides mixing of the light and can help uniformly illuminate a surface of the ambient environment.

During operation, light exiting light guide 1030 through end 1031b impinges on the reflective interfaces at portions of the redirecting surface 1042 and 1044 and is reflected outwardly towards output surfaces 1046 and 1048, respectively, away from the symmetry plane of the luminaire module. The first portion of the redirecting surface 1042 provides light having an angular distribution 138 towards the output surface 1046, the second portion of the redirecting surface 1044 provides light having an angular distribution 138' towards the output surface 1046. The light exits optical extractor through output surfaces 1046 and 1048. In general, the output surfaces 1046 and 1048 have optical power, to redirect the light exiting the optical extractor 1040 in angular ranges 145' and 145", respectively. For example, optical extractor 1040 may be configured to emit light upwards (i.e., towards the plane intersecting the LEEs and parallel to the x-y plane), downwards (i.e., away from that plane) or both upwards and downwards. In general, the direction of light exiting the luminaire module through surfaces 1046 and 1048 depends on the divergence of the light exiting light guide 1030 and the orientation of surfaces 1042 and 1044.

Surfaces 1042 and 1044 may be oriented so that little or no light is output by optical extractor 1040 in forward, backward or forward and backward directions. In implementations where the luminaire module 1000 is attached to a ceiling of a room (e.g., the forward direction is towards the floor) such configurations can help avoid glare and an appearance of non-uniform illuminance.

In general, the light intensity distribution provided by luminaire module 1000 reflects the symmetry of the luminaire module’s structure about the y-z plane. For example, referring to FIG. 3, light output in angular range 145" corresponds to the first output lobe 1145a of the far-field light intensity distribution 399, light output in angular range 145' corresponds to the second output lobe 1245b of the far-field light intensity distribution 399 and light output (leaked) in angular range 145"' corresponds to the third output lobe 1245c of the far-field light intensity distribution 399. In general, an intensity profile of luminaire module 1000 will depend on the configuration of the optical coupler 1020, the light guide 1030 and the optical extractor 1040. For instance, the interplay between the shape of the optical coupler 1020, the shape of the redirecting surface 1043 of the optical extractor 1040 and the shapes of the output surfaces 1046, 1048 of the optical extractor 1040 can be used to control the angular width and prevalent direction (orientation) of the output first 1245a and second 1245b lobes in the far-field light intensity profile 399. Additionally, a ratio of an amount of light in the combination of first 1245a and second 1245b output lobes and light in the third output lobe 1245c is controlled by reflectivity and transmissivity of the redirecting surfaces 1042 and 1044. For example, for a reflectivity of 90% and transmissivity of 10% of the redirecting surfaces 1042, 1044, 45% of light can be output in the output angular range 145" corresponding to the first output lobe 1245a, 45% light can be output in the output angular range 145' corresponding to the second output lobe 1245b, and 10% of light can be output in the output angular range 145"' corresponding to the third output lobe 1245c.

In some implementations, the orientation of the output lobes 1245a, 1245b can be adjusted based on the included angle of the v-shaped groove 1041 formed by the portions of the redirecting surface 1042 and 1044. For example, a first included angle results in a far-field light intensity distribution 399 with output lobes 1245a, 1245b located at relatively smaller angles compared to output lobes 1245a, 1245b of the far-field light intensity distribution 399 that results for a second included angle larger than the first angle. In this manner, light can be extracted from the luminaire module 1000 in a more forward direction for the smaller of two included angles formed by the portions 1042, 1044 of the redirecting surface 1043.

Furthermore, while surfaces 1042 and 1044 are depicted as planar surfaces, other shapes are also possible. For example, these surfaces can be curved or faceted. Curved redirecting surfaces 1042 and 1044 can be used to narrow or widen the output lobes 1245a, 1245b. Depending of the divergence of the angular range 135 of the light that is received at the input end 1032' of the optical extractor, concave reflective surfaces 1042, 1044 can narrow the lobes 1245a, 1245b output by the optical extractor 1040 (and illustrated in FIG. 3), while convex reflective surfaces 1042, 1044 can widen the lobes 1245a, 1245b output by the optical extractor 1040. As such, suitably configured redirecting surfaces 1042, 1044 may introduce convergence or divergence into the light. Such surfaces can have a constant radius of curvature, can be parabolic, hyperbolic, or have some other curvature.

In general, the geometry of the elements can be established using a variety of methods. For example, the geometry can be established empirically. Alternatively, or additionally, the geometry can be established using optical simulation software, such as Lighttools^{TM}, Tracepro^{TM}, FRED^{TM} or Zemax^{TM}, for example.

In general, luminaire module 1000 can be designed to output light into different output angular ranges 145", 145' from those shown in FIG. 10A. In some implementations, luminaire modules can output light into lobes 1245a, 1245b that have a different divergence or propagation direction than those shown in FIG. 3. For example, in general, the output lobes 1245a, 1245b can have a width of up to about 90° (e.g., 80° or less, 70° or less, 60° or less, 50° or less, 40° or less, 30° or less, 20° or less). In general, the direction in which the output lobes 1245a, 1245b are oriented can also differ from the directions shown in FIG. 3. The “direction” refers to the direction at which a lobe is brightest. In FIG. 3, for example, the output lobes 1245a, 1245b are oriented at approx. -130° and approximately +130°. In general, output lobes 1245a, 1245b can be directed more towards the horizontal (e.g., at an angle in the ranges from -90° to -135°, such as at approx. -90°, approx. -100°, approx. -110°, approx. -120°, approx. -130°, and from +90° to +135°, such as at approx. +90°, approx. +100°, approx. +110°, approx. +120°, approx. +130°.

The luminaire modules can include other features useful for tailoring the intensity profile. For example, in some implementations, luminaire modules can include diffuse refractive or reflective interfaces, for example, an optically diffuse material that can diffuse light in a controlled manner to aid homogenizing the luminaire module's intensity profile. Furthermore, surfaces 1042 and 1044 can be roughened or a diffusely reflecting material, rather than a specular reflective material, can be coated on these surfaces. Accordingly, the optical interfaces at surfaces 1042 and 1044 can diffusely reflect light, scattering light into broader lobes than would be provided by similar structures utilizing specular reflection at these interfaces. In some implementations these surfaces can include structure that facilitates various intensity distributions. For example, surfaces 1042 and 1044 can each have multiple planar facets at differing orientations. Accordingly, each facet will reflect light into different directions. In some implementations, surfaces 1042 and 1044 can have structure thereon (e.g., structural features that scatter or diffract light).

Surfaces 1046 and 1048 need not be surfaces having a constant radius of curvature. For example, surfaces 1046 and 1048 can include portions having differing curvature and/or can have structure thereon (e.g., structural features that scatter or diffract light). In certain implementations, a light scattering material can be disposed on surfaces 1046 and 1048 of optical extractor 1040.

In some implementations, optical extractor 1040 is structured so that a negligible amount (e.g., less than 1%) of the light propagating within at least one plane (e.g., the x-z cross-sectional plane) that is reflected by surface 1042 or 1044 experiences TIR at light-exit surface 1046 or 1048. For certain spherical or cylindrical structures, a so-called Weierstrass condition can avoid TIR. A Weierstrass condition is described for a circular structure (i.e., a cross section through a cylinder or sphere) having a surface of radius R and a concentric notional circle having a radius R/n, where n is the refractive index of the structure. Any light ray that passes through the notional circle within the cross-sectional plane is incident on surface of the circular structure and has an angle of incidence less than the critical angle and will exit circular structure without experiencing TIR. Light rays propagating within spherical structure in the plane but not emanating from within notional surface can impinge on the surface of radius R at the critical angle or greater angles of incidence. Accordingly, such light may be subject to TIR and won't exit the circular structure. Furthermore, rays of p-polarized light that pass through a notional space circumscribed by an area with a radius of curvature that is smaller than $R/(1+n^2)^{(-1/2)}$, which is smaller than R/n, will be subject to small Fresnel reflection at the surface of radius R when exiting the circular structure. This condition may be referred to as Brewster geometry. Implementations may be configured accordingly.

Referring again to FIG. 10A, in some implementations, all or part of surfaces 1042 and 1044 may be located within a notional Weierstrass surface defined by surfaces 1046 and 1048. For example, the portions of surfaces 1042 and 1044 that receive light exiting light guide 1030 through end 1031b can reside within this surface so that light within the x-z plane reflected from surfaces 1042 and 1044 exits through surfaces 1046 and 1048, respectively, without experiencing TIR.

In the example implementations described above in connection with FIG. 10A, the luminaire module 1000 is configured to output light into output angular ranges 145' and 145". In other implementations, the light guide-based luminaire module 1000 is modified to output light into a single output angular range 145". In FIG. 10F, such light guide-based luminaire module configured to output light on a single side of the light guide is referred to as a single-sided luminaire module and is denoted 1000*. The single-sided luminaire module 1000* is elongated along the y-axis like the luminaire module 1000 shown in FIG. 10A. Also like the luminaire module 1000, the single-sided luminaire module 1000* includes a mount 1005 and LEEs 1010 disposed on a surface of the mount 1005 along the y-axis to emit light in a first angular range. The single-sided luminaire module 1000* further includes optical couplers 1020 arranged and configured to redirect the light emitted by the LEEs 1010 in the first angular range into a second angular range 135 that has a divergence smaller than the divergence of the first angular range at least in the x-z cross-section. Also, the single-sided luminaire module 1000* includes a light guide 1030 to guide the light redirected by the optical couplers 1020 in the second angular range 135 from a first end 1031a of the light guide to a second end 1031b of the light guide. Additionally, the single-sided luminaire module 1000* includes a single-sided extractor (denoted 1040') to receive the light guided by the light guide 1030. The single-sided extractor 1040' includes a redirecting surface 1044 to redirect the light received from the light guide 1030 into a third angular range 138', like described for luminaire module 1000 with reference to FIG. 10A, and an output surface 1048 to output the light redirected by the redirecting surface 1044 in the third angular range 138' into a fourth angular range 145".

A light intensity profile of the single-sided luminaire module 1000* is represented in FIG. 3 as a single output lobe 1245a. The single output lobe 1245a corresponds to light output by the single-sided luminaire module 1000* in the fourth angular range 145”.

As noted above, some of the disclosed luminaires, e.g., 100, 200, 400, 500, or 600, can include a space between the couplers and/or light guides. This space can be filled with a medium configured to control the amount of light mixing between adjacent light guides during operation or manufacture of luminaires.

FIG. 11A is a cross sectional view of a portion of a luminaire 1100 with two independently controllable sets 1112, 1114 of LEEs and corresponding light guides 1130, 1132 and an electronically controllable fluid 1150 between the light guides 1130, 1132. The sets 1112, 1114 of LEEs can be distributed in respective rows along the y-axis (perpendicular to the page) on a substrate 1110. The electronically controllable fluid 1150 can be enclosed by the light guides 1130, 1132, a dam 1111 and an optical extractor (not shown in Figure 11A, e.g., 112, 212, 412) coupled with the shorter, along the z-axis, of the light guides 1130, 1132. In some implementations, the portion of the luminaire 1100 illustrated in Figure 11A can be used as part of any one of the luminaires 100, 200, 400, 500, 600, for instance.

The electronically controllable fluid 1150 can be manipulated, via electrowetting or other effects, for example. Electrowetting can be used to control where the light guides 1130, 1132 establish contact with the electronically controllable fluid 1150 (e.g., by electronic movement of the electronically adjustable fluid between the dam 1111 and the noted optical extractor.) A transparent electronically controllable fluid 1150 can be used to bridge the space between the light guides at one or more (not illustrated) contact locations and as such frustrate total internal reflection at the contact locations to allow light to cross between the light guides 1130 and 1132. Depending on the embodiment, contact locations may be enabled and disabled by electronically concentrating the fluid 1150 between and moving it along the light guides. Suitable electronic control can be used to determine areas where the fluid 1150 can establish contact with the light guides. In some embodiments, the electronically controllable fluid 1150 may have certain diffusive properties to help mix light within each of the light guides, or cause leakage of light out of the corresponding light guide, for example. Here, light that diffusely reflects off the boundary surface 1151 or 1152 between each of the light guides and the electronically controllable fluid 1150 may emerge into the environment through lateral surfaces 1153 or 1154 of the light guides opposite to the boundary surface 1151 or 1152.

Depending on the embodiment, the electrowetting can be controlled via an electromagnetic field applied between one or more portions of the light guides 1130 and 1132 via suitably disposed pairs of electrodes (not illustrated), in order to control surface charges at the interfaces between the light guides 1130 and/or 1132, for example.

In some implementations, all or parts of the space between the light guides can be filled with a transparent or partly translucent material during manufacturing that can create a controlled optical coupling between adjacent light guides. Such material can be curable and the process can be employed to establish a certain degree of mixing between the light guides or to create a softly diffused illumination from the light guides, which can provide both effective and aesthetic luminance properties.

In some implementations, a liquid crystal material with switchable diffusion properties can be disposed between adjacent light guides. This material can be provided in a custom cut liquid crystal sheet with electrical contacts through which the liquid crystal sheet can be energized.

FIG. 11B is a cross sectional view of a portion of a luminaire 1160 with two independently controllable sets 1112, 1114 of LEEs adjacent light guides 1130, 1132 and a liquid crystal sheet 1155 disposed between light guides 1130, 1132. The sets 1112, 1114 of LEEs can be distributed in respective rows along the y-axis (perpendicular to the page) on a substrate 1110. The liquid crystal sheet 1155 can be enclosed (as described below) between the light guides 1130 and 1132, over at least a portion of the boundary surfaces 1151, 1152 between the light guides 1130, 1132 and the liquid crystal sheet 1155. In some implementations, the portion of the luminaire 1160 illustrated in Figure 11B can be used as part of any one of the luminaires 100, 200, 400, 500, 600, for instance.

When electrical current is applied to the liquid crystal sheet 1155, the crystals align and the liquid crystal sheet 1155 becomes substantially transparent. When electrical current is turned off, the crystals fall back to a random orientation and the liquid crystal sheet 1155 becomes substantially translucent.

Liquid crystal sheets can provide a mode of light tuning for luminaire 1160. For example, various shapes and sizes of liquid crystal sheets can be laminated between adjacent light guides. When current is applied to one or more of the liquid crystal sheets, the crystals in the liquid crystal sheet are activated and the illumination properties of the luminaire module change. For example, the variable diffusion properties of the liquid crystal sheet can change the ratio of light guided along the z-axis towards the optical extractors (not shown in Figure 11B, e.g., the pairs 112 and 122, 212 and 222, 412 and 422) such that more or less light is emitted from the optical extractors versus from side surfaces 1153 and 1154 of the light guides.

The liquid crystal sheets can be applied in a variety of locations within a luminaire 100, 200, 400, 500, or 600, e.g., beyond the interstitial space between light guides. For example, liquid crystal sheets can be placed on any portion of either of the outer surfaces 1153 and/or 1154 of light guides, in full or partial sheets of various lengths, widths and patterns to create various types of diffuse emission designs on either of the outer surfaces 1153 and/or 1154 of the light guides.

In some implementations, a liquid crystal sheet can be applied on one or more light redirecting surfaces of the optical extractors (not shown in Figure 11B.) In such configurations, the amount of light that is redirected can be electronically controlled to change the respective light distributions that are output by the optical extractor. For example, with respect to FIG. 3, the lobes 1145a, 1245a, and optionally 1245b, 1245c, of the light distribution can be varied by adjusting the reflective properties of the redirecting surfaces of the optical extractor, which allows for additional photometric shaping of the luminaire 100, 200 or 400.

The preceding figures and accompanying description illustrate example methods, systems and devices for illumination. It will be understood that these methods, systems, and devices are for illustration purposes only and that the described or similar techniques may be performed at any appropriate time, including concurrently, individually, or in combination. In addition, many of the steps in these processes may take place simultaneously, concurrently, and/or in different orders than as shown. Moreover, the described methods/devices may use additional steps/parts, fewer steps/parts, and/or different steps/parts, as long as the methods/devices remain appropriate.

In other words, although this disclosure has been described in terms of certain aspects or implementations and generally associated methods, alterations and permutations of these aspects or implementations will be apparent to those skilled in the art. Accordingly, the above description of example implementations does not define or constrain this disclosure. Further implementations are described in the following claims.

What Is Claimed Is:

1. A luminaire comprising:
    a. a first optical system configured to output light having a first output light distribution and a second optical system arranged adjacent the first optical system and configured to output light having a second output light distribution different from the first output light distribution; and
    b. a first light engine optically coupled to an input aperture of the first optical system and a second light engine optically coupled to an input aperture or the second optical system, the first and second light engines configured to allow independent control of amounts of light provided to the first and second optical systems;

    wherein each of the first and second optical systems has an output aperture displaced by a predetermined distance along a forward direction from the corresponding input aperture, and is configured to direct light received at the input aperture to the output aperture, wherein the first and second optical systems have elongate extensions extending sideways from the forward direction.

2. The luminaire of claim 1, wherein the forward direction is perpendicular to the elongate extension.
3. The luminaire of claim 2, wherein the first and second optical systems have concentric annular shapes.
4. The luminaire of claim 3, wherein the annular shapes are circles.
5. The luminaire of claim 3, wherein the annular shapes are polygons.

6. The luminaire of claim 1, wherein first and second light distributions include obtuse angles relative to the forward direction.
7. The luminaire of claim 1, wherein first and second light distributions include acute angles relative to the forward direction.
8. The luminaire of claim 1, wherein the first optical system includes a first light guide extending along a forward direction and the second optical system includes a second light guide extending along the forward direction, wherein the forward direction is perpendicular to the elongate extension, the first and second light guide comprising a solid transparent material.
9. The luminaire of claim 8, wherein the first and second light guide are spaced apart.
10. The luminaire of claim 8, wherein the first and second light guide are separated by a transparent material having a first refractive index smaller than a second refractive index of the solid transparent material of the first and second light guides.
11. The luminaire of claim 1, wherein the first and second optical systems have linear elongate extensions and are arranged in parallel.
12. The luminaire of claim 1, wherein the first and second optical systems have elongate curvilinear extensions perpendicular to the forward direction.
13. The luminaire of claim 12, wherein the luminaire undulates multiple times along the elongate curvilinear extension.
14. The luminaire of claim 1, wherein the first optical system comprises multiple first segments.
15. The luminaire module of claim 14, wherein adjacent ones of the multiple first segments are displaced relative to each other.

16. The luminaire module of claim 14, wherein the second optical system comprises multiple second segments and the first and second segments are interlaced.
17. The luminaire of claim 1, wherein the optical systems are formed as solid transparent bodies.
18. The luminaire of claim 1, wherein the first and second light engines include light-emitting diodes.
19. The luminaire of claim 1, wherein the first and second light engines include exit apertures of optical fibers.
20. The luminaire of claim 1, further comprising a socket and configured in a light bulb format.
21. A lighting system comprising
    a. the luminaire of claim 1; and
    b. a controller operatively coupled with the luminaire and configured to independently control the first and second light engines.
22. The lighting system of claim 21, wherein the controller is configured to vary the amounts of light provided by each of the first and second light engines substantially continuously between a fully OFF and fully ON state.

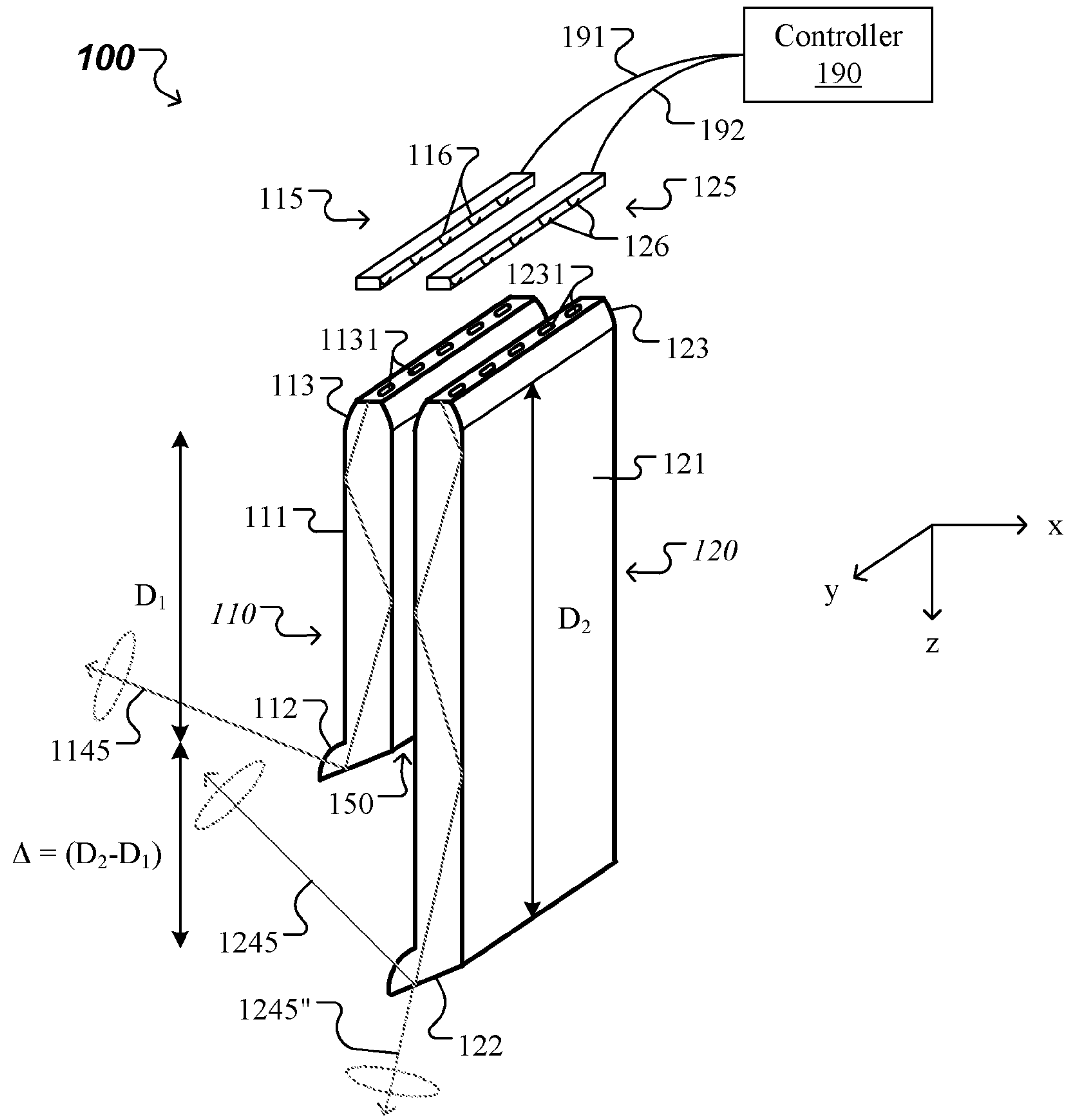
100
Controller
190
191
192
116
115
125
126
1231
1131
123
113
121
111
120
110
D1
D2
x
y
z
112
1145
150
Δ = (D2-D1)
1245
1245"
122

FIG. 1A

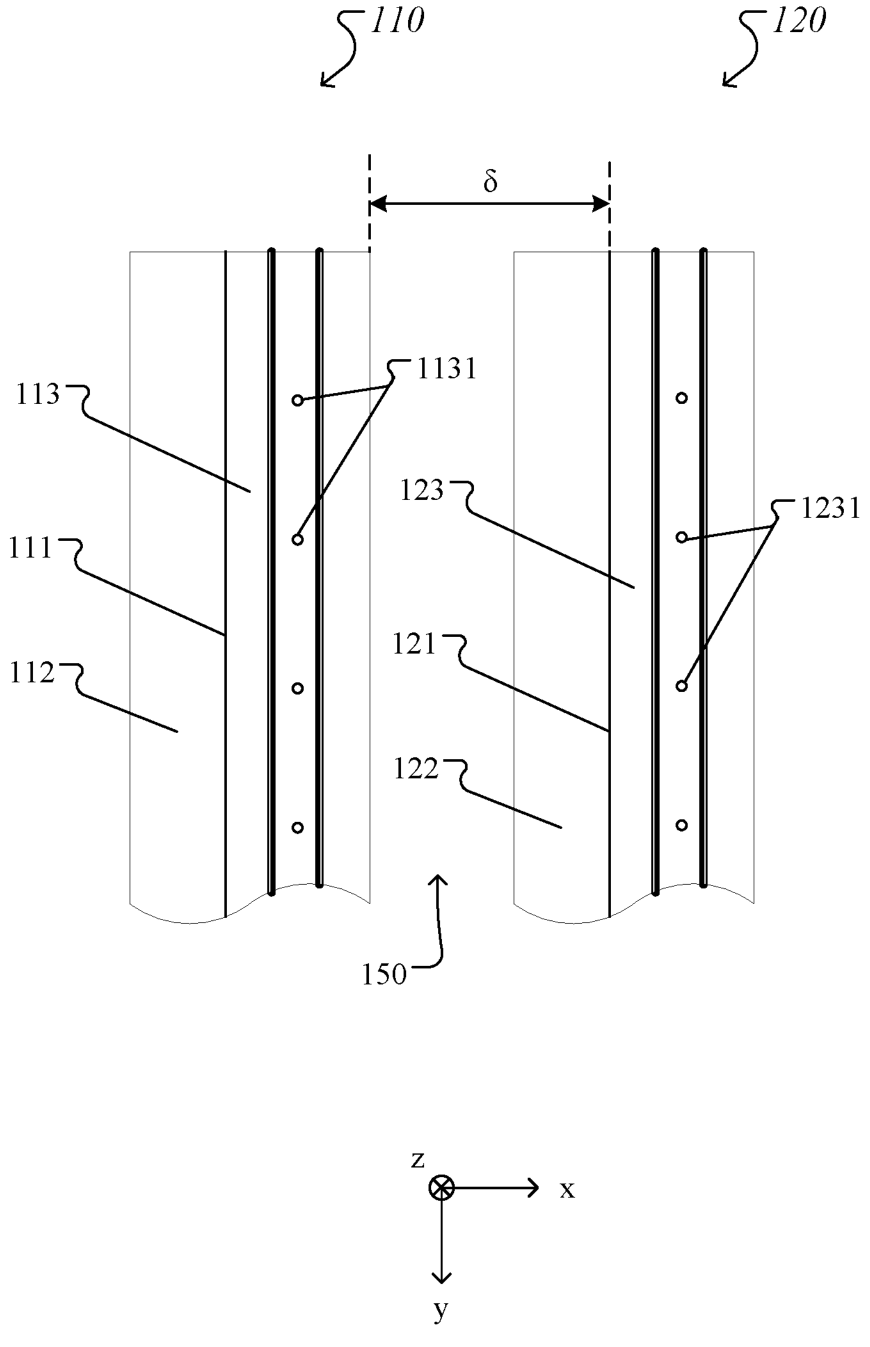

FIG. 1B

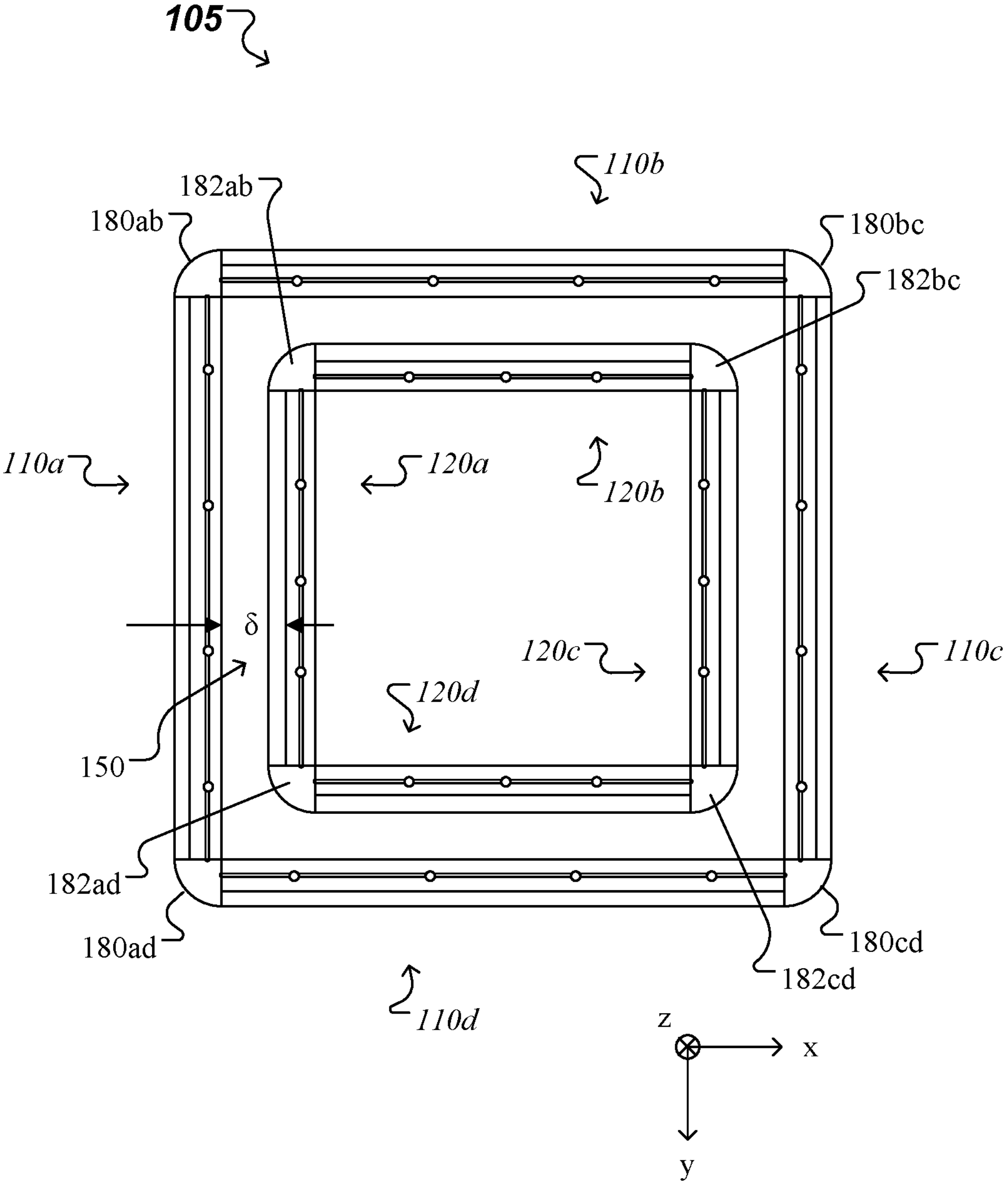
105
110b
182ab
180ab
180bc
182bc
110a
120a
120b
δ
120c
110c
120d
150
182ad
180ad
180cd
182cd
110d
z
x
y

FIG. 1C

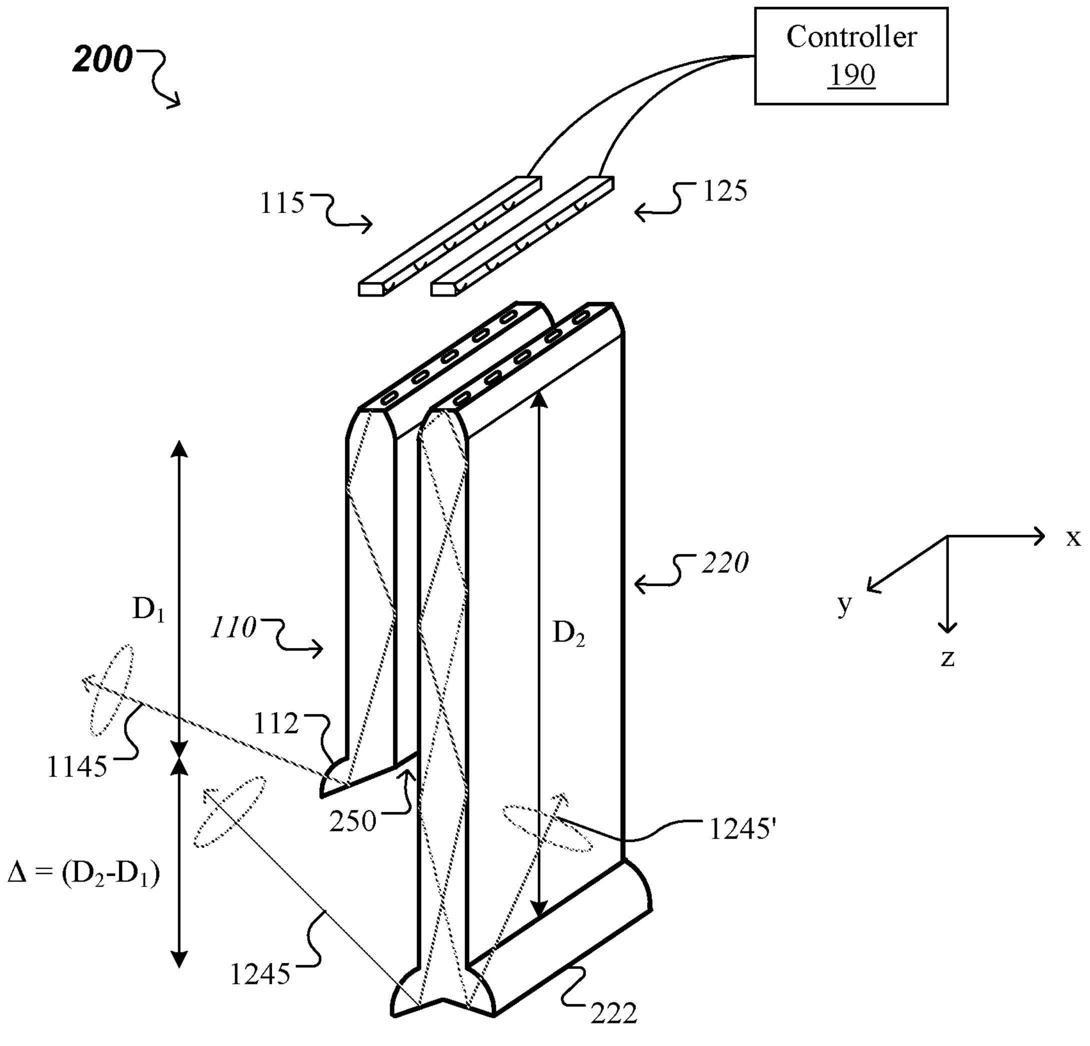
200
Controller
190
115
125
220
110
D_1
D_2
112
1145
250
1245'
$\Delta = (D_2-D_1)$
1245
222
x
y
z

FIG. 2

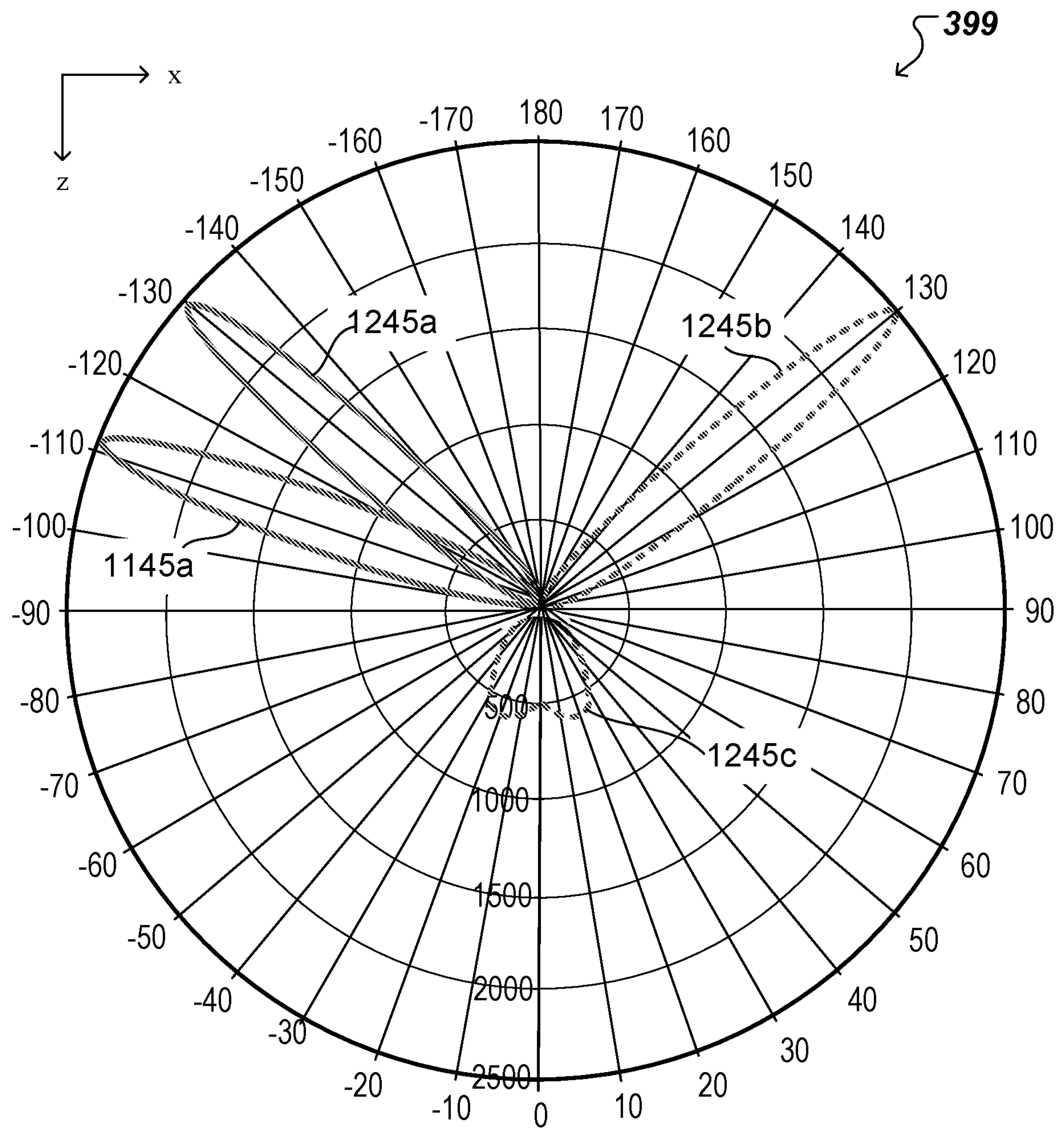
399
x
z
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
500
1000
1500
2000
2500
1245a
1245b
1145a
1245c

FIG. 3

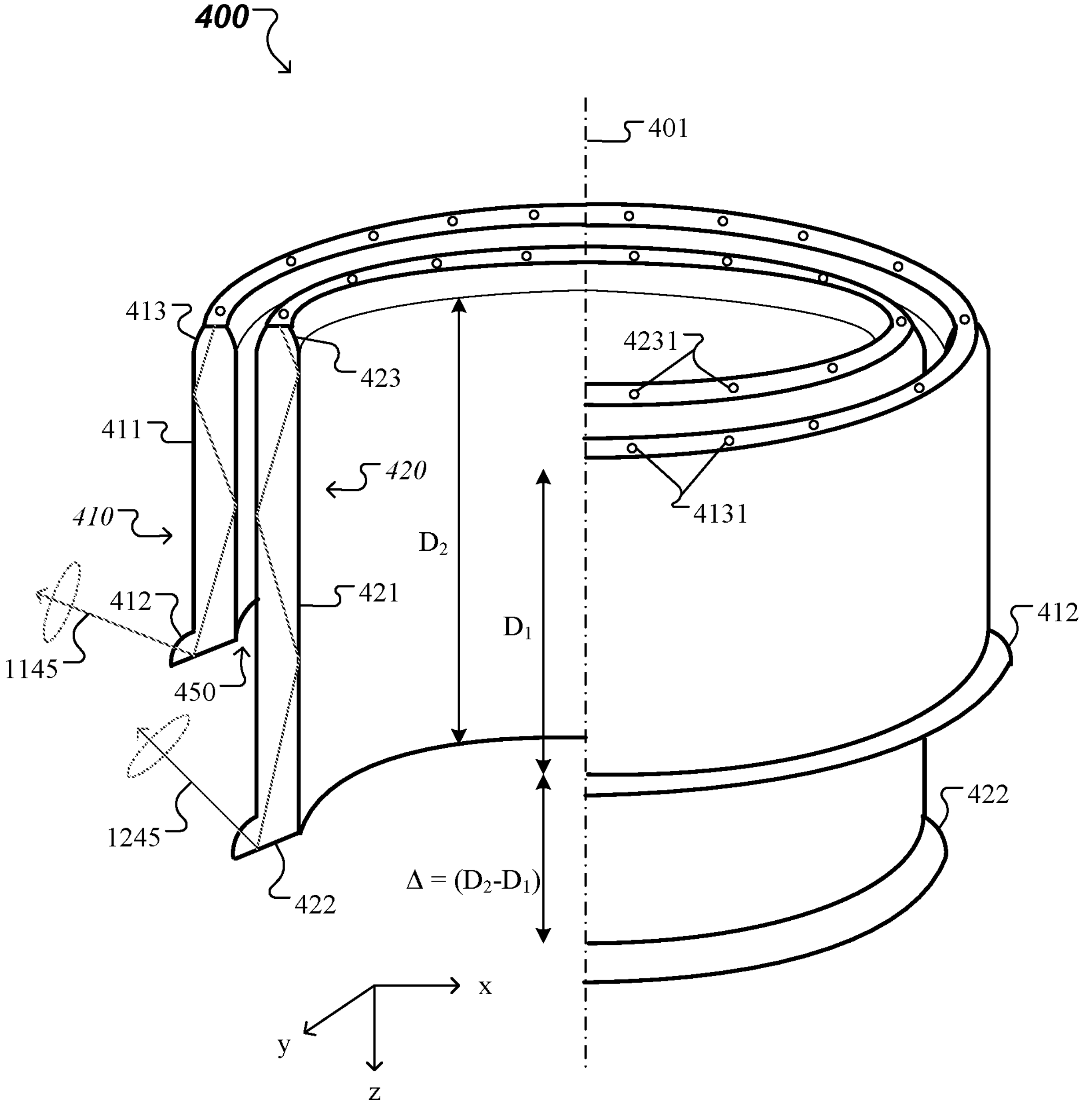
400
401
413
423
4231
411
420
410
4131
D$_2$
412
421
412
1145
D$_1$
450
422
1245
$\Delta = (D_2-D_1)$
422
x
y
z

FIG. 4A

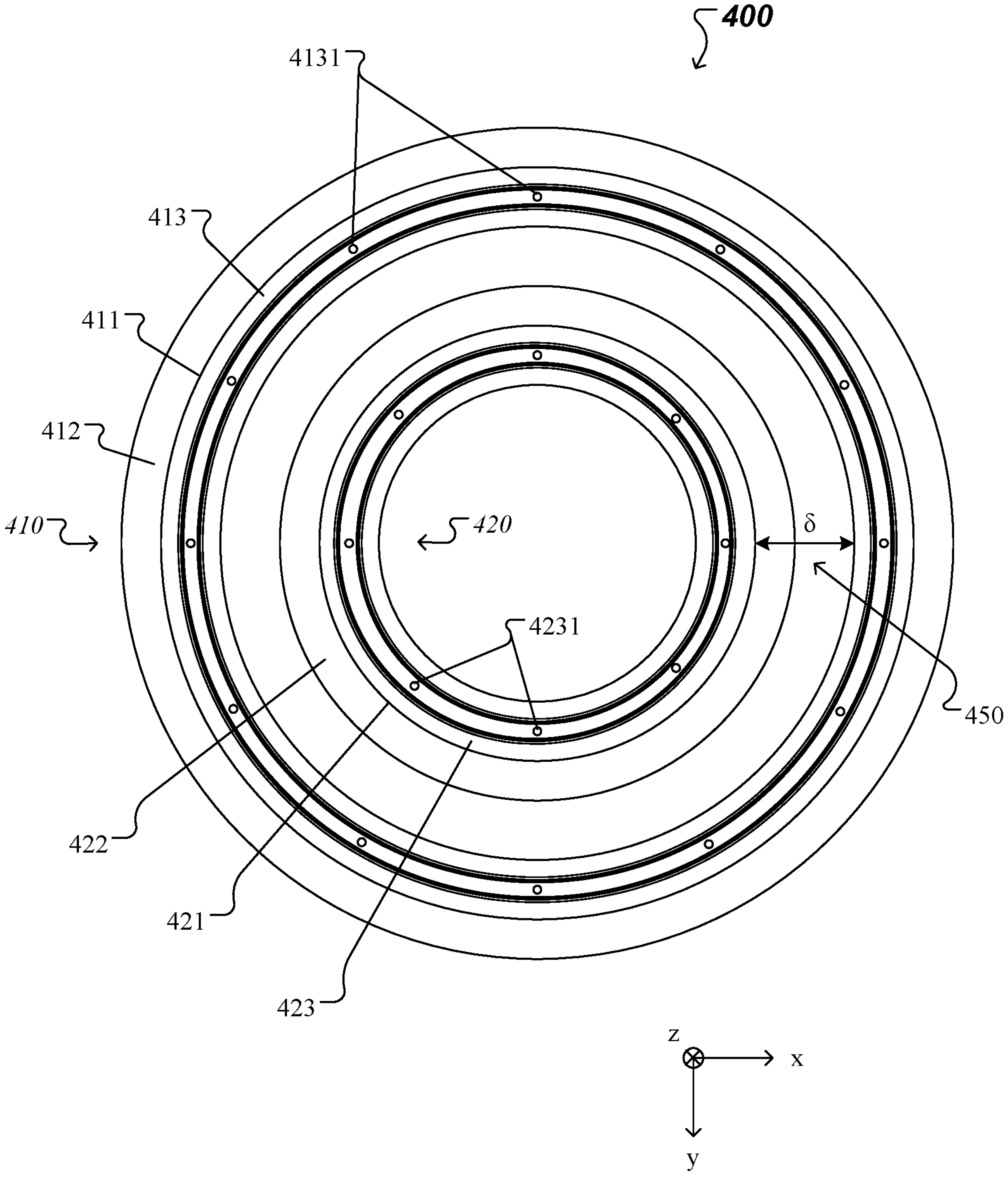

FIG. 4B

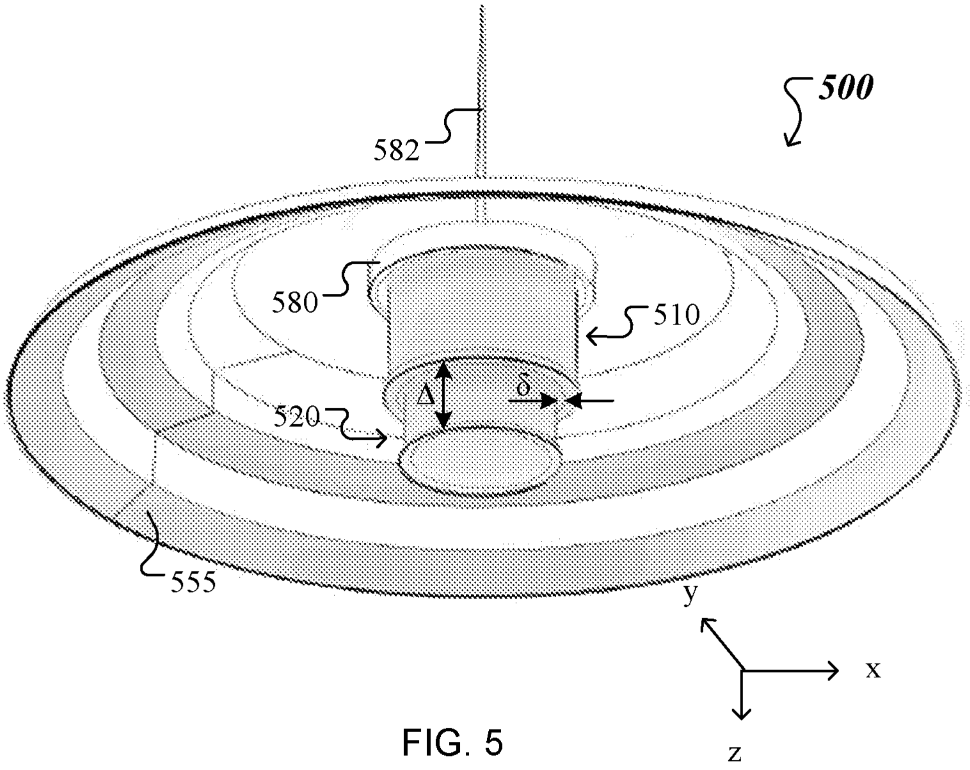

FIG. 5

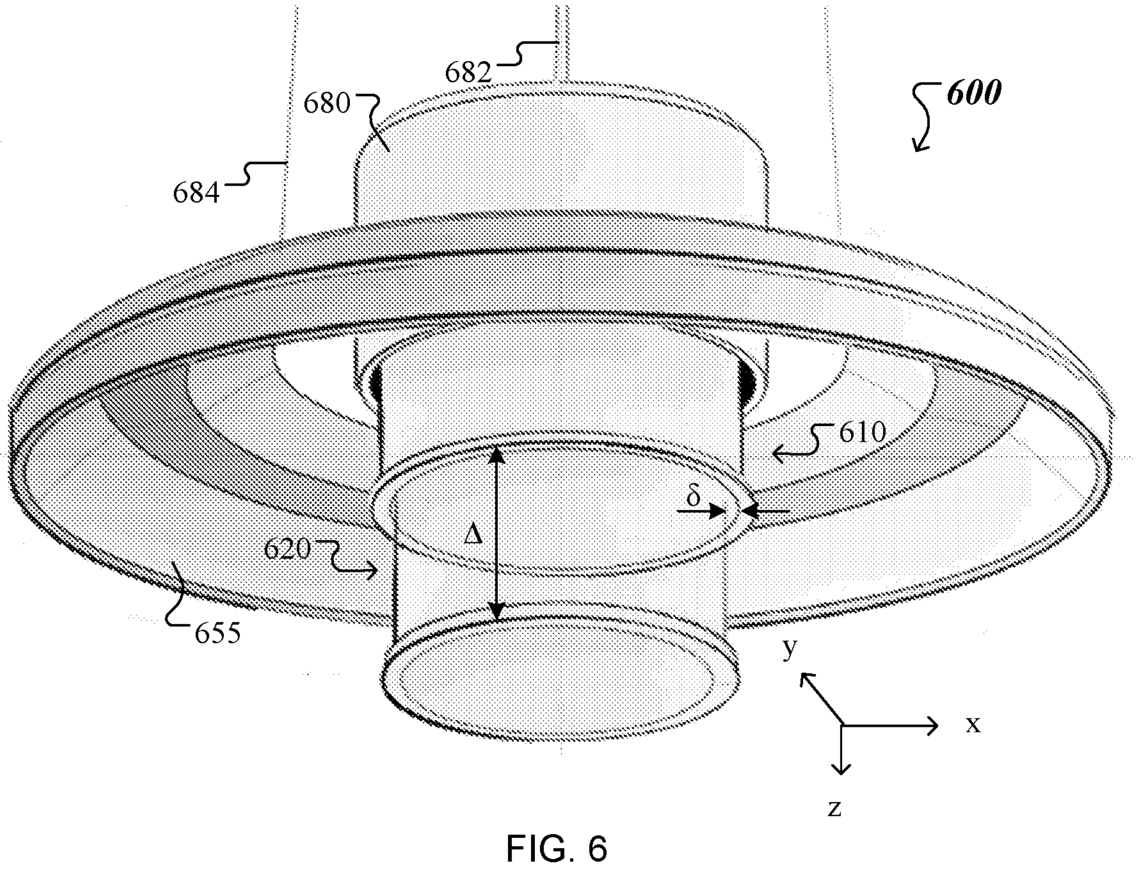

FIG. 6

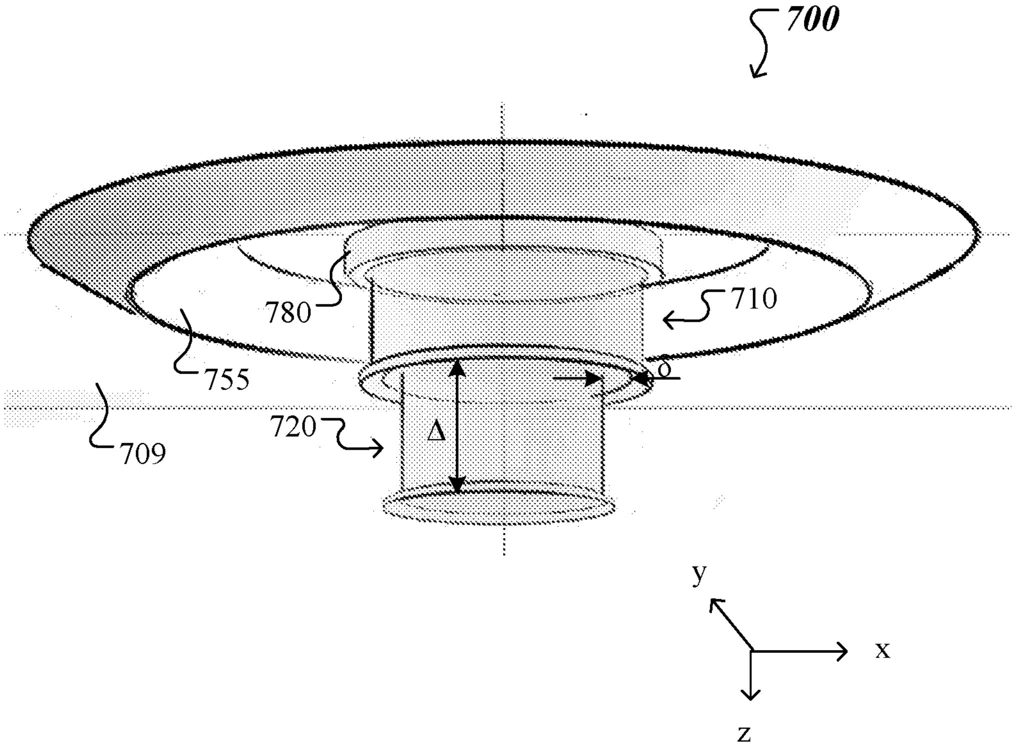

FIG. 7

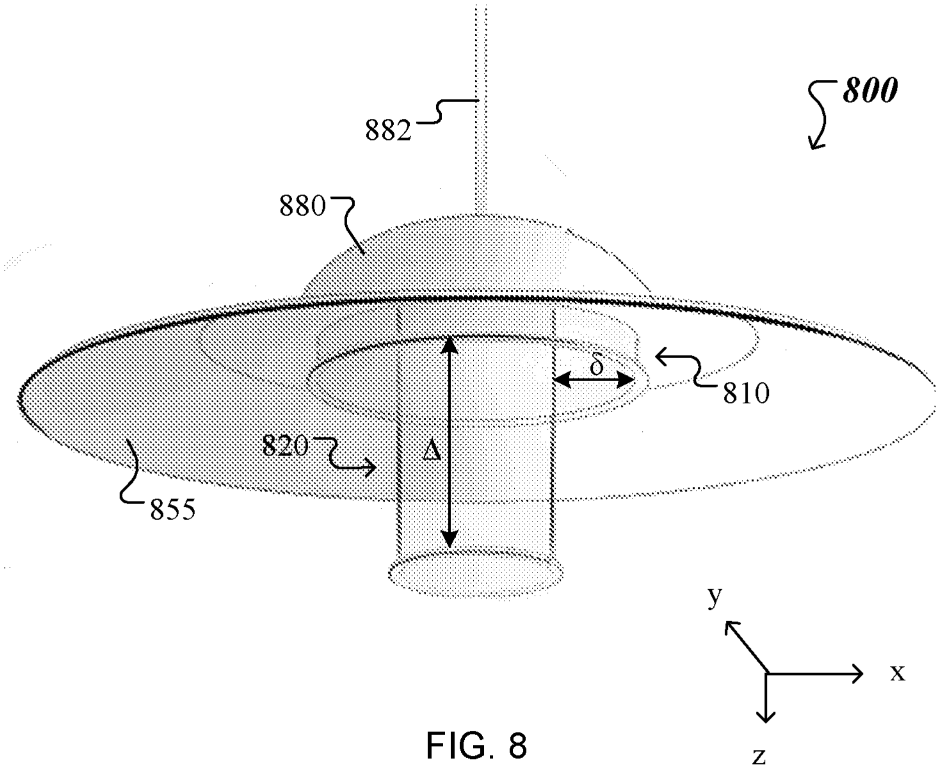
800
882
880
810
δ
820
Δ
855
y
x
z

FIG. 8

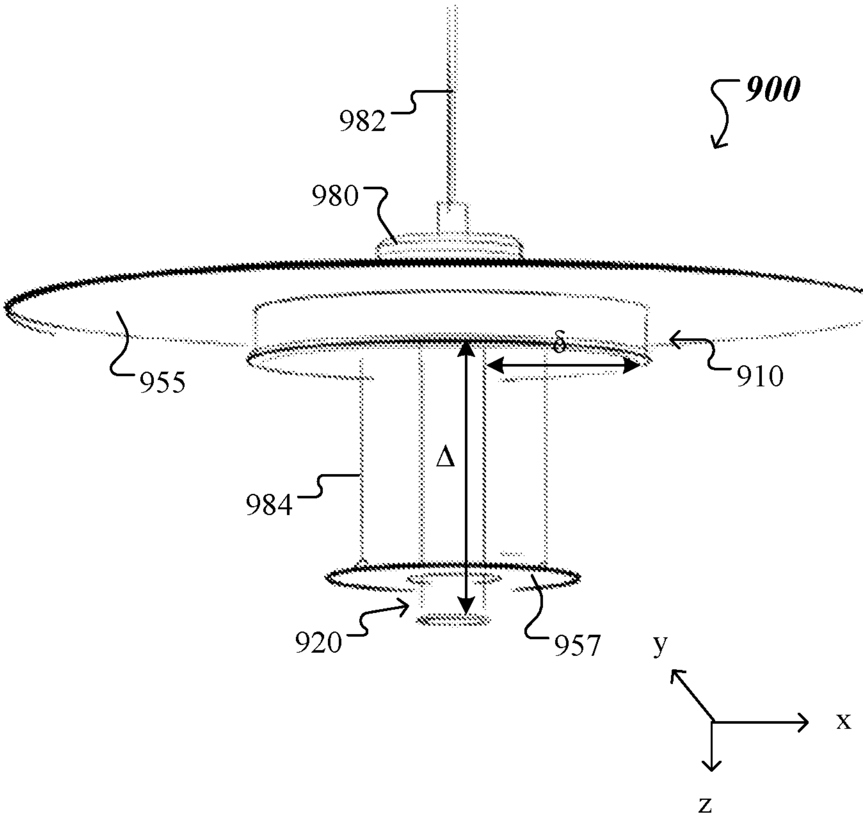
900
982
980
955
910
δ
Δ
984
920
957
y
x
z

FIG. 9

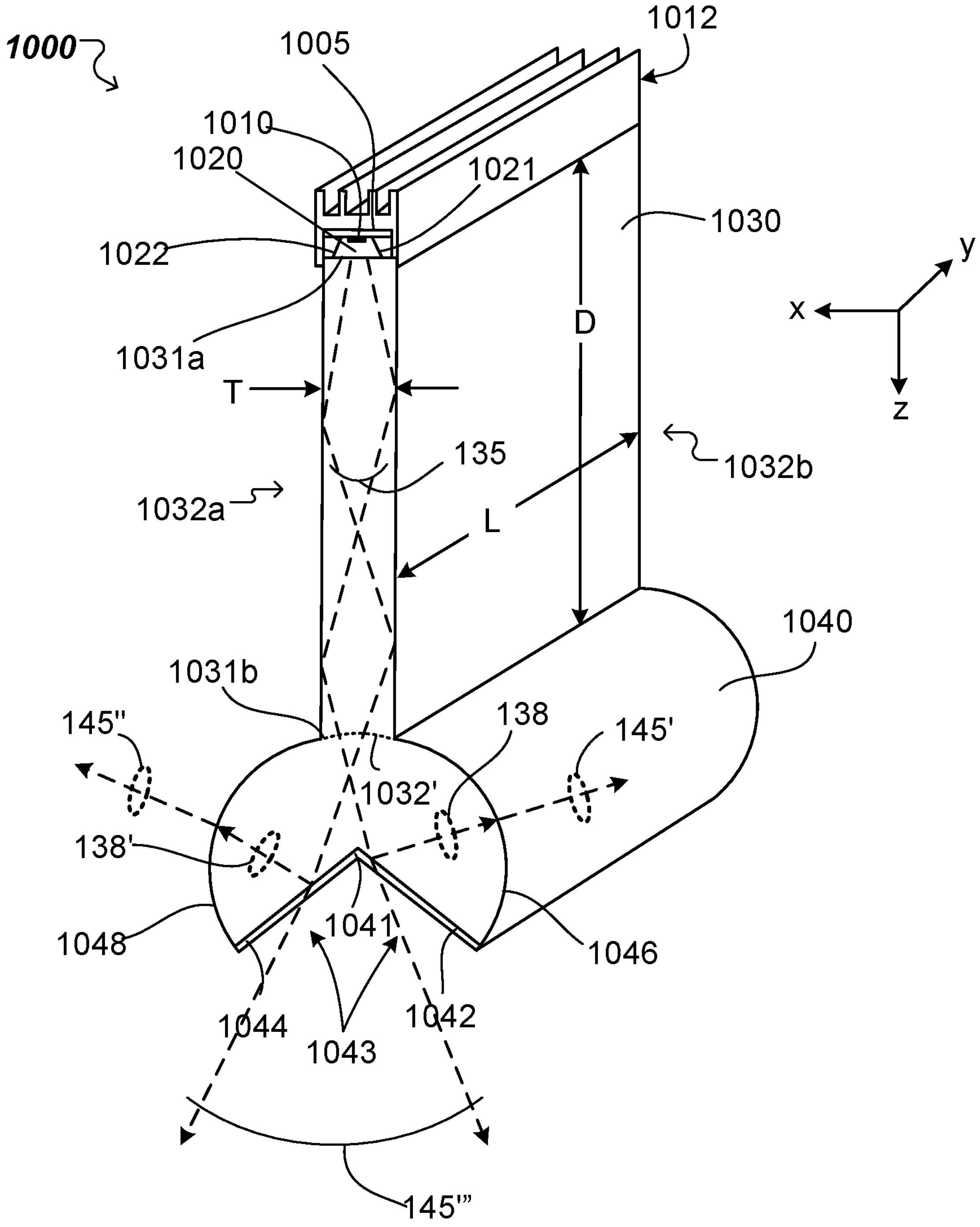
1000
1005
1012
1010
1020
1021
1030
1022
y
x
z
D
1031a
T
135
1032b
1032a
L
1040
1031b
145''
138
145'
1032'
138'
1048
1041
1046
1044
1043
1042
145'"

FIG. 10A

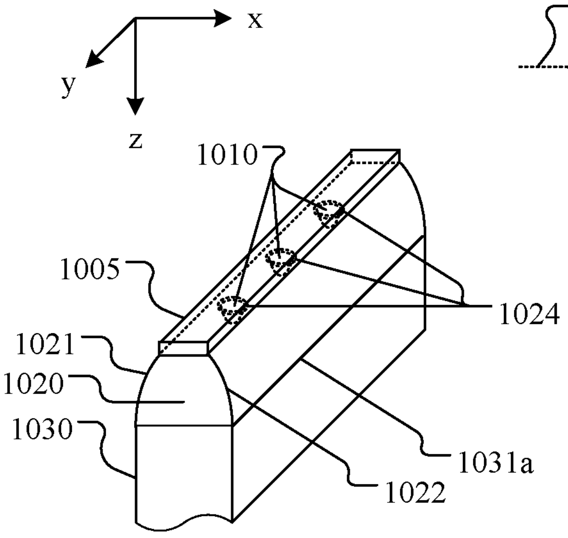

FIG. 10B

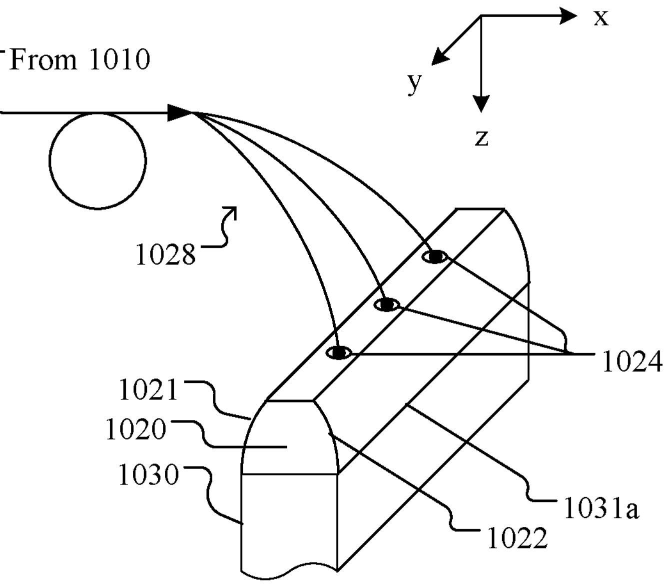

FIG. 10C

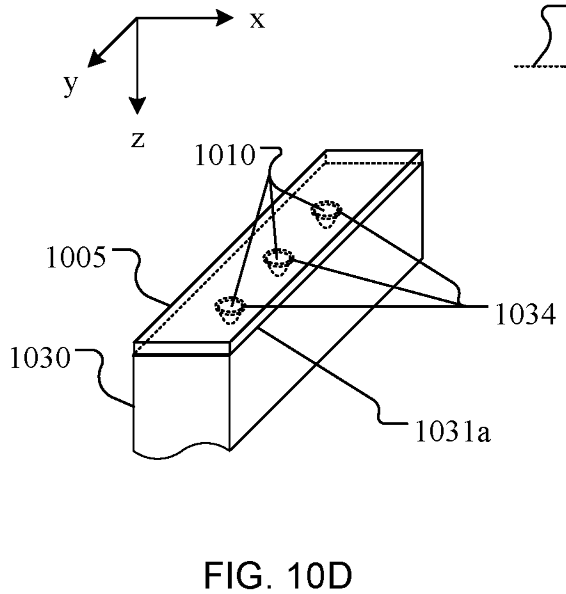

FIG. 10D

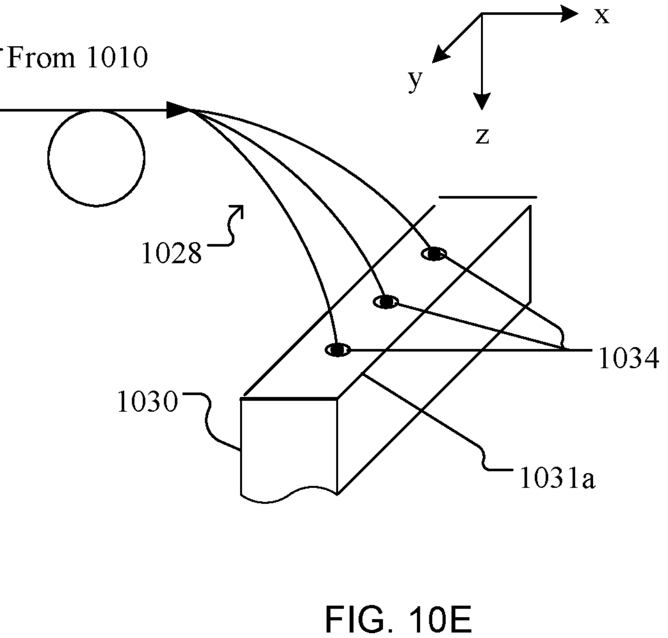

FIG. 10E

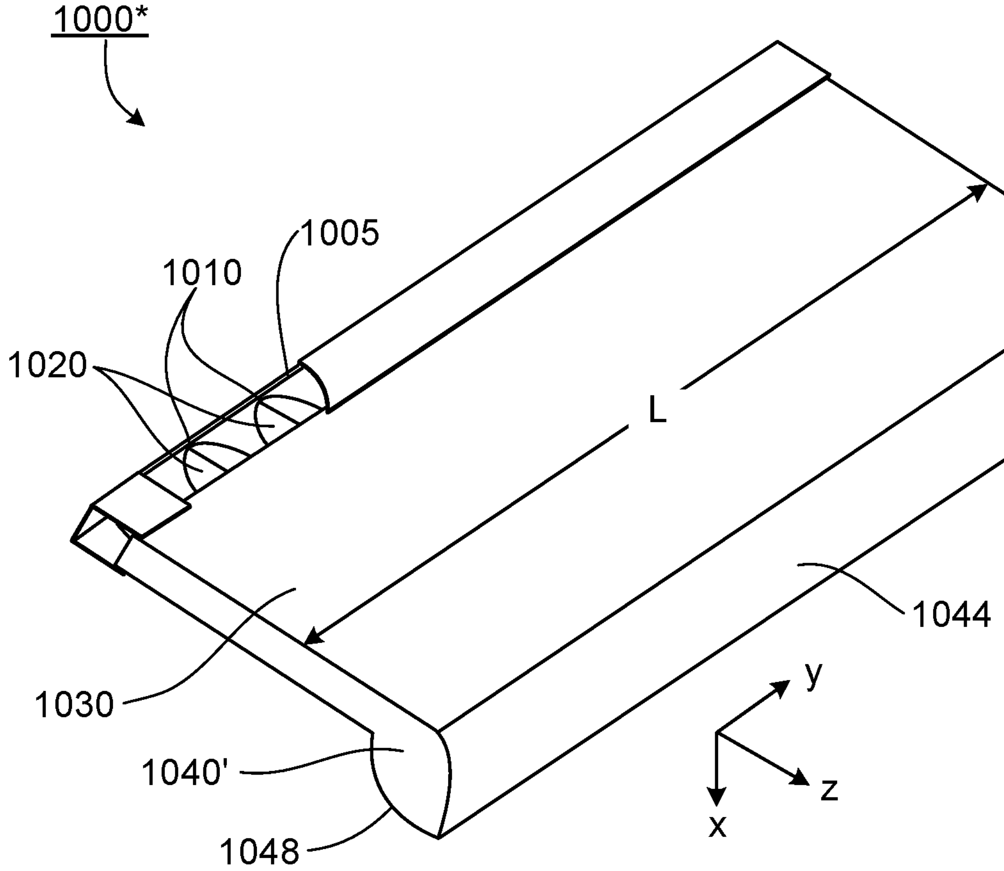

FIG. 10F

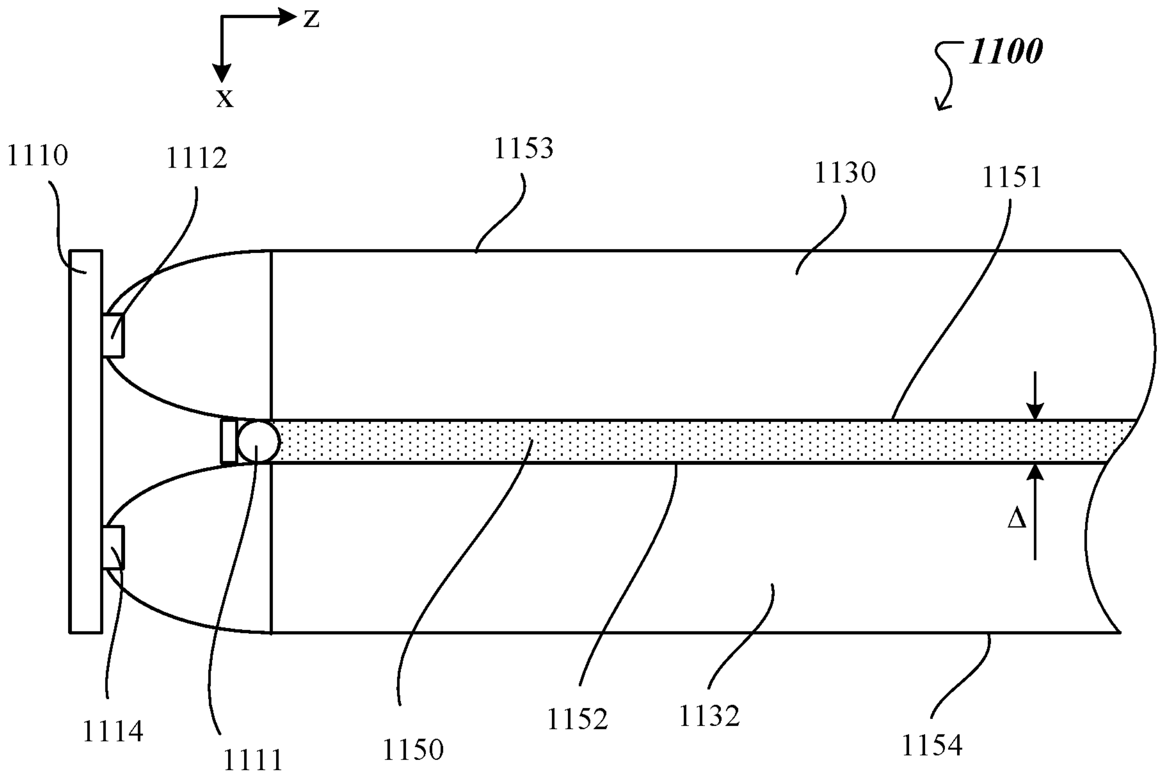

FIG. 11A

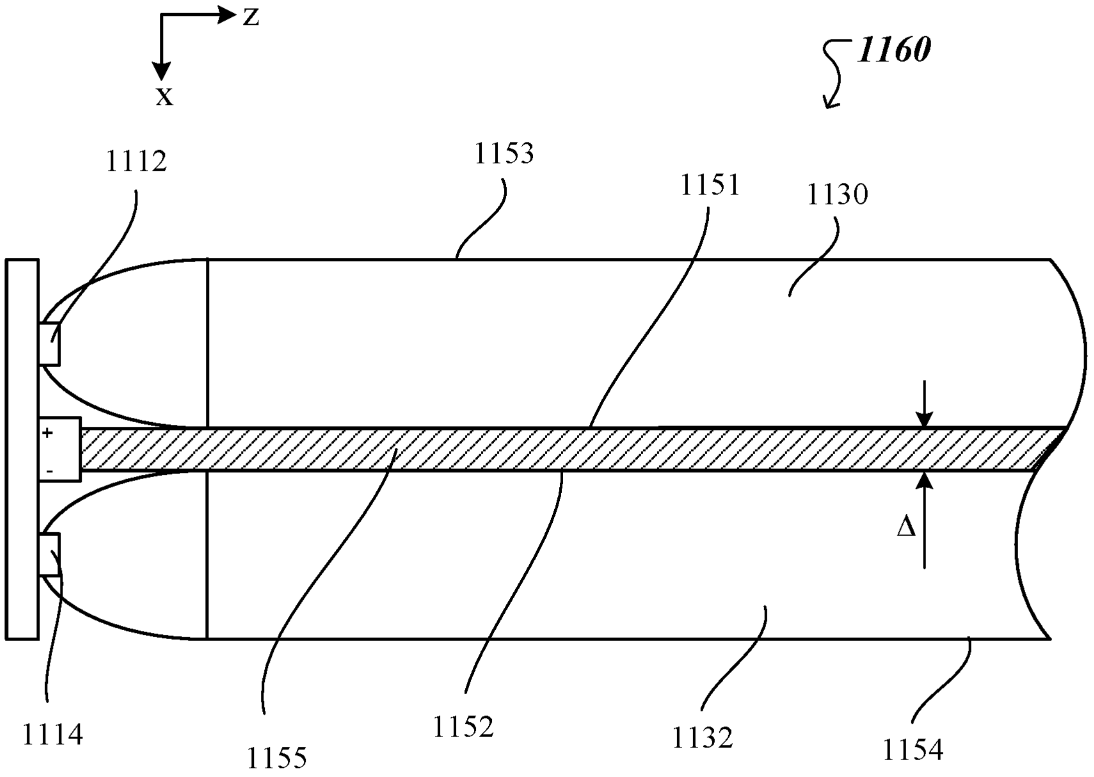

FIG. 11B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/017651

A. CLASSIFICATION OF SUBJECT MATTER
INV. F21V23/04 F21V8/00 F21K9/61
ADD. F21Y115/10

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F21K G02B F21V F21Y

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/309735 A1 (PARKER JEFFERY R [US] ET AL) 22 December 2011 (2011-12-22) figure 16 paragraph [0054] - paragraph [0057] -----	1-5,8,9, 12,17-22
X	US 2015/219836 A1 (YORK ALLAN BRENT [CA]) 6 August 2015 (2015-08-06)	1,2, 5-11,18, 19,21,22
Y	paragraph [0063] - paragraph [0064] paragraph [0068] paragraph [0072] - paragraph [0073] figures 2,3A,3B -----	12-16
	-/--	

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"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 another 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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 30 April 2019	Date of mailing of the international search report 15/05/2019
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Prévot, Eric

2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 9 459 397 B2 (LIGHTING SCIENCE GROUP CORP [US]) 4 October 2016 (2016-10-04) figures 3-5 column 8, line 29 - column 10, line 2 -----	1,2, 6-10, 17-19, 21,22
Y	US 2016/245986 A1 (LIGAS MARTIN [US] ET AL) 25 August 2016 (2016-08-25) figures 9A-9G,10-13 paragraph [0054] - paragraph [0055] -----	12-16
A	US 2013/201715 A1 (DAU WILSON [CA] ET AL) 8 August 2013 (2013-08-08) figures 15A-15D paragraph [0236] -----	1

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2019/017651

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