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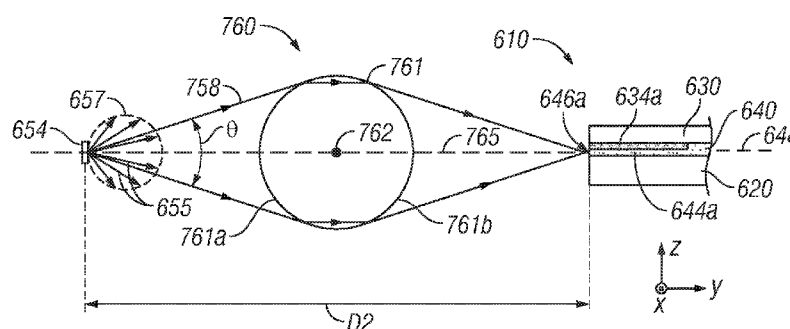
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(54) **Title:** EDGE CURE FOR DISPLAY ASSEMBLIES HAVING A MASKED TRANSPARENT ADHESIVE

**FIG. 7**

(57) **Abstract:** A technique for producing a bonded display assembly uses actinic radiation from a series of discrete LEDs, and an anamorphic optical system. The display assembly comprises a cover glass, a display housing, and an initially uncured adhesive layer. A peripheral mask lies between the adhesive layer and the cover glass, such that corresponding peripheral portions of the adhesive layer are masked from direct illumination through the cover glass. Actinic light from the LEDs is injected into a first masked portion of the adhesive layer through an adhesive edge, after such light passes through or is otherwise redirected by the anamorphic optical system. The anamorphic optical system, such as one or more cylindrical lenses, is configured such that the redirected light (a) spreads out along the adhesive edge, and (b) is focused onto the adhesive edge in a reference plane perpendicular to the adhesive edge.

EDGE CURE FOR DISPLAY ASSEMBLIES HAVING A MASKED TRANSPARENT ADHESIVE

5 FIELD OF THE INVENTION

This invention relates generally to liquid crystal displays and the like, and assemblies and subassemblies thereof, and methods of making such displays and assemblies. The invention also relates to associated articles, systems, and methods.

10 BACKGROUND

Liquid crystal display (LCD) devices are ubiquitous in the modern world. They can be found in numerous products ranging from mobile phones and smart phones to gaming devices, tablet and laptop computers, TVs, watches, and many other portable and semi-portable electronic devices that display images or other information on a screen. The devices use a layer of liquid crystal (LC) material sealed between two transparent plates, and two polarizers on opposite sides of the LC layer. This subassembly of layers and components is referred to herein as a display housing.

The LCD devices also often include a front transparent protective or reinforcing layer which we refer to herein as a cover glass. The cover glass may be made of glass, and is thick or robust enough to adequately protect the display housing from dust, chemicals, abrasion, and other potentially harmful agents, or to provide rigidity or stiffness to reinforce the display housing, or both. The cover glass substantially completely covers the upper or front exposed surface of the display housing. The cover glass permanently attaches to the display housing by a transparent adhesive bonding layer. The adhesive is transparent to permit viewing of the display, since a large central portion of the adhesive layer is in the active or useful area of the display screen, defined by the useable display area of the display housing. During manufacture of the LCD device the transparent adhesive is initially applied in an uncured state, in some cases as a liquid. The transparent adhesive is later cured, e.g. by heat, ultraviolet (UV) light, or a combination of both (depending on the composition of the adhesive), to make the bond between the cover glass and the display housing permanent and robust.

In devices of interest, an opaque mask layer is printed on a marginal or peripheral portion of the cover glass. The mask layer may for example have a generally rectangular

shape similar in appearance to a narrow picture frame, when viewed from the standpoint of an ordinary observer of the LCD device. The mask layer blocks, hides, or otherwise conceals certain components of the display housing—such as light sources, mechanical systems, and electrical components that form the bezel of the display—so they cannot be
5 seen by the ordinary observer.

The mask layer however can interfere with the curing of the adhesive layer, particularly at the margins or periphery of the cover glass for an adhesive that relies on UV light as one of the curing agents, or as the only curing agent. This is because the UV light used for curing is typically directed at the adhesive layer through the cover layer, and
10 therefore also through the mask layer. This approach gives rise to a shadowing effect by the mask layer that greatly reduces the intensity of the UV light in the portion of the adhesive layer under the mask. The shadowing effect can result in one or more of: longer curing times; greatly increased UV light intensity used for curing; or only partial curing of the shadowed portion of the adhesive layer. An adhesive that is not fully cured can lead to
15 toxicity and sensitization concerns for users.

One proposed solution to this problem is disclosed in U.S. Patent 8,599,342 (Kobayashi et al.). Kobayashi describes, among other things, irradiating the photocuring resin from only a side surface of the resin layer. In discussing the light source that is used to do the irradiating, Kobayashi says it may be arranged along the whole long side of the
20 rectangular laminated body, and further, the light source may be formed of a small light source such as a point light source, and the light may be irradiated to the laminated body while moving the light source in an extending direction of a long side of the laminated body.

BRIEF SUMMARY

We recognize that the Kobayashi technique results in an effective cure depth that is substantially larger than the standard technique because curing takes place from the edge rather than the front of the structure, leading to a lower degree of cure, as well as a spatially non-uniform cure and a resulting development of non-uniform stresses. Such
30 stresses can create color non-uniformity in the finished display.

We describe techniques for bonding a masked cover glass to a display housing using a transparent curable adhesive layer, where curing of the adhesive layer is

accomplished using, at least, a series of discrete LEDs in combination with an anamorphic optical system such as one or more cylindrical lenses or mirrors. Actinic radiation, such as blue, violet, or UV light from the LEDs, is captured by the anamorphic optical system and redirected into the adhesive layer through a narrow side surface or edge of the adhesive layer. The anamorphic optical system allows the captured LED light to spread out along the adhesive edge, while also focusing such light in a plane perpendicular to the adhesive edge. This provides a beam of curing radiation that is both high intensity and that has a good spatially uniformity along the edge of the adhesive layer.

Furthermore, we disclose techniques for producing a bonded display assembly using actinic radiation from a series of discrete LEDs, and an anamorphic optical system. The display assembly comprises a cover glass, a display housing, and an initially uncured adhesive layer. A peripheral mask lies between the adhesive layer and the cover glass, such that corresponding peripheral portions of the adhesive layer are masked from direct illumination through the cover glass. Actinic light from the LEDs is injected into a masked portion of the adhesive layer through an adhesive edge, after such light is redirected by the anamorphic optical system. The anamorphic optical system captures or receives light from the LEDs and redirects that light to spread the light out along the adhesive edge, while also focusing the received light onto the adhesive edge in a reference plane perpendicular to the adhesive edge.

We also disclose apparatuses for bonding a cover glass to a display housing in an uncured or non-bonded display assembly to produce a bonded display assembly, where the uncured display assembly includes the cover glass, the display housing, an adhesive layer therebetween, and a peripheral mask attached to the cover glass, the adhesive layer including a masked portion covered by the peripheral mask, and an unmasked portion, the adhesive layer initially being uncured, the adhesive layer also terminating to form an adhesive edge proximate the masked portion. The apparatus includes a stage, a light source arrangement, and an anamorphic optical system. The stage is adapted to receive the uncured display assembly. The light source arrangement includes a series of discrete LEDs that are mounted such that, when the uncured display assembly is received on the stage, the series of discrete LEDs extends along a direction generally parallel to the adhesive edge. The anamorphic optical system is mounted to receive light from the series of discrete LEDs, and to redirect the received light such that, when the uncured display

assembly is received on the stage, the redirected light spreads out along the adhesive edge, while also being focused onto the adhesive edge in a reference plane perpendicular to the adhesive edge.

Related methods, systems, and articles are also discussed.

5 These and other aspects of the present document will be apparent from the detailed description below. In no event, however, should the above summaries be construed as limitations on the claimed subject matter, which subject matter is defined solely by the attached claims, as may be amended during prosecution.

10 **BRIEF DESCRIPTION OF DRAWINGS**

FIG. 1 is a schematic perspective view of a system in which a masked cover glass is to be applied and bonded to a display housing to produce a bonded display assembly;

FIG. 2 is a schematic side or sectional view of a display assembly during a curing operation, where actinic radiation such as UV light passes through the cover glass to cure a transparent adhesive layer, but portions of the adhesive layer are shielded by a peripheral mask;

FIG. 3 is a schematic side or sectional view of a display housing;

FIG. 4 is a schematic side or sectional view of a display assembly that may be bonded or non-bonded, this view showing, among other things, how the edge of the adhesive layer may be recessed within the assembly;

FIG. 5 is a schematic perspective view of a display assembly being side-illuminated with UV light or other actinic radiation from a light source arrangement comprising a series of discrete LEDs;

FIG. 6 is a schematic side or sectional view of a side or end portion of a display assembly, illuminated by an LED or other discrete light source spaced apart from an edge of the adhesive layer, the view also illustrating the inefficient optical coupling represented by the narrow capture angle θ ;

FIG. 7 is a schematic side or sectional view of a side or end portion of a display assembly, illuminated by an LED or other discrete light source, and where an anamorphic optical system, such as a suitable cylindrical lens, receives light from the LED and redirects the received light onto the edge of the adhesive layer, providing a more efficient optical coupling as represented by a substantially wider capture angle θ ;

FIG. 7A is a schematic side or sectional view similar to FIG. 7, but where a reference plane associated with spreading of the LED light by the anamorphic optical system is not parallel to a reference plane defined by the adhesive layer;

FIGS. 8A and 8B are schematic perspective views of a discrete LED irradiating the edge of an adhesive layer with light using an anamorphic optical system, FIG. 8A illustrating how the anamorphic optical system focuses light from the LED onto the adhesive edge in a reference plane perpendicular to the adhesive edge, and FIG. 8B illustrating how the anamorphic optical system allows light from the LED to spread out in a perpendicular plane;

FIG. 9 is a schematic side or sectional view of a system in which light from an LED is collected and focused onto the adhesive layer edge by an anamorphic system comprising two parallel cylindrical lenses;

FIG. 10 is a schematic perspective view of a cylindrical lens, or other anamorphic optical element, whose cross-sectional shape has a constant radius of curvature;

FIG. 11 is a schematic perspective view of a cylindrical lens, or other anamorphic optic, whose cross-sectional shape has a variable radius of curvature to reduce aberrations;

FIG. 12 is a schematic side or sectional view of a system in which light from an LED is collected and focused onto the adhesive layer edge by an anamorphic system comprising a cylindrical mirror;

FIG. 13 is a schematic top view of a bonding or curing apparatus having a stage, a light source arrangement comprising four series of discrete LEDs, one series for each side of the stage, the apparatus also including anamorphic optical systems, in the form of two cylindrical lenses, disposed between each series of LEDs and the stage, the figure also showing a display assembly disposed on the stage;

FIG. 14 is a schematic front view of LED devices arranged to form a series of discrete LEDs, the series configured as two rows of LEDs;

FIG. 15A is a graph of irradiance versus position along the adhesive edge, for a setup in which only air is present between the series of discrete LEDs and the adhesive edge; and

FIG. 15B is a graph similar to FIG. 15A, but where a suitable anamorphic optical system is disposed between the series of LEDs and the adhesive edge.

In the figures, like reference numerals designate like elements.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

As mentioned above, we have developed techniques for more effectively curing the transparent adhesive layer of a display assembly in which a mask layer covers or shades peripheral portion(s) of the adhesive layer. The techniques can be used to provide a faster, easier, and more spatially uniform adhesive bond. When cured, the adhesive layer secures and bonds the display assembly together.

Figure 1 illustrates a display assembly of interest in a schematic, exploded view. The display assembly **110** includes a cover glass **130** and a display housing **120**, which are to be joined together and bonded by a transparent adhesive layer (not shown) to form a bonded display assembly. For convenience of description in this figure and in later figures, the display assembly **110** is shown in the context of a Cartesian x-y-z coordinate system, where the cover glass, the display housing, and the adhesive layer each lies generally in the x-y plane, or in a plane that is parallel to the x-y plane. Similar x-y-z coordinate systems are repeated and included in many of the other figures herein. This however should not be construed to mean that the disclosed display assemblies are limited to only planar configurations.

Mechanically, the cover glass **130** is typically rigid or at least semi-rigid to reinforce the structure of the finished display assembly. Optically, the cover glass **130** is generally transparent to visible light to allow a user to see the image produced by the display panel within the display housing **120**, with minimal reduction in brightness or clarity. The cover glass may thus be or comprise a layer of clear glass, or in some cases an optically clear plastic such as polymethylmethacrylate (PMMA) or polycarbonate. The thickness of the glass or plastic may depend on the physical size of the cover glass **120** in terms of its length, width, diagonal span, or other characteristic lateral dimension, but may typically range from about 200 micrometers for small displays on portable devices to about 10 mm for much larger displays, e.g., for billboards or other large outdoor applications. It is desirable in most cases to keep the cover glass, and all other components of the display assembly **110**, as thin as reasonably possible, so that the finished LCD device is as thin, low-profile, and light (not heavy) as possible.

Significantly, the cover glass **130** is “masked” in the sense that it comprises or has applied to it a mask layer or mask **134** that is limited to areas at or near the periphery of

the cover glass **130**. Such a mask **134** is opaque or substantially opaque, for example, having an average visible light transmission of less than 5%, or less than 1%. The low transmission may be due to optical absorption, optical scattering, or a combination thereof. The mask **134** is limited to peripheral areas in order to hide or conceal components of the display housing **120** located at the periphery of the display housing that would otherwise be visible to the user, such as light sources, mechanical systems, or electrical components, while not substantially encroaching upon the useable area of the display in the large central region of the cover glass **130**. The mask **134** shown in FIG. 1 is composed of four distinct mask portions **134a**, **134b**, **134c**, and **134d** corresponding to the four sides or edges of the cover glass **130** or display housing **120**. These mask portions form a rectangular shape similar in appearance to a narrow picture frame. In alternative embodiments, the mask **134** may have mask portions along only part of (less than all of) the perimeter of the cover glass **130**. For example, any one, or any two, or any three of the mask portions **134a**, **134b**, **134c**, **134d** may in some cases be omitted from the display assembly **110**. Each mask portion **134a**, **134b**, **134c**, **134d** has in-plane length and width dimensions that will depend on the size of the display assembly **110**. The width of a given mask portion may in some embodiments be as small as about 1 mm or even less (e.g. down to 0.1 mm), and in other embodiments may be as large as about 10 or even 25 mm, but these values should not be construed as limiting.

The mask **134** may be made of any suitable opaque material, for example, a black or dark ink printed onto a surface of the cover glass **130**, or a metal or other reflective or non-reflective opaque material selectively coated onto peripheral portions of the cover glass **130**. Materials such as one or more of a polymeric film, a deposited metal or inorganic material, a printed ink, and pigments such as titanium dioxide can be used. The mask **134** significantly blocks visible radiation from the edges of the display panel, and in some cases can form a frame through which the image area of the display is viewed. As a layer, the mask **134** has a thickness that is usually much less than that of the cover glass **130**, but this need not be the case in all embodiments.

The display housing **120**—shown only schematically in FIG. 1—is a subassembly that includes a layer of liquid crystal (LC) material sealed between two transparent plates, and two polarizers are usually also included on opposite sides of the LC layer. Details of typical display housings are discussed further below. The display housing **120** and cover

glass **130** may have the same or similar size and shape, e.g. they may be congruent or similar rectangles as shown in FIG. 1, such that at least some corners and edges of the cover glass **130** line up with corresponding features of the display housing **120** in the finished, bonded display assembly. However, this is not the case in all embodiments, as explained further below. Furthermore, other rectangular and non-rectangular shapes are also contemplated for the display assembly **110** and its constituent components.

In FIG. 2 we see a schematic side or sectional view of a display assembly **210** during a curing operation. The display assembly **210** includes a cover glass **230** and a display housing **220**, between which is a transparent adhesive layer **240**. The display assembly **210** also includes a peripheral mask layer **234**, which includes a first mask portion **234a** and a second mask portion **234b** located on the same surface but at opposite peripheral ends of the cover glass **230**. The mask portions **234a**, **234b** may for example correspond to mask portions **134a**, **134c** respectively of FIG. 1.

In the figure, the display assembly **210** is assumed to be non-bonded or uncured, by which we mean the adhesive layer **240** is uncured. This is apparent from the figure because actinic radiation or light **255** is being directed at the adhesive layer **240** through the cover glass **230** for the purpose of curing the adhesive layer **240**. Eventually, after sufficient exposure to the actinic light **255**, curing of the adhesive layer **240** can be considered complete. The reader familiar with organic chemistry will appreciate that curing is a process in which a monomer, an oligomer, or both are polymerized, causing an increase in the molecular weight of the material, and that the transition of a material from being (substantially) fully uncured to being (substantially) fully cured is an incremental process in which the material exhibits progressively greater levels of partial curing.

While we acknowledge this fact, in order to avoid becoming unnecessarily mired in this level of detail and to simplify our discussion of the invention, for purposes of this document (unless otherwise indicated to the contrary), we refer to an adhesive layer, or a display assembly containing such an adhesive layer, as “cured” or “bonded” when the degree of partial curing is high enough to satisfy a specified curing condition, whereas the adhesive layer or display assembly is considered “uncured” or “non-bonded” if such specified curing condition is not satisfied. We define the specified curing condition as follows: (a) at least 20% of the carbon-carbon double bonds (for example in a given masked portion of the adhesive layer, or in all such masked portions) have been converted

or reacted, as measured by FT-IR spectroscopy at the 6100-6200 cm^{-1} band, or (b) the adhesive layer exhibits a mechanical property wherein $G'/G'' > 1$ at room temperature and at 1 Hz via DMA, or (c) both (a) and (b).

The adhesive layer **240** may be any suitable adhesive material that is sufficiently
5 transparent. In an uncured state, the adhesive layer may be liquid and flowable, but in other cases it need not be liquid, e.g., it may be solid or substantially solid. In a cured state, the adhesive layer is solid or substantially solid, e.g., it may be a flowable material of extremely high viscosity. In the cured state, and in most cases in the uncured state, the adhesive layer is substantially transparent, i.e., it has a high average transmission over the
10 visible wavelength spectrum. Not counting Fresnel reflections at the outer major surfaces, the adhesive layer may have an average transmission over visible wavelengths of at least 80%, or at least 90%, or at least 95%. Known materials for use as the adhesive layer may include (depending on specific requirements of the intended application) any of the available 3M™ Optically Clear Adhesive (OCA) products, including product codes 8211,
15 8212, 8213, 8214, and 8215.

During fabrication of the display assembly **210**, before the cover glass **230** and display housing **220** are brought together to form the uncured display assembly, the uncured adhesive may initially be coated in a layer onto, or otherwise be applied to, (a) the lower major surface of the cover glass, or (b) the upper major surface of the display
20 housing, or (c) some uncured adhesive may be applied to the cover glass, and some may be applied to the display housing. In any of these cases, after the adhesive application procedure, the two parts are then brought together to form the uncured display assembly **210**.

Adhesive materials of interest for use in the layer **240** are curable by UV light or
25 other actinic light, but may also be at least partially curable with heat. The actinic light **255** may be ultraviolet (UV) light, or light of other wavelengths or bands of wavelengths, that interacts with the material composition of the adhesive layer **240** to promote chemical curing of the adhesive. In exemplary embodiments, the actinic light **255** is in the “A” region of the UV spectrum, i.e., in a wavelength range from 315 to 400 nm, rather than in
30 the shorter wavelength UVB (280 to 315 nm) or UVC (100 to 280 nm) ranges, but this should not be construed in an unduly limiting way. Violet light, at the short wavelength end of the visible spectrum close to the UV spectrum, may also be used for curing in some

cases. Generally, light in the UV spectrum, or short wavelength visible light such as blue or violet light, is more effective as actinic radiation than longer wavelength light, such as light in the infrared region of the spectrum, or long wavelength visible light, because of the higher quantum energy associated with the shorter wavelength radiation. However, long term or high exposure levels of short wavelength light such as UV light can sometimes cause yellowing or other damage in optical plastics or other optical materials.

The adhesive layer **240** may be or comprise a UV curable pressure-sensitive adhesive (PSA), as well as a liquid optically clear adhesive. Optically clear adhesives may be used in a transfer tape format, for example, where a liquid adhesive composition precursor is applied between two siliconized release liners, at least one of which is transparent to UV radiation that is useful for curing. The adhesive composition can then be cured (polymerized) by exposure to actinic radiation at a wavelength at least partially absorbed by a photoinitiator contained therein. A thermally activated free-radical initiator may also be used, where the liquid adhesive composition is coated between two siliconized release liners and exposed to heat to complete the polymerization of the composition. A transfer tape that includes a PSA can be thus formed. The formation of a transfer tape can reduce stress in the adhesive by allowing the cured adhesive to relax before lamination. For example, in a typical assembly process, one of the release liners of the transfer tape can be removed and the adhesive can be applied to the display housing. Then, the second release liner can be removed and lamination to the cover glass can be completed. In cases where the cover glass and the display housing are rigid, adhesive bonding can be assisted with vacuum lamination equipment to assure that bubbles are not formed in the adhesive or at the interfaces between the adhesive and the bonded components. The assembled components may then be submitted to an autoclave step to finalize the bond and make the display assembly **210** free of lamination defects.

In cases where a partially cured adhesive transfer tape is laminated between a masked cover glass (e.g. printed with an ink to form a peripheral mask) and a display housing, prevention of optical defects can be challenging because the partially cured adhesive may have to conform to a sometimes large ink step (e.g., 50-70 micrometers), and the total adhesive thickness acceptable in the display may for example only be 150-250 micrometers. Completely wetting this large ink step during initial assembly can be important, because any trapped air bubbles may become difficult to remove in subsequent

display assembly steps. The optically clear adhesive transfer tape may desirably have sufficient compliance (for example, low shear storage modulus, G' , at lamination temperature, typically 25°C, of $< 10^5$ Pascal (Pa) when measured at 1Hz frequency) to enable good ink wetting, by being able to deform quickly, and to comply to the sharp edge of the ink step contour. The adhesive of the transfer tape may also have sufficient flow to not only comply with the ink step but also wet more completely to the ink (mask) surface. The flow of the adhesive can be reflected in the high tan delta value of the material over a broad range of temperatures, e.g., $\tan \delta > 0.5$ between the glass transition temperature (T_g) of the adhesive (measured by DMTA) and about 50°C or slightly higher. The stress caused by the rapid deformation of the optically clear adhesive tape by the ink step requires the adhesive to respond much faster than the common stress caused by a coefficient of thermal expansion mismatch, such as in polarizer attachment applications where the stress can be relieved over hours instead of seconds or shorter. However, even those adhesives that can achieve this initial ink step wetting may still have too much elastic contribution from the bulk rheology, which can cause the bonded components to distort acceptably. Even if the bonded display components are dimensionally stable, the stored elastic energy (due to the rapid deformation of the adhesive over the ink step) may find a way to relieve itself by constantly exercising stress on the adhesive, eventually causing failure. Thus, as in the case of liquid bonding of the display components, the design of a transfer tape to successfully bond the display components requires a delicate balance of adhesion, optics, drop test tolerance, as well as compliance to high ink steps, and good flow even when the ink step pushes into the adhesive layer up to as much as 30% or more of its thickness.

Inspection of FIG. 2 reveals that while most of the actinic light **255** passes through the cover glass **230** to cure the adhesive material in the transparent adhesive layer **240**, portions of the adhesive layer **240** are shielded or shadowed by the opaque mask **234**. In this regard, as a result of the mask **234**, the display assembly **210** can be divided into a central unmasked region **212**, and peripheral masked regions **214a**, **214b**. In the unmasked region **212**, the actinic light **255** passes through the cover glass **230** and reaches the large central unmasked portion **242** of the adhesive layer **240**, where it is absorbed and its energy is used to crosslink molecules of the uncured adhesive. In the masked regions **214a**, **214b**, direct illumination of the masked portions **244a**, **244b** of the adhesive layer

240 is substantially or greatly diminished, depending on the angle(s) of incidence of the actinic light **255**. (In the figure, the propagation direction of the light **255** is shown as being normal (perpendicular) to the cover glass **230**, with an angle of incidence of 0 degrees, but the reader will understand the light **255** may be incident over a range of incidence angles from 0 to 90 degrees. Such light that propagates obliquely is refracted towards the perpendicular direction (z-axis) relative to its propagation direction in air as it passes through the cover glass **230** and the adhesive layer **240**.) Some indirect illumination of the masked portions **244a**, **244b** by the actinic light **255** may occur by secondary processes, e.g. by reflection or scattering of the actinic light **255** from surfaces or regions in the unmasked portion **242** of the adhesive layer. In any case, the flux level of the actinic light **255** in the masked portions **244a**, **244b** is diminished relative to the flux level the unmasked portion **242**, which can give rise to problems such as those mentioned above - longer curing times, greatly increased UV light intensity needed for curing, or only partial curing of the shadowed portion of the adhesive layer, as well as possible toxicity and sensitization concerns for users.

After curing is complete and the finished display assembly is incorporated into a LC display system, visible light from a backlight (not shown) disposed beneath or behind the assembly **210** can, in the unmasked region **212** of the assembly **210**, pass through the active area of the display housing, then through the adhesive layer **240**, and then through the cover glass **230** before reaching the eye of the user.

Additional features of the display assembly **210** are also labeled in FIG. 2, and will be briefly described here. The adhesive layer **240** lies generally in, or defines, a reference plane **248**. The reference plane **248** may be parallel to the x-y plane. The adhesive layer **240** also terminates to form a side surface or edge **246a** proximate the masked portion **244a**. On the opposite end of the adhesive layer, the layer **240** terminates to form a side surface or edge **246b** proximate the masked portion **244b**. The adhesive edges **246a**, **246b** both extend along longitudinal directions or axes that are parallel to the x-axis. The display housing **220** similarly terminates on its opposed sides or ends to form edges **226a**, **226b**. In the figure, the edges **246a**, **246b** of the adhesive layer are shown as being aligned or coplanar with the edges **226a**, **226b** respectively of the display housing. However, these edges may in other embodiments not be aligned with each other, as shown further below.

Turning now to FIG. 3, this figure schematically shows elements, components, and features that may be present in a display housing for use in the disclosed display assemblies. The display housing **320**, shown as extending generally parallel to the x-y plane, includes a layer of liquid crystal (LC) material **321** sealed between a front transparent plate **322** and a back transparent plate **323**. A sealant, comprising sealant portions **328a**, **328b**, prevents the LC material **321** from leaking. A front polarizer **324** is applied to the front transparent plate **322**, and a back polarizer **325** is applied to the back transparent plate **323**. These two polarizers are typically absorbing polarizers, and they are typically in a crossed configuration, whereby their respective pass axes (and their respective block axes) form an angle of about 90 degrees in the x-y plane. The polarizers **324**, **325** may be applied to their respective plates **322**, **323** by a suitable optically clear adhesive.

To the extent we may wish to refer to side surfaces or edges **326a**, **326b** of the display housing **320**, such edges may be a complex assortment or group of edges of the constituent layers of the display housing, in those cases where such constituent edges are not in alignment. The display housing **210** may also include a bezel made of metal, plastic, or other suitable bendable material(s). The bezel, which includes bezel portions **327a**, **327b**, may wrap entirely around the edge of the display housing **320**, or it may wrap around only a portion thereof. The bezel may also serve to hold together and reinforce the constituent elements of the display housing **320**.

In FIG. 4 we see in schematic form a display assembly **410** that may be bonded or non-bonded, i.e., the transparent adhesive layer **440** may be cured or uncured. The adhesive layer **440** contacts on a front major surface thereof a cover glass **430**, and on a back major surface thereof a display housing **420**. The adhesive layer **440**, cover glass **430**, and display housing **420** may be the same as or similar to other adhesive layers, cover glasses, and display housings discussed herein. The adhesive layer **440** extends along or defines a reference plane **448** parallel to the x-y plane. The adhesive layer **440** also terminates at outer ends or edges **446a**, **446b**. Each of the adhesive edges **446a**, **446b** extends along a direction or axis that is parallel to the x-axis. Surface forces between the transparent adhesive and surfaces in contact with the adhesive layer **440** may cause the adhesive edges **446a**, **446b** to curve or bow inwardly (as shown) or outwardly in a meniscus, rather than being substantially flat.

The cover glass **430** includes, or has applied to one or both major surfaces thereof, an opaque mask layer or mask **434**, which may be the same as or similar to other masks discussed herein. The mask **434**, which comprises opposed mask portions **434a**, **434b**, shadows or shields portions of the adhesive layer in such a way as to define an unmasked portion **442** of the adhesive layer **440** and peripheral masked portions **444a**, **444b** of the adhesive layer. The adhesive edge **446a** is disposed proximate the masked portion **444a**, and the adhesive edge **446b** is disposed proximate the masked portion **444b**. The adhesive layer **440** in fact contacts the surface of the mask portions **434a**, **434b** in the vicinity of the adhesive edges **446a**, **446b**, respectively.

The display housing **420** has outer edges **426a**, **426b** as shown, which are covered by bezel portions **427a**, **427b**, the bezel portions being part of a bezel which may wrap entirely or partially around the display housing **420**. The adhesive layer **440** has a lateral dimension (e.g. length or width) less than that of the cover glass **430**, and also less than that of the display housing **420**, such that the adhesive edges **446a**, **446b** are recessed to some extent within the display assembly **410**. One reason a display designer may wish to recess the adhesive edges **446a**, **446b** relative to the display housing **420** is to prevent the adhesive, when it is in a liquid or flowable state, from making contact with, and then wicking underneath, the bezel of the display housing.

We have already discussed problems that may result from the masked adhesive layer portions experiencing a slower curing than the unmasked adhesive layer portion. One approach to solving this problem is to supplement, or replace, the front actinic exposure (represented by actinic light **255** in FIG. 2) with side- or end-actinic light exposure. One embodiment of this approach is shown schematically in FIG. 5.

In this embodiment, a display assembly **510** that includes a cover glass **530**, a display housing **520**, and an adhesive layer **540** therebetween, is shown being illuminated from the side or end with actinic light **555** from a light source arrangement **550**. If desired, additional actinic light from other light sources (not shown) may impinge on the front surface of the cover glass **530**, similar to FIG. 2. The cover glass **530** includes, or has applied to it, a mask layer or mask **534** at peripheral portions of the cover glass. The cover glass **530**, mask **534**, adhesive layer **540**, and display housing **520** may be the same as or similar to corresponding elements discussed elsewhere herein. At or near one edge of the display assembly, the mask **534** has a first mask portion **534a**, the display housing

has a first edge **526a**, and the adhesive layer has a first masked portion **544a** and terminates at a first edge **546a** proximate the masked portion **544a**. At or near an intersecting edge of the display assembly, the mask **534** has a second mask portion **534b**, the display housing has a second edge **526b**, and the adhesive layer has a second masked portion **544b** and terminates at a second edge **546b** proximate the masked portion **544b**.

Actinic light **555** from the light source arrangement **550** illuminates the adhesive layer **540** from the side or edge, and enters the masked portion **544a** of the adhesive layer **540** predominantly through the adhesive edge **546a**. Such actinic light **555**—whose properties may be the same as or similar to the actinic light **255** discussed above—injected into the adhesive layer **540** in this fashion accelerates or promotes curing in the masked portion **544a** by increasing the flux of actinic light in that portion of the adhesive layer. If desired, other light source arrangements similar to the arrangement **550** may be used to side-illuminate other edges and masked portions of the adhesive layer **540**, such as the adhesive edge **546b** and the masked portion **544b**.

Although a variety of light sources may be used to provide the actinic light **555** used for curing the adhesive, the light source arrangement **550** is shown to use a series **552** of small, discrete light sources **554**, which we identify specifically as light emitting diodes (LEDs). LEDs provide some distinguishing features over other kinds of light sources that make them particularly suited for this application, although other features of LEDs present challenges. Before discussing these distinguishing features, we digress briefly to help explain what is meant by the term LED for purposes of this document. For our purposes, unless otherwise indicated, "LED" refers to a diode that emits light, whether visible, ultraviolet, or infrared, although ultraviolet and short wavelength visible wavelengths are of particular applicability to the disclosed embodiments for reasons discussed elsewhere. The term includes incoherent encased or encapsulated semiconductor devices marketed as "LEDs", whether of the conventional or super radiant variety, that emit incoherent light. The term also includes semi-coherent, or even coherent, light sources such as laser diodes (LDs), such coherent or semi-coherent sources typically having a spectral bandwidth substantially narrower than that of incoherent sources. The LED may be packaged to include a phosphor (or it may illuminate a remotely disposed phosphor) to convert short wavelength light to longer wavelength light. An "LED die" is an LED in its most basic form, i.e., in the form of an individual component or chip made by semiconductor

processing procedures. The component or chip can include electrical contacts suitable for application of power to energize the device. The individual layers and other functional elements of the component or chip are typically formed on the wafer scale, and the finished wafer can then be diced into individual piece parts to yield a multiplicity of LED dies.

LEDs are currently available with relatively high electrical-to-optical efficiencies, and high brightnesses in the blue and UV regions of the spectrum, of particular applicability in material curing applications. LEDs are also physically robust, not easily susceptible to damage or breakage, and they are known to have good reliability and long lifetimes even though their outputs degrade gradually over time.

The emitting die or chip of an LED is small, for example, square in shape with a side dimension of typically about 1 mm or less. As a result of the small size of the LED emitting area, in order to provide adequate actinic illumination along the entire adhesive edge **546a**, the light source arrangement **550** includes a plurality of LEDs **554** grouped in a series. In the illustrated embodiment, the LEDs **554** are spread out in a line along an axis **559**. The axis **559** may be parallel to an axis **549a** along which the adhesive edge **546a** extends, and spaced apart from the axis **549a** or from the adhesive edge **546a** by a distance **D** as shown. The LEDs **554** may have a uniform spacing **S** along the axis **559**, or their spacing may be non-uniform or variable.

One disadvantage of the setup of FIG. 5 is the geometrical inefficiency relating to the coupling geometry from the LED to the adhesive edge. The LED emits light over a wide range of directions, but only a small fraction of that emitted light enters the masked portion of the adhesive layer through the adhesive edge. This situation is illustrated in FIG. 6.

In the figure, a display assembly **610** includes a cover glass **630**, a display housing **620**, a transparent adhesive layer **640** therebetween, and an opaque mask that includes a mask portion **634a** disposed at a periphery of the cover glass **630**. The cover glass **630**, mask portion **634a**, display housing **620**, and adhesive layer **640** may be the same as or similar to corresponding elements discussed herein. The adhesive layer extends along or defines a reference plane **648**, which may be parallel to the x-y plane. The mask portion **634a** shields a masked portion **644a** of the adhesive layer **640** from front illumination

through the cover glass **630**. Proximate the masked portion **644a**, the adhesive layer **640** terminates to form an edge **646a**.

A stationary, side-mounted discrete LED **654** is located a distance **D1** from the adhesive edge **646a**. The LED **654**, which may be a non-encapsulated LED die, emits UV light or other actinic light **655**. The LED **654** may be the same as or similar to any of the LEDs **554** discussed above, and the light **655** may likewise be the same as or similar to actinic light **555**. The LED **654** may also be one LED in a series of discrete LEDs, as discussed above. The bare emitting surface of the LED **654** emits the light **655** in a wide angle output distribution or emission cone, which is labeled **657** in the figure. The output distribution **657** may for example be a Lambertian distribution. In any case, the LED **654** emits actinic light **655** over a fairly wide range of angles and directions. In the plane of the figure (the y-z plane), the portion of the light **655** that is directed toward, and propagates into, the adhesive edge **646a** is represented by the light capture envelope **658**. The capture envelope **658** is characterized by a capture angle θ .

Aspects of the arrangement of FIG. 6 can be modified to increase the amount of the actinic light **655** from the LED **654** that impinges on the adhesive edge **646a** in the y-z plane, but there are limits and tradeoffs when making such modifications. For example, the capture angle θ of the capture envelope **658** can be increased by decreasing the distance **D1**. However, decreasing **D1** produces increased non-uniformity along the length of the adhesive edge **646a** (i.e., hot spots along the x-axis near each LED **654**), for a given LED-to-LED spacing (see spacing **S** in FIG. 5). In another approach, the LED **654** could be encapsulated in a conventional domed encapsulant. This would cause the output distribution **657** to become narrower and more directed along the y-axis, thus increasing the amount of actinic light contained within the capture envelope **658**. However, the output distribution would also become narrower along the x-axis, which would again increase the non-uniformity of actinic light along the length of the adhesive edge **646a**. Furthermore, the encapsulant material would be susceptible to degradation and yellowing from extended exposure to high flux levels of short wavelength radiation.

To increase the flux of the actinic light impinging upon the adhesive edge without some of the negative consequences discussed above, in an arrangement that still uses a series of discrete LEDs as the source of side-illuminated actinic light, we propose introducing a suitable anamorphic optical system to help capture and focus or concentrate

actinic light in one plane, while allowing the actinic light to spread out along the adhesive edge in an orthogonal plane. A simple form of such an optical system is a cylindrical lens or mirror.

Turning then to FIG. 7, presented there is an arrangement for curing the adhesive layer of a display assembly much like that of FIG. 6, except that an anamorphic optical system is included. Like elements are identified with like reference numerals – such as display assembly **610**, cover glass **630**, display housing **620**, transparent adhesive layer **640**, opaque mask with mask portion **634a**, reference plane **648**, masked adhesive layer portion **644a**, adhesive layer edge **646**, LED **654**, actinic light **655**, and output distribution **657** – and their descriptions need not be repeated here. Figure 7 differs from FIG. 6 by the introduction of anamorphic optical system **760**, which receives the actinic light **655** from the LED **654**, and redirects the received light onto the adhesive edge **646a** of the transparent adhesive layer **640**.

In the illustrated embodiment, the anamorphic optical system **760** is a single cylindrical lens **761**. The cylindrical lens extends along a longitudinal axis **762** which is perpendicular to the plane of the figure, and hence parallel to the x-axis. The axis **762** may be an axis of symmetry of the lens. The term “cylindrical” is used herein in its mathematical sense; as such, the reader should understand that although the cross-sectional shape of the cylindrical lens **761** in the y-z plane is constant along the axis **762**, and the cross-sectional shape may in some cases be circular, the cross-sectional shape is not restricted to a circle, but may be any closed shape, for example, an ellipse, an oval, a many-sided polygon, or combinations thereof, such as where one or some portions of the cross-sectional shape are curved, and one or some other portions are straight or segmented.

The lens **761** has a first optical surface **761a** and a second optical surface **761b**. Both of these optical surfaces are curved in the illustrated embodiment in the y-z plane. Both optical surfaces thus provide refractive optical power in the y-z plane as a function of the curvature of the surfaces and the refractive index of the lens **761**. Because of this optical power, the lens **761** is able to intercept or receive actinic light **655** that propagates within a light capture envelope **758** characterized by a capture angle θ in the y-z plane, and focus a that light onto the adhesive edge **646a**. Note that the capture angle θ for the envelope **758** is substantially wider than the capture angle θ for comparable capture envelope **658** above.

The distance **D2** from the LED **654** to the adhesive edge **646a** in FIG. 7 may be adjusted relative to the distance **D1** in FIG. 6 to accommodate optimal LED-to-lens and lens-to-adhesive edge distances to ensure maximum illumination of the adhesive edge **646a**. The LED-to-lens and lens-to-adhesive edge distances may furthermore be selected such that the adhesive edge **646a** resides at a paraxial image plane for the LED **654**. That is, the lens **761** may image (in the y-z plane) the emitting surface of the LED **654** directly onto the adhesive edge **646a**. Furthermore, the distances can be selected to provide a desired magnification factor between the object (LED **654**) and the image (adhesive edge **646a**). The desired magnification factor may depend on the relative z-axis dimensions of the LED **654** and the adhesive edge **646a**, but may typically lie in a range from 0.25 to 4, or from 0.5 to 2, or the desired magnification may be about 1. In some cases it may be advantageous to slightly blur the actinic light **655** focused by the cylindrical lens **761** by positioning the adhesive edge **646a** a small distance away from (in front of or behind) the paraxial image plane.

A reference plane **765** can be drawn that passes through the center of the LED **654** and that contains the longitudinal axis **762** of the cylindrical lens **761**. In a cross-section of the cylindrical lens **761** through this reference plane **765**, the optical surfaces **761a** and **761b** become straight lines with no curvature. Consequently, actinic light **655** that propagates in or close to this plane **765** will experience little or no focusing by the lens **761**. Such light is thus relatively free to spread out within the plane **765** as the light travels from the LED **654** to the adhesive edge **646a**.

In alternative embodiments, the cylindrical lens **761** may be replaced or supplemented with an optical element or a combination of optical elements selected from: one or more cylindrical lenses, one or more cylindrical mirrors, and one or more non-cylindrical anamorphic lenses or mirrors. An anamorphic lens or mirror that is not cylindrical has at least one optical surface with a non-zero curvature (and thus a non-zero optical power) in a reference plane counterpart to reference plane **765**. Despite the non-zero optical power in the reference plane (for example where the anamorphic lens has a weak positive focusing power in the reference plane), such a non-cylindrical anamorphic lens or mirror may nevertheless be used by itself, or in combination with other suitable lenses or mirrors, to spread out actinic light **655** from the LED **654** along the adhesive

edge **646a**, provided the LED **654** is appropriately positioned relative to such non-cylindrical anamorphic lens or mirror.

In the embodiment of FIG. 7, the LED **654**, cylindrical lens **761**, and display assembly **610** are positioned such that the reference plane **765** defined by the LED and cylindrical lens is coplanar, or nearly coplanar, with the reference plane **648** defined by the adhesive layer of the display assembly. Other configurations are also possible. One such other configuration is shown in FIG. 7A, where like elements are identified with like reference numerals, with no further description needed. The setup of FIG. 7A differs from that of FIG. 7 only by a shift in the orientation of the display assembly **610** relative to the LED/cylindrical lens combination such that the reference planes **648** and **765** are no longer coplanar, and no longer parallel. In FIG. 7A, the planes **648**, **765** exhibit a non-zero and significant relative tilt angle γ . Despite this relative tilt, the anamorphic optical system **761** of FIG. 7A (like the system **761** of FIG. 7) receives light from the discrete LED **654** and redirects the received light to spread out along the adhesive edge **646a**, and focuses the received light onto the adhesive edge **646a** in a reference plane (e.g. the y-z plane) perpendicular to the adhesive edge **646a**.

The adhesive layer **640**, at least in its uncured state, may have a refractive index for the actinic light **655** that is greater than or less than that of the cover glass **630**, and greater than or less than that of the display housing **620** (or the portion of the display housing proximate the adhesive layer). By selecting the composition of the adhesive layer **640** such that its refractive index is greater than the cover glass **630**, or greater than the display housing **620** (or portion thereof proximate the adhesive layer), or both, light guiding e.g. by total internal reflection at one or both major surfaces of the adhesive layer can occur to trap at least some of the side-injected light **655** in the adhesive layer **640**, thus also increasing the curing depth and curing efficiency.

Figures 8A and 8B help illustrate some of the reference planes referred to above in connection with embodiments that include an anamorphic optical system. In these figures a discrete LED **854**, which may be one of a series of discrete LEDs, emits actinic light **855**, and some of that light is captured or received by an anamorphic optical system **860**. The anamorphic system **860** then injects the received light into a masked portion of a transparent adhesive layer through an edge of the adhesive layer to cure the adhesive.

Still referring to FIGS. 8A and 8B, actinic light **855** from a discrete LED **854** is used to crosslink or cure an uncured transparent adhesive layer **840**. The adhesive layer is part of a display assembly such as those of FIGS. 2, 4, or 5, but other elements of the display assembly, such as the cover glass, mask, and display housing, are omitted from
5 FIGS. 8A and 8B for ease of illustration. The adhesive layer **840** has a masked portion **844**, and the layer **840** terminates to form an adhesive side surface or edge **846** proximate the masked portion **844**, the adhesive edge extending along an axis **849**. The adhesive layer **840** may reside in the x-y plane, or in a reference plane parallel to the x-y plane, and the axis **849** may be parallel to the x-axis.

10 An anamorphic optical system **860** is provided that intercepts or receives some of the actinic light **855** from the discrete LED **854**. For simplicity, the system **860** is shown to have only one anamorphic lens **861**. The lens **861** extends along a longitudinal axis **862**, which may also be an axis of symmetry for the lens. The axis **862** is parallel to the x-axis and to the axis **849** associated with the adhesive edge **846**. The lens **861** may be
15 cylindrical, or it may be non-cylindrical, e.g., wherein its optical surfaces have a slight curvature in the x-y plane. The lens **861** may be made of any suitable optical material such as glass or plastic. Desirably, the optical material that is used is resistant to yellowing or other damage from prolonged exposure to UV or short wavelength light.

An optical axis **867** passes through the LED **854** and through the adhesive edge
20 **846**, and is perpendicular to the axis **849**. The optical axis **867** may also intersect the longitudinal axis **862**. A reference plane **866** is perpendicular to the adhesive edge **846**, passes through the LED **854**, and contains the optical axis **867**. In this reference plane **866**, the anamorphic lens **861** possesses optical power. The LED **854**, the anamorphic lens **861**, and the adhesive edge **846** are positioned with respect to each other so that actinic
25 light **855** received by the lens **861** is focused onto the adhesive edge **846** in the reference plane **866**.

Another reference plane **865** passes through the LED **854** and contains the longitudinal axis **849**. The reference plane **865** may also contain the longitudinal axis **862** and the optical axis **867**. The reference plane **865** is perpendicular to the reference plane
30 **866**. The reference plane **865** may in some cases be coplanar with the x-y plane, while in other cases there may be a nonzero angle of tilt γ between these planes. In the reference plane **865**, the anamorphic lens **861** may possess no optical power (if the lens is

cylindrical), or a small amount of optical power (if the lens is non-cylindrical). The LED **854**, the anamorphic lens **861**, and the adhesive edge **846** are positioned with respect to each other so that actinic light **855** received by the lens **861** spreads out along the adhesive edge **846** in the reference plane **865**. The spreading of the light in the plane **865** allows for
5 a more uniform exposure of the masked portion **844** of the adhesive layer to the actinic light **855**, and thus a more uniform curing of that portion of the adhesive layer.

In some cases, such as where the LED is or includes an incoherent LED die, the LED **854** may emit light **855** in an angular output distribution or emission cone that has the same or similar angular width (e.g. as determined by the full-angular-width-at-half-
10 maximum (FWHM) intensity) in the reference plane **865** as in the reference plane **866**. In other cases, such as where the LED is or includes a coherent source such as a laser diode, the LED **854** may emit light **855** in an angular output distribution or emission cone whose angular width (e.g. as determined by the FWHM intensity) is substantially narrower in one reference plane than the other. In such cases, the LED **854** is preferably oriented such that
15 the narrower angular width is oriented perpendicular to the adhesive edge **846** (e.g., parallel to the reference plane **866**), and the wider angular width is oriented parallel to the adhesive edge (e.g., parallel to the reference plane **865**).

Figure 9 shows a curing system in which an anamorphic optical system comprising two cylindrical lenses is used to collect and redirect actinic light from a discrete LED onto
20 an edge of a masked adhesive layer in a display assembly to cure the adhesive layer. The LED is represented by point **954**, and the edge of the adhesive layer is represented by point **946**. The anamorphic optical system **960** is made up of two cylindrical lenses **961**, **963**, having respective longitudinal axes **962**, **964**. A reference plane **965** contains the axes **962**, **964** as well as an optical axis, and passes through the LED **954** and through the
25 adhesive edge **946**, which is assumed to extend parallel to the x-axis (perpendicular to the plane of the figure). The optical powers and relative positions of the lenses **961**, **963** are selected so that the LED **954** is imaged onto the adhesive edge **946** in the y-z plane, or in a broader sense so that actinic light **955** from the LED **954** is concentrated or focused onto the adhesive edge **946**. In a perpendicular reference plane, light from the LED **954** that is
30 captured by the anamorphic optical system **960** illuminates and spreads out along the adhesive edge **946**.

Figures 10 and 11 explore details of curved optical surfaces that may be used in some of the anamorphic lenses and mirrors disclosed herein. In FIG. 10, a cylindrical lens **1061** extends along a longitudinal axis **1061**, which may also be an axis of symmetry. The axis **1061** is assumed to be parallel to the x-axis. A cross-section of the lens **1061** in the y-z plane reveals a curved shape for a first optical surface **1061a**, and a curved shape for a second optical surface **1061b**. The first optical surface **1061a** is assumed to be a semicircle, i.e., an arc or curve of constant curvature. Thus, a first portion **1061a-1**, a second portion **1061a-2**, and a third portion **1061a-3** of the optical surface **1061a** all have the same radius of curvature **R** and the same center of curvature **C**. In one possible embodiment, the lens **1061** may be circularly symmetric about the axis **1062**, such that the cross-sectional shape formed by the first and second optical surfaces is a circle of radius **R**.

In FIG. 11, a cylindrical lens **1161** extends along a longitudinal axis **1161**, which may also be an axis of symmetry. The axis **1161** is assumed to be parallel to the x-axis. A cross-section of the lens **1161** in the y-z plane reveals a curved shape for a first optical surface **1161a**, and a curved shape for a second optical surface **1161b**. The first optical surface **1161a** has a variable radius of curvature. Thus, a first portion **1161a-1** of the surface **1161a** has a first radius of curvature **R1** and a first center of curvature **C1**, a second portion **1161a-2** of the surface **1161a** has a second radius of curvature **R2** and a second center of curvature **C2**, and a third portion **1161a-3** of the optical surface **1161a** has a third radius of curvature **R3** and a third center of curvature **C3**, where **R1**, **R2**, and **R3** are unequal, and **C1**, **C2**, and **C3** are also unequal. The variable radius of curvature across the optical surface **1161a** may be tailored to reduce aberrations and increase the amount of flux from the discrete LED that is injected in to the edge of the adhesive layer. The second optical surface **1161b** may also have a variable radius of curvature, e.g. it may be a mirror image of the surface **1161a**, or it may have a constant curvature.

Figure 12 shows another curing system in which an anamorphic optical system is used to collect and redirect actinic light from a discrete LED onto an edge of a masked adhesive layer in a display assembly to cure the adhesive layer. Figure 12 is similar in that regard to FIG. 9, except that the two cylindrical lenses **961**, **963** are replaced with a single cylindrical reflector **1261**. The LED is represented by point **1254**, and the edge of the adhesive layer is represented by point **1246**. The anamorphic optical system **1260** is made

up of one cylindrical mirror **1261**, which may extend parallel to the x-axis (perpendicular to the plane of the figure). A reference plane **1265** contains an optical axis, and passes through the LED **1254** and through the adhesive edge **1246**, which is also assumed to extend parallel to the x-axis (perpendicular to the plane of the figure). The optical power and relative position of the mirror **1261** is selected so that the LED **1254** is imaged onto the adhesive edge **1246** in the y-z plane, or in a broader sense so that actinic light **1255** from the LED **1254** is concentrated or focused onto the adhesive edge **1246**. In a perpendicular reference plane, light from the LED **1254** that is captured by the anamorphic optical system **1260** illuminates and spreads out along the adhesive edge **1246**.

The foregoing lighting and curing systems can be used to construct an apparatus for bonding a cover glass to a display housing in an uncured display assembly to produce a bonded display assembly. Such an apparatus **1370** is shown schematically in FIG. 13. The apparatus **1370** is designed to receive an uncured display assembly, and to cure the adhesive layer—particularly the masked portions of the adhesive layer—using discrete LED sources of actinic light in a fast, efficient, and spatially uniform manner.

The apparatus **1370** comprises a stage **1372**, which may extend parallel to the x-y plane, and upon which an uncured display assembly **1310** can be placed. For simplicity we assume the display assembly includes: a cover glass **1330**; a mask **1334** having four mask portions **1334a**, **1334b**, **1334c**, **1334d**; an initially uncured adhesive layer that terminates to form four adhesive edges **1346a**, **1346b**, **1346c**, and **1346d** proximate corresponding masked portions of the adhesive layer; and a display housing, all arranged as discussed in detail above. Around the stage **1372** are mounted or otherwise arranged four side-illumination stations for efficiently coupling actinic light from discrete LEDs into masked portions of the adhesive layer when the display assembly **1310** is present on the stage **1372**, one such station for each of the four masked portions and edges of the adhesive layer. The apparatus **1370** uses a light source arrangement **1350** of discrete LED sources **1354** divided into four distinct series.

A first side-illumination station uses a first series **1352a** of LEDs **1354** and an anamorphic optical system **1360a** proximate the series **1352a**. In the first series **1352a**, the LEDs **1354** are spaced apart along a first axis **1359a**, which is parallel to the adhesive edge **1346a** and parallel to the x-axis. The LEDs **1354** emit actinic light (see e.g. the series **552** of LEDs in FIG. 5), a portion of which is received by the anamorphic optical

system **1360a**. The anamorphic system **1360a** redirects the received light to spread the light out along the adhesive edge **1346a**, and to focus the light onto the adhesive edge **1346a** in a reference plane parallel to the y-z plane. The anamorphic optical system **1360a** is composed of two cylindrical lenses **1361a**, **1363a**, similar to the system of FIG. 9.

5 A second side-illumination station uses a second series **1352b** of LEDs **1354** and an anamorphic optical system **1360b** proximate the series **1352b**. In the second series **1352b**, the LEDs **1354** are spaced apart along a second axis **1359b**, which is parallel to the adhesive edge **1346b** and parallel to the y-axis. The LEDs **1354** emit actinic light, a portion of which is received by the anamorphic optical system **1360b**. The anamorphic
10 system **1360b** redirects the received light to spread the light out along the adhesive edge **1346b**, and to focus the light onto the adhesive edge **1346b** in a reference plane parallel to the x-z plane. The anamorphic optical system **1360b** is composed of two cylindrical lenses **1361b**, **1363b**, similar to the system **1360a**.

 A third side-illumination station uses a third series **1352c** of LEDs **1354** and an
15 anamorphic optical system **1360c** proximate the series **1352c**. In the third series **1352c**, the LEDs **1354** are spaced apart along a third axis **1359c**, which is parallel to the adhesive edge **1346c** and parallel to the x-axis. The LEDs **1354** emit actinic light, a portion of which is received by the anamorphic optical system **1360c**. The anamorphic system **1360c**
20 redirects the received light to spread the light out along the adhesive edge **1346c**, and to focus the light onto the adhesive edge **1346c** in a reference plane parallel to the y-z plane. The anamorphic optical system **1360c** is composed of two cylindrical lenses **1361c**, **1363c**, similar to the system **1360a**.

 A fourth side-illumination station uses a fourth series **1352d** of LEDs **1354** and an
25 anamorphic optical system **1360d** proximate the series **1352d**. In the fourth series **1352d**, the LEDs **1354** are spaced apart along a fourth axis **1359d**, which is parallel to the adhesive edge **1346d** and parallel to the y-axis. The LEDs **1354** emit actinic light, a portion of which is received by the anamorphic optical system **1360d**. The anamorphic
30 system **1360d** redirects the received light to spread the light out along the adhesive edge **1346d**, and to focus the light onto the adhesive edge **1346d** in a reference plane parallel to the x-z plane. The anamorphic optical system **1360d** is composed of two cylindrical lenses **1361d**, **1363d**, similar to the system **1360b**.

In any or all of the four anamorphic optical systems, the two cylindrical lenses may be replaced with a single cylindrical lens, or a single cylindrical mirror, or non-cylindrical anamorphic lens(es) or mirror(s), or combinations thereof.

Upon placing the uncured display assembly on the stage **1372**, the discrete LEDs **1354** in one, some, or all of the series **1352a**, **1352b**, **1352c**, **1352d** may be energized to provide the actinic light needed to cure the masked portions of the adhesive layer. Additional discrete LEDs (not shown) may be provided in an array on a cover or lid that fits over the stage **1372** and display assembly **1310** to provide front surface actinic light as shown and described in connection with FIG. 2 above. In this manner, substantially all portions of the adhesive layer, both masked and unmasked, can experience high flux levels of actinic light for faster and more spatially uniform curing results.

Figure 14 illustrates a specific arrangement of LED devices that was used as the basis of a modeling simulation. In the simulation, three LED devices **1451** were provided to define a light source arrangement **1450** that included a series of discrete LEDs **1454a**, **1454b**. Each LED device **1451** included four LEDs: two upper LEDs **1454a** and two lower LEDs **1454b** arranged in a square formation as shown. These four LEDs were disposed behind a disk-shaped cover glass **1453**, which was in turn disposed on a circuit board. The LEDs **1454a**, **1454b** were assumed to be identical to each other, each having a 1 x 1 mm emitting area, each emitting the same UV actinic light, and each assumed to have a Lambertian output distribution or emission cone. The three LED devices **1451** were positioned together as shown in FIG. 14 such that the six LEDs **1454a** formed a first row along a first axis **1459a**, and the six LEDs **1454b** formed a second row along a second axis **1459b**. This light source arrangement is referred to hereafter as the modeled light source arrangement.

The modeled light source arrangement was used to simulate the light intensity as a function of position along the (modeled) adhesive edge of a display assembly. In a first simulation, the modeled light source arrangement was used in a system similar to that shown in FIG. 9. With reference to that figure, the modeled light source arrangement was oriented to face the cylindrical lens **961**, with the modeled light source arrangement centered at the point **954**, and with the axes **1459a**, **1459b** (FIG. 14) extending parallel to the x-axis. The edge of the adhesive layer was simulated as a narrow rectangular detector plane centered at the point **946** and extending parallel to the x-axis, the width of the

rectangle (i.e., its dimension parallel to the z-axis) being 0.150 mm. The cylindrical lenses **961**, **963** were assumed to have a refractive index of 1.53, and each was assumed to have a circular cross-sectional shape with a radius of 7.5 mm. The center-to-center distance between the cylindrical lenses **961**, **963** was 30 mm. Optical software was then used to
5 calculate the intensity of the actinic light (originating from the LEDs in the modeled light source arrangement) at the edge of the adhesive layer, as a function of position along the adhesive edge. The calculated light intensity versus position is shown as curve **1500b** in FIG. 15B.

For comparison, another simulation was done. This simulation was the same as the
10 prior simulation, except that the anamorphic optical system **960** was removed, and the distance between the modeled light source arrangement and the adhesive edge was shortened to the point where the average light intensity at the adhesive edge was the same as in the earlier simulation. The resulting calculated light intensity versus position on the adhesive edge is shown as curve **1500a** in FIG. 15A. Comparison of FIGS. 15A and 15B
15 demonstrates that the simulated anamorphic optical system provides better uniformity for curing the adhesive layer than by simply placing the LED sources closer to the adhesive edge.

Unless otherwise indicated, all numbers expressing quantities, measurement of properties, and so forth used in the specification and claims are to be understood as being
20 modified by the term “about”. Accordingly, unless indicated to the contrary, the numerical parameters set forth in the specification and claims are approximations that can vary depending on the desired properties sought to be obtained by those skilled in the art utilizing the teachings of the present application. Not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should
25 at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, to the extent any numerical values are set forth in specific examples described herein, they are reported as precisely as reasonably possible. Any numerical value, however, may well contain errors
30 associated with testing or measurement limitations.

Various modifications and alterations of this invention will be apparent to those skilled in the art without departing from the spirit and scope of this invention, and it

should be understood that this invention is not limited to the illustrative embodiments set forth herein. The reader should assume that features of one disclosed embodiment can also be applied to all other disclosed embodiments unless otherwise indicated. It should also be understood that all U.S. patents, patent application publications, and other patent
5 and non-patent documents referred to herein are incorporated by reference, to the extent they do not contradict the foregoing disclosure.

CLAIMS

1. A method of bonding a cover glass to a display housing to provide a bonded display
5 assembly, the method comprising:

providing a light source arrangement including a first series of discrete LEDs;
providing an assembly comprising the cover glass, the display housing, an adhesive
layer therebetween, and a peripheral mask between the cover glass and the adhesive
layer, wherein the adhesive layer:

10 is initially uncured,

includes a first masked portion covered by the peripheral mask, and an unmasked
portion, and

terminates to form a first adhesive edge proximate the first masked portion;

providing a first anamorphic optical system proximate the first series of discrete LEDs
15 to receive light from the first series of discrete LEDs and to redirect the received
light to (a) spread out along the first adhesive edge, and (b) focus the received light
onto the first adhesive edge in a first reference plane perpendicular to the first
adhesive edge; and

energizing the first series of discrete LEDs so that light from the first series of discrete
20 LEDs, after being redirected by the first anamorphic optical system, enters the
adhesive layer through the first adhesive edge to cure at least the first masked portion
of the adhesive layer.

2. The method of claim 1, wherein the adhesive layer defines a second reference plane,
25 and wherein the second reference plane is perpendicular to the first reference plane.

3. The method of claim 2, wherein the providing the first anamorphic optical system is
carried out such that the first anamorphic optical system spreads out the received light in
the second reference plane.

30 4. The method of claim 1, further comprising:

positioning the assembly proximate the light source arrangement such that the first series of discrete LEDs extends along a direction generally parallel to the first adhesive edge.

5 5. The method of claim 1, wherein providing the first anamorphic optical system includes providing a first cylindrical lens between the first series of discrete LEDs and the first adhesive edge.

6. The method of claim 5, wherein the first cylindrical lens has a cross-sectional shape
10 whose radius of curvature is constant.

7. The method of claim 5, wherein the first cylindrical lens has a cross-sectional shape whose radius of curvature is variable.

15 8. The method of claim 5, wherein the first anamorphic optical system includes no cylindrical lenses other than the first cylindrical lens.

9. The method of claim 5, wherein the first anamorphic optical system includes the first cylindrical lens and a second cylindrical lens.

20 10. The method of claim 1, wherein the first anamorphic optical system includes a first cylindrical mirror.

11. The method of claim 1, wherein the first series of discrete LEDs comprises two
25 distinct rows of LEDs, each such row extending along a direction generally parallel to the first adhesive edge.

12. The method of claim 1, wherein the light source arrangement further includes a second series of discrete LEDs, and wherein the adhesive layer terminates to form a
30 second adhesive edge proximate a second masked portion of the adhesive layer, the second adhesive edge being opposite the first adhesive edge, the method further comprising:

providing a second anamorphic optical system proximate the second series of discrete LEDs to receive light from the second series of discrete LEDs and to redirect the received light to (a) spread out along the second adhesive edge, and (b) focus the received light onto the second adhesive edge in the first reference plane.

5

13. The method of claim 12, wherein the light source arrangement further includes a third series of discrete LEDs, and wherein the adhesive layer defines a second reference plane perpendicular to the first reference plane, and terminates to form a third adhesive edge proximate a third masked portion of the adhesive layer, the third adhesive edge being disposed between the first and second adhesive edges, the method further comprising:

10

providing a third anamorphic optical system proximate the third series of discrete LEDs to receive light from the third series of discrete LEDs and to redirect the received light to (a) spread out along the third adhesive edge, and (b) focus the received light onto the third adhesive edge in a third reference plane, the third reference plane being perpendicular to both the first and second reference planes.

15

14. The method of claim 13, wherein the light source arrangement further includes a fourth series of discrete LEDs, and wherein the adhesive layer terminates to form a fourth adhesive edge proximate a fourth masked portion of the adhesive layer, the fourth adhesive edge being opposite the third adhesive edge, the method further comprising:

20

providing a fourth anamorphic optical system proximate the fourth series of discrete LEDs to receive light from the fourth series of discrete LEDs and to redirect the received light to (a) spread out along the fourth adhesive edge, and (b) focus the received light onto the fourth adhesive edge in the third reference plane.

25

15. The method of claim 14, wherein the first, second, third, and fourth adhesive edges form a rectangular shape.

16. An apparatus for bonding a cover glass to a display housing in an uncured display assembly to produce a bonded display assembly, the uncured display assembly comprising the cover glass, the display housing, an adhesive layer therebetween, and a peripheral mask attached to the cover glass, the adhesive layer including a first masked portion

30

covered by the peripheral mask, and an unmasked portion, the adhesive layer initially being uncured, and terminating to form a first adhesive edge proximate the first masked portion, the apparatus comprising:

a stage adapted to receive the uncured display assembly;

5 a light source arrangement including a first series of discrete LEDs that are mounted such that, when the uncured display assembly is received on the stage, the first series of discrete LEDs extends along a direction generally parallel to the first adhesive edge; and

10 a first anamorphic optical system mounted to receive light from the first series of discrete LEDs and to redirect the received light such that, when the uncured display assembly is received on the stage, the redirected light (a) spreads out along the first adhesive edge, and (b) is focused onto the first adhesive edge in a first reference plane perpendicular to the first adhesive edge.

15 17. The apparatus of claim 16, wherein the first anamorphic optical system includes a first cylindrical lens.

18. The apparatus of claim 17, wherein the first cylindrical lens has a cross-sectional shape whose radius of curvature is constant.

20

19. The apparatus of claim 17, wherein the first cylindrical lens has a cross-sectional shape whose radius of curvature is variable.

20. The apparatus of claim 17, wherein the first anamorphic optical system includes no
25 cylindrical lenses other than the first cylindrical lens.

21. The apparatus of claim 17, wherein the first anamorphic optical system includes the first cylindrical lens and a second cylindrical lens.

30 22. The apparatus of claim 16, wherein the first anamorphic optical system includes a first cylindrical mirror.

23. The apparatus of claim 16, wherein the first series of discrete LEDs comprises two distinct rows of LEDs.

24. The apparatus of claim 16, wherein the stage defines a second reference plane
5 perpendicular to the first reference plane.

25. The apparatus of claim 16, wherein the light source arrangement further includes a second series of discrete LEDs, the second series of discrete LEDs being mounted on a side of the stage opposite the first series of discrete LEDs.

10

26. The apparatus of claim 25, wherein the light source arrangement further includes a third and fourth series of discrete LEDs, the third and fourth series of discrete LEDs being mounted on opposite sides of the stage relative to each other.

15 27. The apparatus of claim 26, wherein the first, second, third, and fourth series of discrete LEDs form a rectangular shape.

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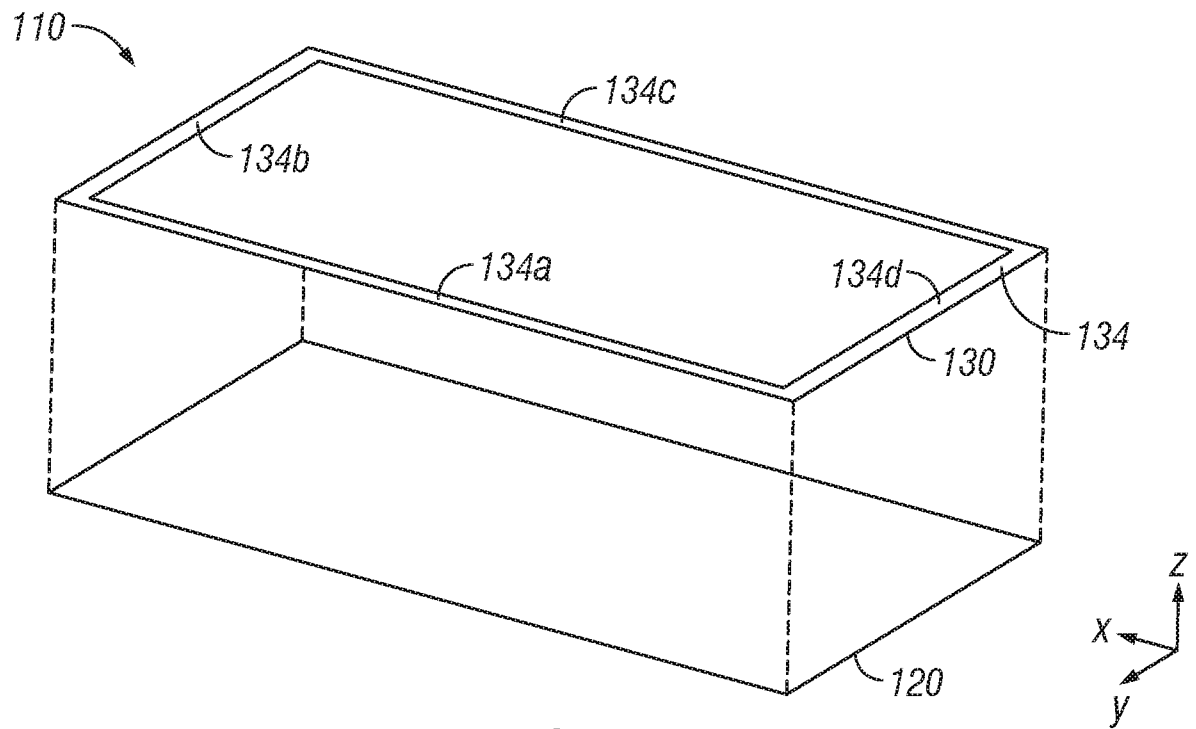


FIG. 1

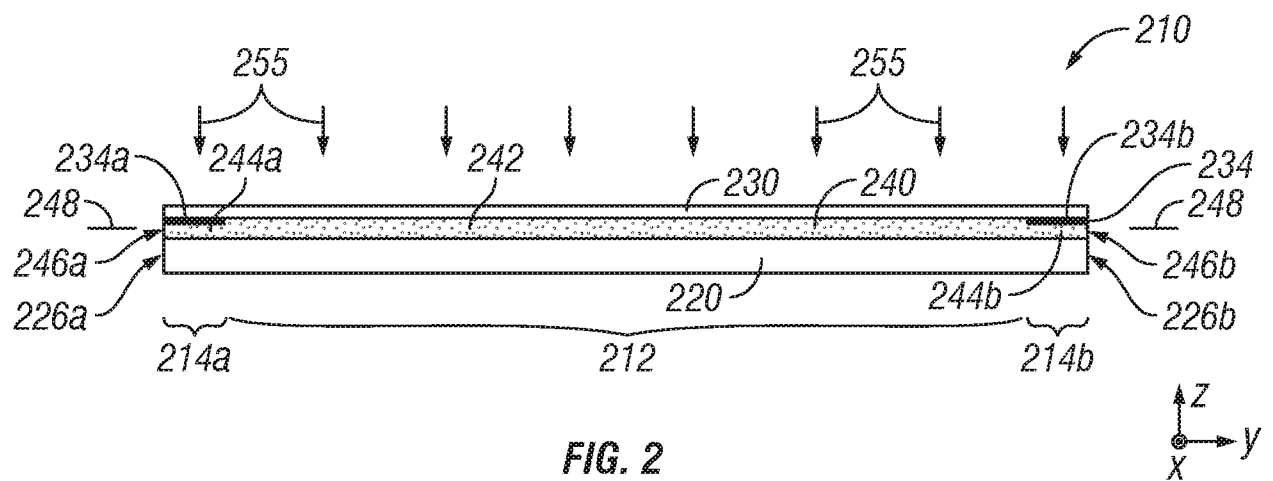
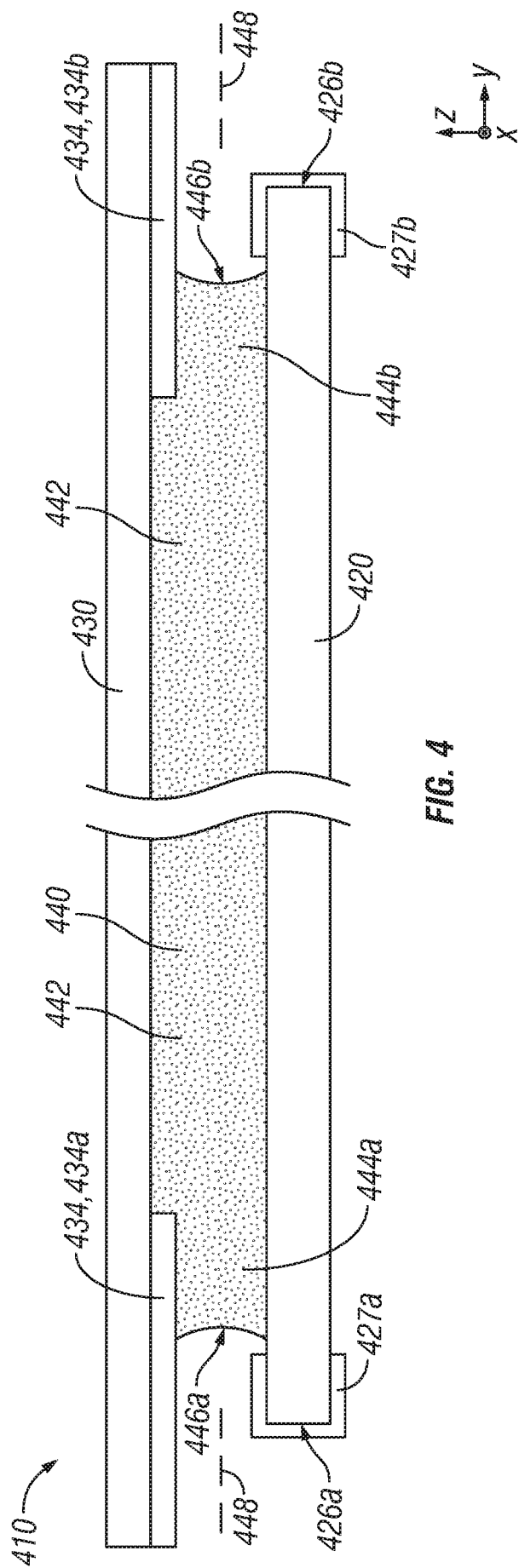
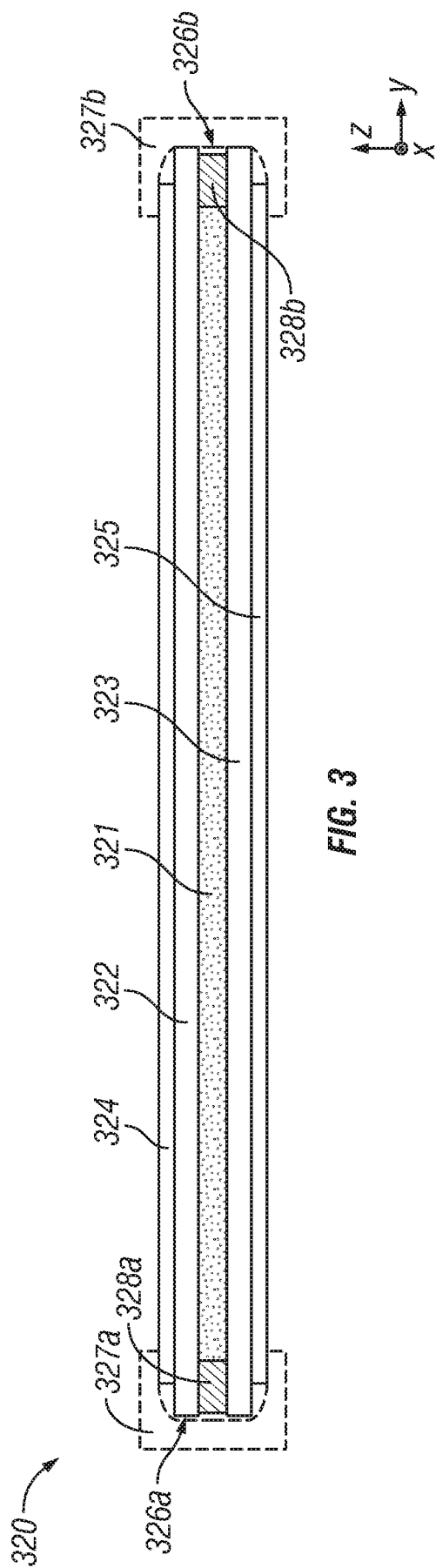


FIG. 2



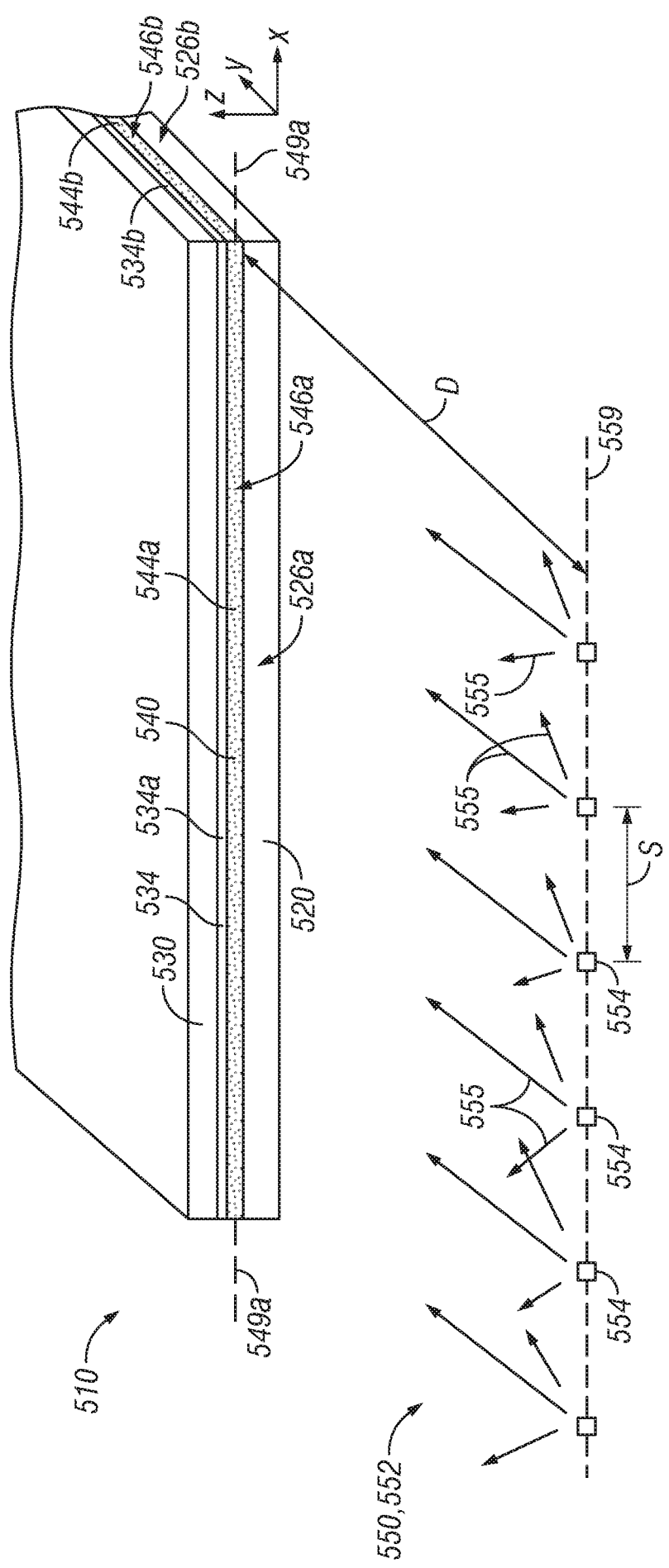


FIG. 5

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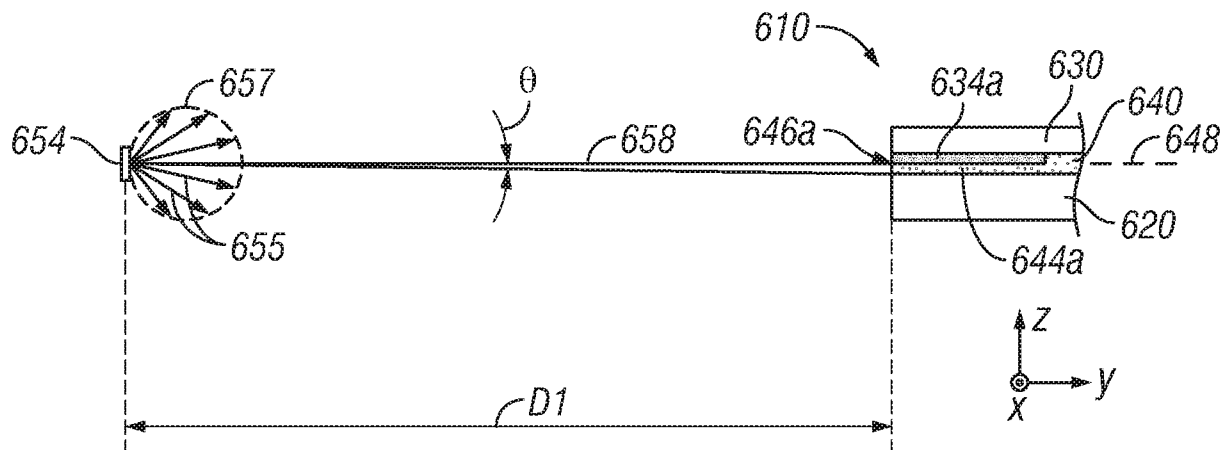


FIG. 6

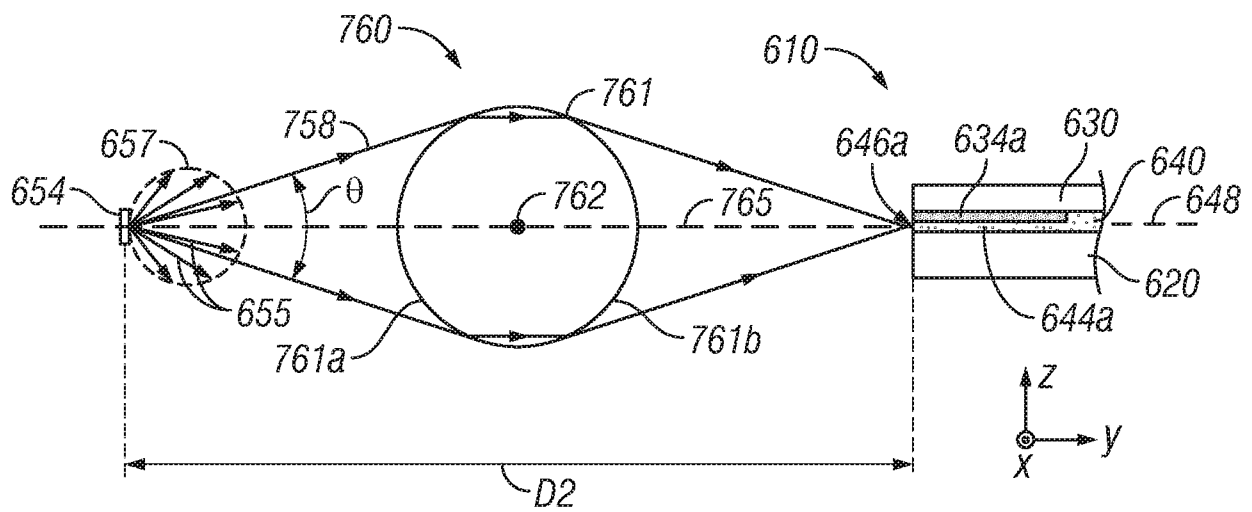


FIG. 7

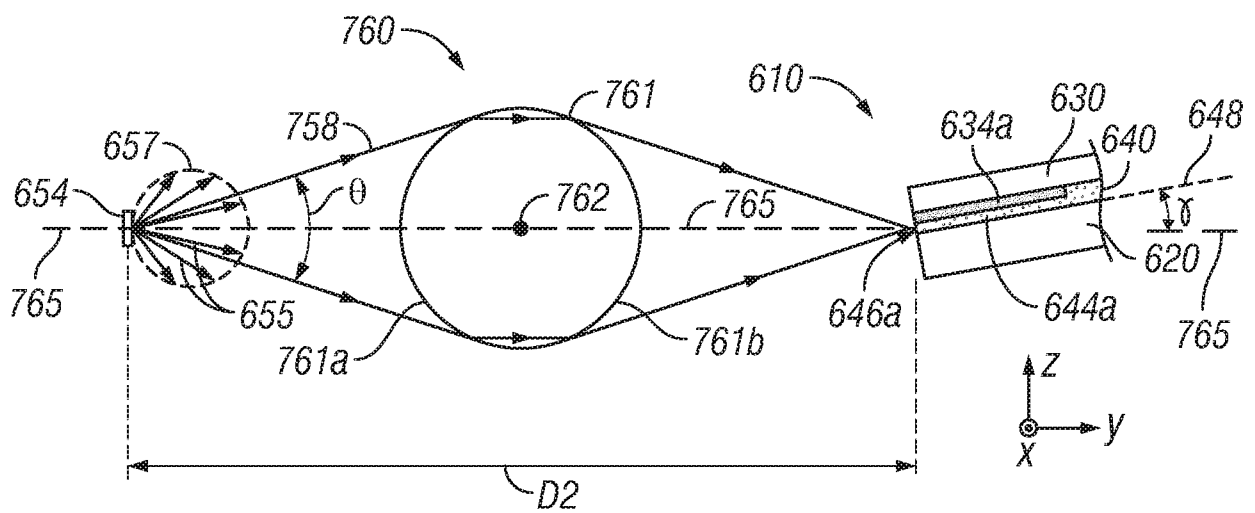


FIG. 7A

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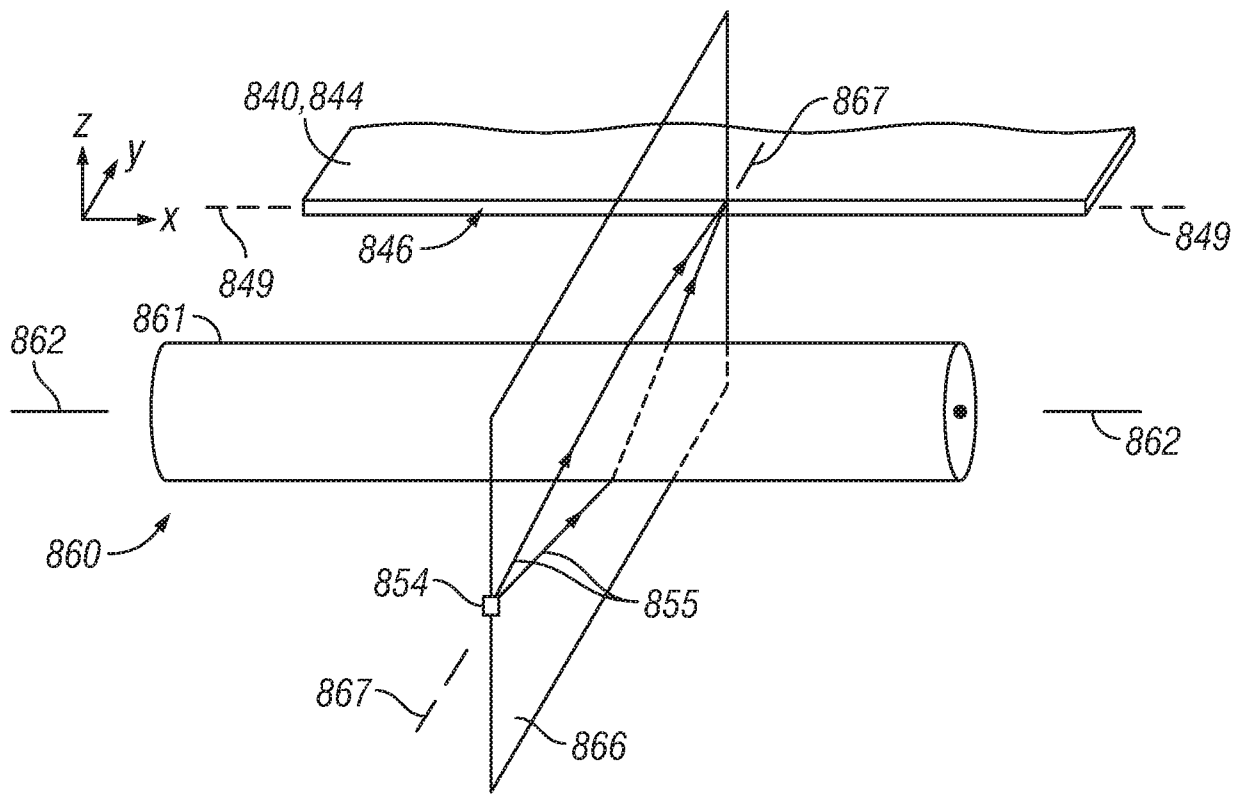


FIG. 8A

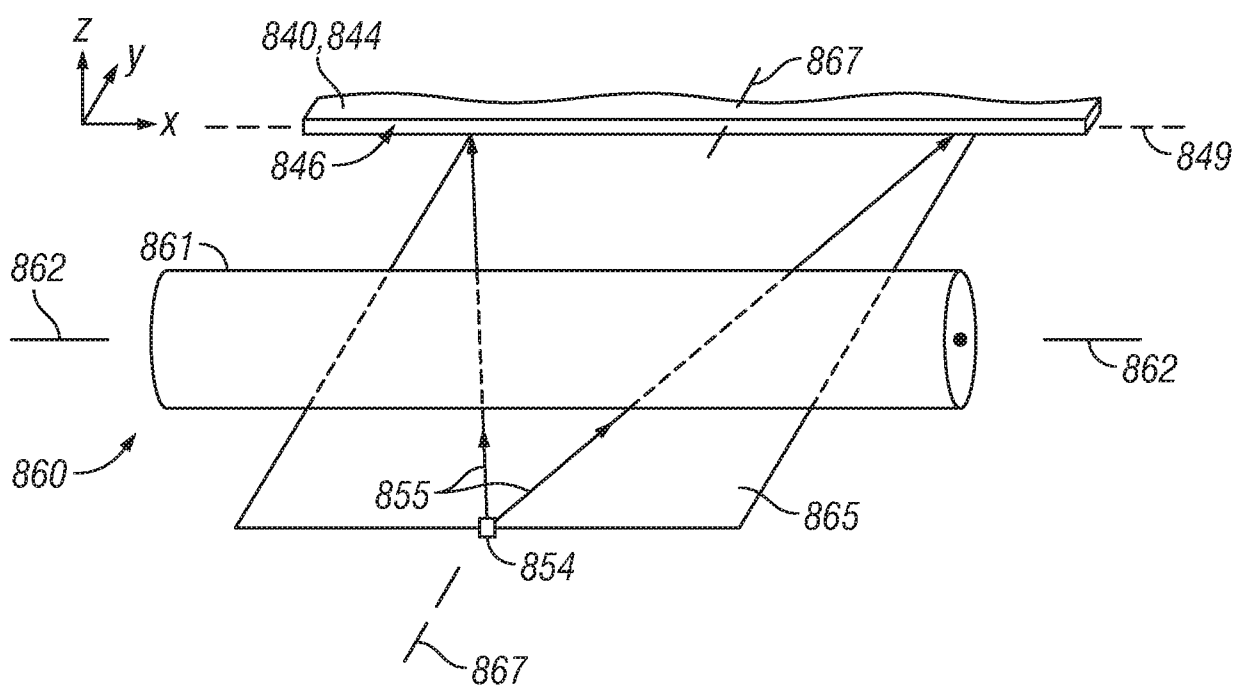


FIG. 8B

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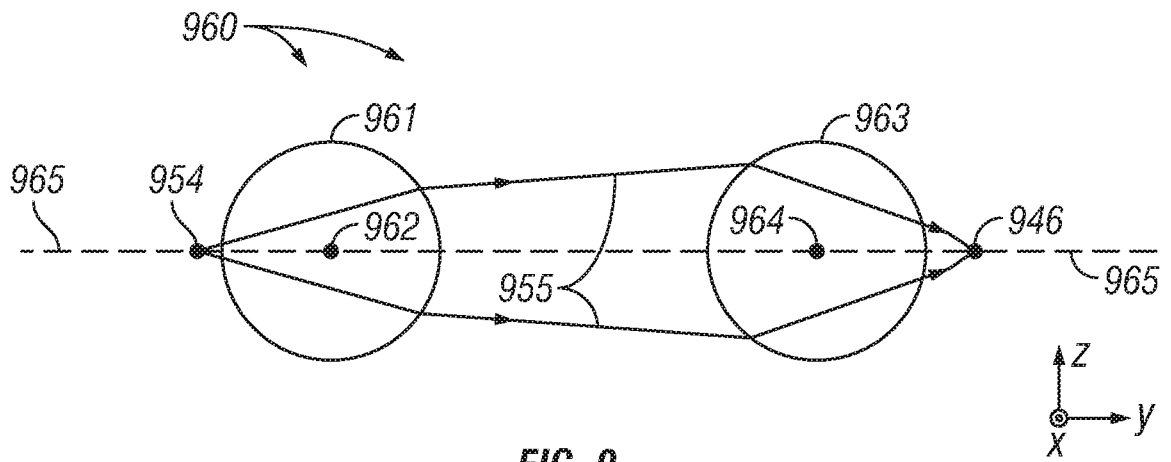


FIG. 9

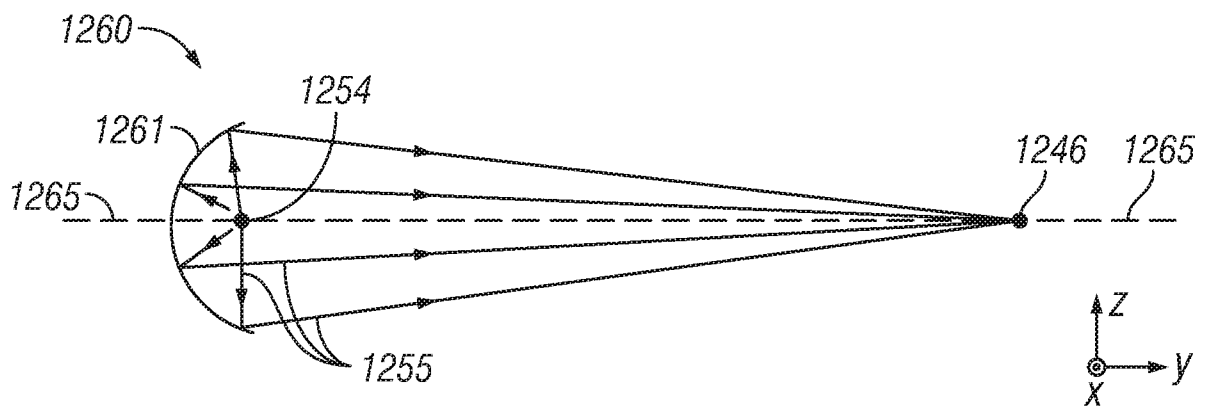


FIG. 12

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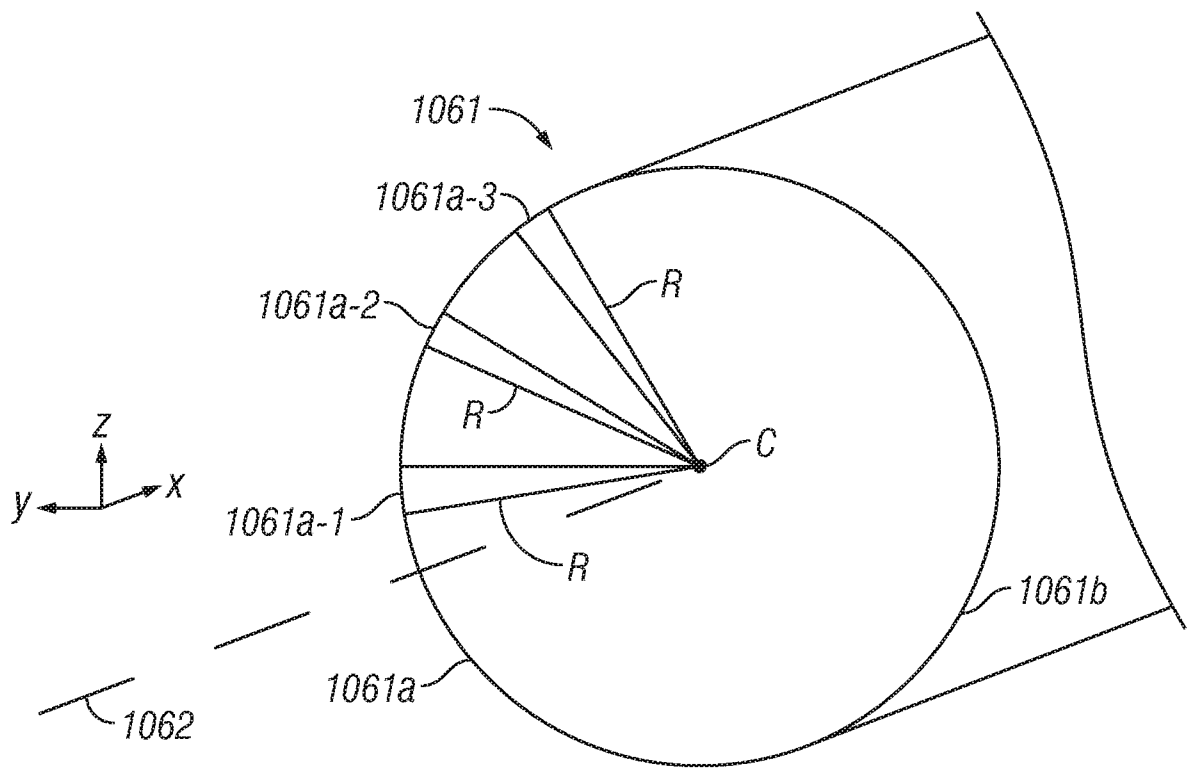


FIG. 10

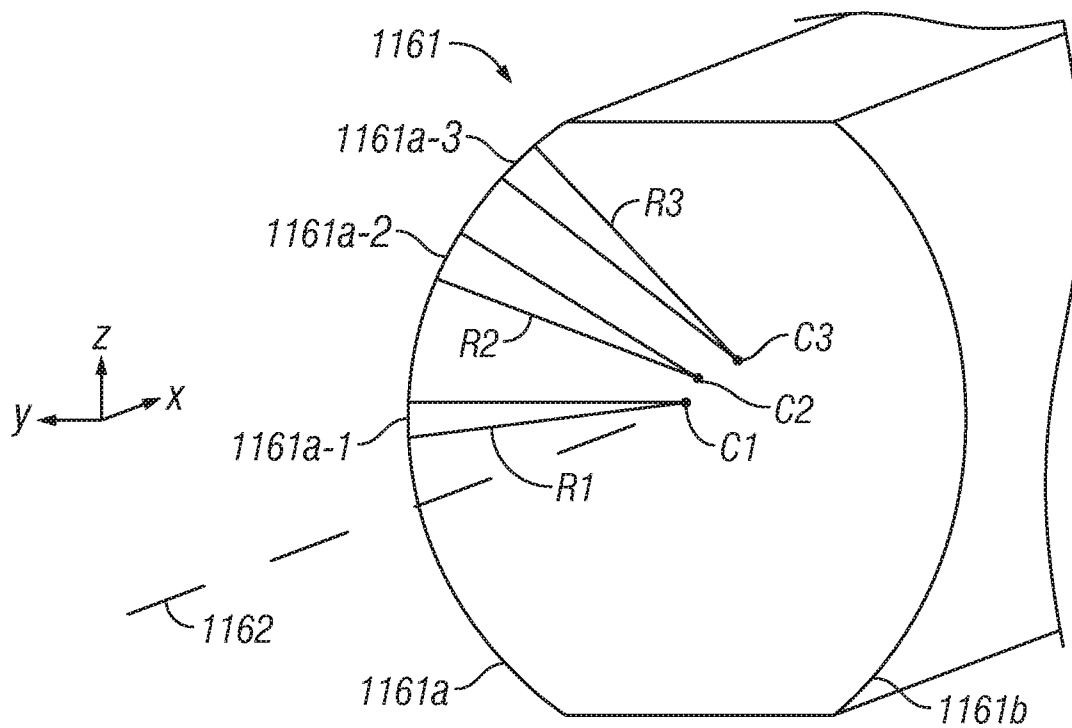


FIG. 11

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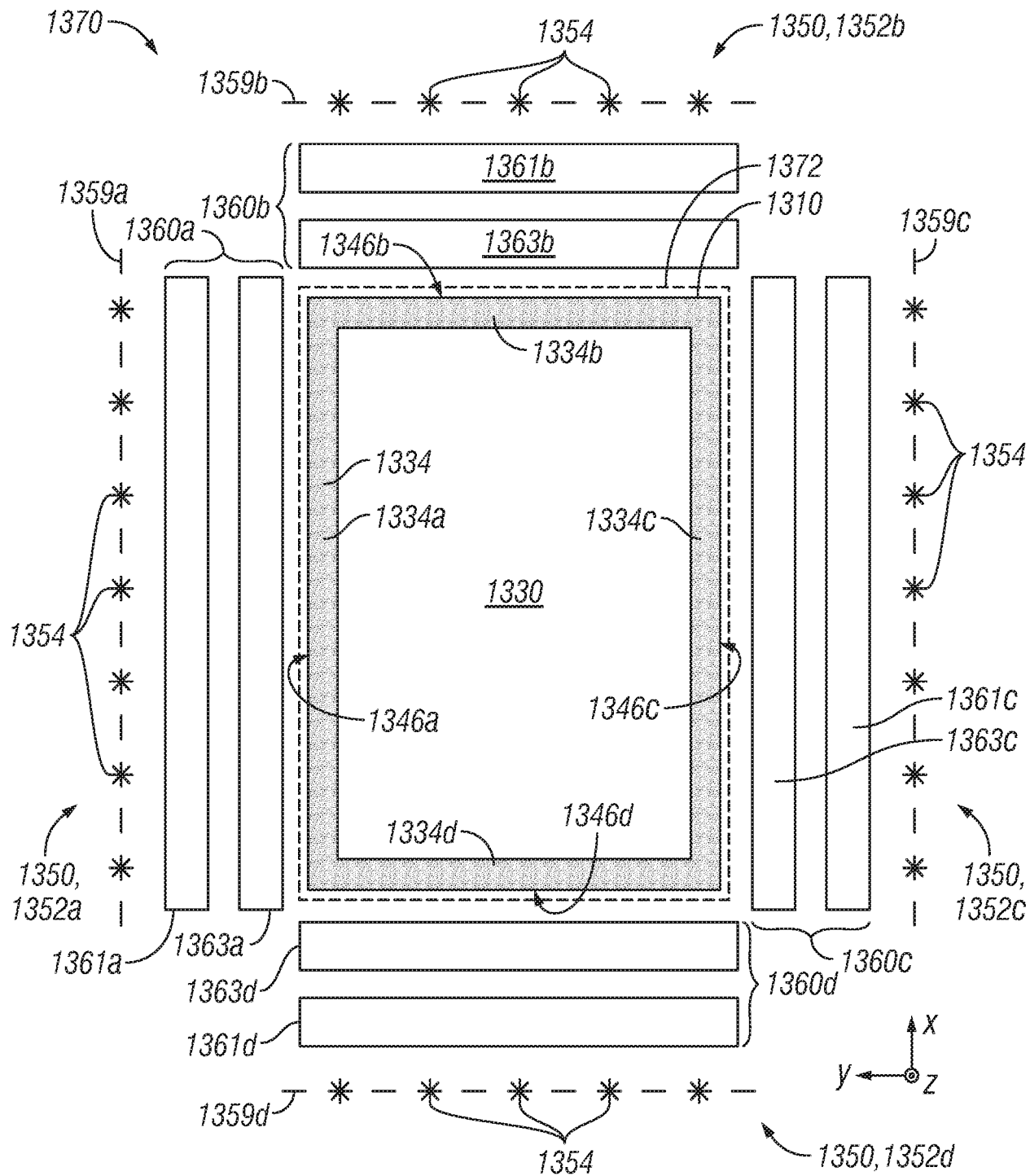


FIG. 13

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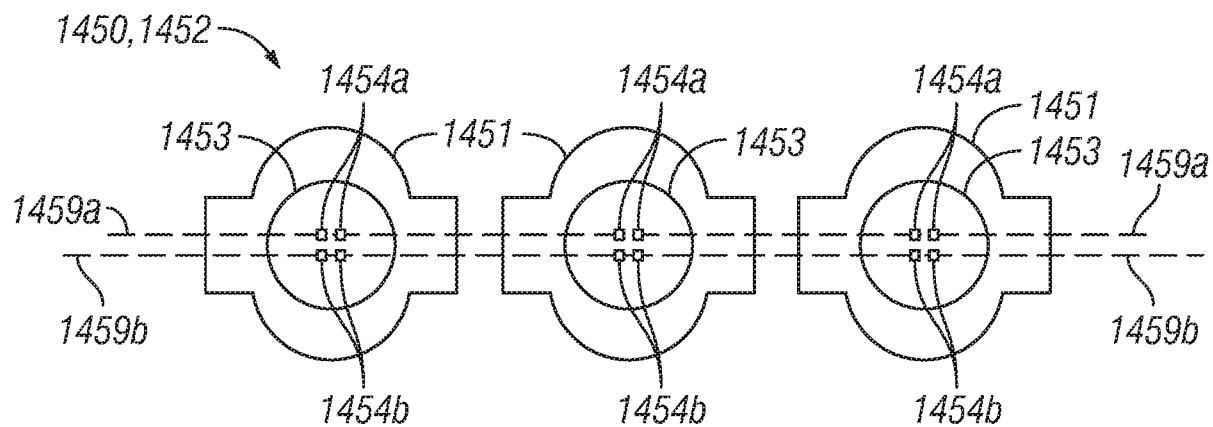


FIG. 14

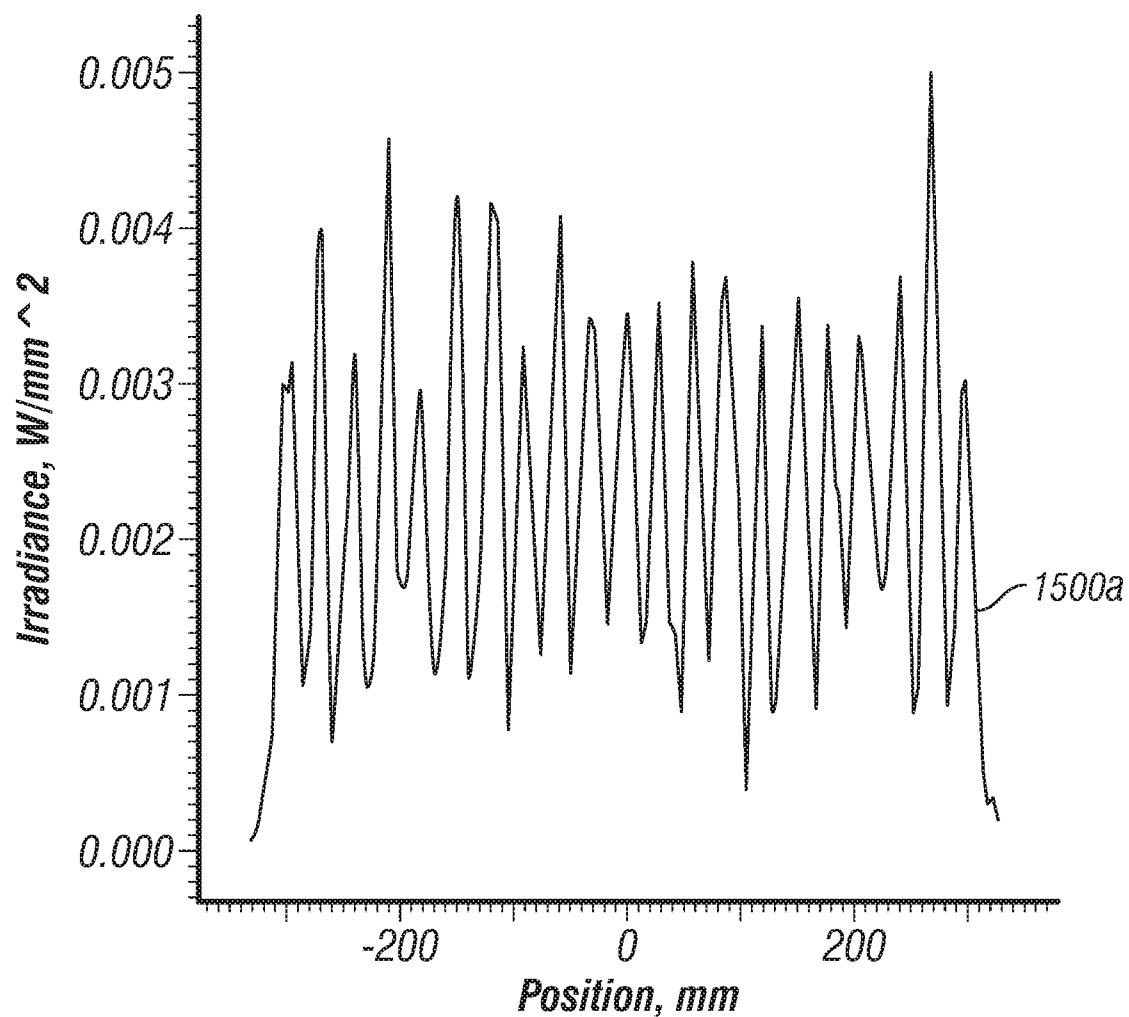


FIG. 15A

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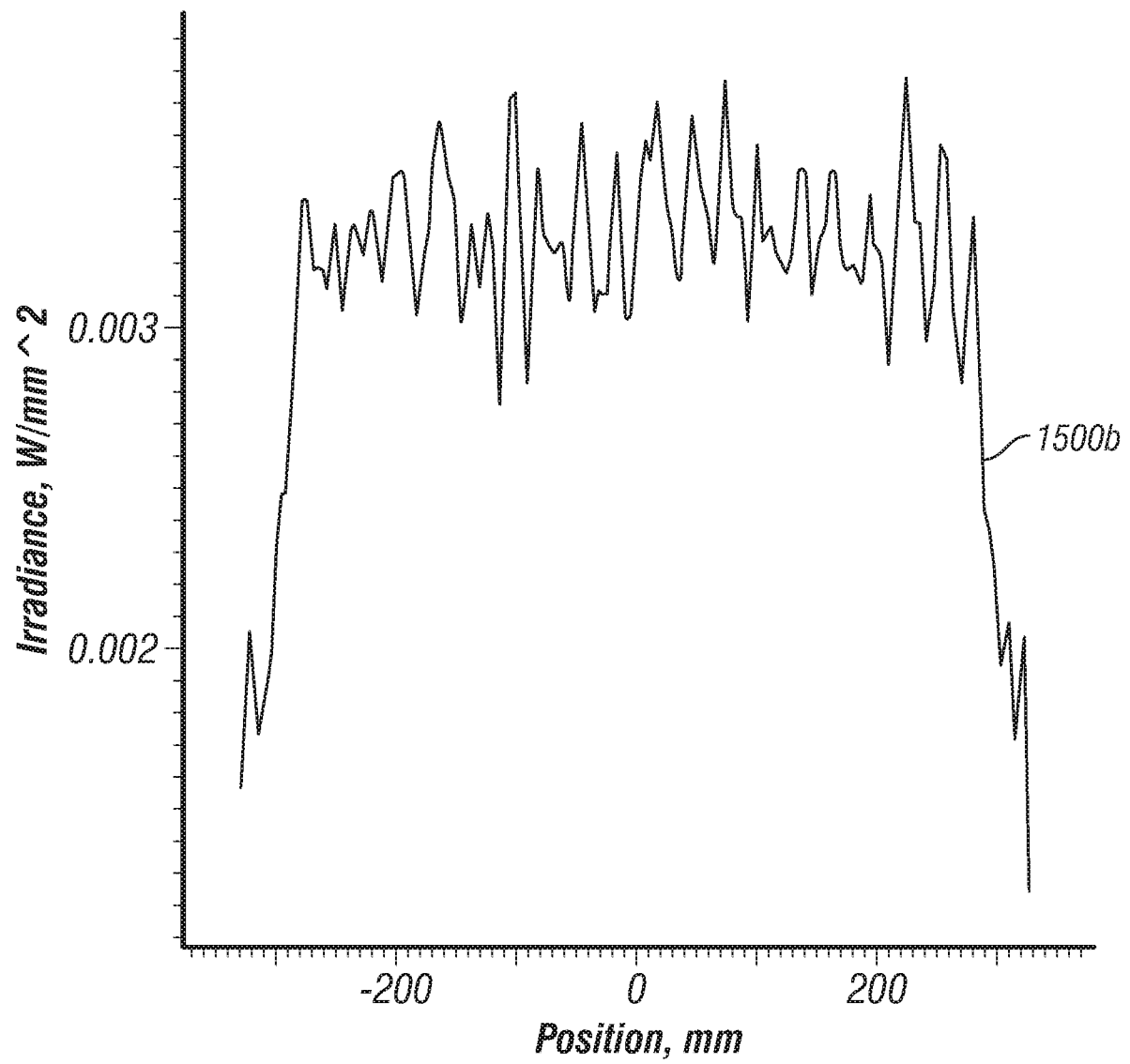


FIG. 15B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/013699

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02F1/1333 G02F1/13
ADD.

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)
G02F

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.
A	US 2009/186552 A1 (SHINYA YOSHIHISA [JP] ET AL) 23 July 2009 (2009-07-23) the whole document	1-27
A	US 2014/374006 A1 (PARK YUN HEUM [KR]) 25 December 2014 (2014-12-25) the whole document	1-27



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

23 March 2017

Date of mailing of the international search report

04/04/2017

Name and mailing address of the ISA/

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Fax: (+31-70) 340-3016

Authorized officer

Lüssem, Georg

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/013699

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