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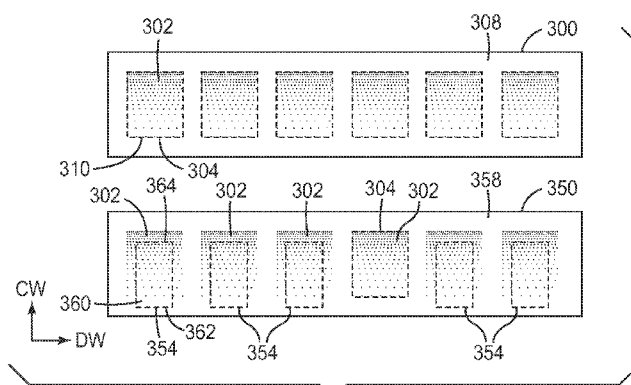


FIG. 3

(57) Abstract: A method for manufacturing light guides and the output of such a method is described. The steps include designing a first extraction pattern for use with a first light guide, where the first extraction pattern includes light extractor locations, and forming light extractors in the light extractor locations of the first extraction pattern on a first substrate location. The method further includes forming light extractors in the light extractor locations of the first extraction pattern on a second substrate location, cutting the first light guide having the first extraction pattern from the first substrate location, and cutting a second light guide from the second substrate location, where the second light guide has a first major surface that has at least one dimension that is different than the dimensions of the first major surface of the first light guide. The second light guide includes at least a portion of but not all of one of the copies of the first extraction pattern.



LIGHT GUIDES WITH FLEXIBLE EXTRACTION PATTERN LAYOUTS AND METHODS FOR FORMING LIGHT GUIDES

FIELD OF THE INVENTION

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This invention generally relates to light guides and displays incorporating same. In particular, the invention relates to flexible light guides.

BACKGROUND

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Optical displays, such as liquid crystal displays (LCDs), are becoming increasingly commonplace, finding use for example in mobile telephones, portable computer devices ranging from hand held personal digital assistants (PDAs) to laptop computers, portable digital music players, LCD desktop computer monitors, and LCD televisions. In addition
15 to becoming more prevalent, LCDs are becoming thinner as the manufacturers of electronic devices incorporating LCDs strive for smaller package sizes.

Many LCDs use a backlight for illuminating the LCD's display area. The backlight typically includes a light guide in the form of a slab or wedge often of an optically transparent polymeric material produced by, for example, injection molding. In
20 many applications, the backlight includes one or more light sources that couple light into the light guide from one or more edges of the light guide. In a slab waveguide, the coupled light typically travels through the light guide by total internal reflection from the top and bottom surfaces of the light guide until encountering some feature that causes a portion of the light to exit the light guide.

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SUMMARY OF THE INVENTION

Generally, the present invention relates to light guides. The present invention also relates to displays incorporating light guides.

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In one embodiment described herein, a method for manufacturing light guides includes the steps of designing a first extraction pattern for use with a first light guide, where the first extraction pattern includes light extractor locations for use on a first major

surface of the first light guide, and forming light extractors in the light extractor locations of the first extraction pattern on a first substrate location. The method further includes forming light extractors in the light extractor locations of the first extraction pattern on a second substrate location, cutting the first light guide having the first extraction pattern from the first substrate location, and cutting a second light guide from the second substrate location, where the second light guide has a first major surface that has at least one dimension that is different than the dimensions of the first major surface of the first light guide. The second light guide includes a portion of but not all of one of the copies of the first extraction pattern.

In another embodiment, a method for manufacturing light guides comprising the steps of designing a first extraction pattern for use with at least a first light guide and a second light guide, where the first extraction pattern has light extractor locations for use on a first major surface of the first light guide and on a first major surface of the second light guide, and forming light extractors in the light extractor locations of the first extraction pattern on a first substrate location. The method further includes forming light extractors in the light extractor locations of the first extraction pattern on a second substrate location, cutting the first light guide from the first substrate location comprising at least a portion of the first extraction pattern, and cutting the second light guide from the second substrate location comprising a portion of but not all of the first extraction pattern, wherein the second light guide has different dimensions than the first light guide.

In yet another embodiment, a light guide includes a first major surface and a second major surface, an extraction pattern on the first major surface comprising light extractors capable of extracting light propagating in the first light guide, and one or more light sources positioned along a first edge of the light guide which introduce light into the light guide. The light guide has an efficiency of 88% or less and the edges of the light guide are not configured to recycle or return light into the light guide.

In still another embodiment, an output of a light guide manufacturing process includes a first light guide having a first major surface that has a first dimension and a second dimension, the first light guide having a first edge and a second edge opposite the first edge. The first light guide includes a first extraction pattern on the first major surface comprising light extractors capable of extracting light propagating in the first light guide, where the first extraction pattern is configured to perform with a first level of efficiency

which is at least 80%, wherein efficiency is measured as the percentage of light introduced into the first light guide at the first edge that is extracted by the light extractors and does not reach the second edge of the first light guide. The output of the manufacturing process further includes a second light guide having a first major surface that has a first dimension and a second dimension, the second light guide further having a first edge and a second edge opposite the first edge. The second light guide includes a second extraction pattern on the first major surface comprising light extractors capable of extracting light propagating in the first light guide. The second extraction pattern is identical to a portion of but not all of the first extraction pattern, wherein the second light guide performs at a second level of efficiency lower than the first level of efficiency. At least one of the first and second dimensions of the first major surface of the second light guide are different from at least one of the first and second dimensions of the first major surface of the first light guide.

BRIEF DESCRIPTION OF DRAWINGS

The invention may be more completely understood and appreciated in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

FIG. 1 is a schematic side view of a back light system.

FIG. 2 is a schematic top view of a back light system having discrete light extractors.

FIG. 3 is a schematic top view of a first web substrate and a second web substrate, each having a pattern of light extractors, with light guide outlines shown in dashed lines for cutting out individual light guides.

FIG. 4 is a schematic top view of a continuous pattern of light extractors on a web substrate with light guide outlines shown in dashed lines for cutting out individual light guides.

FIG. 5 is a schematic top view of a repeating pattern of light extractors on a web substrate with light guide outlines shown in dashed lines for cutting out individual light guides.

FIG. 6 is a schematic top view of a back light system having discrete light extractors, created using the same light extractor pattern as FIG. 2.

FIG. 7 is a schematic top view of a back light system having discrete light extractors.

5 FIG. 8 is a schematic side view of a display system.

FIG. 9 is a schematic top view of a light guide, where the darker areas are capable of greater light extraction than the lighter areas.

FIG. 10 is a schematic top view of a different light guide, where the darker areas are capable of greater light extraction than the lighter areas.

10 FIG. 11 is a schematic top view of yet another light guide, where the darker areas are capable of greater light extraction than the lighter areas, and where the light extraction pattern is designed for use with more than one light guide characteristic.

FIG. 12 and 13 show the outlines of the first light guide 1200 and the second light guide 1300, respectively.

15 FIGS. 14-16 are iso-luminance diagrams showing a luminance distribution of output emission yielded by the first and second light guides for the three different light extractor patterns.

DETAILED DESCRIPTION

20 The present invention generally applies to back lights that incorporate a light guide for providing a desired illumination in a display system. The invention particularly applies to thin flexible light guides that can be easily and economically manufactured. Such thin flexible light guides are described in co-owned, co-pending U.S. Published Patent Application 2007-0279935, titled FLEXIBLE LIGHT GUIDE, which is hereby
25 incorporated herein in its entirety.

U.S. Published Patent Application 2007-0279935 discloses a multilayer thin and flexible light guide for use in a backlight. The light guide includes two flexible layers, and can be fabricated using a continuous roll to roll process, such as a continuous cast and cure process. One advantage of this flexible light guide is reduced display thickness. Another
30 advantage of the present invention is reduced cost in the manufacturing process. Yet another advantage is the opportunity to create light guides of different configurations

(display sizes and light source arrangements) from one pattern of light extraction features. Such a system and method for manufacturing light guides is described herein in detail.

Backlight System Having Binary Light Guide with Light Extractors

5 An exemplary backlight system will now be described. Light guides according to the present invention may be used in the context of such a backlight system, though it is also possible for light guides of the present invention to be used in the context of different backlight and other systems.

10 FIG. 1 is a schematic side-view of a backlight system 100. Backlight system 100 includes a light guide 110, a light source 150 placed proximate an edge 111 of light guide 110, and an optical coupler 160 for facilitating the coupling of light from light source 150 to light guide 110. In the exemplary embodiment shown in FIG. 1, optical coupler 160 is distinct from light guide 110. In some applications, optical coupler 160 may be an integral part of light guide 110, for example, by providing an appropriate curvature to edge 111 of
15 light guide 110. Optical coupler 160 can also be an integral part of the light guide by increasing the edge height near the light source or light sources 150.

Light guide 110 includes a first major surface 121. Light guide 110 also includes a first flexible layer 120 having the same first major surface 121 and a second major surface 122, and a second flexible layer 130 having a first major surface 131 and a second major
20 surface 132. Second major surface 122 of the first flexible layer 120 is in contact with first major surface 131 of the second flexible layer 130 such as in physical contact. In some embodiments, substantially the entire second major surface 122 is in contact with substantially the entire first major surface 131. A light guide with two flexible layers is described more fully in U.S. Published Patent Application 2007-0279935, titled
25 FLEXIBLE LIGHT GUIDE, which was previously incorporated herein by reference. It is possible for the present invention to be utilized with other light guide configurations as well.

Light from light source 150 propagates in light guide 110 in the general z-direction by reflection from major surfaces 121 and 132, where the reflections can primarily be total
30 internal reflections if desired. For example, light ray 173 undergoes total internal reflection at major surface 121 at point 173A and at major surface 132 at point 173B.

Light source 150 may be any suitable type of light source such as a fluorescent lamp or a light emitting diode (LED). Furthermore, light source 150 may include a plurality of discrete light sources such as a plurality of discrete LEDs. Cold cathode fluorescent lamps (CCFLs) may also be used.

5 In the exemplary embodiment shown in FIG. 1, light source 150 is positioned proximate one edge of light guide 110. In general, one or more light sources may be positioned proximate one or more edges of light guide 110. For example, in FIG. 1, an additional light source may be placed near edge 112 of light guide 110.

10 Light guide 110 can be manufactured using any suitable manufacturing method, such as UV cast and cure, extrusion such as extrusion casting, co-extrusion, or other known methods. As an example, light guide 110 can be manufactured by co-extruding flexible layers 120 and 130, followed by a compression molding step during which extractors 140 are formed in surface 121.

15 **Pattern of Light Extractors**

First major surface 121 includes a plurality of discrete light extractors 140 that are capable of extracting light that propagates in the light guide 110. For example, light extractor 140 extracts at least a portion of light ray 171 that propagates in light guide 110 and is incident on light extractor 140. As another example, light extractor 140A extracts at
20 least a fraction of light ray 173 that propagates in light guide 110 and is incident on light extractor 140A. In general, the spacing between neighboring light extractors can be different at different locations on major surface 121. Furthermore, the shape, respective heights, and/or the size of the light extractors can be different for different light extractors. Such variation is useful in controlling the amount of light extracted at different locations
25 on major surface 121.

Generally, it is desirable for light extractors 140 to be designed and arranged along first major surface 121 such that light is extracted in a predetermined pattern over substantially the entire first major surface 121. One such predetermined pattern is for the light to be extracted uniformly over substantially the entire first major surface.

30 The distribution and density of light extractors 140 depends on a number of factors such as the shape of light source 150, number of light sources and dimensions of the display area.

Furthermore, neighboring light extractors can be separated by substantially flat land area 180 having an average thickness “d.” In some embodiments, the average thickness of land area 180 is no greater than 20, or 15, or 10, or 5, or 2 microns.

In the exemplary embodiment shown in FIG. 1, light extractors 140 form a plurality of discrete light extractors. In some applications, light extractors 140 may form a continuous profile, such as a sinusoidal profile, that may extend, for example, along the y- and z-axes.

The exemplary embodiment of FIG. 1 shows convex lenslets as light extractors 140, meaning that each lenslet forms a bump on surface 121. In general, light extractors 140 can have any shape that can result in a desired light extraction. For example, light extractors 140 can include concave structures forming depressions in surface 121, convex structures such as hemispherical convex lenslets, prismatic structures, sinusoidal structures, or any other shape with linear or nonlinear facets or sides that may be suitable in providing, for example, a desired light extraction pattern.

FIG. 2 shows a backlight system 200 that includes an extended light source 250, such as a line-light source, placed proximate an entire first edge 111 of light guide 110. In this example, the plurality of discrete light extractors 140 are arranged along a plurality of mutually parallel lines, such as parallel lines 210 and parallel lines 211 where each line includes at least two discrete light extractors.

In general, density, shape, and size of light extractors 140 can be different at different locations along surface 121 to provide a desired light distribution for the extracted light. These features of the light extractors 140 form a light extraction pattern on the first major surface 121 of the light guide. For example, in FIG. 2, the size and shape of the light extractors 140 are identical to each other, but the density of the light extractors 140 increases along the z-direction moving away from the light source 250.

Typically, light extraction patterns are designed to maximize the uniformity and efficiency of light output from a first major surface of the light guide for a specific backlight system configuration. A specific backlight system configuration includes the display size, light source type, number of light sources and light source placement. For example, the light extraction pattern shown in FIG. 2 is designed for use with an extended light source 250 placed at edge 111 and a display size having a down-guide (DG) dimension of a , and a cross-guide (CG) dimension of b . The term down-guide refers to

the direction of the primary travel of the light away from the light source. The term cross-guide refers to the direction perpendicular to the down-guide direction, in the plane of the light guide. Accordingly, when a light guide is needed for a new backlight configuration, a new extraction pattern is typically designed to maximize uniformity and efficiency for that backlight configuration.

On flexible light guides mentioned herein, the extraction pattern is typically created on a substrate using a microreplication tool which modifies the surface of a substrate to produce a repeating pattern of light extractors. Then, portions of the substrate are cut out to form light guides.

FIG. 3 is a top view of a portion of two web substrates, including a first web substrate 300 and a second web substrate 350. The first web substrate 300 has copies of a specific extraction pattern 302 which was created with a microreplication tool at various substrate locations. The extraction pattern 302 is present on a first major surface 308 of the substrate 300. In the portion of the first web substrate 300 illustrated, six copies of the extraction pattern 302 are present at six substrate locations. However, it is understood that the web substrate can be longer and include many more copies of the extraction pattern 302.

In FIG. 3, the extraction pattern 302 represents the extraction features of the light guide. The denser the extraction pattern 302 in a given area, the more light is extracted in that area. The extraction qualities can be varied by varying the density, size and shape of the discrete extractors.

The dashed line around each extraction pattern 302 is a first light guide outline 304, showing where the substrate 300 will be cut in order to create individual light guides.

The cross-web direction is indicated by the axis CW while the down-web direction is indicated by the axis DW in FIG. 3. The web substrate typically has a down web dimension at least 10 times greater than a cross web dimension. In the example of FIG. 3 each copy of the extraction pattern 302 varies in the cross-web direction. Moving away from a first edge 310 of the extraction pattern 302 in the cross-web direction, the extractors become more concentrated, indicating that the light extraction increases. It is also possible for the extraction pattern 302 to vary in the down-web direction or a combination of the down-web and cross web directions. In a backlight using one of these light guides, a light source will be positioned adjacent to first edge 310.

In the embodiment of FIG. 3, each copy of the extraction pattern does not vary in the down-web direction. In some embodiments, this type of extraction pattern is used with an extended light source that extends along the first edge 310 of the light guide.

5 The first light guide outline 304 has a cross-web dimension and a down-web dimension on the first major surface 308. Complex converting operations are used to cut the light guides from the web 300 along the outlines at the required locations.

Flexible Extraction of Light Guides from an Extraction Pattern

10 Because a new extraction pattern has been thought to be required for each new backlight configuration, a new microreplication tool has also been thought to be required for each new backlight configuration. However, it has been recognized by the inventors that a range of different light guide sizes and/or outlines can be produced from one extraction pattern. One example of differences in outlines is differences in the use of and position of alignment tabs. Where the term dimension is used, it refers to the length or
15 width of the light guide excluding any tabs or corner configurations. The dimension along a particular direction excludes any tabs that exist along that direction. As a result, a single microreplication tool can be used for more than one light guide size and/or outline, thereby reducing the number of microreplication tools that need to be generated and inventoried. In addition, a web substrate having multiple copies of a single extraction pattern can be
20 converted into a range of light guide sizes, thereby reducing the inventory of replicated material and providing the ability to respond to customer orders more quickly.

The desired light guide size can be selected much later in the manufacturing supply chain. Manufacturing yields are improved by reducing the amount of material left in the supply chain when a particular display size is discontinued, because the remaining rolls of
25 replicated material can be used for other display sizes.

Accordingly, referring again to FIG. 3, the first substrate is shown side-by-side with a second substrate 350. The second substrate 350 can be used to form light guides with a different configuration than those shown on substrate 300. The second substrate 350 has multiple copies of the first extraction pattern 302 and was formed by the same
30 microreplication tool as the first substrate 300. The second substrate 350 can be used to form light guides having a different configuration than the light guides formed from the first substrate 300. For example, a second light guide outline 354 can be used to cut one

or more second light guides from the substrate 350. A light guide having the first light guide outline 304 can also be present on the second substrate.

The second light guide outline 354 has a cross-web dimension and a down web dimension on a first major surface 358 of the substrate 350. At least one of the two dimensions of the second light guide outline 354 is different from the dimensions of the first light guide outline 304. In the example of FIG. 3, the second light guide outline 354 has a down-web dimension that is smaller than the down-web dimension of the first light guide outline 304. The second light guide outline 354 has a cross-web dimension that is identical to the cross-web dimension of the first light guide outline 304. However, the second light guide outline 354 is off-set from the extraction pattern 302. There is a mixing region 360 with no light extractors in second light guide outline 354 at edge 362. A mixing region 360 is often used when discrete light sources are positioned along a first edge 362. Also, the edge 364 opposite from the mixing region is offset from the border of the light extractor pattern 302. It is also possible for a single substrate to include both of the two rows of extraction patterns 302, or even more than two rows of extraction patterns on a single substrate.

In one embodiment, the extraction pattern 302 is designed for use with a light guide having an extended light source positioned along edge 310 and having the dimensions of first light guide outline 304 of FIG. 3. When the extraction pattern 302 is used with the second light guide outline 354 having different dimensions than first light guide outline, and positioned in a backlight having discrete light sources along the first edge 362, the uniformity and efficiency are not as high as with a backlight system using the first light guide outline 304. However, the second light guide created by cutting along the second light guide outline 354 still performs adequately as a light guide.

In another embodiment, the extraction pattern 302 is designed for use with a first light guide having four tabs along its outline, and having clipped corners. When the extraction pattern 302 is used with a second light guide having a second outline, such as an outline having square corners and five tabs, the second light guide still performs adequately as a light guide.

Continuous Pattern of Light Extractors

A substrate 400 having extraction pattern 402 of one embodiment of the present invention is shown in FIG. 4. In this extraction pattern 402, the pattern of light extractors varies only in the cross-web direction and is constant in the down-web direction. The density of the light extractors in each region of the extraction pattern 402 represents the extraction capability of that area. Where there are fewer light extractors, such as near first edge 404 of the extraction pattern 402, there is less light extracted due to either fewer light extractors, smaller light extractors, differently shaped light extractors or some combination of these characteristics. Where there are more numerous light extractors, such as near second edge 406 of the extraction pattern 402, there is more light extracted due to either a higher density of light extractors, larger light extractors, differently shaped light extractors, or a combination of these features. The individual extraction features in the extraction pattern 402 are either linear structures, such as prisms, or discrete structures, such as lenslets. Extraction pattern 402 is configured for a light source to be positioned near the first edge 404 of the extraction pattern 402.

Five different light guide outlines 420 to 428 are shown in FIG. 4 having different dimensions on a first major surface 430 of the substrate 400. It has been found that acceptable performance in light guide efficiency and uniformity is observed when one extraction pattern is used for multiple display sizes.

In one embodiment of the manufacturing process for substrate 400, the extraction pattern 402 was designed to provide efficient and uniform light extraction for a specific display configuration, that is, a specific display size, light source type and light source placement. In one embodiment, the extraction pattern 402 is designed specifically for a light guide with the dimensions of first light guide outline 420.

Second light guide outline 422 has at least one dimension that is different than the dimensions of the first light guide outline 420. In the example of FIG. 4, both the width and length of the second light guide outline 422 are different from the width and length of the first light guide outline 420. Third, fourth and fifth light guide outlines 424, 426 and 428 also have at least one dimension different from the first light guide outline 420.

The extraction pattern 420 is designed for used with a light guide having the dimensions of first light guide outline 420 of FIG. 4 in order to maximize the produce uniformity of light output over the surface of the first light guide and to maximize

efficiency. When the extraction pattern 402 is used with the second light guide outline 422, the uniformity and efficiency are not as high as with the first light guide outline 420. Because the cross-web dimension of outline 422 is smaller than the cross-web dimension 420, and the extraction pattern 402 is designed to maximize efficiency or uniformity for
5 outline 420, not all light in the light guide will be extracted before it reaches the edge. As a result, the light guide made from light guide outline 422 will be less efficient than the light guide made from light guide outline 402. However, the second light guide created by cutting along the second light guide outline 422 still performs satisfactorily as a light guide.

10 In another embodiment, the extraction pattern 402 of FIG. 4 is used as a lighted strip or lighted trim on a larger structure, such as a sign. The extraction pattern 402 could also be used in a general lighting application.

In another embodiment, the extraction pattern 402 of FIG. 4 is created on two separate substrates, where the extraction pattern is formed on both substrates using the
15 same microreplication tool. From one substrate, at least a first light guide outline is cut, such as outline 420. From a second substrate, a second light guide outline is cut, such as outline 422, is cut. As a result, light guides of two different sizes are created although only one microreplication tool is used.

Now referring to FIG. 5, substrate 500 includes six copies of an extraction pattern
20 502. Each extraction pattern 502 extends from its first edge 504 to its second, opposite edge 506. Surrounding at least a portion of each extraction pattern 502 is a light guide outline 510, 512, 514, 516, 518 and 520 showing how each light guide can be cut from the substrate. On the left side of substrate 500, the first light guide outline 510 includes a first edge 522 that establishes a mixing region 508 without any light extractors. The rest of the
25 edges of the light guide outline 510 are the same as the edges of the light extraction pattern.

Light guide outlines 512, 514 and 516 also include mixing regions where there are no light extractors. These light guide outlines have one or two dimensions that are different from the first light guide outline 510. Light guide outlines 518 and 520 are
30 smaller than the extraction pattern 502 and do not include a mixing region.

FIGS. 2 and 6 provide another example of a pattern of extraction features 140 that can be used with a first light guide (light guide 110 of FIG. 2) or a second light guide

(light guide 600 of FIG. 6), where the first and second light guides have at least one dimension different from each other. FIG. 2 illustrates the first light guide 110 incorporated into a backlight system 200. FIG. 2 shows a second light guide outline 250, having a down-guide dimension of c and a cross-guide dimension of d , drawn on the first light guide 220. After cutting along the second light guide outline 250, the second light guide 600 is created, having a portion of the extraction pattern that was present on the first light guide 110 on a first major surface 602.

The second light guide 600 includes light extractors 140 and is incorporated into a backlight system 604, which includes an extended light source 606 positioned along edge 608 of the second light guide 600.

Absorbers 610 and 612 are positioned along cut edges 614 and 616 in the backlight system 604. The pattern of light extractors 140 was designed to provide uniform light extraction for a light guide with dimensions a and b as shown in FIG. 2. When only a portion of the pattern is used for the second light guide 600, the cut edges 614 and 616 can be brighter than desired. Absorbers 610 and 612 can prevent unwanted brightness along the edges.

Extractor Pattern with a Single LED Light Source

As another example, FIG. 7 shows a backlight system 700 that includes a first light guide 702 and a single light source 704, such as an LED. In this example, the plurality of discrete light extractors 740 are arranged along concentric arcs, such as arcs 710, centered on the light source, where each arc includes at least two discrete light extractors.

The density of light extractors 740 can vary across first major surface 721. For example, the density can increase with distance along the z -axis. Such an arrangement can, for example, result in light extracted from light guide 710 having substantially uniform irradiance across first major surface 721.

The same pattern of light extractors 740 formed by the same microreplication tool can be used to form a second light guide having different dimensions than the first light guide 710. If the extraction pattern is cut from its substrate along cut lines 750 and 752 to form a second light guide, for example, then the first major surface 721 includes a portion of the light extraction pattern that is present on the first light guide. The dimension of the second light guide in the direction of the y -axis is different than for the first light guide.

When the second light guide is positioned in a backlight system, absorbers are positioned along the cut edges formed along lines 750 and 752, in one embodiment.

Additional Examples of Extractor Patterns

FIG. 9 is representation of another light guide 900 having a first light guide outline 901 and an extractor pattern 902 within that outline. Light sources 904 are positioned along a first edge 905 of the light guide. The extractor pattern 902 includes discrete light extractors of different heights, thereby providing differing degrees of light extraction. In FIG. 9, the areas with the largest light extractors are depicted with the darkest shading. For example, portion 908 is farthest away from the light sources 904, and therefore has the largest light extractors, and so is shown with the darkest shading. Portion 910 is very close to the light sources 904, and so includes much smaller light extractors, and is shown with the lightest shading. Portions 912 and 914 include light extractors having a size between those of portions 908 and 910.

Although the embodiment of FIG. 9, as well as the embodiments of FIGS. 10 and 11, are described as having light extractors with varying heights, it is also possible to achieve the same effect of substantially uniform light extraction by having light extractors that vary in density or shape. In addition, it is possible to vary the two or three characteristics of the light extractors across the surface of the light guide. For convenience, the light extractor patterns of FIGS. 9-11 will be described as varying in height, though it is known to one of skill in the art how to achieve the same effects with the variance of one or more other characteristics. Another way to describe the variance in characteristics is by effective number of features in a particular area. Features which extract more light, such as features with greater height, have a similar effect to a larger number of features.

The light sources 904 are spaced away from the first edge 906 of the extraction pattern 902. The mixing zone 916 separating the light sources and the extraction pattern allows for the light from the different sources to mix and be more uniformly distributed on the display area across the edge 906.

The extractor pattern 902 was designed to achieve good uniformity and efficiency for the first light guide dimensions and the light source types, number and placement. It is also possible to cut light guide 900 along cut lines 920 and 922 to create a second light

guide. The second light guide has one dimension, the cross guide dimension, that is different than the first light guide, and it includes a portion of the extraction pattern 902.

FIG. 10 is a representation of another light guide 1000, where the method of depiction is similar to FIG. 9. The light guide 1000 has a first light guide outline 1001, an extractor pattern 1002 within that outline, and light sources 1004 positioned along a first edge 1005 of the light guide. The extractor pattern 1002 includes discrete light extractors of different heights, thereby providing differing degrees of light extraction. Again, the areas with the largest light extractors are depicted with the darkest shading, such as portion 1008, which is positioned between light sources adjacent to a first edge 1006 of the extraction pattern 1002. Portion 1010 is also very close to the light sources 1004, and so includes much smaller light extractors, and is shown with the lightest shading. Portions 1012 and 1014 include light extractors having a size between those of portions 1008 and 1010.

The light sources 1004 are spaced away from the first edge 1006 of the extraction pattern 1002 by a mixing zone 1016, but it is not as large as the mixing zone 916 of FIG. 9. The extraction pattern 1002 accommodates this by having larger extractors in areas between the light sources along the first edge, such as portion 1008.

The extractor pattern 1002 is designed to achieve good uniformity and efficiency for the first light guide dimensions and the light source types, number and placement. It is also possible to cut light guide 1000 along cut lines 1020 and 1022 to create a second light guide. The second light guide has one dimension, the cross guide dimension, that is different than the first light guide, and it includes a portion of the extraction pattern 1002.

Light Extractor Patterns Designed for Flexible Extraction

FIG. 11 illustrates yet another light guide 1100 with an extraction pattern 1102 where the depiction of the light extractor pattern is similar to FIGS. 9 and 10. The darker portion 1108 near the center of the pattern indicates that there are extractor features with greater height in that portion. The lighter shading in portion 1110 surrounding the portion 1108 indicates smaller light extractor features or less. The extraction pattern 1102 is designed for use with multiple light guide configurations, and has more effective features in the center of the pattern. Because the extraction pattern 1102 is designed with fewer

effective features near its edges, trimming the light guide near its edges will result in less impact on the uniformity of the display area.

Some examples of different light guide outlines that could be used with the extraction pattern 1102 include first light guide outline 1111, second light guide outline 1112, third light guide outline 1114. The first light guide 1100 is shown integrated into a display device 1116.

In another embodiment, the light extractor pattern 1102 is a uniform pattern of light extractors in a first direction, such as having the same shape, height and density across a first direction of a first major surface of the light guide. In another embodiment, the light extractor pattern 1102 is a uniform pattern of light extractors in two directions: the first direction and a second perpendicular direction in the plane of the light guide.

Performance Characteristics of the First and Second Light Guides

Typical light guides, that have an extraction pattern that is designed for a particular light guide configuration, often achieve efficiency of 96% or greater. It is not uncommon for light guides to have even higher efficiency of 98%, 99% or 99.5%. The term efficiency means the percentage of the light coupled into the light guide at the edge adjacent to the light sources that is emitted from the first major surface of the light guide. One method of testing efficiency will be further described herein.

According to one embodiment of the light guide manufacturing process described herein, a second light guide uses an extraction pattern that was designed for a specific first light guide configuration, where the second light guide has at least one different dimension of its first major surface compared to the first light guide. The second light guide will have an efficiency that is equal to or less than the efficiency of the first light guide.

For example, in one embodiment, the output of a light guide manufacturing process includes a first light guide which includes a first extraction pattern on its first major surface. The light extractors of the first extraction pattern are configured to perform with a first level of efficiency which is at least 80%. The output of the light guide manufacturing process also includes a second light guide including a second extraction pattern on the first major surface of the second light guide. For the second light guide, the level of efficiency is at the first level or lower. At least one of the first and second dimensions of the first major surface of the second light guide are different from at least

one of the first and second dimensions of the first major surface of the first light guide. The second extraction pattern is identical to a portion of but not all of first extraction pattern. In one embodiment, the first level of efficiency is at least 90%.

In one embodiment, the second light guide allows at least 12% of the light introduced into the light guide to reach a second edge of the light guide opposite from the first edge where the light sources are located, where the second edge is not configured to recycle or return light into the light guide.

Method of Manufacturing Light Guides

One embodiment of a method of manufacturing light guides will now be discussed with reference to the specific example of the first light guide and the second light guide of FIG. 3. Though this discussion will reference FIG. 3, the same method steps could be applied to the first and second light guides shown and described with respect to FIGS. 2-6, 9 and 10.

First, a first extraction pattern 302 is designed for use with a first light guide. The first light guide has a specific configuration, including dimensions and has an associated set of light sources, which is taken into account when designing the first extraction pattern. For the example of FIG. 3, the first light guide has the dimensions of the first light guide outline 304 and has an extended light source, which is positioned along a first edge 310. The first extraction pattern includes light extractor locations for use on a first major surface 308 of the first light guide.

Next steps are forming light extractors in the light extractor locations of the first extraction pattern on a first substrate 300 and a second substrate 350. The light guide can be manufactured using any suitable manufacturing method, such as UV cast and cure, extrusion such as extrusion casting, co-extrusion, or other known methods. Molding methods including compression molding, insert molding and injection molding are also possible. As an example, a light guide 110 of FIG. 1 can be manufactured by co-extruding flexible layers 120 and 130, followed by a compression molding step during which extractors 140 are formed in surface 121 using a microreplication tool.

A further step is cutting the first light guide having the first extraction pattern 302 from the first substrate 300. The cutting is performed along the first light guide outline 310.

In some situations, there may be a desire to use the second substrate to manufacture a light guide of a different configuration than the first light guide. To accomplish this, another step is cutting a second light guide from the second substrate 350, where the second light guide has a first major surface 358 that has at least one dimension that is different than the dimensions of the first major surface of the first light guide. The second light guide includes at least a portion of one of the copies of the first extraction pattern. It is possible for all four edges of the substrate to be cut in the same step.

In some embodiments of the method, the substrates 300, 350 are web substrates where each web substrate has a down web dimension that is at least 10 times greater than its cross web dimension. In some embodiments, a cross guide dimension, a down guide dimension, or both dimensions of the first light guide are different than for the second light guide.

In some embodiments, an absorber is positioned along at least one edge of the second light guide.

In another embodiment of a method of manufacturing, the extraction pattern is designed to be used with multiple light guide configurations. This method will be described with reference to FIG. 11. A first step is designing a first extraction pattern 1110 for use with at least a first light guide 1111 and a second light guide 1112. The first extraction pattern comprises light extractor locations for use on a first major surface of the first light guide and on a first major surface of the second light guide. Another step is forming light extractors in the light extractor locations of the first extraction pattern on a first substrate. Yet another step is forming light extractors in the light extractor locations of the first extraction pattern on a second substrate.

A further step is cutting the first substrate to form the first light guide, which includes at least a portion of the first extraction pattern. Another step is cutting the second light guide from the second substrate including at least a portion of the first extraction pattern, wherein the second light guide has different dimensions than the first light guide.

Display System

FIG. 8 shows a schematic side-view of a display system 800 in accordance with one embodiment of the invention. Display system 800 includes light guide 110, a diffuser 820, a first light redirecting layer 830, a second light redirecting layer 840, and a display

panel 850 such as a liquid crystal panel. The light guide 110 includes the first flexible layer 120 and second flexible layer 130. The first flexible layer 120 includes light extractor bumps extending away from the second flexible layer 130. It is also possible for the light extractor bumps to extend toward the second flexible layer 130, which may be referred to as an inverted light guide configuration.

Display system 800 further includes a reflector 810 attached to light guide 110 by adhesive 801. Diffuser 820 is attached to light guide 110 and first light redirecting layer 830 with adhesives 802 and 803, respectively. Furthermore, first and second light redirecting layers 830 and 840 are attached by adhesive 804.

FIG. 8 shows adhesives 801-804 placed along opposite edges of display system 800. In general, each adhesive can be placed at one or multiple locations to provide adequate attachment between adjacent layers. For example, an adhesive may be placed along all edges of neighboring layers. In some applications, an adhesive may be placed at discrete locations along the periphery of adjacent layers. In some other applications, an adhesive may cover entire surfaces of adjacent layers. For example, adhesive 801 may cover substantially the entire surfaces 811 and 812 of reflector 810 and light guide 110, respectively.

Light redirecting layer 830 includes a microstructured layer 831 disposed on a substrate 832. Similarly, light redirecting layer 840 includes a microstructured layer 841 disposed on a substrate 842. Light redirecting layers 830 and 840 can be conventional prismatic light directing layers previously disclosed, for example, in U.S. Patent Nos. 4,906,070 (Cobb) and 5,056,892 (Cobb). For example, microstructured layer 831 can include linear prisms extended linearly along the y-axis and microstructured layer 841 can include linear prisms extended linearly along the z-axis.

The operation of a conventional light redirecting layer has been previously described, for example, in U.S. Patent No. 5,056,892 (Cobb). In summary, light rays that strike the structures in microstructured layers 831 and 841 at incident angles larger than the critical angle are totally internally reflected back and recycled by reflector 810. On the other hand, light rays which are incident on the structures at angles less than the critical angle are partly transmitted and partly reflected. An end result is that light redirecting layers 830 and 840 can result in display brightness enhancement by recycling light that is totally internally reflected.

The exemplary embodiment shown in FIG. 8 includes a number of adhesive layers such as adhesive layers 802 and 803. In some applications, one or more of the adhesive layers in display system 800 may be eliminated. For example, in some applications adhesive layers 802, 803, and 804 may be eliminated in which case the remaining layers
 5 may be aligned with respect to each other by other means such as by aligning the edges of the layers or by including alignment tabs.

Efficiency Measurements

The efficiency of a light guide can be determined using an integrating sphere
 10 which is designed for measurement of the total flux output of light sources. The light guide with its LEDs exposed is positioned within the integrating sphere. One example of a detector that can be used with an integrating sphere assembly is the SDA-050-P photo detector assembly available from Labsphere, Inc., North Sutton, New Hampshire. The photo detector assembly includes a silicon photovoltaic detector. A sphere light is present
 15 in the integrating sphere. The output of the photo detector assembly is used to determine efficiency according to the following formula:

$$E = S_m / (S_t(S_1 * S_a) / (S_0 * S_b))$$

20 The following variables are readings of the photo detector assembly when the following conditions are present:

- S_m is the light guide and LED masked, LED only is on.
- S_t is the LED only, LED only is on (total light output of LED)
- S_1 is the light guide and LED masked, LED is off, sphere light is on
- 25 • S_a is the current meter reading for the light guide and LED masked, LED only is on
- S_0 is the LED only, LED is off, sphere light is on
- S_b is the current meter reading for the LED, LED only is on

Examples

30 To illustrate the effectiveness of the approach described herein, three sets of example first and second light guides were produced and then were tested for a variety of luminance characteristics including uniformity of luminance across the display, total

luminance of the display and the ratio of the standard deviation of the luminance to the average luminance. Three different web substrates were used, each having an extraction pattern. Then a first light guide and second light guide were produced from each of the three web substrates, where the first and second light guides have different dimensions and outlines.

FIG. 12 and 13 show the outlines of the first light guide 1200 and the second light guide 1300, respectively. Some of the aspects of the first and second light guides are listed in Table A below.

First light guide 1200 in FIG. 12 includes five LED light sources 1202. The outline of the light guide 1200 is generally rectangular but includes clipped corners 1204 near the leading edge 1206, and two tabs 1208 on each side, for a total of four tabs 1208. The outer down guide dimension DG is 49.01 mm, and the cross guide dimension CG (not including the tabs) is 35.15 mm. First light guide 1200 includes a mixing zone 1210 adjacent to the leading edge 1206, where no light extractors are present. The down guide dimension of the mixing zone MZ is 1.73 mm.

Second light guide 1300 in FIG. 13 also includes five LED light sources 1302. The outline of the light guide is generally rectangular with square corners 1304, a leading edge 1306, two tabs 1308 on each side, and a fifth tab 1308 on the edge 1312 opposite from the leading edge 1306. The outer down guide dimension DG is 49.92 mm, and the cross guide dimension CG (not including the tabs) is 35.34 mm. No mixing zone is present in the second light guide.

Table A. Comparison of Characteristics of First and Second Light Guides

	First light guide	Second light guide
Outer Down Guide Dimension	49.01 mm	49.92 mm
Cross Guide Dimension without Tabs	35.15 mm	35.34 mm
Length of Mixing Zone	1.73 mm	None
Corner Configuration	Clipped	Square
Number of Tabs	4	5

Table B shows the results for the first and second light guides prepared from three different web substrates, each web substrate having different patterns of light extractors. The luminance characteristics of each light guide were measured using a luminance detector. Maximizing the total luminance from a display device is an important goal, so

that power can be conserved in the device. But also important is the uniformity of light across the surface of the display device.

Table B. Comparison of Characteristics of First and Second Light Guides

	First light guide	Second light guide
FIRST PATTERN – FIG. 14		
Uniformity	81%	70.8%
Luminance	5065 nits	5107 nits
ST/AVG Luminance	8%	11.9%
SECOND PATTERN – FIG. 15		
Uniformity	83%	86.2%
Luminance	5179 nits	5410 nits
ST/AVG Luminance	7%	6.5%
THIRD PATTERN – FIG. 16		
Uniformity	78.8%	73.5%
Luminance	5129 nits	5362 nits
ST/AVG Luminance	8.2%	9.8%

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Luminance was measured using a digital camera to record an image of the display at specific display points, where the camera was directly above the display point to be measured. The digital image was then used to determine a luminance value. The specific display points were those set forth in the Video Electronic Standards Association (VESA) 3.0 luminance measurement standard. FIGS. 14-16 include iso-luminance diagrams showing a luminance distribution of output emission yielded by the first and second light guides for the three patterns. FIG. 14 shows the diagrams for the first pattern, where diagram 1402 is for the first light guide and diagram 1404 is for the second light guide. FIG. 15 shows the diagrams for the second pattern, where diagram 1502 is for the first light guide and diagram 1504 is for the second light guide. FIG. 16 shows the diagrams for the third pattern, where diagram 1602 is for the first light guide and diagram 1604 is for the second light guide. Edges 1406, 1408, 1506, 1508, 1606 and 1608 of the diagrams in FIGS. 14-16 correspond to the leading edges of the light guides tested.

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In each iso-luminance diagram the different regions of shading indicate different levels of luminance, where the scale on the FIG. indicates the level of luminance in nits, or candela per square meter. The diagrams were originally created using a color scale to indicate the level of luminance, which has been converted to a gray scale. While some of the shades of gray are difficult to distinguish from each other, the iso-luminance diagrams

are useful for showing that the luminance distributions is still acceptable even when the dimensions of the light guide and outline of the light guide changes. It will be appreciated that the regions closest to the leading edges are generally brighter than the areas near the middle of the light guides. Also, brighter areas are present opposite to the leading edges,
5 because a reflector is positioned at the far edge of the light guide.

For the diagrams for the second light guides 1404, 1504 and 1604, which do not include a mixing zone, bright areas are observable near the locations of the LEDs.

Generally, the luminance characteristics are desirable for both the first and second light guides, illustrating that a web substrate having an extraction pattern can be used for light
10 guides with more than one different configuration.

All patents, patent applications, and other publications cited above are incorporated by reference into this document as if reproduced in full. While specific examples of the invention are described in detail above to facilitate explanation of various aspects of the invention, it should be understood that the intention is not to limit the invention to the
15 specifics of the examples. Rather, the intention is to cover all modifications, embodiments, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A method for manufacturing light guides comprising the steps of:
 - a. designing a first extraction pattern for use with a first light guide, wherein:
 - 5 i. the first extraction pattern comprises light extractor locations for use on a first major surface of the first light guide;
 - b. forming light extractors in the light extractor locations of the first extraction pattern on a first substrate location;
 - c. forming light extractors in the light extractor locations of the first extraction
10 pattern on a second substrate location;
 - d. cutting the first light guide having the first extraction pattern from the first substrate location; and
 - e. cutting a second light guide from the second substrate location, wherein:
 - 15 i. the second light guide has a first major surface that has at least one dimension that is different than the dimensions of the first major surface of the first light guide, and
 - ii. the second light guide includes at least a portion of but not all of one of the copies of the first extraction pattern.
- 20 2. The method of claim 1, wherein the first and second substrate locations are on one or more substrates, wherein the substrates are web substrates, each web substrate having a cross web direction and a down web direction, wherein for each web substrate the down web dimension is at least 10 times greater than its cross web dimension.
- 25 3. The method of claim 2 wherein a cross web dimension, a down web dimension, or both dimensions of the first light guide are different than for the second light guide.
- 30 4. The method of claim 1 further comprising the step of positioning an absorber along at least one edge of the second light guide.

5. The method of claim 1 wherein each of the first and second light guides comprises a first flexible layer and a second flexible layer, the light extractors being discrete light extractors capable of extracting light propagating in the light guide such that light is extracted uniformly over substantially the entire first major surface of the first light guide.
6. The method of claim 5 wherein the first flexible layer of each of the first and second light guides has a substantially flat land area separating the plurality of discrete light extractors, the average thickness of the land area being no greater than 10 microns.
7. The method of claim 1 wherein the first and second substrate locations are on a single substrate.
8. The method of claim 1 wherein the first and second substrate locations are on two different substrates.
9. A method for manufacturing light guides comprising the steps of:
- designing a first extraction pattern for use with at least a first light guide and a second light guide, wherein:
 - the first extraction pattern comprises light extractor locations for use on a first major surface of the first light guide and on a first major surface of the second light guide;
 - forming light extractors in the light extractor locations of the first extraction pattern on a first substrate location;
 - forming light extractors in the light extractor locations of the first extraction pattern on a second substrate location;
 - cutting the first light guide from the first substrate location comprising at least a portion of but not all of the first extraction pattern;
 - cutting the second light guide from the second substrate location comprising at least a portion of the first extraction pattern, wherein the second light guide has different dimensions than the first light guide.

10. The method of claim 9, wherein the first extraction pattern is a pattern of light extractor locations that are evenly spaced along at least one direction.

5 11. The method of claim 10, wherein the light extractor locations are evenly spaced along a second direction perpendicular to the one direction.

12. The method of claim 9, wherein the first and second substrate locations are on one or more substrates, wherein the substrates are web substrates having a cross web direction and a down web direction, wherein for each web substrate the down web dimension is at
10 least 10 times greater than its cross web dimension

13. The method of claim 12 wherein a cross web dimension, a down web dimension, or both dimensions of the first light guide are different than the second light guide.

15 14. The method of claim 9 further comprising the step of:
a. positioning an absorber along at least one edge of the first light guide.

15. The method of claim 14 further comprising positioning an absorber along at least
20 one edge of the second light guide.

16. The method of claim 9 wherein the first and second substrate locations are on a single substrate.

25 17. The method of claim 9 wherein the first and second substrate locations are on two different substrates.

18. A light guide comprising:
a. a first major surface and a second major surface,
30 b. an extraction pattern on the first major surface comprising light extractors capable of extracting light propagating in the first light guide;

- c. one or more light sources positioned along a first edge of the light guide which introduce light into the light guide;
- d. wherein the light guide has an efficiency of 88% or less and
- e. wherein the edges of the light guide are not configured to recycle or return
5 light into the light guide.

19. The light guide of claim 18 further comprising an absorber positioned along the second edge.

10 20. The light guide of claim 18 wherein the light guide comprises a first flexible layer and a second flexible layer, the light extractors located on the first flexible layer and being discrete light extractors capable of extracting light propagating in the light guide such that light is extracted uniformly over substantially the entire first major surface of the light
15 guide.

21. The light guide of claim 20 wherein the first flexible layer has a substantially flat land area separating the plurality of discrete light extractors, the average thickness of the land area being no greater than 10 microns.

20 22. An output of a light guide manufacturing process comprising:

a. a first light guide having a first major surface that has a first dimension and a second dimension, the first light guide having a first edge and a second edge opposite the first edge, the first light guide comprising:

25 a first extraction pattern on the first major surface comprising light extractors capable of extracting light propagating in the first light guide, wherein the first extraction pattern is configured to perform with a first level of efficiency which is at least 80%, wherein efficiency is measured as the percentage of light introduced into the first light guide at the first edge that is extracted by the light extractors and does not reach the second edge of the first light guide; and

30 b. a second light guide having a first major surface that has a first dimension and a second dimension, the second light guide further having a first edge and a second edge opposite the first edge; the second light guide comprising:

a second extraction pattern on the first major surface comprising light extractors capable of extracting light propagating in the first light guide, wherein the second extraction pattern is identical to a portion of but not all of the first extraction pattern, wherein the second light guide performs at a second level of efficiency lower than the first level of efficiency ;

wherein at least one of the first and second dimensions of the first major surface of the second light guide are different from at least one of the first and second dimensions of the first major surface of the first light guide.

23. The output of claim 22 wherein the first level of efficiency is at least 90%.

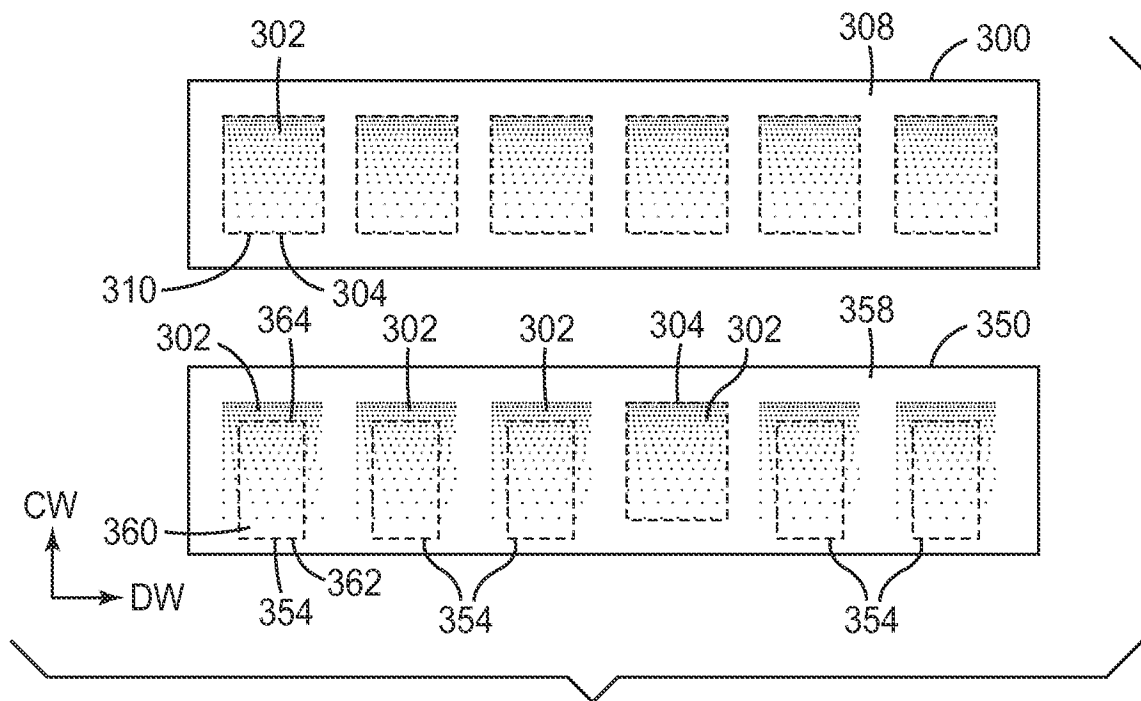


FIG. 3

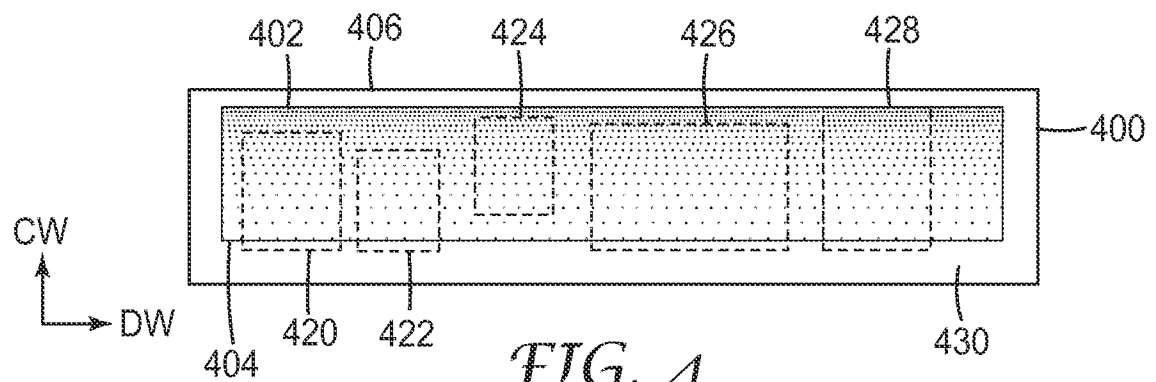


FIG. 4

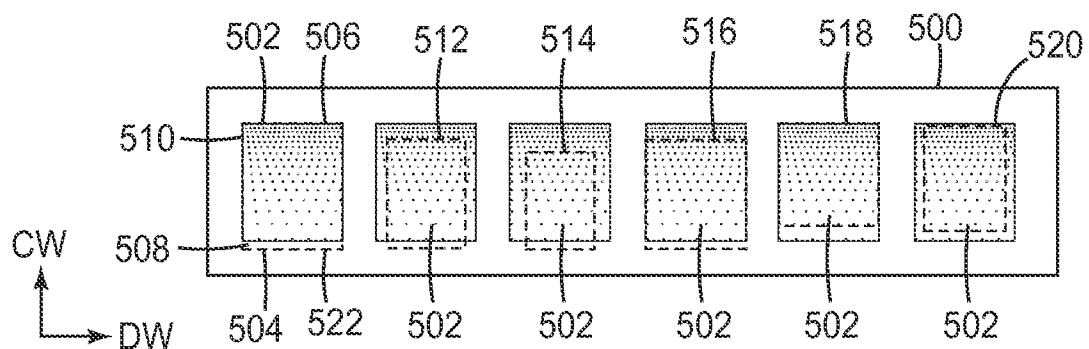


FIG. 5

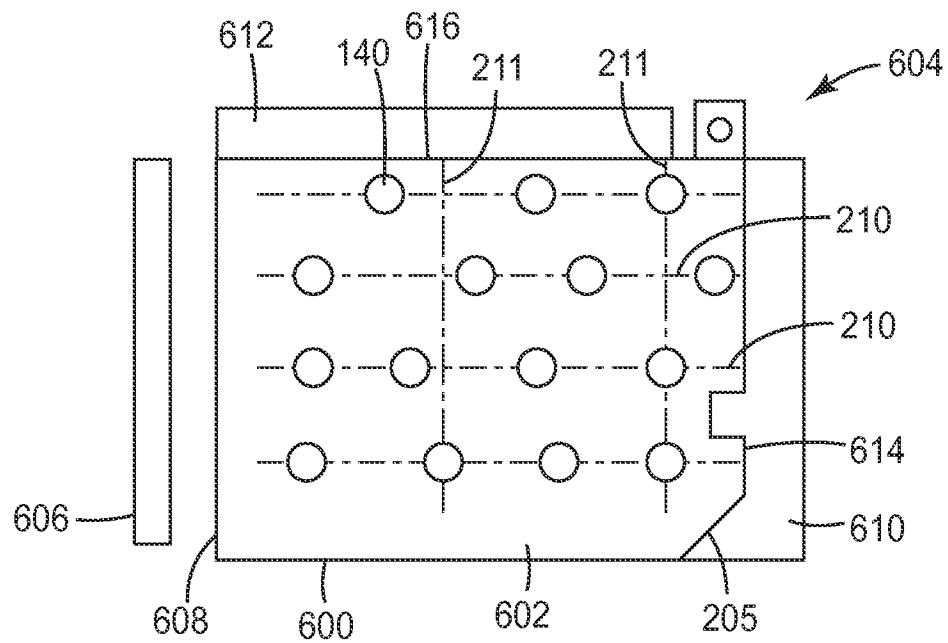


FIG. 6

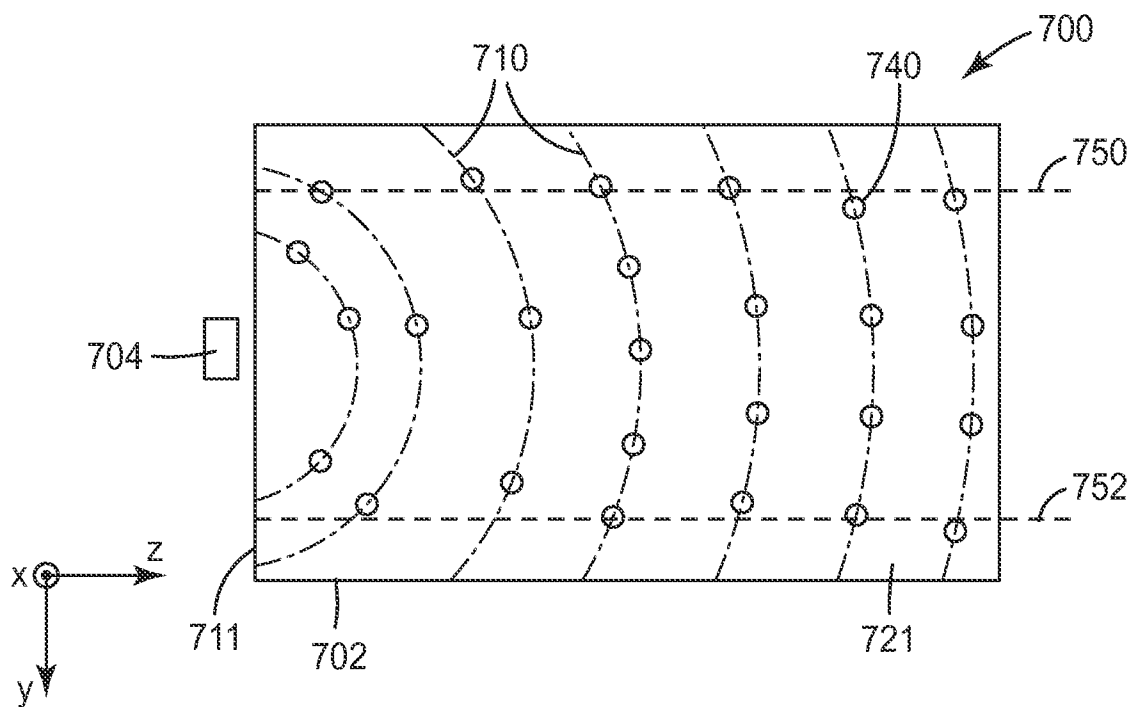
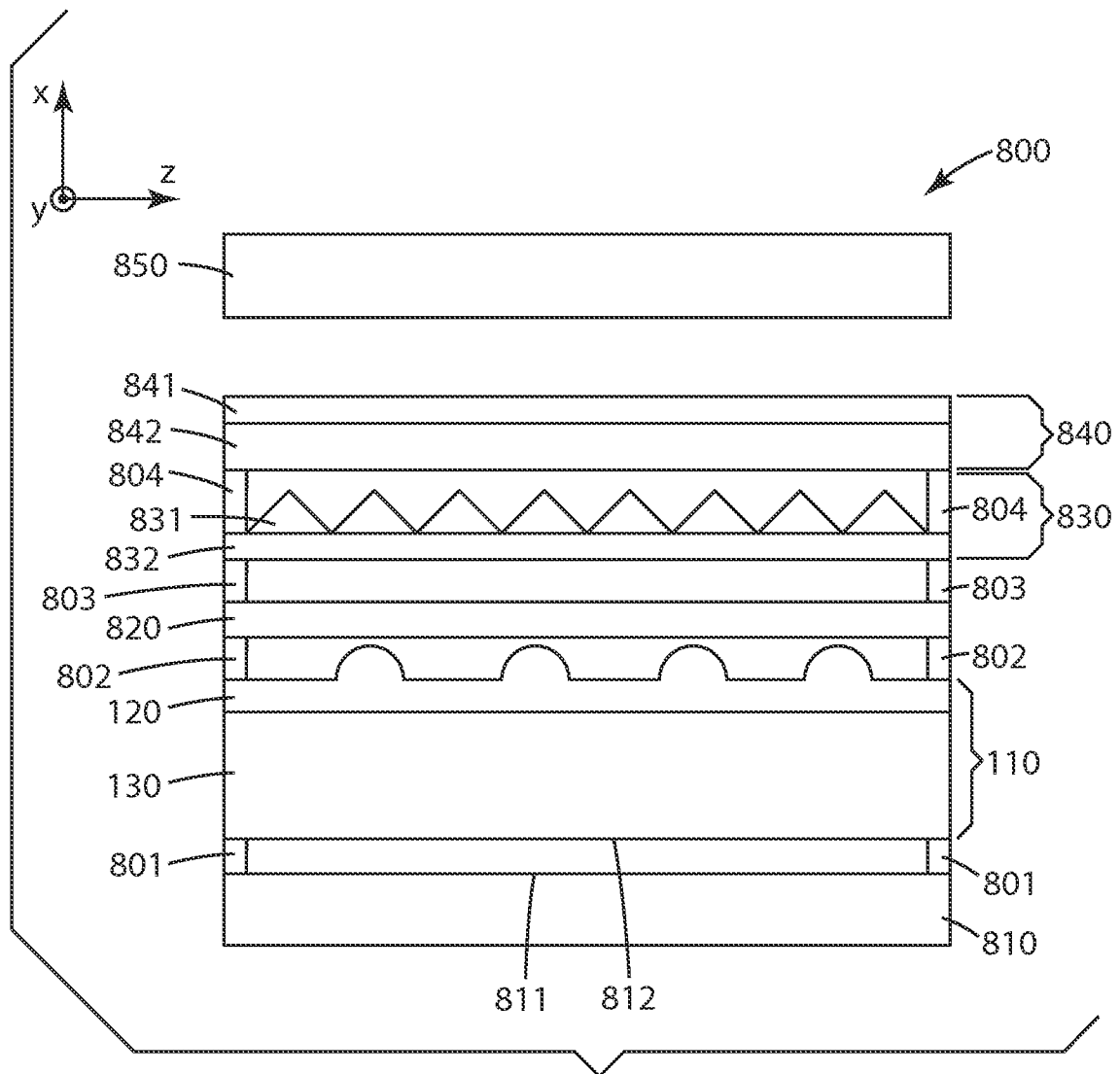
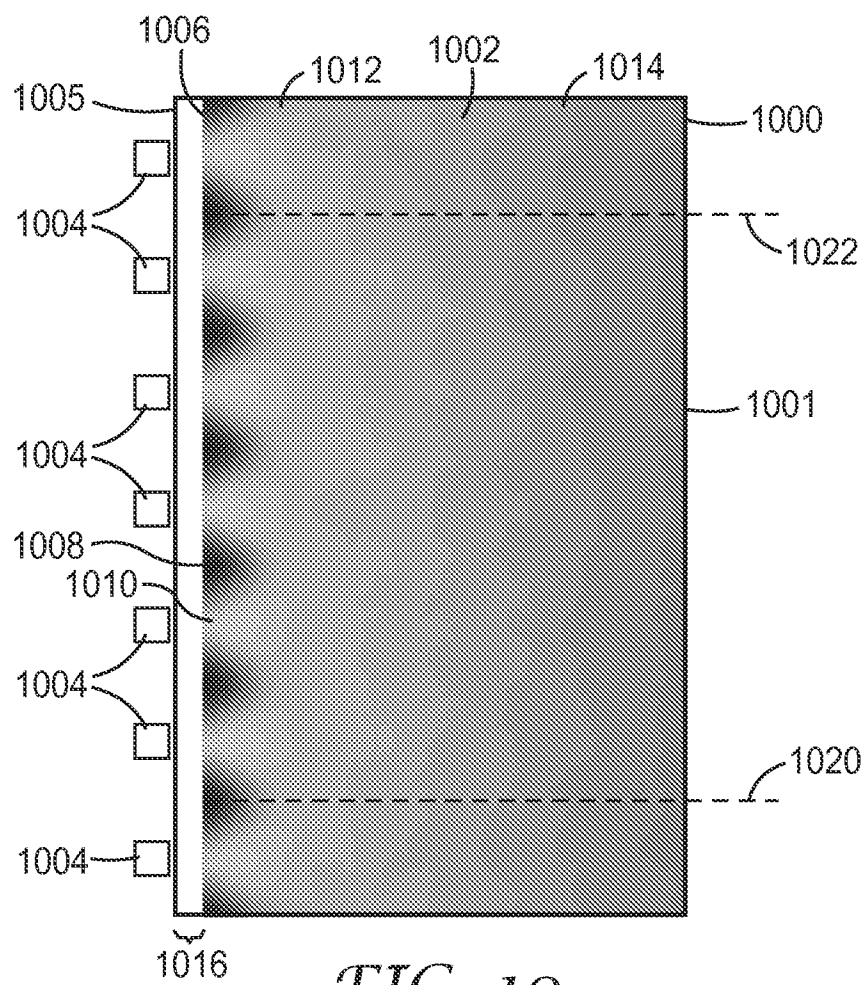
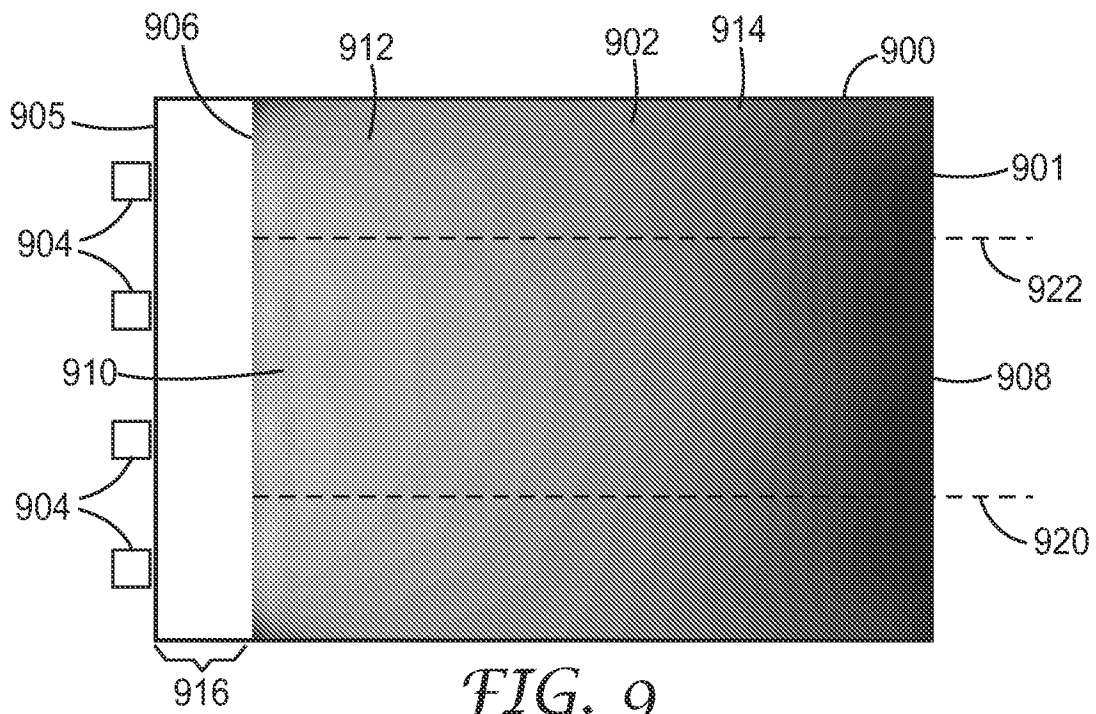
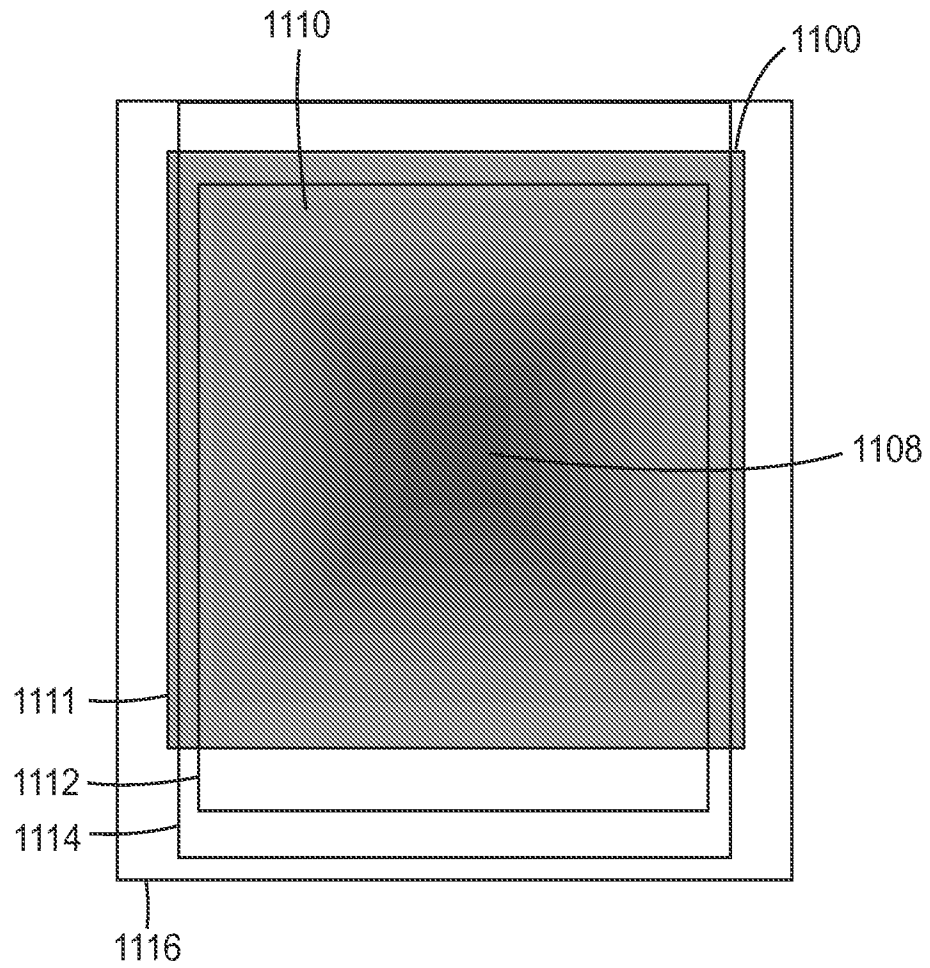


FIG. 7

*FIG. 8*

5/10



*FIG. 11*

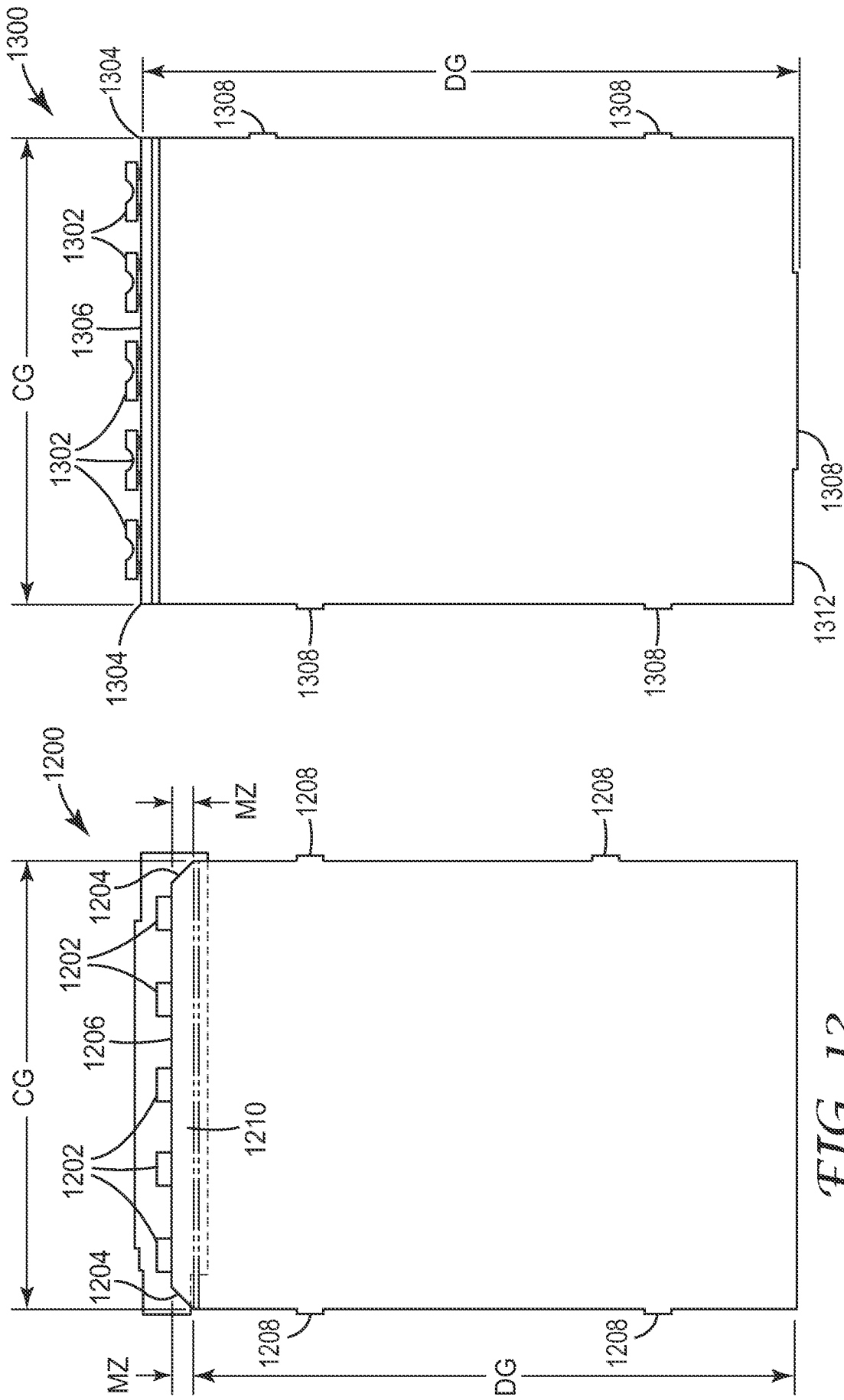


FIG. 12

FIG. 13

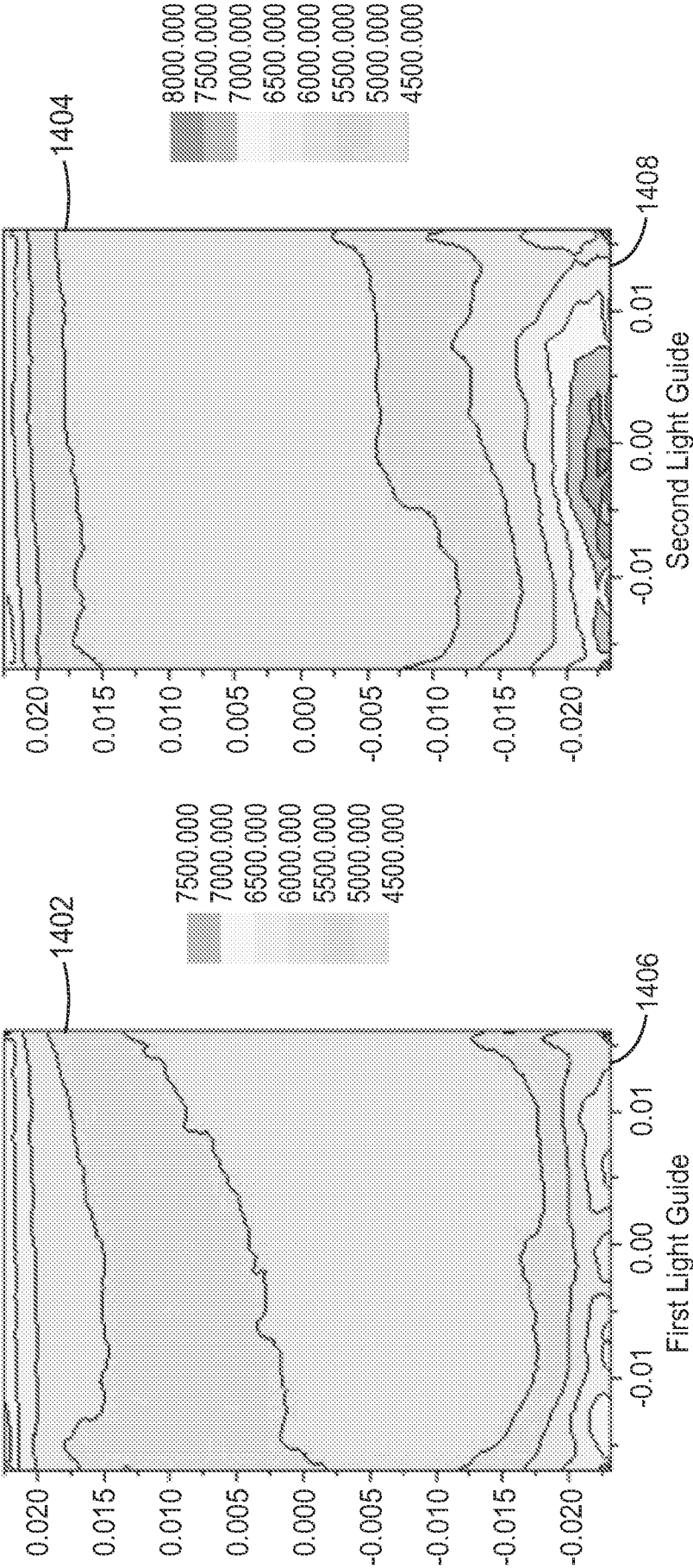


FIG. 14

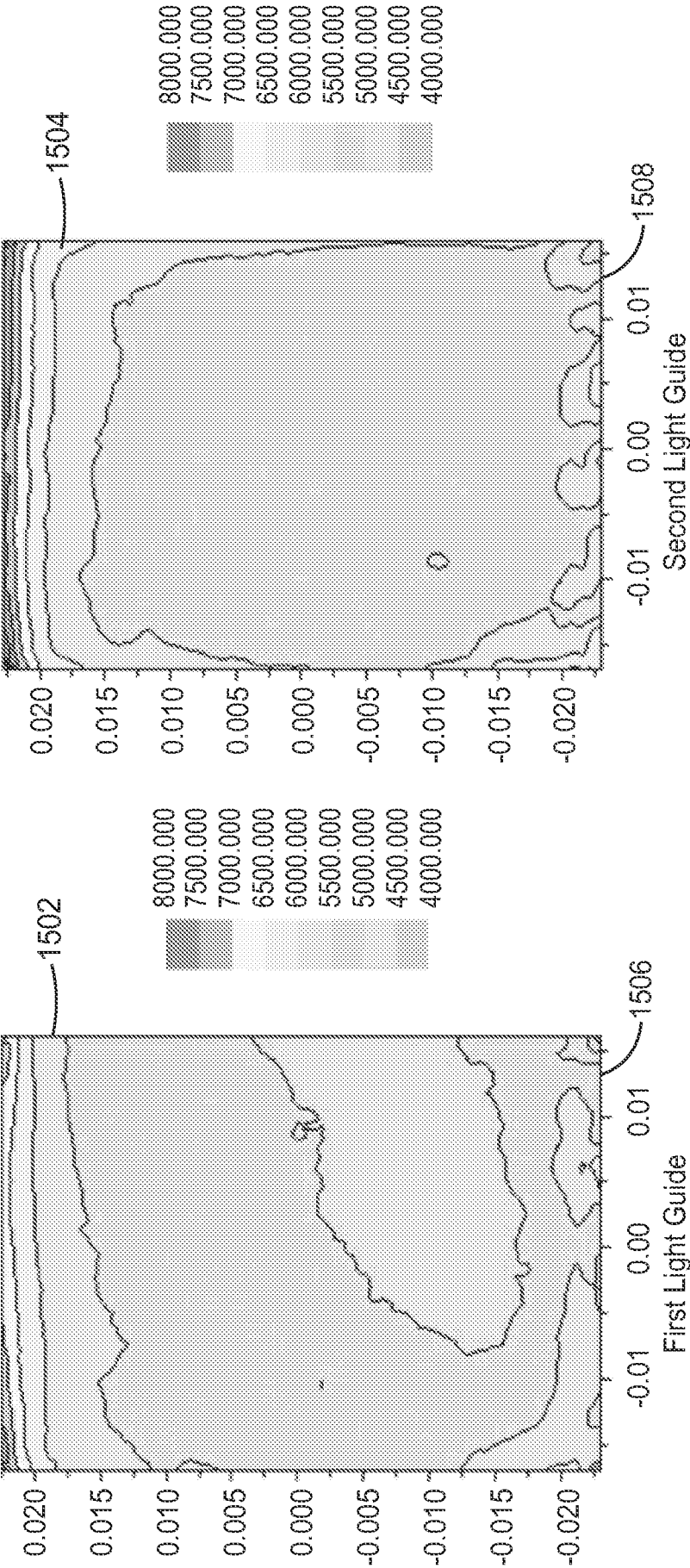


FIG. 15

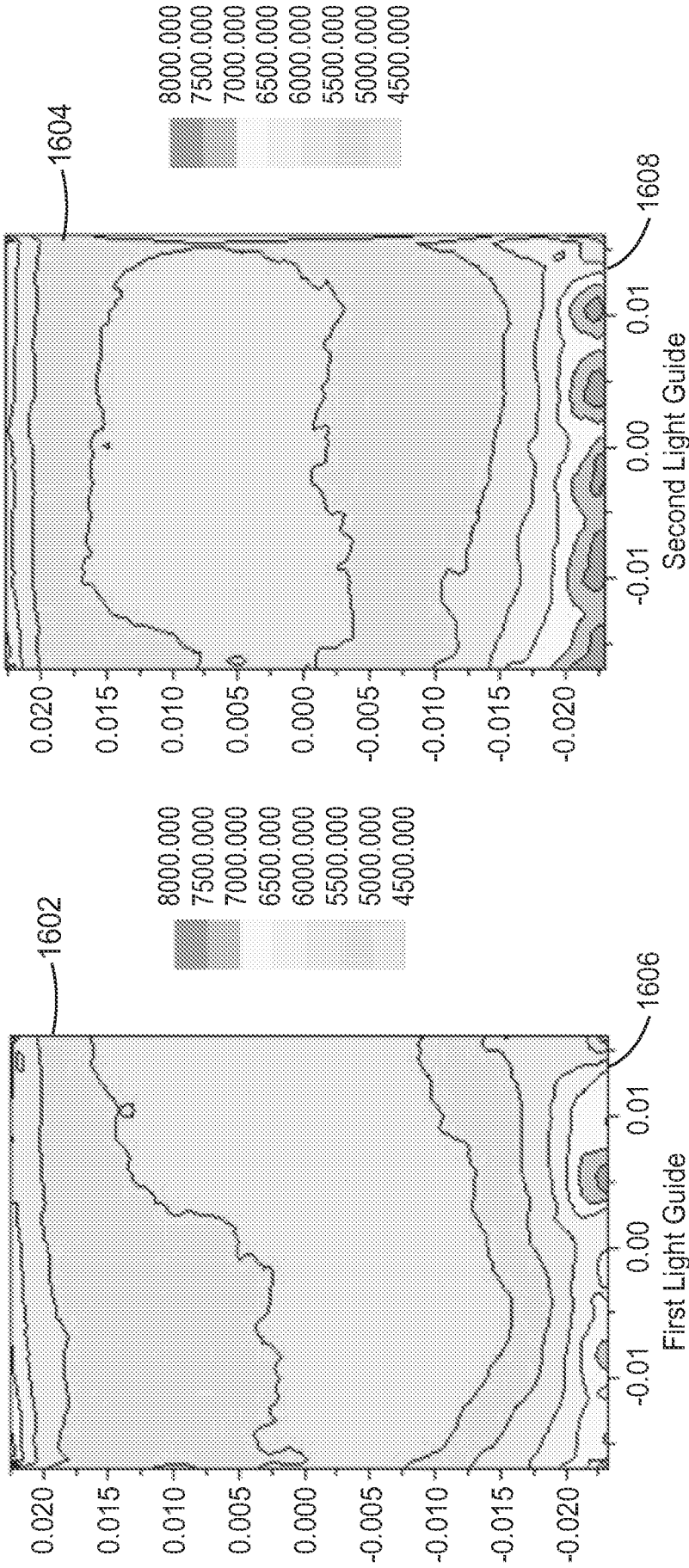


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/065312

A. CLASSIFICATION OF SUBJECT MATTER

INV. G02B6/00

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)
G02B

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 practical, search terms used)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/088367 A1 (NOKIA CORP [FI]; OESTERGARD TONI [FI]) 22 September 2005 (2005-09-22) abstract; figures 5-8 page 19, last paragraph - page 20, last paragraph	1-23
X	WO 2005/062908 A2 (SOLID STATE OPTO LTD [GB]; PARKER JEFFERY R [US]; MC COLLUM TIMOTHY A) 14 July 2005 (2005-07-14) abstract; figures 56-60 page 23, line 30 - page 25, line 16	1-23
X	WO 2005/050298 A1 (JEONG MOON INFORMATION CO LTD [KR]; LEE JAE-SOOK [KR]) 2 June 2005 (2005-06-02) abstract; figures 3a,3b page 6, line 1 - page 7, line 5	1-23

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

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

17 February 2010

Date of mailing of the international search report

24/02/2010

Name and mailing address of the ISA/

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Authorized officer

Jakober, François

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2009/065312

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