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Rohatgi

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(54) **LOCAL SEAL FOR ENCAPSULATION OF ELECTRO-OPTICAL ELEMENT ON A FLEXIBLE SUBSTRATE**

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(73) Assignee: **Global OLED Technology LLC**, Herndon, VA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/695,956**

(22) Filed: **Apr. 24, 2015**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 14/446,470, filed on Jul. 30, 2014.

(60) Provisional application No. 61/859,989, filed on Jul. 30, 2013.

(51) **Int. Cl.**
H01L 51/56 (2006.01)
H01L 51/52 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 51/5268*** (2013.01); ***H01L 51/5253*** (2013.01); *H01L 2251/5338* (2013.01); *H01L 2251/5369* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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Primary Examiner — Pamela E Perkins

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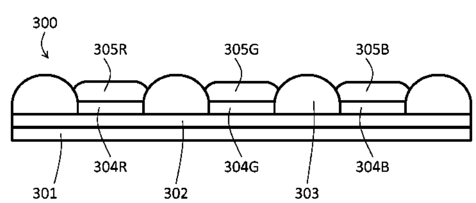
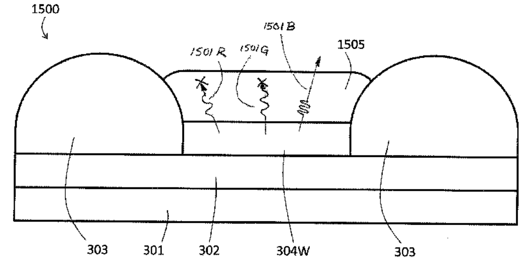
(57) **ABSTRACT**

An electroluminescent display or lighting product incorporates a panel comprising a collection of distinct light-emitting elements formed on a substrate. A plurality of distinct local seals are formed over respective individual light-emitting elements or groups of light-emitting elements. Each local seal is formed by depositing a low melting temperature glass powder suspension or paste, and fusing the glass powder. Fusing may be performed using selective heating by microwave or laser irradiation. Energy absorption may be enhanced by incorporating absorbing particles in the glass powder paste or suspension. The local seal may be used in conjunction with a continuous thin film encapsulation structure. Optical functions can be provided by each local seal, including refraction, filtering, color shifting, and scattering.

1 Claim, 38 Drawing Sheets





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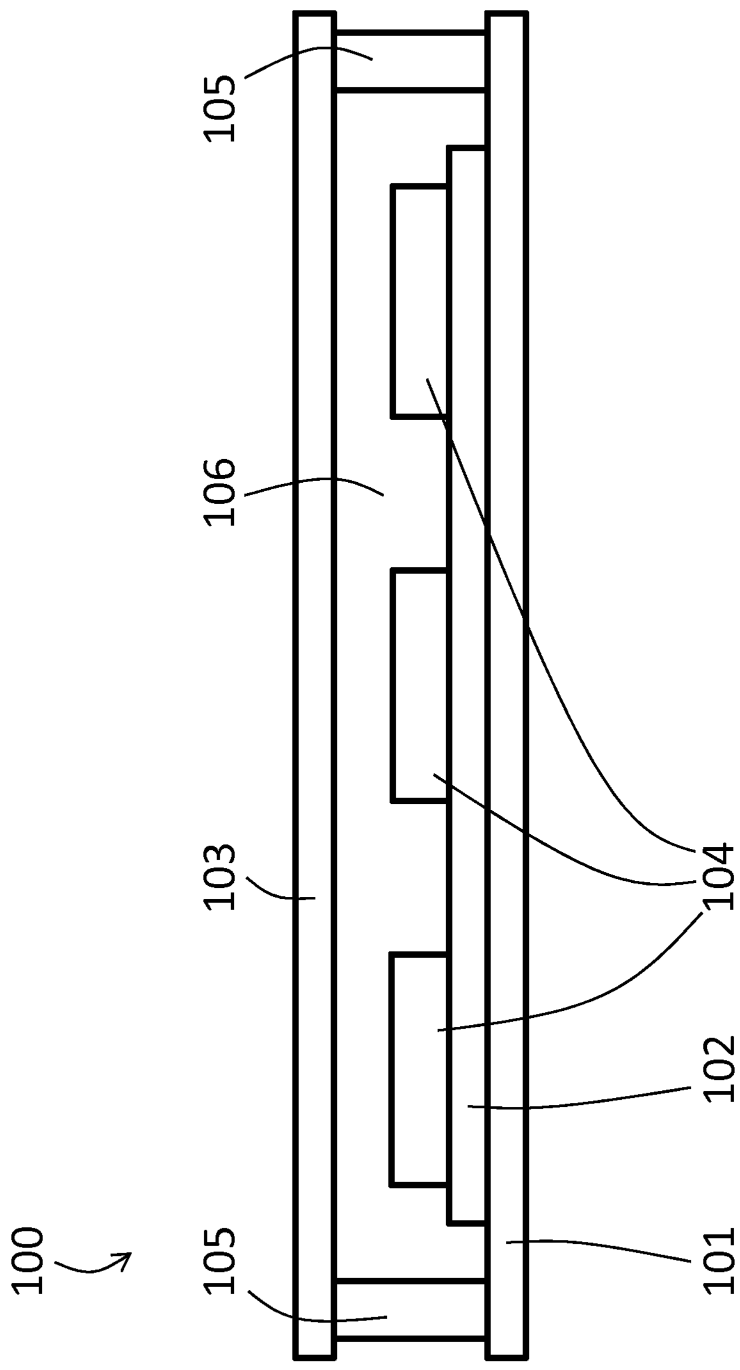


FIG. 1 (PRIOR ART)

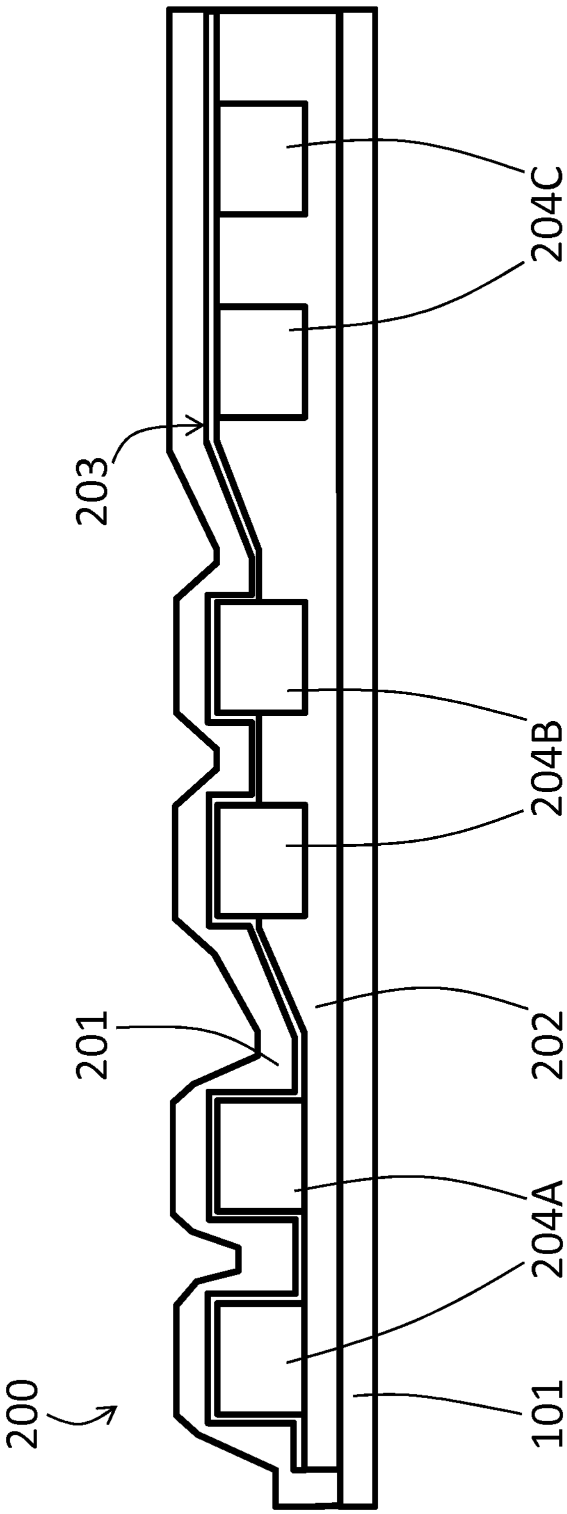


FIG. 2 (PRIOR ART)

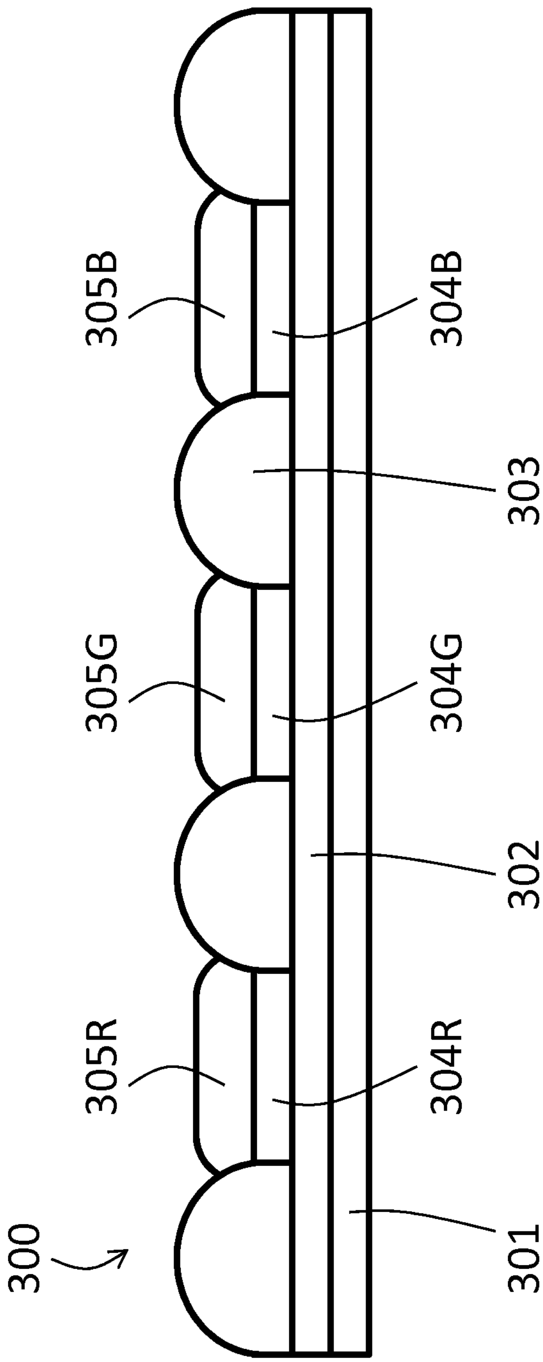


FIG. 3

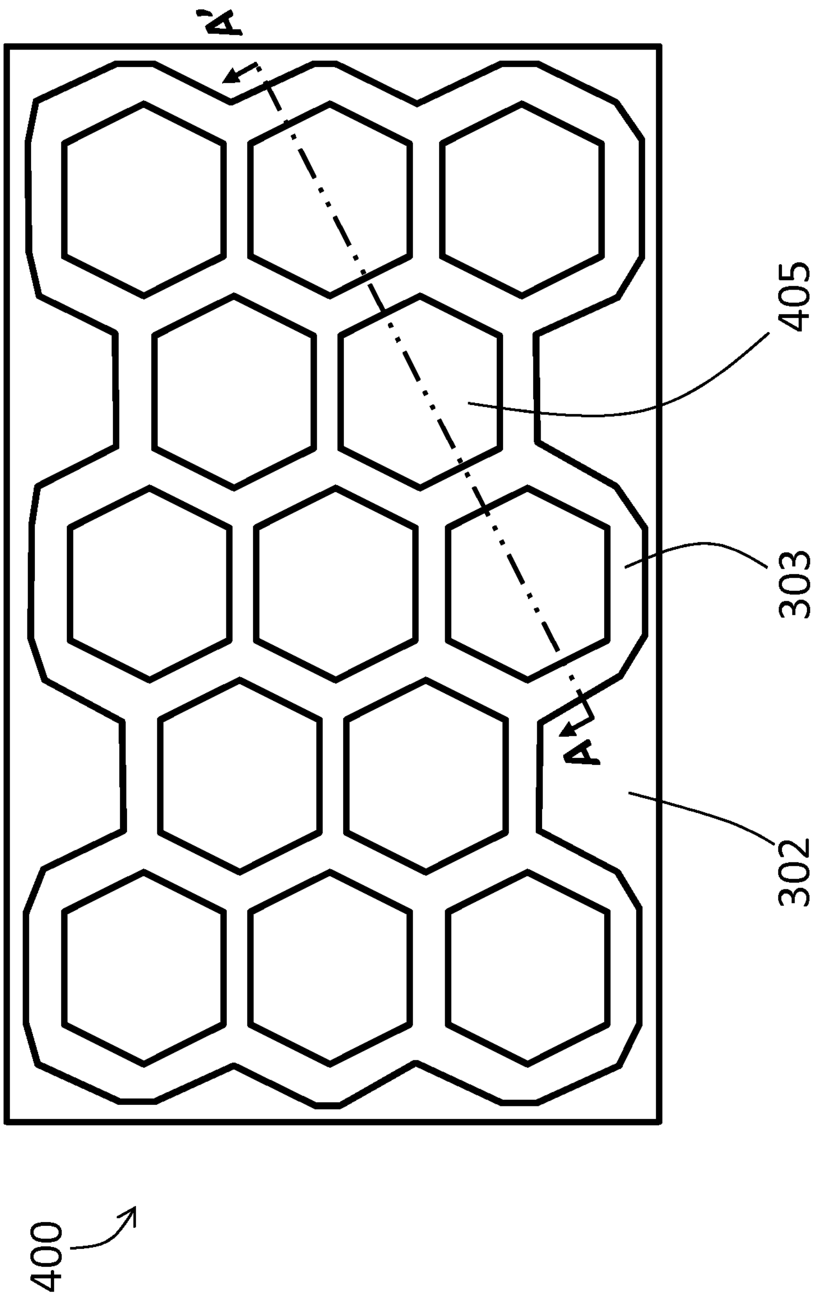


FIG. 4A

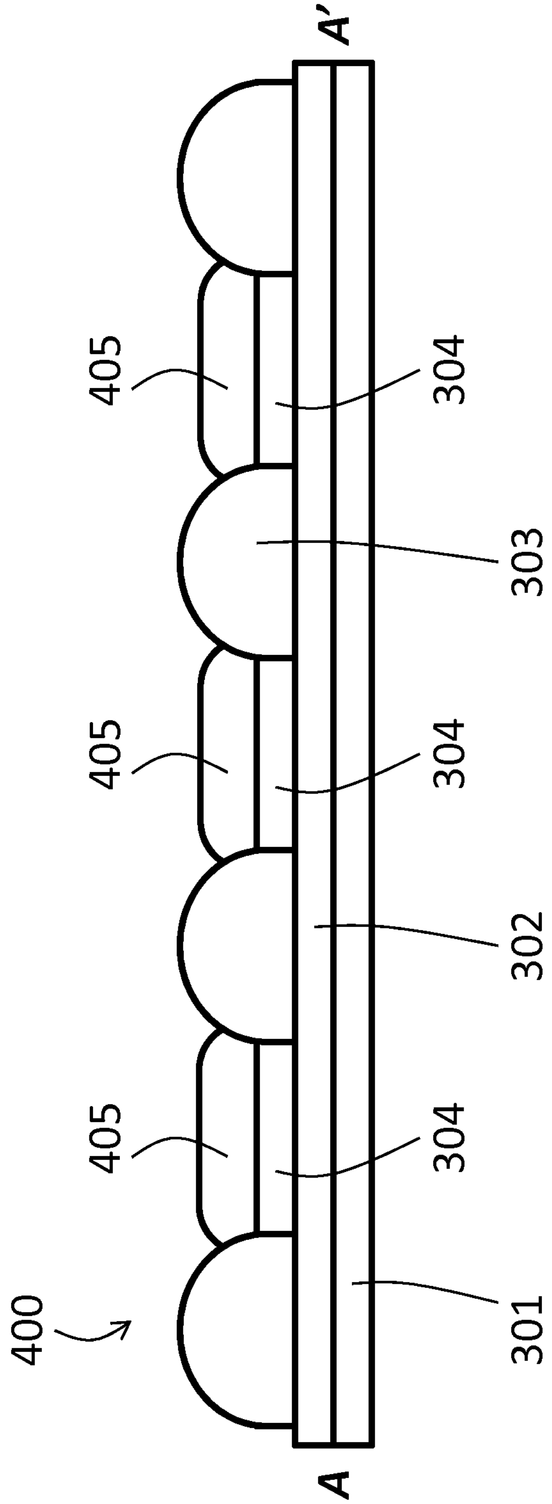


FIG. 4B Section A-A'

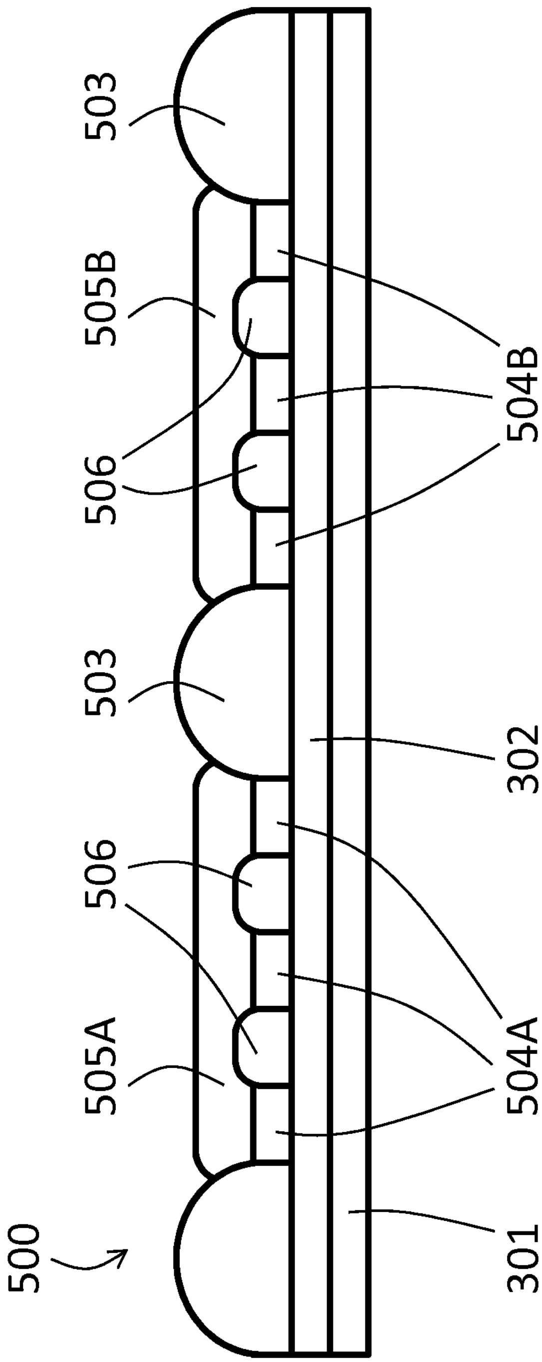


FIG. 5

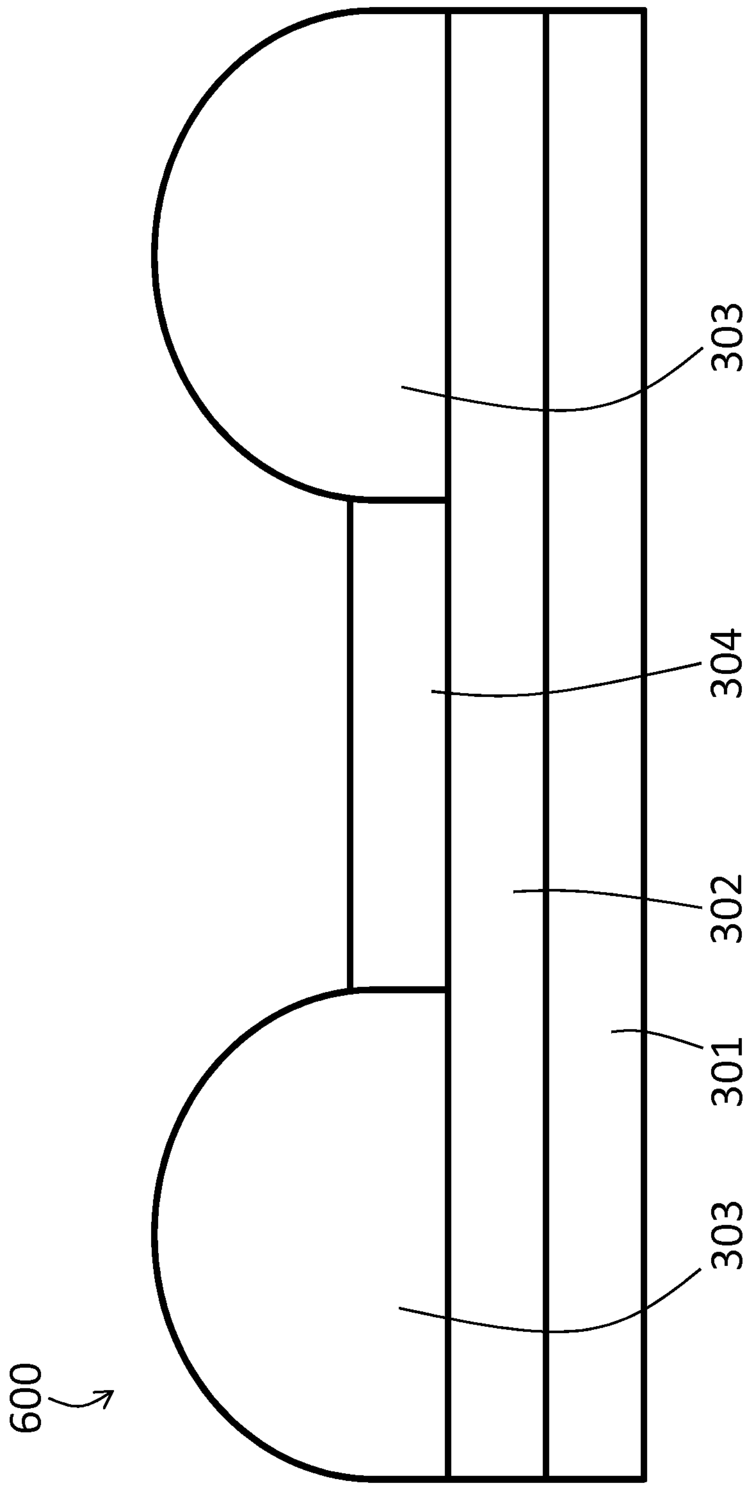


FIG. 6A

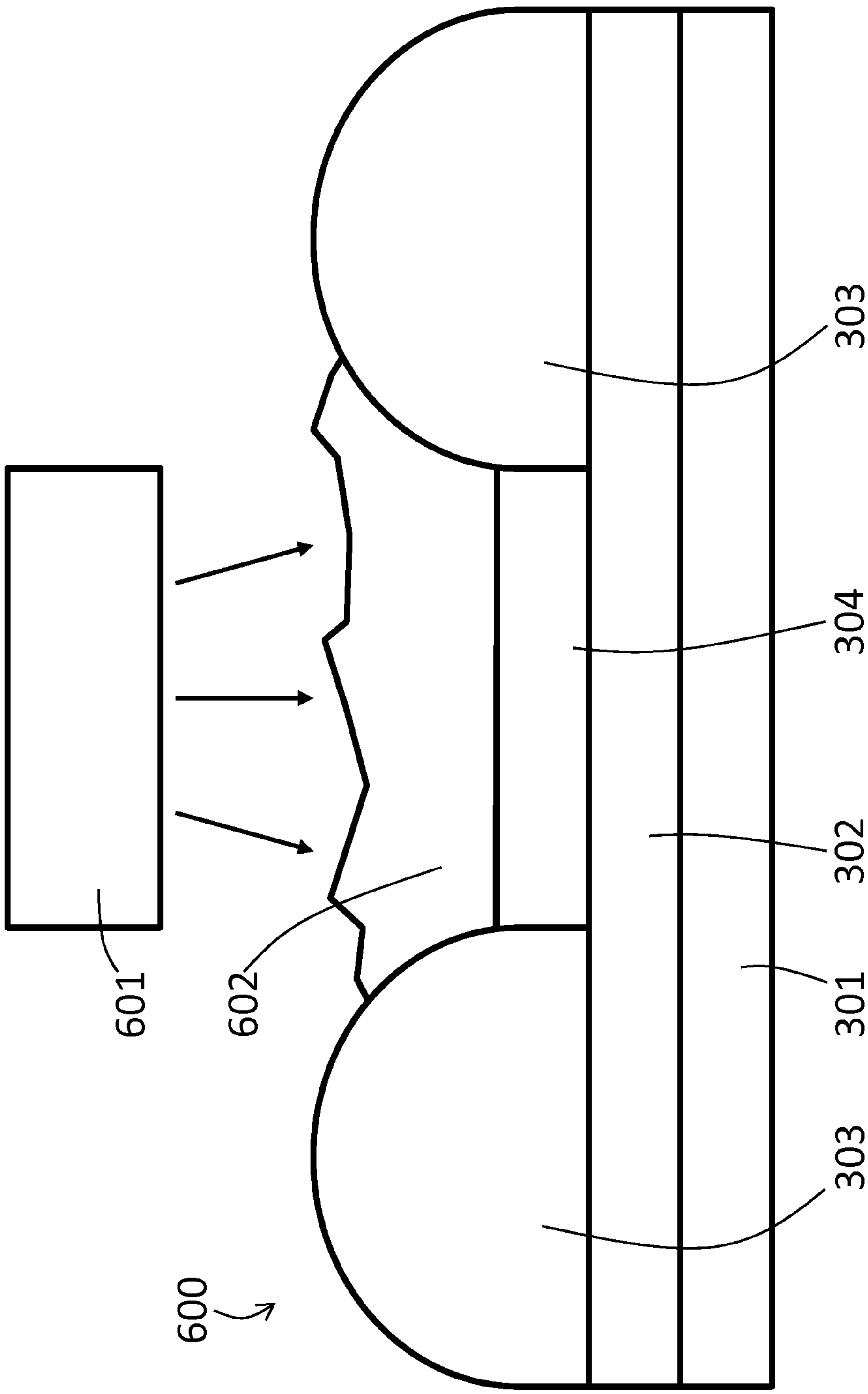


FIG. 6B

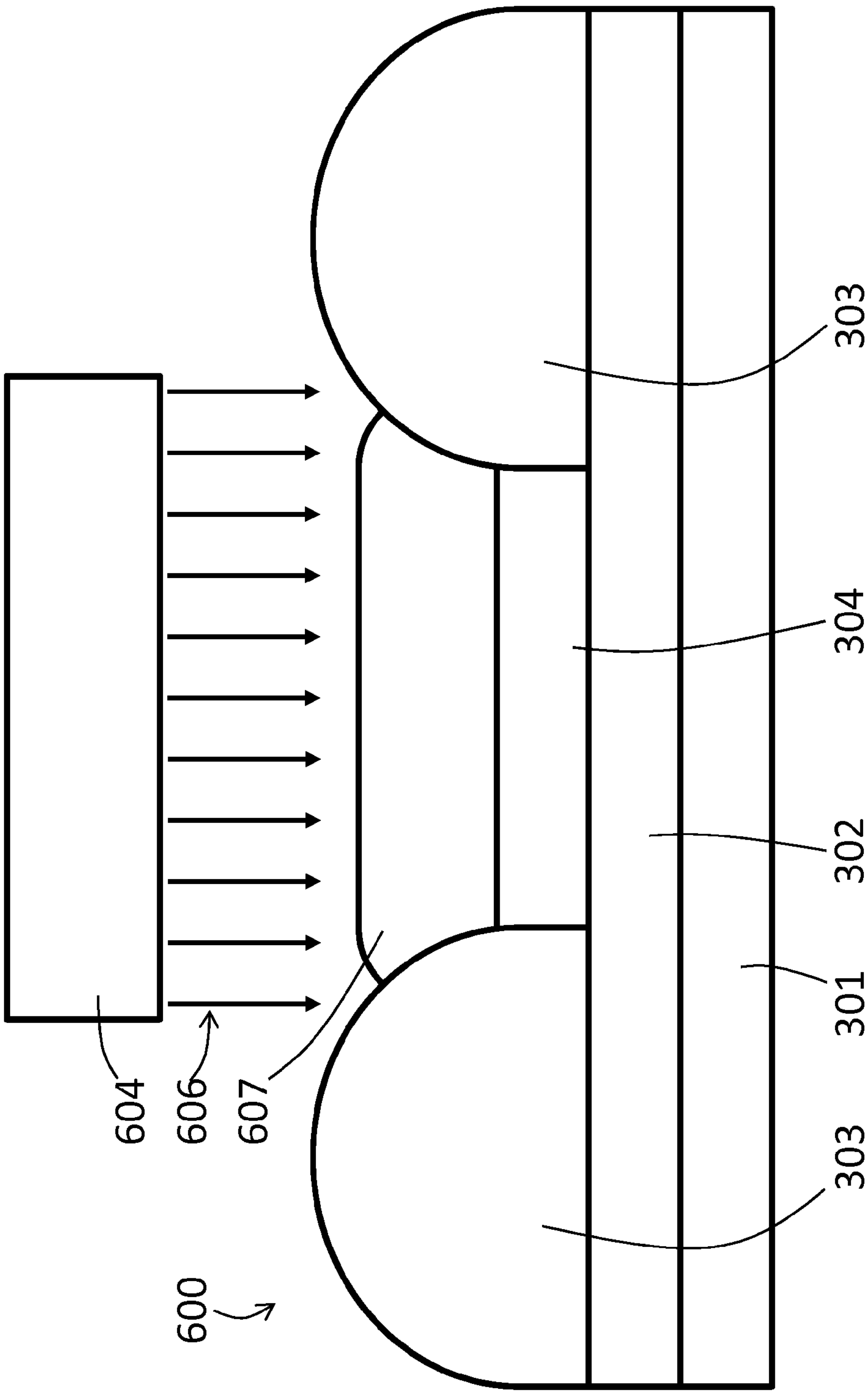


FIG. 6C

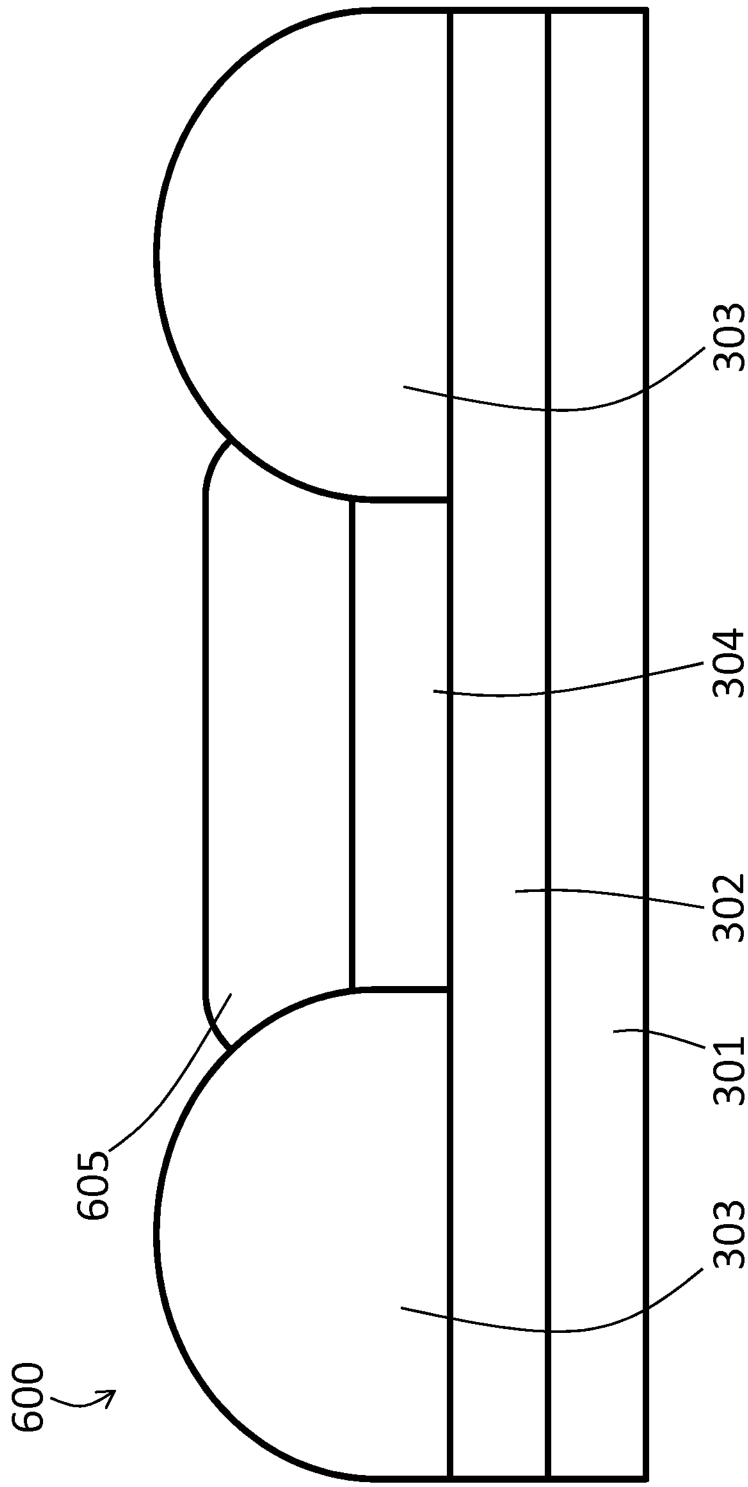


FIG. 6D

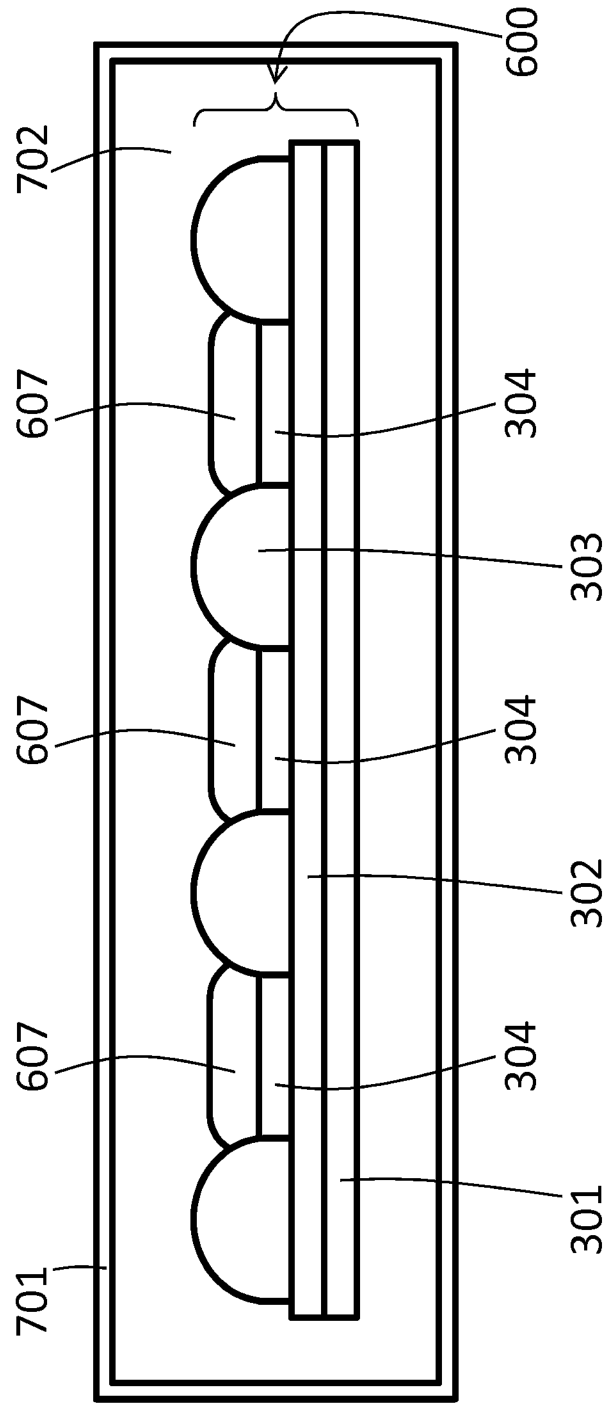


FIG. 7A

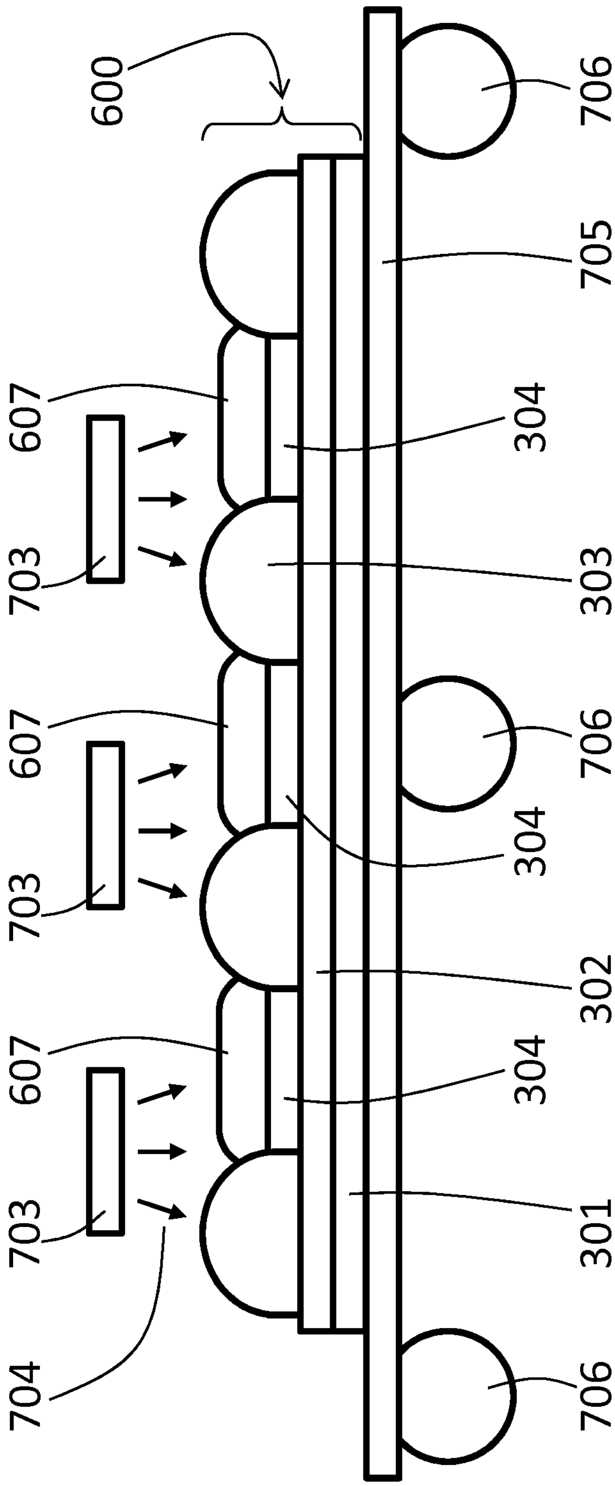

600
706
705
607
304
703
303
607
706
703
304
302
607
304
703
301
704
706

FIG. 7B

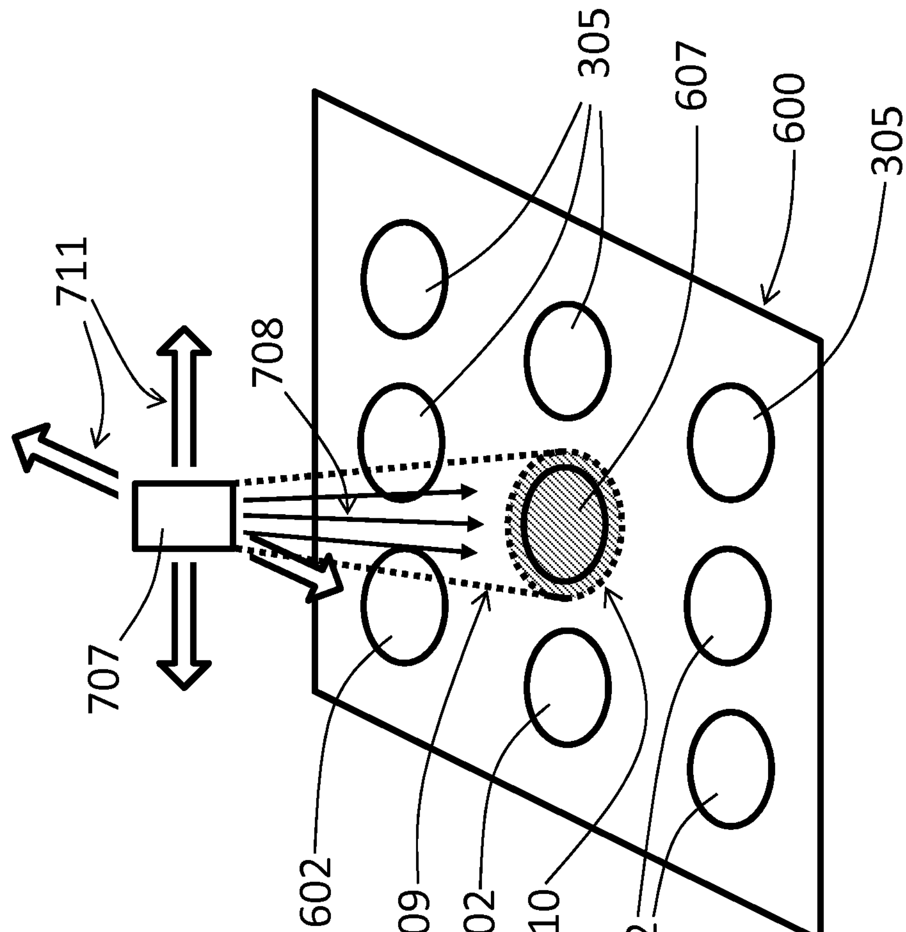


FIG. 7C

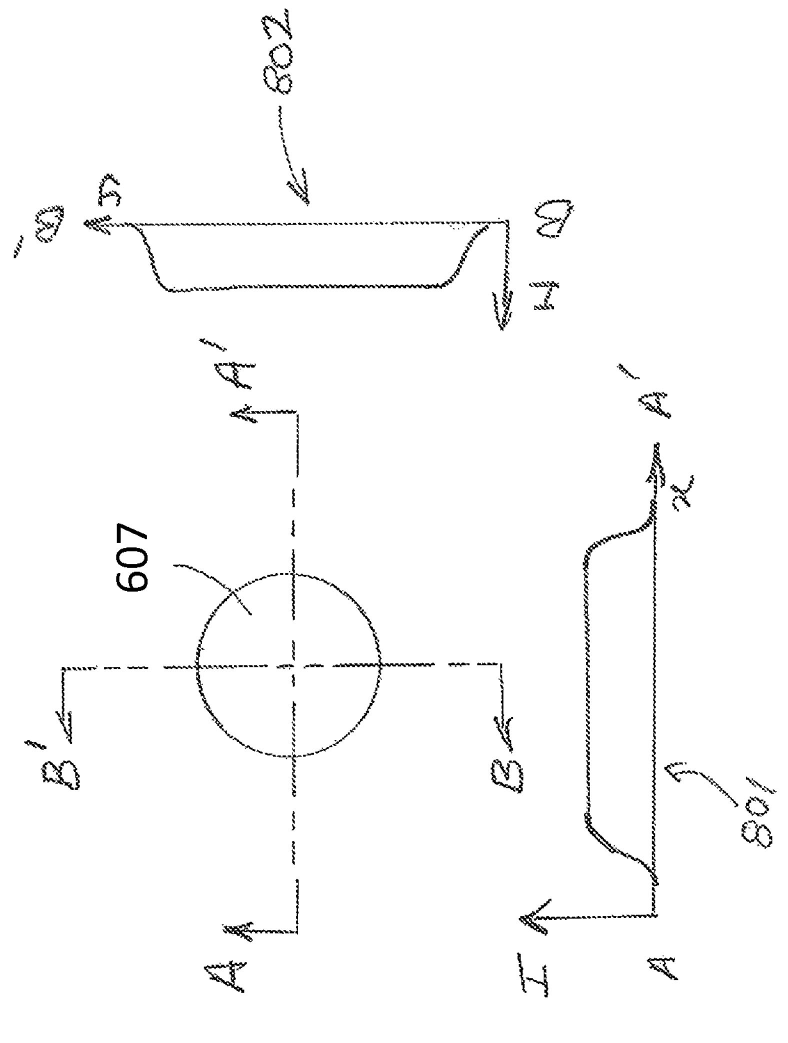


FIG. 8A

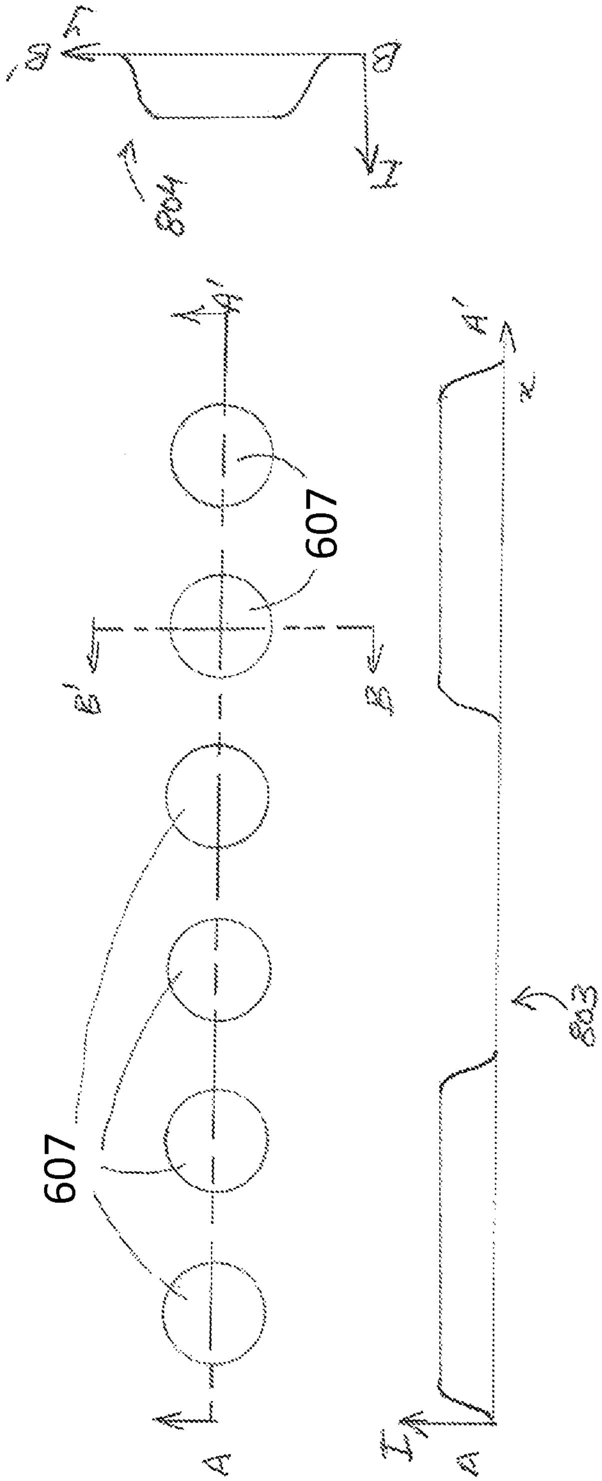


FIG. 8B

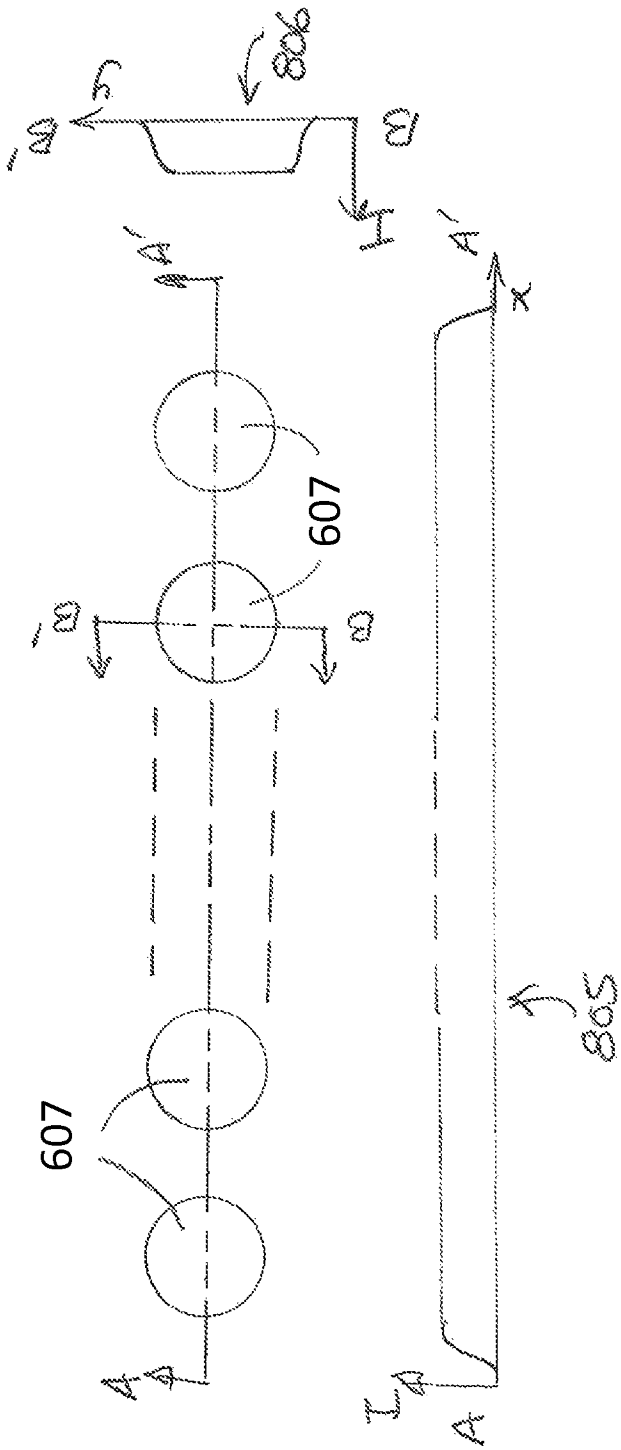


FIG. 8C

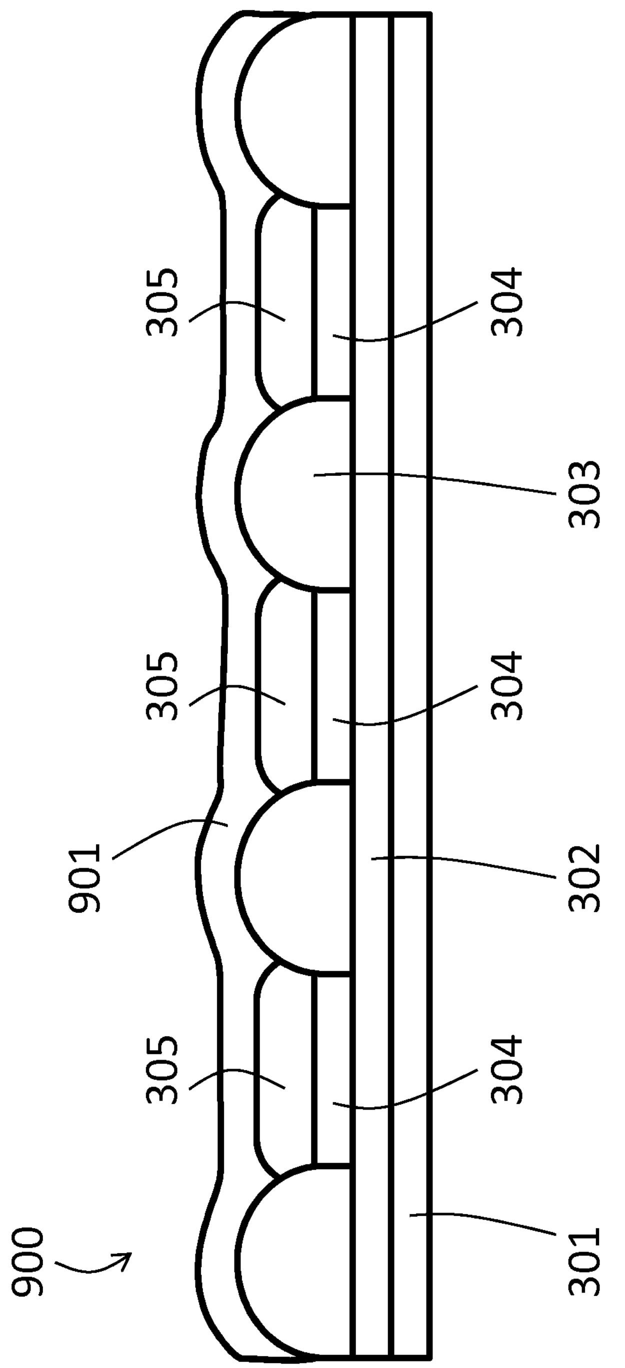


FIG. 9

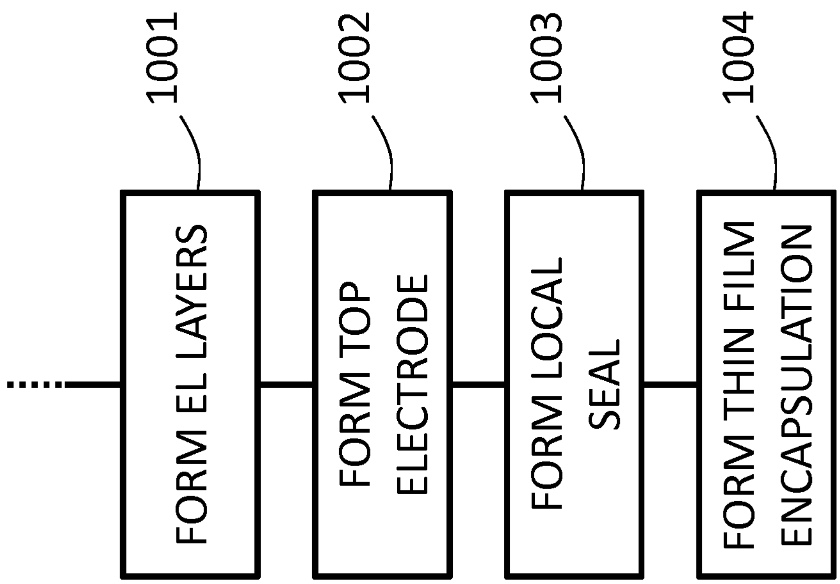

FORM EL LAYERS
FORM TOP ELECTRODE
FORM LOCAL SEAL
FORM THIN FILM ENCAPSULATION
1001
1002
1003
1004

FIG. 10

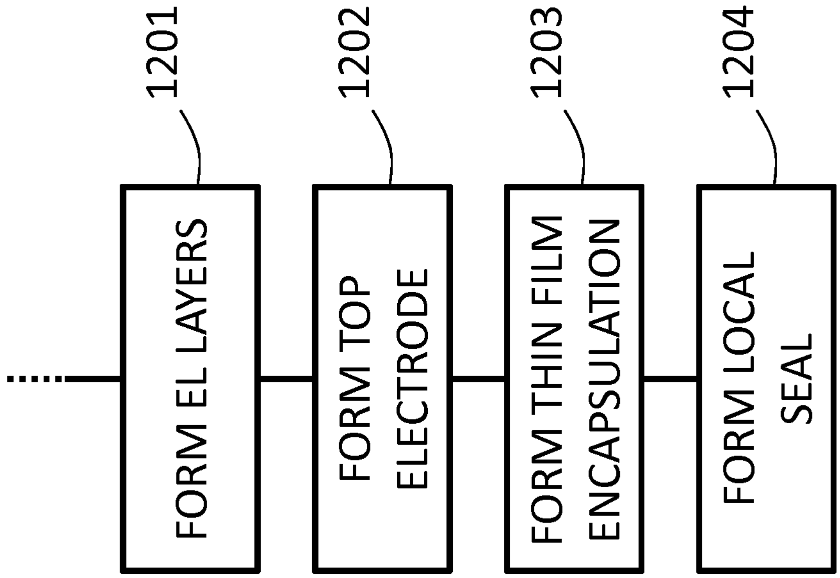

FORM EL LAYERS
FORM TOP ELECTRODE
FORM THIN FILM ENCAPSULATION
FORM LOCAL SEAL
1201
1202
1203
1204

FIG. 12

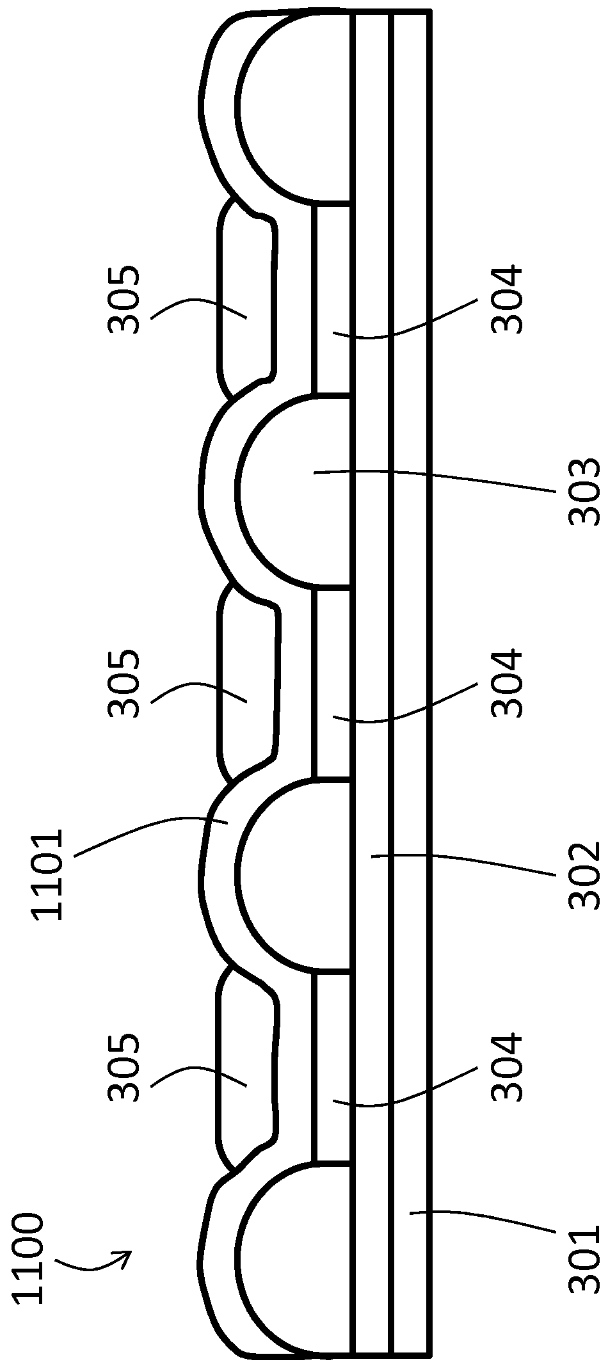
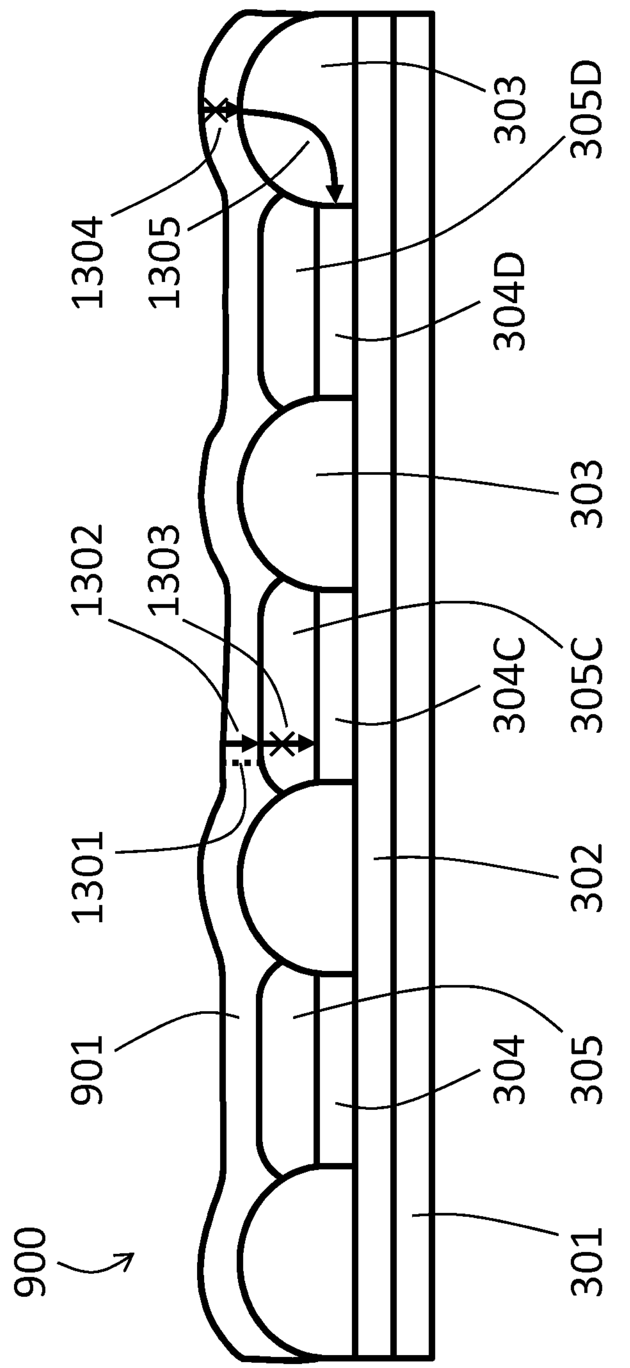
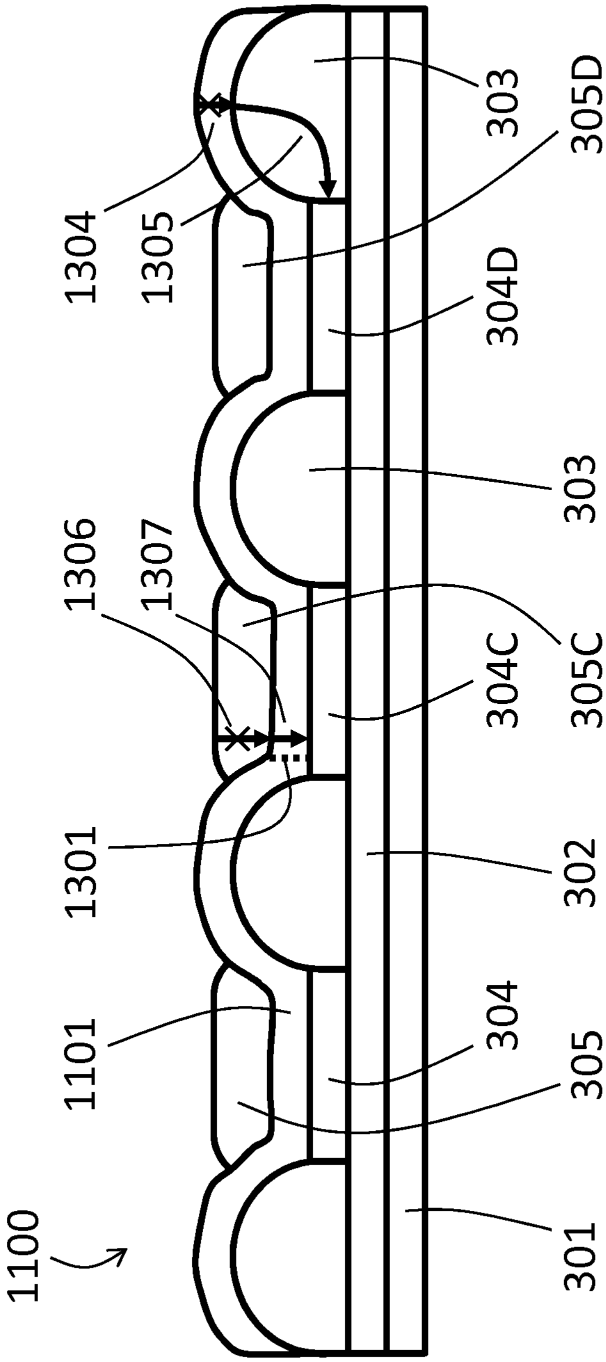


FIG. 11



900
1304
1305
303
305D
304D
303
1302
1303
304C
305C
1301
302
901
304
305
301

FIG. 13A


1100
1304
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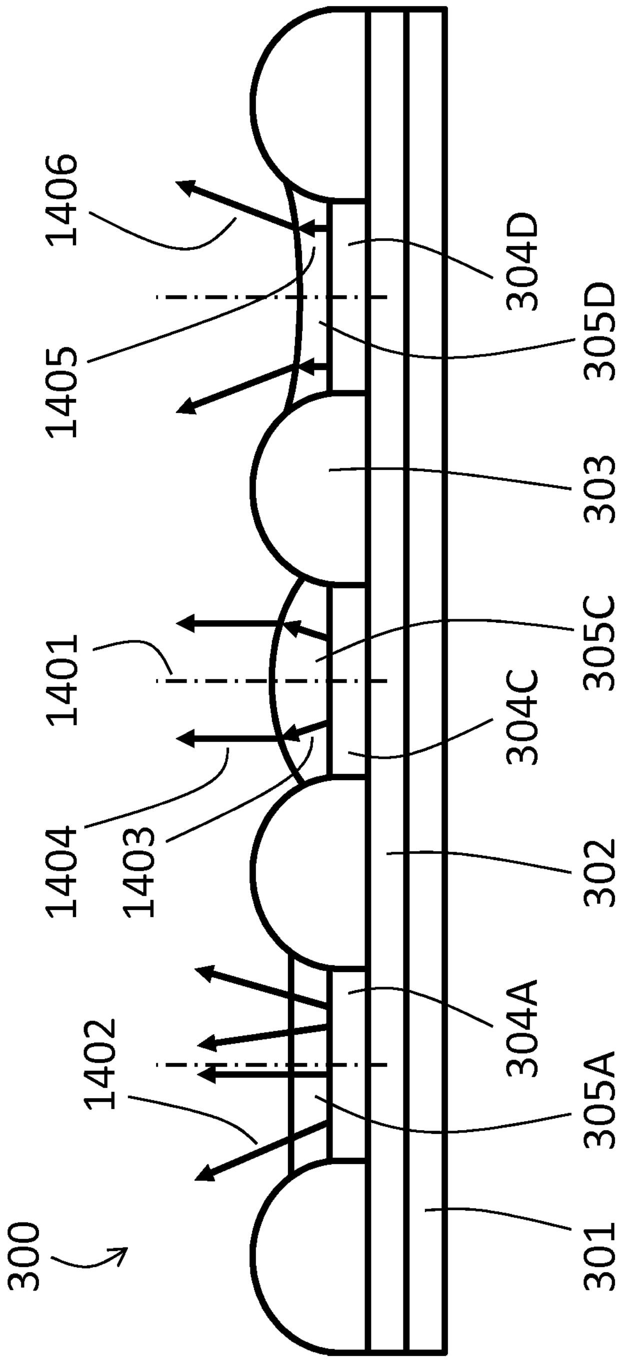
1307
304C
305C
1301
302
1101
304
305
301

FIG. 13B


300
301
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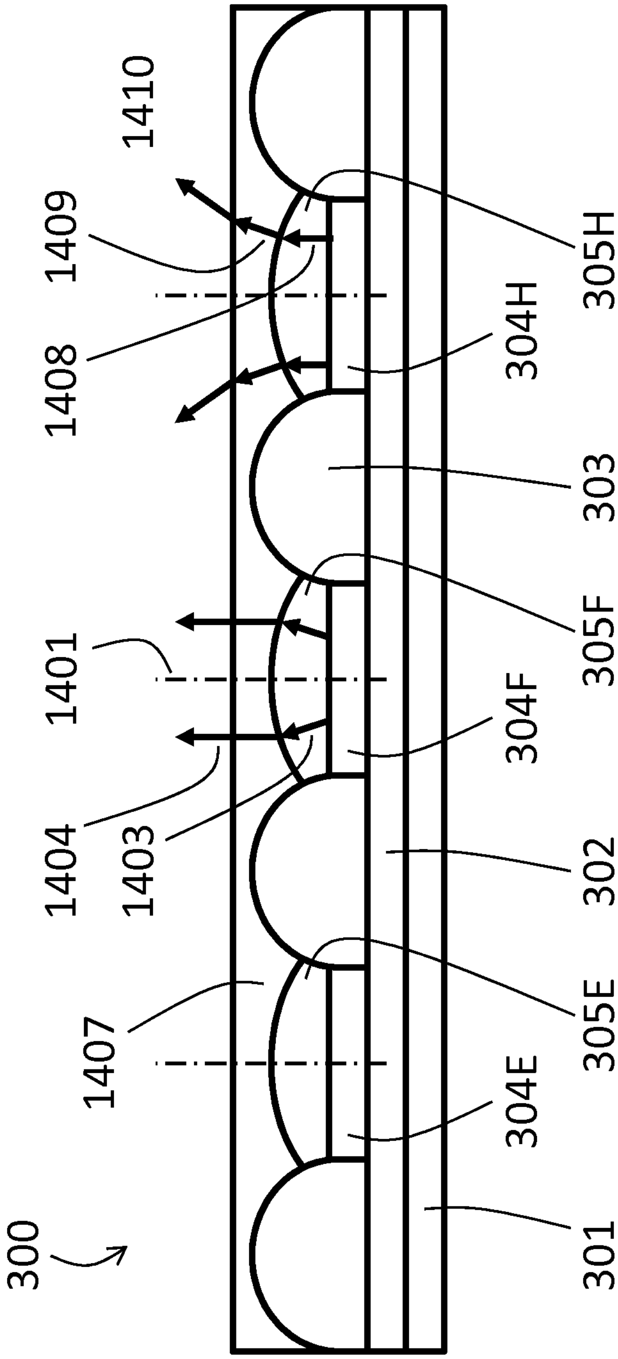
304D
305A
305C
305D
1401
1402
1403
1404
1405
1406

FIG. 14A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1404
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1407
304E
300
301

FIG. 14B

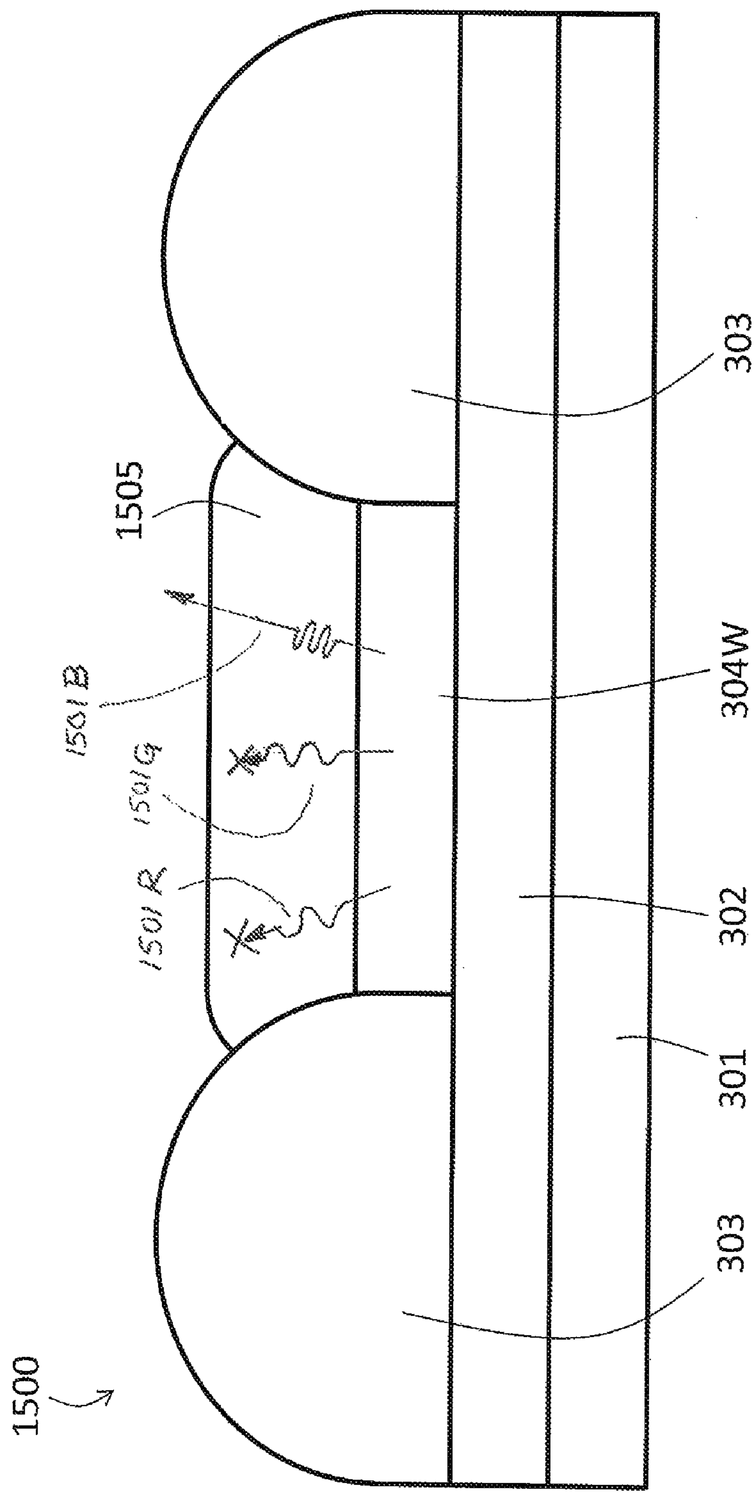

FIG. 15

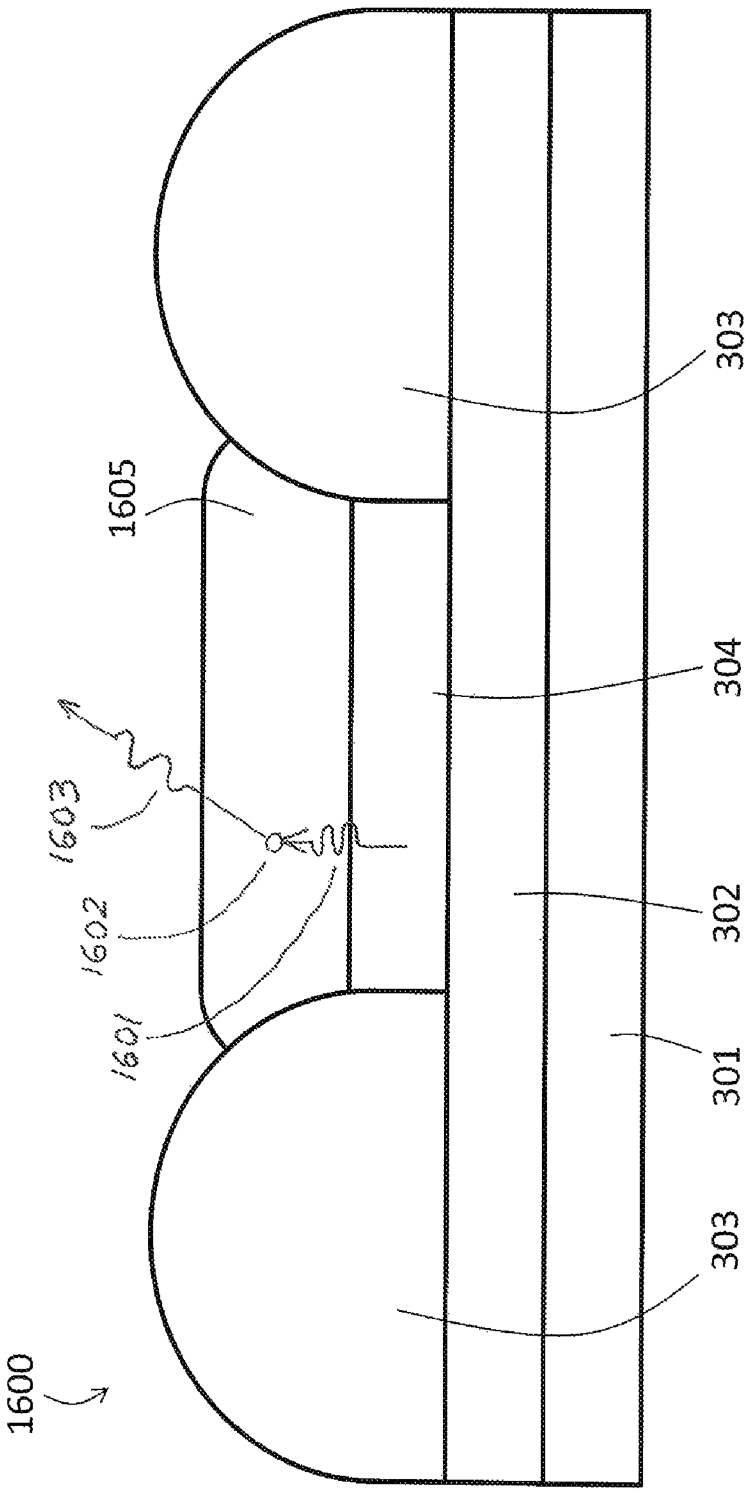

FIG. 16

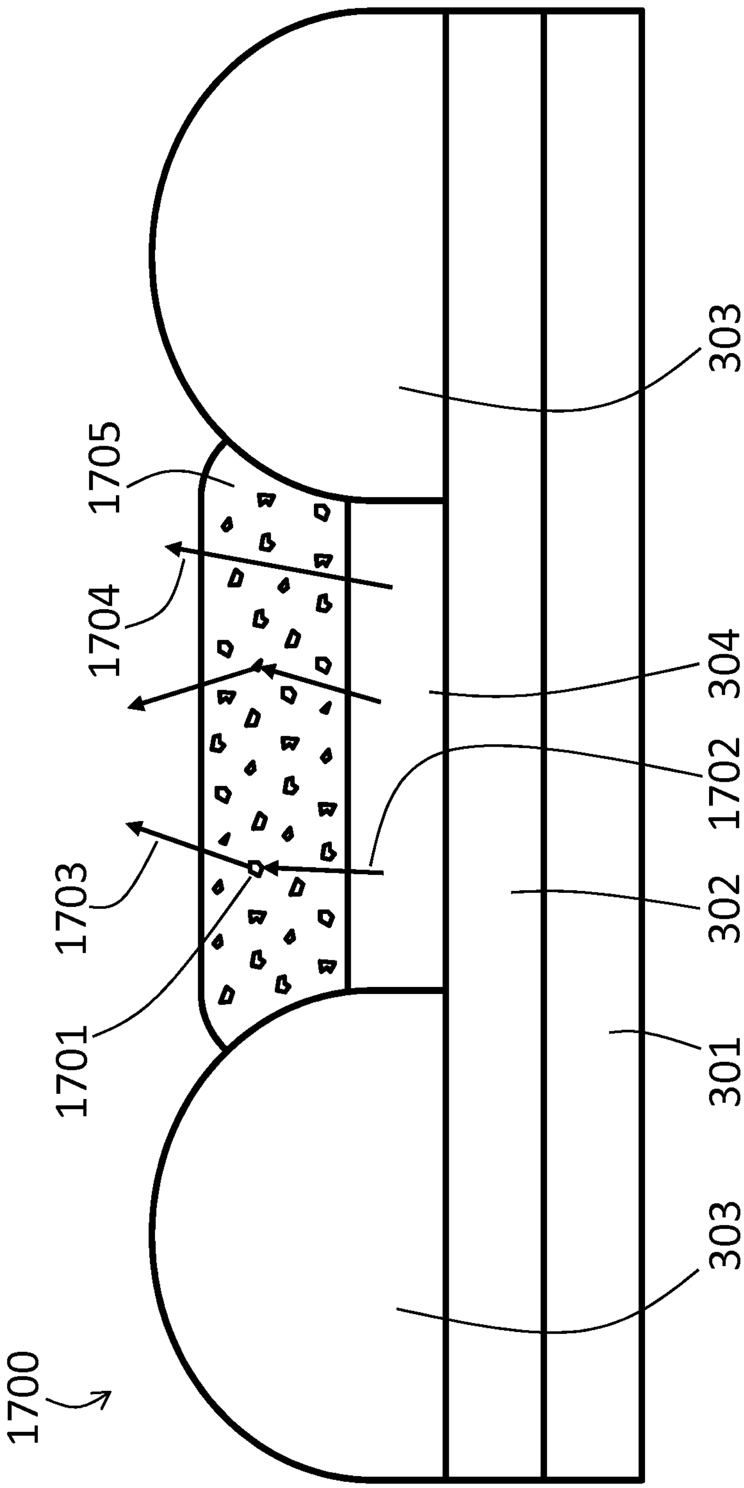

FIG. 17

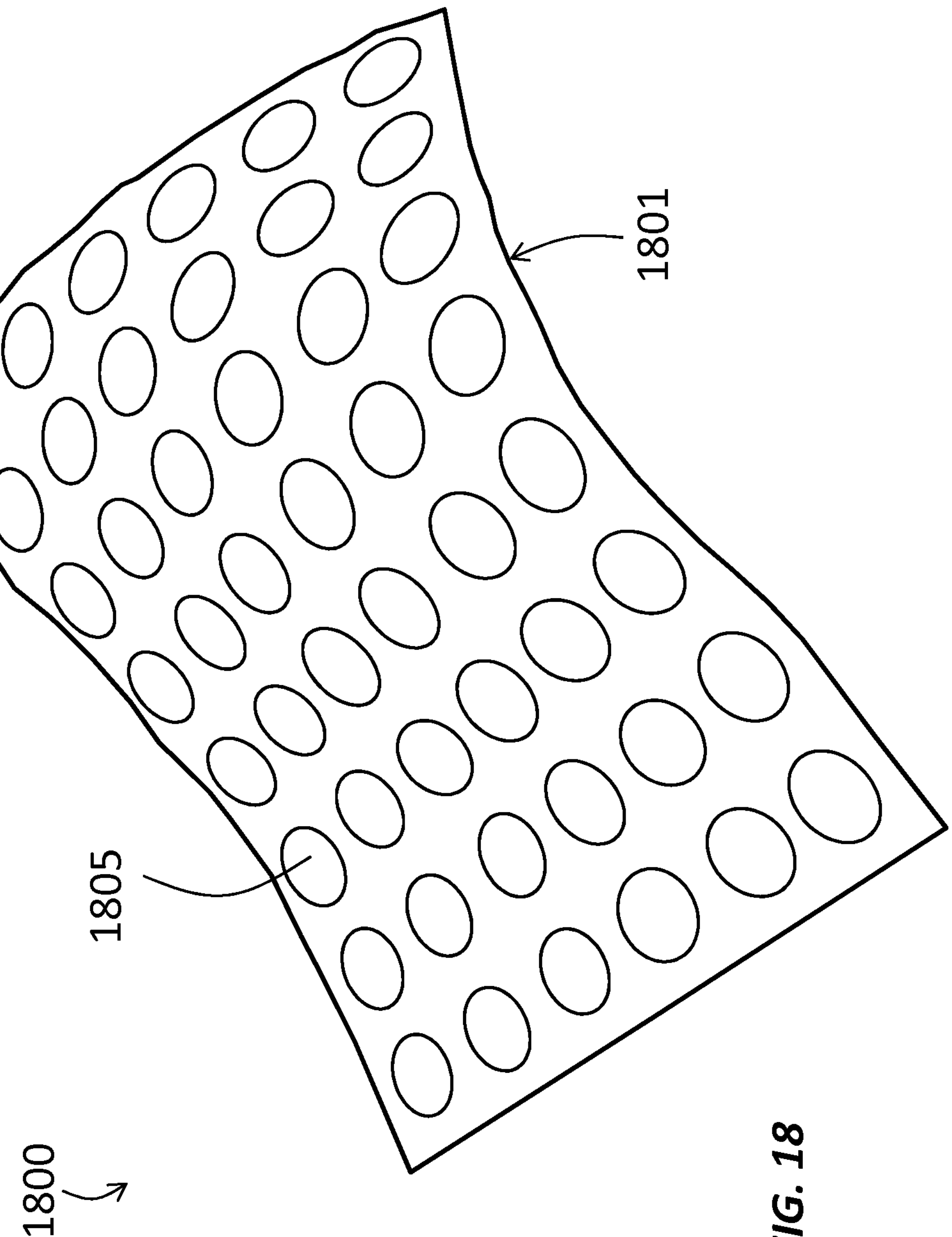

FIG. 18

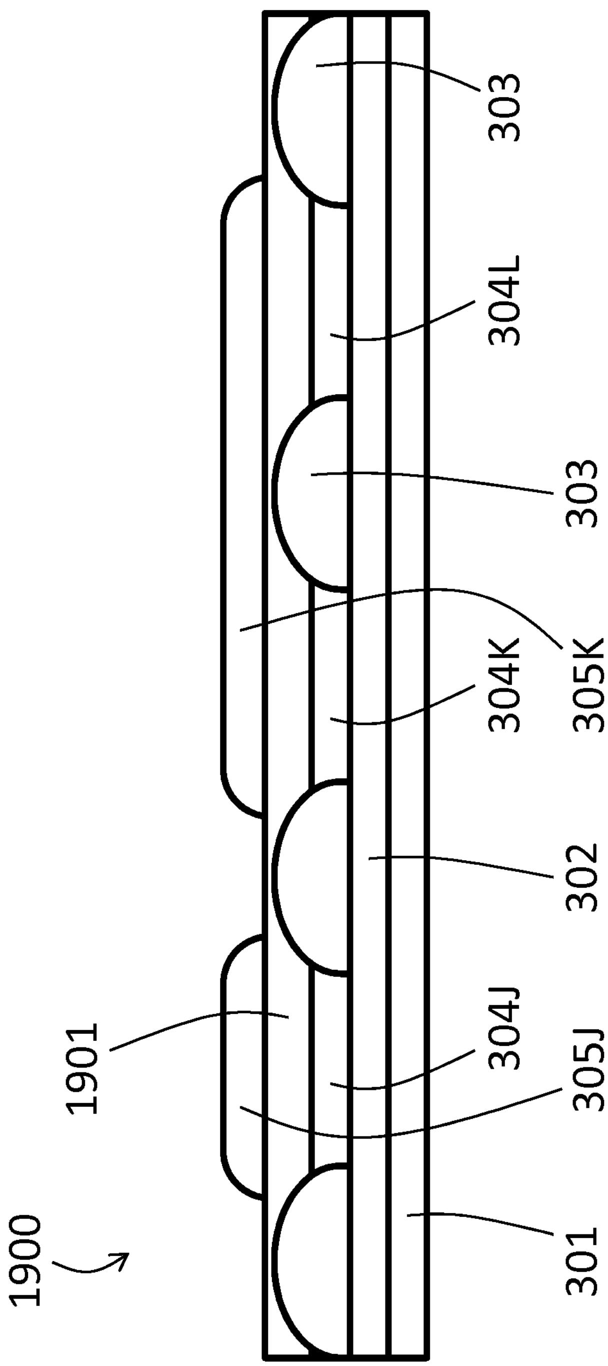

FIG. 19

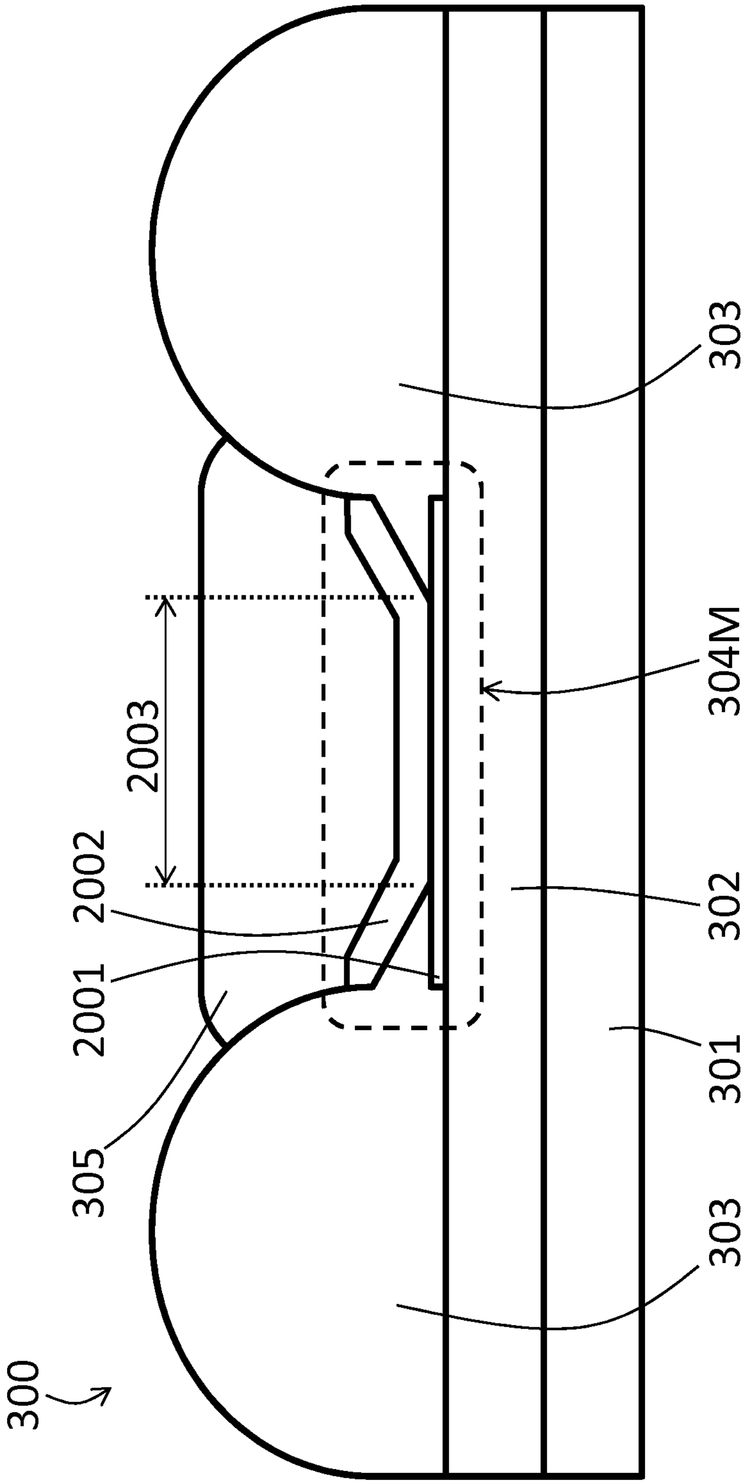

FIG. 20

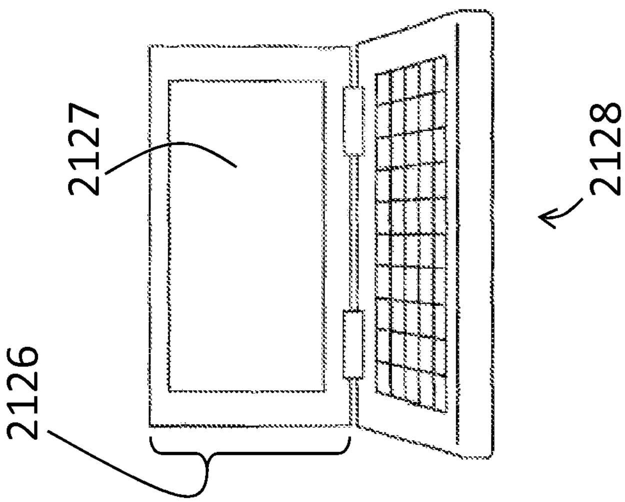

FIG. 21B

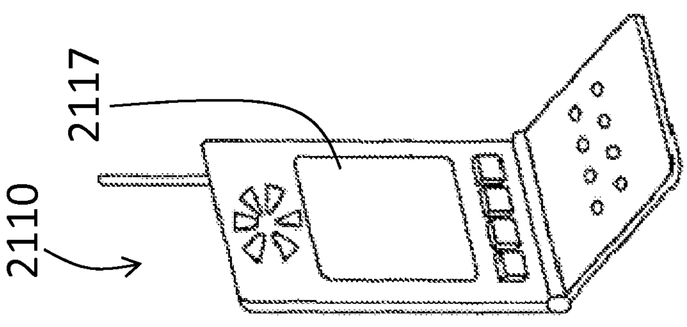

FIG. 21A

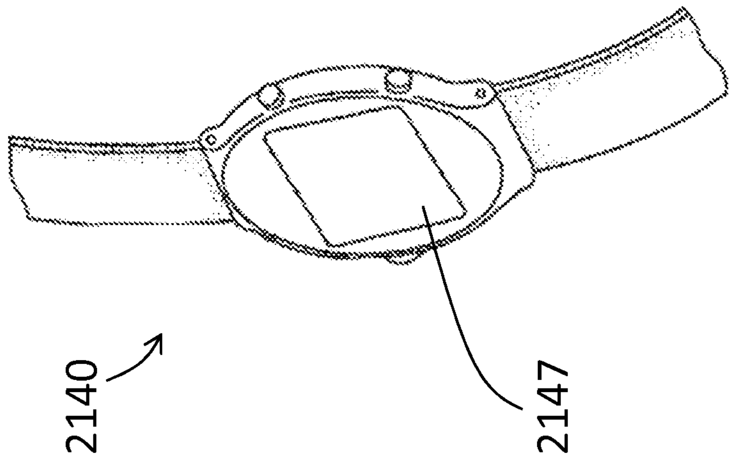

FIG. 21D

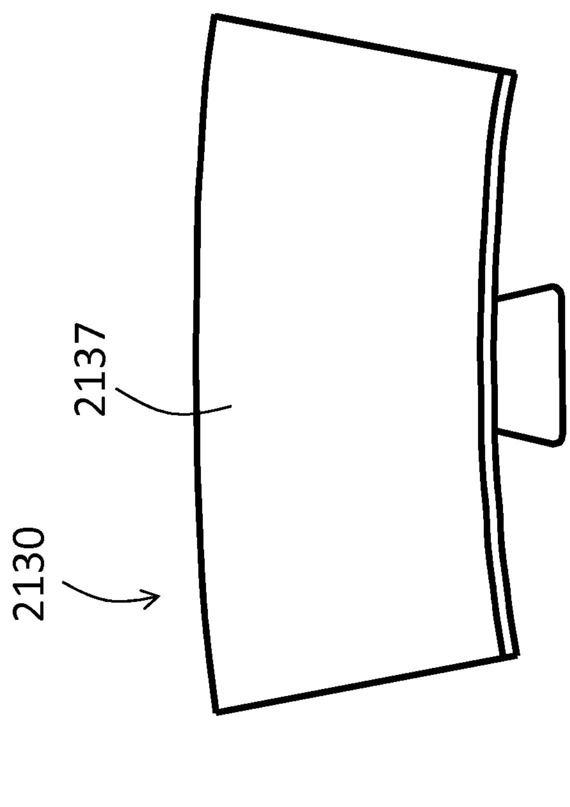

FIG. 21C

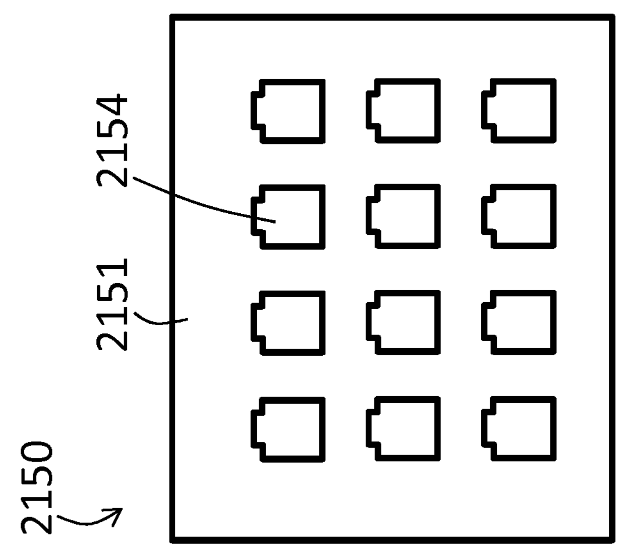

FIG. 21E

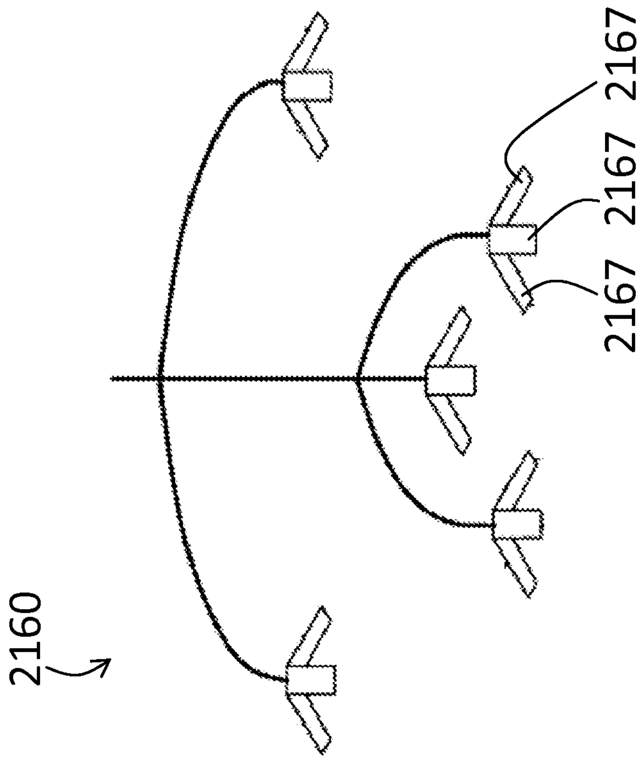

FIG. 21F

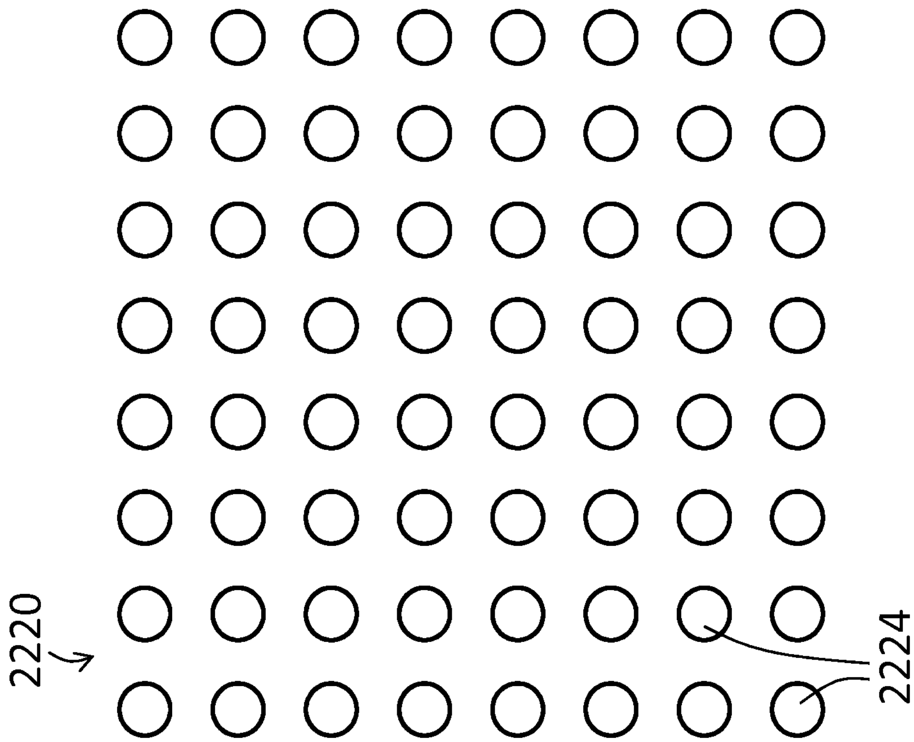

FIG. 22B

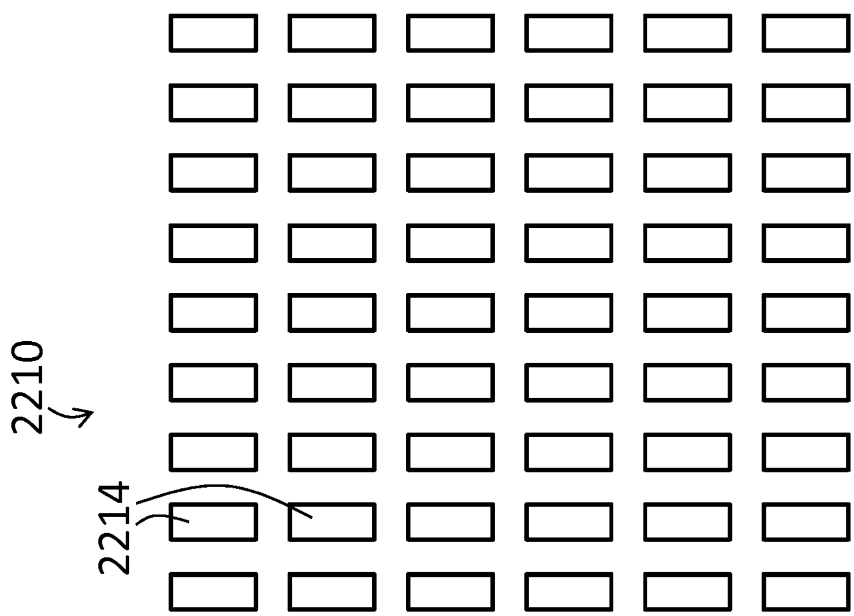

FIG. 22A

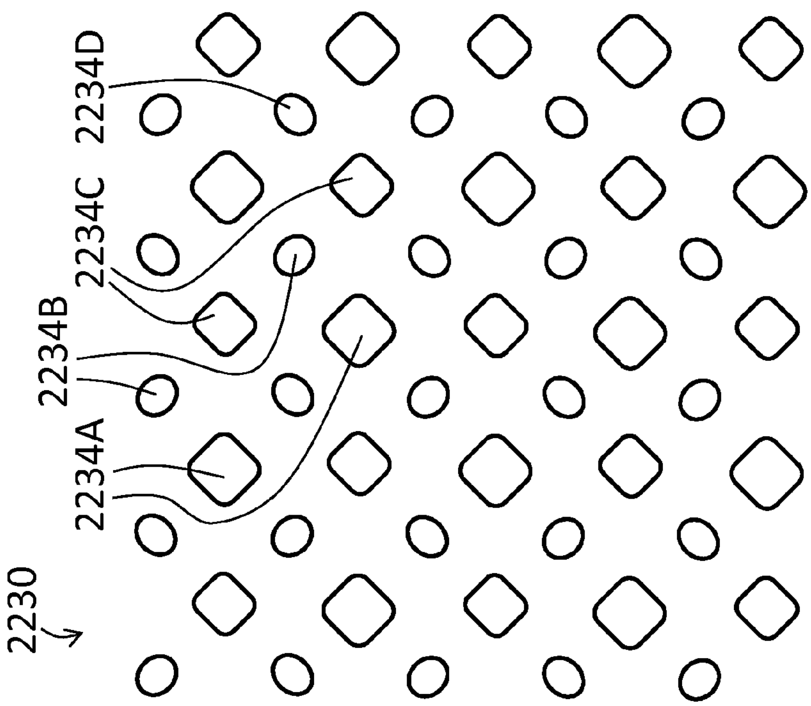

FIG. 22C

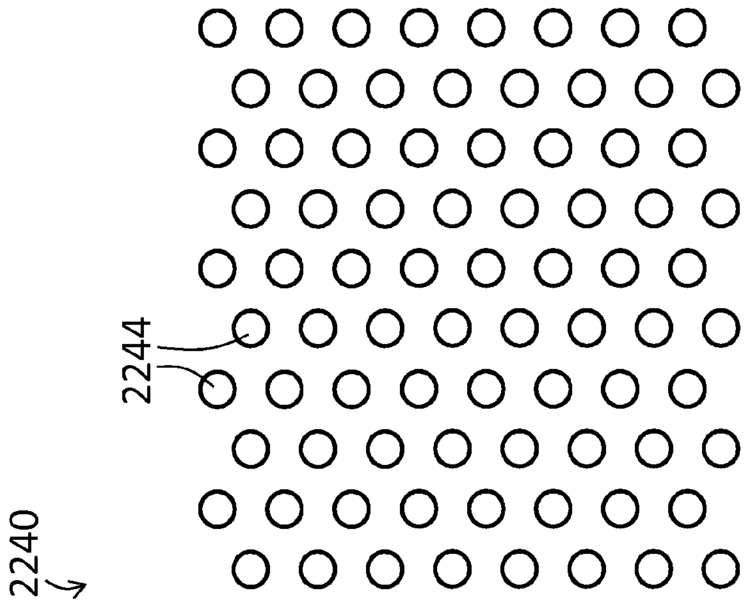

FIG. 22D

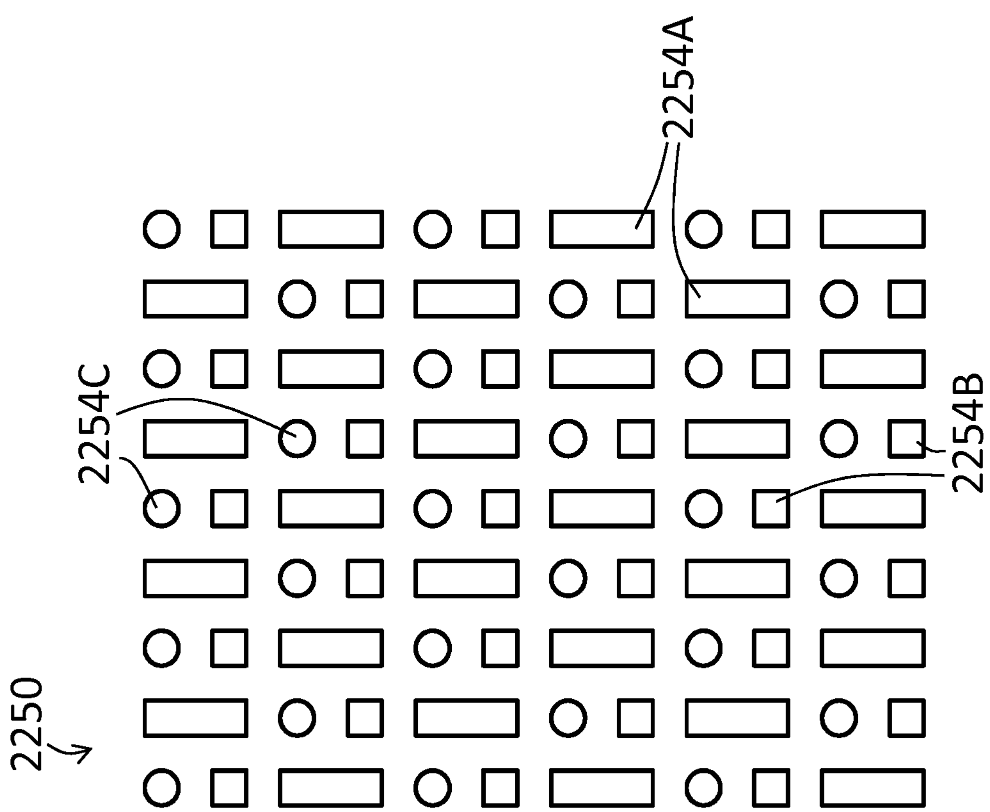

FIG. 22E

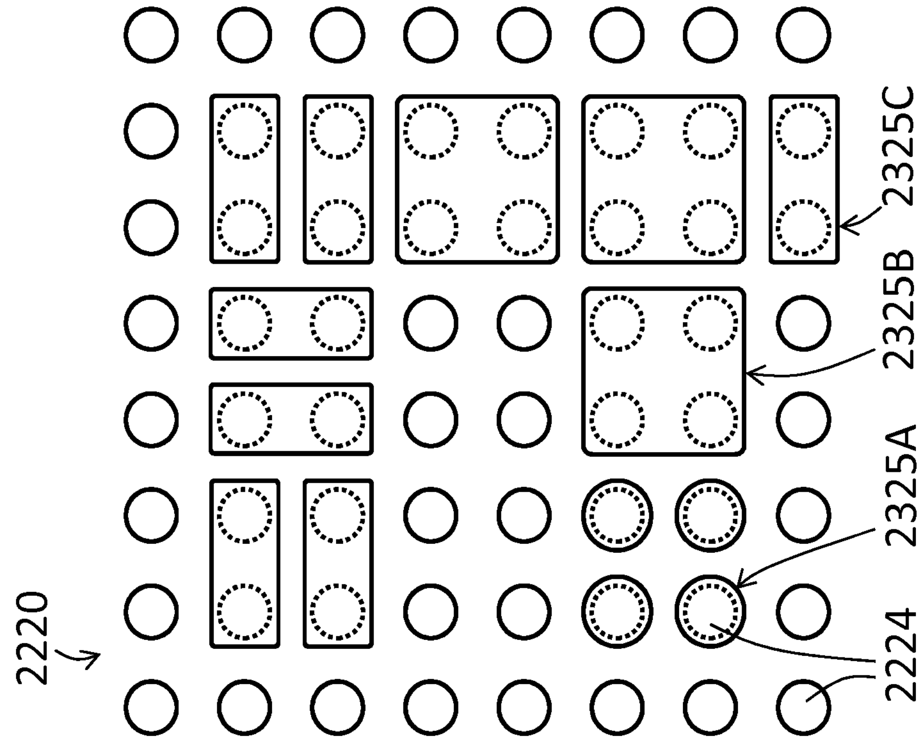

FIG. 23B

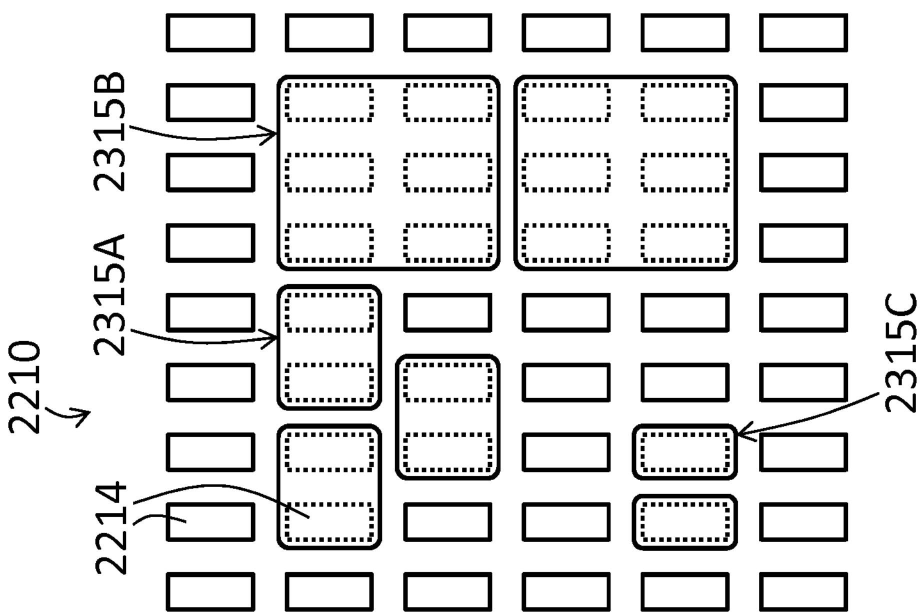

FIG. 23A

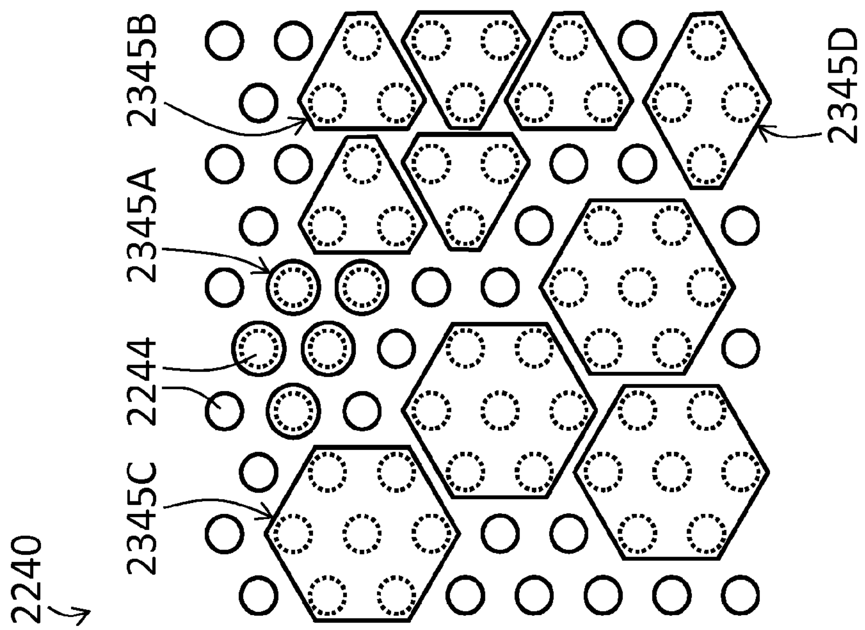

FIG. 23D

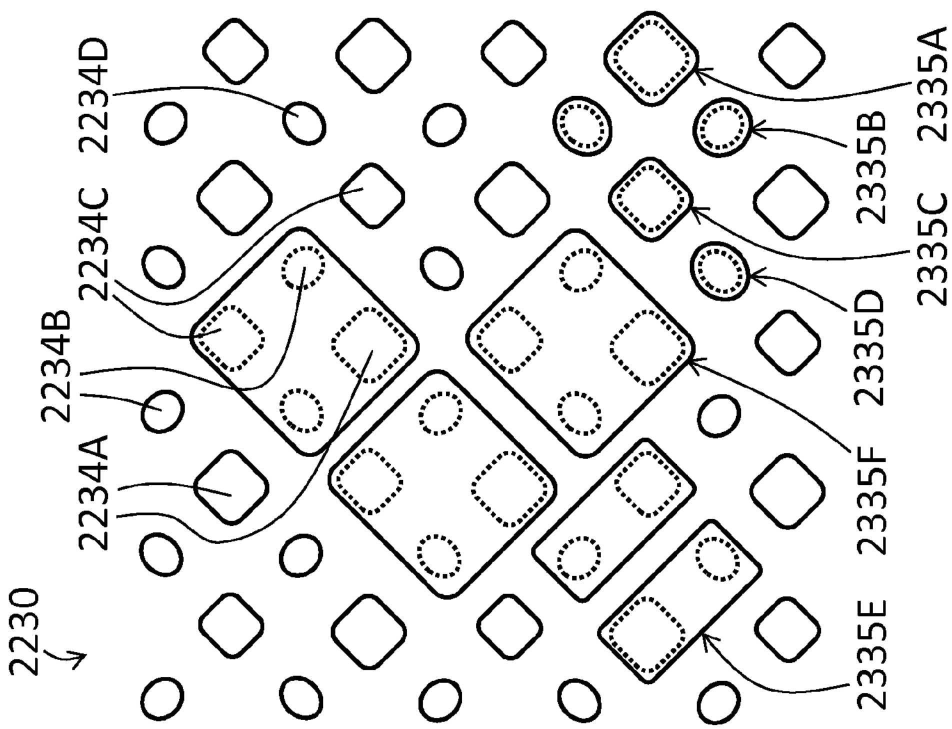

FIG. 23C

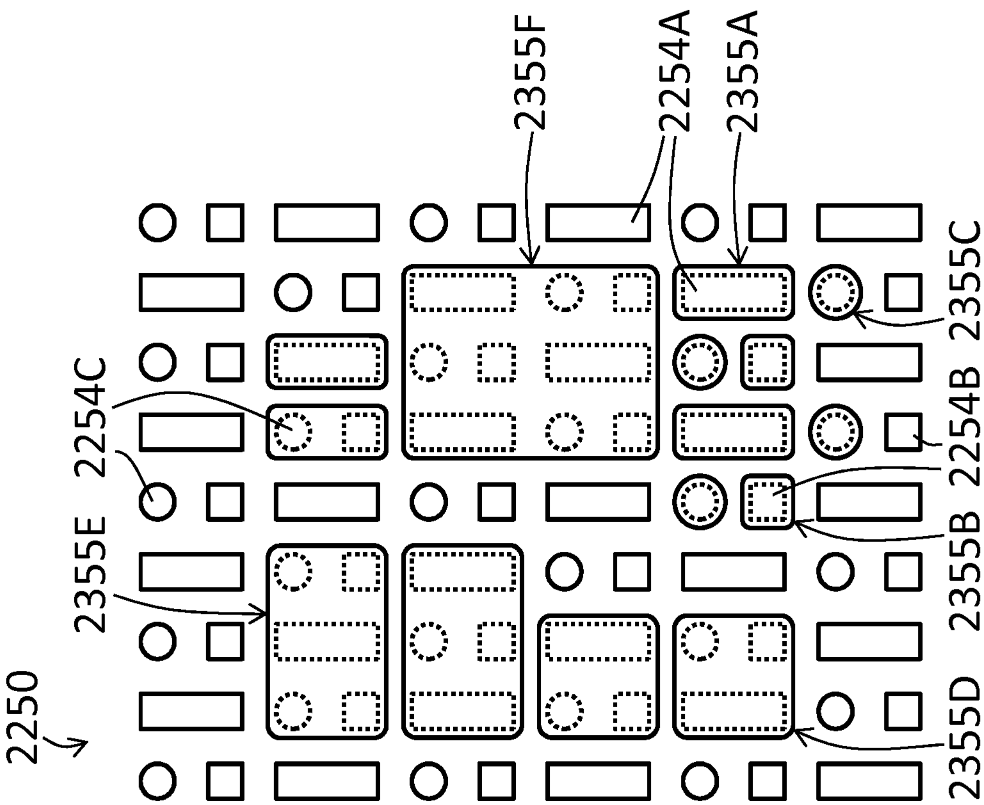

FIG. 23E

LOCAL SEAL FOR ENCAPSULATION OF ELECTRO-OPTICAL ELEMENT ON A FLEXIBLE SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. Ser. No. 14/446,470, filed Jul. 30, 2014 entitled "LOCAL SEAL FOR ENCAPSULATION OF ELECTRO-OPTICAL ELEMENT ON A FLEXIBLE SUBSTRATE" by Rajeev Rohatgi, since published as U.S. 2015/0034934, which claims the benefit of U.S. Ser. No. 61/859,989, filed Jul. 30, 2013, which are hereby incorporated by reference for all purposes as if fully set forth herein.

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Not applicable.

FIELD OF THE INVENTION

The present invention relates to encapsulation of a flexible electroluminescent device or similar electro-optical panel.

BACKGROUND

Electro-optical arrays are widely used in commercial products. Examples of such products include a phone, a monitor, a television set, and a wristwatch, all of which have pixel arrays used for information display. Further examples include an OLED lighting panel and an OLED luminaire, which have arrays of OLED elements used for illumination.

Display Products

In recent years, there has been a blurring of lines between some of the abovementioned product categories. For example, modern smartphones routinely include cameras and allow viewing of video and television received over wireless networks and the Internet. Additionally, smartphones offer access to many of the same classes of applications (or, "apps" for short) that consumers previously accessed using computers with monitors. These application classes include news, email, instant messaging, games, and office productivity tools. Therefore, within this disclosure, we mean "phone" as commonly understood at present: a relatively small devices with display less than 30 cm in extent, preferably less than 20 cm in extent, more preferably less than 15 cm in extent, and commonly less than 10.2 cm in extent. The term "extent" means the largest transverse dimension along a surface of a display, lighting device, or other electro-optical array. For rectangular displays as are found in common phones and televisions, the extent is the same as the diagonal measure commonly cited as the size of the display. For curved products, "extent" is measured as if the product was laid out flat.

The term "array", as applied to electro-optical or electroluminescent elements, is understood to refer to a two-dimensional array of such elements formed over a single substrate. A two-dimensional layout of OLED panels, each having a single electroluminescent element would not be considered an array of electroluminescent elements, since each OLED panel has a different substrate from the other OLED panels. The array is considered to be two-dimensional regardless of whether the surface is flat or curved. The surface on the substrate over which such an array is formed is nominally considered to be the top surface of the substrate, regardless of the orientation or curvature of the substrate within a particular product.

It is also useful to define the concept of neighboring elements in such an array. Consider first and second elements of such an array, which have respective first and second centroids. The first and second elements are neighbors if the number of distinct points on the top surface of the substrate that are (a) equidistant from first and second centroid, and (b) farther from the centroids of all other elements of the array, is greater than or equal to two. According to this definition of "neighbor" two adjacent squares on a chessboard are neighbors (all except corner points along their common boundary satisfy both conditions (a) and (b)), two diagonally touching squares on the chessboard are not neighbors (the corner where the squares touch is equidistant from four squares of the chessboard, hence this point does not satisfy condition (b), and no other point meets both conditions (a) and (b) either), and two squares remote from each other on the chessboard are not neighbors (all points satisfying condition (a) are closer to the centroid of some third square than to the first and second centroids).

We use "television" as commonly understood in the art: a relatively large device for playing video-plus-audio programming received from over-the-air broadcast, cable TV, the Internet, wireless network, or by wired transmission from separate nearby equipment such as an optical disk player, a digital video recorder, a computer, or a camera. The display of a television may range from 2 cm to 305 cm in extent, preferably 20 cm to 155 cm, and often 80 cm to 140 cm in extent.

We use "monitor" to mean a display capable of showing changing information over time. Monitors include those found in airport terminals, lobbies of commercial buildings, and kiosks, as well as those associated with a specific computing device such as a tablet, a laptop, or a desktop computer, or otherwise known in the art. "Monitor" may also refers to an information display found in or on a host of embedded systems, ranging from thermostats, refrigerators, automobiles, GPS navigation devices, alarm systems, and many more. Large information display monitors often have an extent from 75 cm to 200 cm, preferably less than 155 cm. Ultra-large information displays are also known. For example, sports stadiums commonly have displays exceeding 100 m^2 in area; the stadium exterior display built for the Kazan Universiade measures an astonishing 3700 m^2. Of course, these ultra-large displays often comprise a modular array of smaller information display monitors. In such a case, the term "monitor" includes within its scope both the entire stadium display, as well as a single module. In other cases, large information displays are comprised of discrete lamps. A lamp is understood herein to mean a single light-emitting element that cannot be spatially resolved as smaller elements. A lamp is not a monitor, as understood herein. A monitor may be a commercial product by itself, such as a stand-alone monitor for a desktop computer, or it may be part of an integrated system, such as the information display of a tablet computer.

There is a burgeoning class of commercial products known as wearable electronics, many of which incorporate a display. Wristwatches have been common for over one hundred years, and electronic wristwatches have been known for over forty years. Recently, watches with full-color displays have emerged in the marketplace. Other wearable electronic devices with displays include personal music players (such as the Apple iPod™), and head-mount optical displays (such as the Google Glass™). There have been proposals to incorporate wearable electronics into clothing, shoes, jewelry, and other articles of apparel.

All of these commercial products may have displays that are full-color or monochromatic; black and white displays being a special case of monochromatic displays. Displays commonly incorporate individual elements, known as pixels, on a common substrate. Typically, pixels are electrically controlled and are individually controlled, however pixels may be commonly controlled in groups. In an electroluminescent display, such as an OLED display, pixels are individually light-emitting. Other displays have a common light source for multiple pixels, which could be a backlight or edge lighting or ambient light. One common light source may illuminate all the pixels of the display, or merely a group of pixels in a region of the display. In displays with one or more common light source, the individual pixels incorporate electro-optical elements that control the transmission or reflection of light from the one or more common light source. Displays of this type include liquid crystal displays, electrochromic displays, ferro liquid displays, electrophoretic displays, and electrowetting displays. The term "electro-optical element" includes electroluminescent elements such as LED and OLED. Many of these electro-optical elements contain organic materials and have limited tolerance for heat. Many of these electro-optical elements are sensitive to moisture and oxygen. OLED elements are particularly sensitive to moisture, are sensitive to oxygen, and have limited tolerance for heat. While heat tolerance of an OLED varies according to the device architecture and the particular compounds used, 300° C. has been cited as a maximum substrate temperature during an encapsulation process, by Federovskaya in U.S. 2009/0081356.

Lighting Products

Electro-optical arrays, in particular electroluminescent arrays, also find use in lighting products. The term "lighting product" refers to any product whose function is to provide illumination of space or objects external to the product. Illumination may be in the visible spectrum or in other portions of the electromagnetic spectrum. OLED panels may be lighting products; OLED lighting panels are commonly organized as an array of commonly controlled but separate light emitting elements on a single substrate. At present, the extent of the array of light emitting elements in an OLED panel may lie within the range from 2 cm to 30 cm, commonly 5 cm to 21 cm, and often 10 cm to 16 cm. In future, as manufacturing technology improves, this array extent may increase to 50 cm, 100 cm, or even larger. In some instances, OLED panels may have light-emitting elements having a plurality of differently colored emissions. For example, ⅓ of the elements may be red, ⅓ green, and ⅓ blue. By varying the relative excitation of red, blue, and green elements, the color and the color temperature of the light may be controlled. Light emitting elements in an OLED panel are commonly organized in rectangular or hexagonal layouts. Although many or all of the light emitting elements in an electroluminescent array of a lighting product are commonly controlled, from the point of view of structure and organizational layout, these light emitting elements are substantially similar to the pixels of a display product. Furthermore, for any given electroluminescent technology, the encapsulation requirements of light emitting elements in display and lighting products are substantially similar. Since encapsulation is of particular interest in this disclosure, it is understood that discussions using the term "pixel" are generally applicable to lighting elements of a lighting product as well, except in those cases where it is clear from the context that the discussion is specific to display products only.

Because OLED panels are at present relatively small, and because designers have exercised their imagination to create complex and artistic structures, many lighting fixtures and luminaires have been conceived as each comprising multiple OLED panels. Such a lighting fixture or luminaire would be a commercial product incorporating a plurality of electro-optical arrays, since each OLED panel itself incorporates an electroluminescent array. A lighting fixture or luminaire is understood to mean a single detachable assembly directly mounted onto a wall, ceiling, floor, furniture, building, frame, pole, tower, truss, or other civil structure, for the purpose of providing illumination. A lighting panel is understood to mean the smallest removable unit from a lighting fixture or luminaire that can be removed and replaced as an integral unit without impairing the capacity of this unit to generate light, in other words, without breaking anything. Although lighting panels and lighting fixtures are often distinct, they can also be the same, for example the common inexpensive plug-in electroluminescent night lights available today. Of course, depending on the electroluminescent technology in use, not all electroluminescent panels will incorporate a two-dimensional array of separate light emitting elements; some technologies may readily allow a panel to be built as a single light-emitting element, or alternatively as a one-dimensional array of light-emitting elements.

Flexible Products

Another current trend is toward flexible products. From a manufacturer's standpoint, flexible products are desirable because they can be manufactured at large scale and high volume using a relatively inexpensive roll to roll process, as against the more common discrete manufacturing used today for both display and lighting products. From a designer's standpoint, flexible products are desirable because they can be configured into curved devices, some of which will be rigid curved devices, such as a curved television, while others will be flexible, such as could be integrated into clothing. From a consumer's standpoint, flexible products are desirable because they offer the prospect of lightweight, compact, foldable, and even unbreakable devices.

However, as discussed below, encapsulation suitable for flexible products has not been satisfactorily addressed to date, especially for the stringent encapsulation requirements of OLED elements.

Encapsulation Technology

Materials used in organic light emitting diodes (OLEDs) are well known to be sensitive to oxygen and moisture. Degradation mechanisms are described, for example, by So et al., Advanced Materials, vol. 223, pp. 3762-3777, 2010. As a result, encapsulation is an important part of OLED design. Two main classes of encapsulation are known: (1) use of an encapsulation substrate, i.e. a preformed sheet, and (2) thin film encapsulation.

Encapsulation substrates may commonly be glass or metal, and are commonly spaced from underlying electroluminescent elements with e.g. nitrogen gas fill in between. For example, U.S. Pat. No. 6,111,357 to P. Fleming describes an encapsulation substrate in the form of a glass, metal, or ceramic cover that is attached to an underlying display substrate by a perimeter seal located outside the active area of the display. A metal substrate is opaque and is only suitable for a bottom-emitting display, while a glass substrate is relatively thick and rigid, and not well-suited for roll-to-roll manufacture or flexible displays.

Thin film encapsulation offers manufacturing benefits, but suffers from the relatively high permeability of polymer materials, and the difficulty of depositing or forming thin film layers that are free of pinholes. The permeability requirements for OLED are stringent and limit the choice of suitable materials. One approach to overcoming these problems has been preparation of laminated layers. See, for example, U.S. Pat. No. 4,104,555 to G. Fleming, U.S. Pat. No. 5,811,177 to Shi, and Lewis et al., IEEE Journal of Selected Topics in

Quantum Electronics, vol. 10, no. 1, pp. 45-57, 2004. But, the use of laminated layers requires additional process steps, with attendant costs.

Additionally, many variants are known. In U.S. 2012/0319141, Kim discloses a combination of a multi-layer thin film seal with a cover attached by a perimeter seal. U.S. Pat. No. 7,368,307 to Cok discloses a flexible substrate attached to a rigid curved encapsulating cover. Neither of these solve the abovementioned problems with encapsulation substrates on one hand, or thin film seals on the other.

It is also known to combine the encapsulant function with other functions. In U.S. 2011/0241051, Carter discloses a structured film encapsulant with an integrated microlens array and diffraction grating. This encapsulant is pre-formed, which entails additional manufacturing equipment and cost, and also requires careful alignment between the pre-formed optical structures on the encapsulant and a pixel pattern on an underlying display substrate. Further, Carter's encapsulant is described as comprising an elastomeric polymer (such as polydimethylsiloxane (PDMS)) with one or two coating layers (such as silicon nitride (SiN)). This multi-layer structure involves additional process steps and costs as described above.

A number of authors have been concerned with the separate encapsulation of distinct devices on a mother glass, prior to singulation. U.S. Pat. Nos. 7,091,605, and 7,329,560 both require a perimeter seal around each distinct device, which requires too much space to be workable between neighboring electro-optical elements in a two-dimensional array of elements of a single device. U.S. Pat. No. 6,949,382 to Pichler requires hardening of a planarization layer that substantially covers an entire device, and is fundamentally at odds with encapsulating a flexible device.

Thus, there remains a need for an encapsulation technology that is compatible with roll-to-roll manufacturing, and flexible, unbreakable, or deformable products that incorporate a two-dimensional array of electro-optical elements.

BRIEF SUMMARY OF THE INVENTION

The present invention is directed to apparatus and methods for encapsulation of an electroluminescent product comprising a collection of distinct light-emitting elements such as pixels.

In a first aspect, local encapsulation seals are provided over respective individual light-emitting elements. In accordance with preferred embodiments of the present invention, the local encapsulation seals are formed of a glass material. The advantages of glass include low permeation rates for both moisture and oxygen, as well as optical clarity. See, for example, U.S. Pat. No. 7,026,758 to Guenther. These advantages can be retained by forming a local glass seal above each light-emitting element. Because the glass need not be a continuous sheet, flexibility of a finished light emitting product is not compromised. In a second aspect, local encapsulation seals are provided over respective groups of light-emitting elements.

In a third aspect, each individual light-emitting element is a pixel (sometimes called a subpixel) of a display product. In a fourth aspect, each individual light-emitting element is a distinct element of a collection of such elements forming a lighting product.

Henceforth in this document, the term pixel will be used to denote a distinct light-emitting element in any of a display product or a lighting product. In preferred embodiments, a distinct light-emitting element is an organic light-emitting diode, or OLED, however the invention is not limited to OLED products. The term distinct is used to indicate that a light-emitting element is physically separated from other light-emitting elements. For both display and lighting products, the product may have many such distinct light-emitting elements formed together integrally as a two-dimensional array of elements on a single substrate. Two distinct light-emitting elements in a product may be controlled by same or different circuitry, and may or may not be operable independently of one another.

In a fifth aspect of the present invention, local glass seals are formed using a suspension or paste of glass powder. In a sixth aspect, the glass powder used has a low fusing temperature, which may be less than or equal to 300° C.

Glass powders with low fusing temperatures in the range 220-300° C. have recently become available. These melting temperatures are compatible with many OLED materials. An example of such a powder with melting temperature in the range 220-300° C. has been added to Hitachi Chemical's Vaneetect product line. See, for example, Hitachi News Release, "220-300° C. low-melting glass for hermetic sealing", Nov. 26, 2012, http://www.hitachi.com/New/cnews/121126a.pdf.

In a seventh aspect of the present invention, the glass powder suspension or paste is deposited using inkjet technology. Glass powders are widely used in industry, and are commonly applied in the form of a suspension or a paste. Inkjet technologies have already been proposed for deposition of electroluminescent materials in a light-emitting pixel, for example by Duineveld in U.S. Pat. No. 7,011,561. The same technology can be applied for deposition of a glass powder suspension or paste above a pixel or other small light-emitting element. In U.S. Pat. No. 6,855,367, Nakao describes a glass powder jet ink.

In an eighth aspect of the present invention, the deposited glass powder is fused without damaging the underlying electroluminescent layers. In some embodiments, fusing of the glass powder can be achieved by bulk heating of the entire product. In other embodiments, fusing of the glass powder can be achieved by uniformly heating a surface of the product on which local seals are being formed. In yet other embodiments, heat is deposited locally so that the areas to be sealed absorb more energy per unit area than areas between seals.

In a ninth aspect of the present invention, a laser source producing a tailored beam profile is used to provide non-uniform irradiation of the product surface on which local seals are being formed. In some embodiments, the tailored beam profile may be a spot. In other embodiments, the tailored beam profile may be a group of distinct spots. In yet other embodiments, the tailored beam profile may be a line.

In a tenth aspect of the present invention, the local seals may be combined with a thin film encapsulation structure over the glass seals. In an eleventh aspect of the present invention, the local seals may be provided over a previously formed thin film encapsulation structure. In some embodiments, the thin film encapsulation structure comprises a single layer, while in other embodiments, the thin film encapsulation structure comprises multiple layers.

The combination of a thin film encapsulation structure with local seals is mutually beneficial. The local seals provide protection against pixel damage due to pinhole defects in the thin film encapsulation structure. Conversely, the thin film encapsulation structure reduces uptake of moisture or oxygen by areas of underlying layers between the pixels. While such uptake of moisture or oxygen may not directly impact performance of a display or lighting product, the moisture or oxygen so absorbed can migrate laterally into the active area of a light-emitting element, where the moisture or oxygen will likely impact product performance. Thus, the thin film encapsulation structure can greatly improve protection of a light-emitting element against secondary paths of moisture or oxygen ingress.

The local seals may additionally perform an optical function. Optical functions may include operation as a lens, operation as a filter, operation as a color converter, and operation as a scatterer.

In a twelfth aspect of the present invention, a local seal has substantially planar top and bottom surfaces, and performs no lens function. In a thirteenth aspect, a local seal has a curved top or bottom surface and acts as a converging lens. A converging lens function is desirable, for example, in a battery-powered personal device, where light emitted in directions away from a user represents wasted energy and reduced battery life. In a fourteenth aspect, a local seal has a curved top or bottom surface and acts as a diverging lens. A diverging lens function is advantageous, for example, in television products, digital signage, and some lighting products, where wide field of view is desirable.

In a fifteenth aspect of the present invention, the local seal is formed of a glass powder suspension doped with one or more pigments, so as to tailor the emission profile with respect to the natural emission profile of the underlying electroluminescent element. This aspect of the invention is advantageous for display products having a common emissive layer for different color pixels. This aspect of the invention is also advantageous for lighting products to tailor the color temperature of the emitted light.

In a sixteenth aspect of the present invention, the glass powder suspension is doped with a fluorescent or other color shifting material. This aspect of the invention is advantageous, for example, in a lighting product, to convert cold bluish light to a warmer color.

In a seventeenth aspect of the present invention, the glass powder suspension may be mixed with a powder of a refractory material. When the glass is fused during manufacture of the local seals, the refractory materials remain intact. Thereby the local seals lose some of their optical clarity and take on a scattering function.

It will be clear to a practitioner that the various aspects of the present invention can be combined in a variety of combinations to suit a particular application or manufacturing process. Furthermore, these various aspects can also be combined with yet other features not enumerated herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The following detailed description will be better understood when read in conjunction with the appended drawings, in which there is shown one or more of the multiple embodiments of the present invention. It should be understood, however, that the various embodiments of the present invention are not limited to the precise arrangements and instrumentalities shown in the drawings. Further, because of the widely disparate dimensions of the features shown, these drawings are not to scale.

FIG. **1** is a diagram of a prior art device encapsulated using an encapsulation substrate.

FIG. **2** is a diagram of a prior art device encapsulated using a thin film encapsulation.

FIG. **3** is a diagram of a first embodiment of the present invention having local glass seals above electro-optical elements of a panel such as a display panel.

FIG. **4**A is a diagram of a second embodiment of the present invention having local glass seals above light emitting elements of a lighting panel.

FIG. **4**B is a diagram showing a cross-sectional view of the embodiment of FIG. **4**A.

FIG. **5** is a diagram of a third embodiment of the present invention having local glass seals above groups of light emitting elements.

FIG. **6**A-**6**D are diagrams of an electroluminescent panel at different stages of formation of local glass seals.

FIGS. **7**A-**7**C are diagrams showing different forms of heating that may be used to fuse local glass seals.

FIGS. **8**A-**8**C are diagrams of different laser beam profiles that may be used for selective heating of glass seals.

FIG. **9** is a diagram of a fourth embodiment of the present invention having thin film encapsulation above local glass seals.

FIG. **10** is a flow chart showing process steps for manufacture of the fourth embodiment.

FIG. **11** is a diagram of a fifth embodiment of the present invention having local glass seals above a thin film encapsulation layer.

FIG. **12** is a flow chart showing process steps for manufacture of the fifth embodiment.

FIGS. **13**A-**13**B are diagrams of ingress paths that are blocked by a combination of a thin film encapsulation structure and a local glass seal.

FIGS. **14**A-**14**B are diagrams of lens functions that may be performed by a local glass seal.

FIG. **15** is a diagram of a local glass seal acting as an optical filter.

FIG. **16** is a diagram of a local glass seal performing a color shift function.

FIG. **17** is a diagram of a local glass seal performing a scattering function.

FIG. **18** is a diagram of a flexible electroluminescent panel having local glass seals.

FIG. **19** is a diagram of a sixth embodiment having local glass seals above a thin film encapsulation layer.

FIG. **20** is a diagram showing a detail of an OLED element beneath a local glass seal.

FIGS. **21**A-**21**F depict exemplary commercial products: a phone, a monitor, a television, a wristwatch, an OLED panel, and a luminaire, respectively.

FIGS. **22**A-**22**E are conceptual representations of two-dimensional arrays of electro-optical elements.

FIGS. **23**A-**23**E are conceptual representations of local encapsulation seals covering respective two-dimensional arrays of electro-optical elements.

DETAILED DESCRIPTION OF THE INVENTION

Electro-optical arrays are widely used in commercial products. FIGS. **21**A-**21**D show respectively a phone, a monitor, a television set, and a wristwatch, all of which have pixel arrays used for information display. FIGS. **21**E-**21**F show respectively an OLED lighting panel and an OLED luminaire, both of which have arrays of OLED elements used for illumination.

By way of example, Company A may manufacture phone displays on a mother glass; following fabrication of display elements and encapsulation, singulation, and possibly other finishing steps such as assembly with cover layers, connectorization, and packaging, a large number of display panels or display modules are obtained. These display panels are further assembled into phones, either by Company A or by another company. The manufacture of other display products of interest is similar, in that a finished display panel is incorporated into a finished product. The manufacture of lighting products of interest is also similar, in that a finished lighting panel is incorporated into a finished product. Generally, electro-optical arrays are manufactured as panels, although singulation from a mother glass may not always be used. The skilled practitioner will recognize that many manufacturing variations are possible, and the steps described above are not necessary steps in the process of manufacturing a panel.

The term "panel product" is used to mean any product that is or that incorporates a finished electro-optical panel. Thus, the term encompasses a wide range of display panels, lighting panels, other electro-optical panels, display products (such as television, phone, camera, monitor, wristwatch), lighting products (such as an OLED luminaire).

Not all phones are display products (for example, a rotary dial phone), and not all lighting products incorporate a finished electro-optical panel (for example, an incandescent light bulb). Also, a mother substrate is not a panel product, because prior to singulation and finishing steps, it does not comprise a finished electro-optical panel. However, increasing numbers of display and lighting products do incorporate electro-optical panels (such as display panels and lighting panels), and are panel products as understood in this disclosure. Common features of electro-optical panels of interest in this disclosure include: a single substrate, a two-dimensional array of electro-optical elements formed on the substrate, and encapsulation. Of course, depending on the technology, application requirements, and particular design, embodiments will have a varied range of additional features. Panels may be rigid or flexible.

FIG. **1** depicts a prior art electroluminescent device **100** having encapsulation provided by an encapsulation substrate **103**. Light-emitting elements **104** are formed over a lower substrate **101**. Customarily, the encapsulation substrate **103** is attached to the lower substrate **101** using a perimeter seal **105**. Thus, the encapsulation around light-emitting devices is formed by lower substrate **101**, perimeter seal **105**, and encapsulation substrate **103**. Most commonly, both lower substrate **101** and the encapsulation substrate **103** are formed of glass. The perimeter **105** seal may commonly be a cured resin or a glass frit. The encapsulation defines a cavity **106** that may be filled with dry nitrogen gas.

Between lower substrate **101** and light-emitting elements **104** there are commonly intermediate layers variously including one or more of buffer layers, planarization layers, dielectric layers, banks, passive wiring layers, and active TFT layers: these are collectively represented in FIG. **1** by structure **102**. Prior art device **100** may have additional elements between the light-emitting elements **104** and encapsulation substrate **103**. These additional elements are not shown in FIG. **1**, but may include one or more of top electrode interconnection, a protection layer, color filters, a black matrix, desiccant, and a scattering layer.

The device **100** may commonly be a top-emitter, in which case light is emitted through a transparent encapsulation substrate **103**, or a bottom-emitter, in which case light is emitted through transparent portions of structure **102** and a transparent lower substrate **101**.

FIG. **2** depicts a prior art electroluminescent device **200** having encapsulation provided by a thin film encapsulation structure **201**. Light-emitting elements **204**A, **204**B, **204**C are formed over a lower substrate **101**. Between lower substrate **101** and light-emitting elements **204**A, **204**B, **204**C there are commonly intermediate layers variously including one or more of buffer layers, planarization layers, dielectric layers, banks, passive wiring layers, and active TFT layers: these are collectively represented in FIG. **2** by lower structure **202**. Between light-emitting elements **204**A, **204**B, **204**C and thin film encapsulation structure **201** there may be an upper structure **203**. Commonly, structure **203** comprises top electrode interconnection, but may also include other elements such as a protection layer, color filters, a black matrix, desiccant, and a scattering layer.

The thin film encapsulation structure **201** may be attached to lower substrate **101** directly, as shown on the left-hand side of FIG. **2**, or through structure **202** and/or structure **203**, as shown on the right-hand side of FIG. **2**. Thus, the encapsulation around light-emitting devices **204**A, **204**B, **204**C is formed by lower substrate **101**, thin film encapsulation structure **201**, and optionally structure **202** and/or structure **203**.

Different physical configurations are possible. Light emitting elements **204**A are shown being built substantially on top of structure **202**, so that the thin film encapsulation structure **201** fills in the gaps between light emitting elements **204**A. Alternatively, light emitting elements **204**C may be formed in recesses in the structure **202**, so that the underside of the thin film encapsulation structure **201** over light-emitting elements **204**C is more smooth and/or more flat than the underside of the thin film encapsulation structure **201** over light-emitting elements **204**A. As a further alternative, light-emitting elements **204**B may be partially submerged in recesses in structure **202**. While light-emitting elements **204**A, **204**B, **204**C are depicted as having rectangular cross-section, any of the surfaces may in fact be curved or slanted.

The device **200** may commonly be a top-emitter, in which case light is emitted through a transparent thin film encapsulation structure **201**, or a bottom-emitter, in which case light is emitted through transparent portions of layers **202** and a transparent lower substrate **101**.

FIG. **3** depicts a first embodiment of the present invention. Panel **300** comprises electro-optical elements **304**R, **304**G, **304**B formed over a lower substrate **301**. Electro-optical elements **304**R, **304**G, **304**B are part of a two-dimensional array of electro-optical elements **304** formed over the substrate **301**. (Two-dimensional arrays of elements are discussed further, below, in context of FIG. **22**.) Above each electro-optical element **304**R, **304**G, **304**B is a respective local seal **305**R, **305**G, **305**B. Between lower substrate **301** and electro-optical elements **304**R, **304**G, **304**B there may be intermediate layers variously including one or more of buffer layers, planarization layers, dielectric layers, banks, passive wiring layers, and active TFT layers: these are collectively represented in FIG. **3** by structure **302**.

Individual electro-optical elements **304**R, **304**G, **304**B are separated by banks **303**. The banks **303** may be formed integrally with structure **302** or separately. The banks are shown extending in height above the electro-optical elements **304**R, **304**G, **304**B, and also above the local seals **305**R, **305**G, **305**B, which offers manufacturing advantages in delineating the lateral boundaries of the electro-optical elements **304**R, **304**G, **304**B and the local seals **305**R, **305**G, **305**B. Nevertheless, the bank height is not a necessary feature of the present invention. In some embodiments the topmost extent of the bank may be lower than the top surface of local seals **305**R, **305**G, **305**B, and even lower than the top surface of electro-optical elements **304**R, **304**G, **304**B. In other embodiments, banks **303** may be altogether absent.

Similarly the presence of structure **302** is not a necessary feature of the present invention. In some embodiments, the functions of structure **302** may be provided by a structure located beneath the lower substrate **301**. In other embodiments, structure **302** and lower substrate **301** may be fabricated as an integrated unit.

In a preferred embodiment, each of electro-optical elements **304**R, **304**G, **304**B may be an organic electroluminescent element such as OLED (organic light emitting diode) comprising an organic layer stack between a bottom electrode and a top electrode. Some organic layer stacks, and methods of manufacture are described in U.S. Pat. Nos. 4,769,292, 5,904,961, and 5,937,272. The organic layer stack may include an electroluminescent layer as well as one or more of the following layers: a hole injection layer, a hole transport layer, an electron transport layer, and an electron injection layer. Energy is released in the form of light during electron-hole recombination in the electroluminescent layer. The electroluminescent material may be a fluorescent material or a phosphorescent material. Additionally the OLED may have tandem structure, in which case multiple OLED electroluminescent layers are separated by powered or unpowered connectors, and light from a first electroluminescent layer passes through a second electroluminescent layer before emerging from the light emitting panel **300**. Tandem OLED structures are described, for example, in U.S. Pat. No. 6,717,358 to Liao. As used herein, an organic layer stack has a plurality of layers, at least one layer of which comprises 50% or more by weight of one or more organic compounds. As such, the organic layer stack may include one or more layers comprising only inorganic material, such as LiF, or one or more layer comprising an inorganic material as a minority constituent, such as a layer doped with metal atoms.

The present invention is not limited to organic electroluminescent elements. Electro-optical elements **304**R, **304**G, **304**B may also be one or more of the following: liquid crystal elements, inorganic light emitting diodes (LEDs), quantum dot LEDs, electrochromic elements, inorganic electroluminescent elements, thick film dielectric electroluminescent elements, plasma elements, field emission elements, electronic paper, interferometric modulator elements, surface conduction electron emitter elements, micromirror elements, and MEMS elements.

In a preferred first embodiment, panel **300** is an emissive display panel, and elements **304**R, **304**G, **304**B emit red, green, and blue light respectively. Alternatively, panel **300** may be a transmissive, reflective, or transflective display panel. Panel **300** may further be a lighting panel emitting fixed white light, temperature tunable white light, fixed colored light, or programmable colored light. Panel **300** may also be part of a transmissive product such as an electronic window, or signage. Panel **300** may be substantially flat, or it may have perceptible curvature. Panel **300** may also be a component of a projection display.

The panel **300** may be observed from the top in some embodiments, in which case light from elements **304**R, **304**G, **304**B emerges through local seals **305**R, **305**G, **305**B. In other embodiments panel **300** may be observed from the bottom, in which case light from elements **304**R, **304**G, **304**B emerges through transparent portions of structure **302** and a transparent lower substrate **301**. In some embodiments, panel **300** may be observed from both top and bottom.

In many embodiments, each of electro-optical elements **304**R, **304**G, **304**B comprise a bottom electrode and a top electrode, neither of which is shown in FIG. **3**. The bottom electrode is directly connected to passive matrix or active matrix circuitry in structure **302**. The top electrode connection can be made in a variety of ways, not shown in FIG. **3**. In some embodiments, top electrodes are connected to each other over the entire panel **300**, i.e. the entire panel **300** has a common top electrode. In other embodiments, top electrodes are connected to each other in stripes which may be oriented along rows, columns, or diagonals of the panel **300**. The stripes may be straight, zigzag, or other substantially linear forms. In still other embodiments, the top electrodes are connected to each other within each of a plurality of two-dimensional regions of the panel **300**. Top electrode interconnections of any of these forms are routed above banks **303** in some embodiments or under banks **303** in other embodiments. In still other embodiments, the top electrode is connected locally at each element to circuitry within the structure **302**.

As an example, element **304**G is encapsulated by local seal **305**G, bank **303**, structure **302**, lower substrate **301**, and optionally a top electrode interconnection. The encapsulation around electro-optical elements **304**R and **304**B is similar.

Some embodiments may include additional upper elements between the top electrode of an electro-optical element **304**R, **304**G, **304**B and the local seal **305**R, **305**G, **305**B. Such elements may variously include one or more of: a protection layer, a reflective layer, color filters, a black matrix, desiccant, and a scattering layer, according to the needs and design of a particular embodiment. In some embodiments, one or more of these additional upper elements may extend beyond a single local seal **305**R, **305**G, **305**B and therefore form part of the encapsulation surrounding a corresponding electro-optical element **304**R, **304**G, **304**B.

It will be recognized that as the various components forming encapsulation around element **304**G serve different functions, are formed of different materials by a variety of manufacturing processes, so the permeation rates of moisture, oxygen, and/or other detrimental materials through the various encapsulating components will not be the same. As a general rule, a thick layer of material offers a longer migration path for a detrimental material and a lower permeation rate, compared to a thin layer of the same material. Additionally, electro-optical elements **304**R, **304**G, **304**B may have a functional area less than the physical area.

FIG. **20** shows a detail of an embodiment in which electro-optical element **304**M is an OLED element **304**M having bottom electrode **2001** and a stack of functional layers **2002**. The area of contact between bottom electrode **2001** and functional layer stack **2002** defines an active region **2003** of the OLED element. Moisture-sensitive material may extend laterally beyond the active region **2003**. In this case the lateral edges of the electro-optical element **304**M lie outside the functional area **2003**, and therefore penetration of oxygen, moisture, and/or other detrimental materials to a lateral edge of electro-optical element **304**M may have less impact on product performance than penetration of the same amount of oxygen, moisture, and/or other detrimental material to the center of the electro-optical element **304**M.

The functional layer stack **2002** may incorporate layers such as a hole injection layer, a hole transport layer, an emissive layer, an electron transport layer, an electron injection layer, and a cathode layer. Each of these layers has a respective lateral extent, which may all be the same in some embodiments, and some of which may be different in other embodiments.

For reasons such as these, satisfactory encapsulation of element **304**G (FIG. **3**) or **304**M (FIG. **20**) can be achieved with a combination of the various components forming encapsulation around the element **304**G or **304**M, despite considerable variation in the permeation rates through the materials constituting the various encapsulating components.

In some embodiments, the local seals **305**R, **305**G, **305**B, provide a benefit of an optically transmissive and/or optically transparent seal over respective electro-optical elements **304**R, **304**G, **304**B. In some embodiments, the local seals **305**R, **305**G, **305**B, provide a benefit of a glass seal without compromising deformability, flexibility, or unbreakability of the panel **300**. While each individual local seal **305**R, **305**G, **305**B, is rigid, the areas between neighboring seals can flex more readily.

In order to preserve flexibility of the finished product in different directions of flexing, some preferred embodiments restrict the size of each local encapsulation seal in all directions along the surface of an underlying substrate. More specifically, if the substrate is laid out horizontally flat and the size of the two-dimensional array of electro-optical elements along a direction D along the top surface of the substrate is A_D, and the size of a local encapsulation seal in the same direction is S_D, then these preferred embodiments will, for all directions D, have the ratio S_D/A_D less than or equal to ⅕, preferably less than or equal to 1/10, commonly less than or equal 1/30, and often less than or equal to 1/100. Alternatively, the size of a local encapsulation seal, measured as area in the plane of the underlying two-dimensional array of electro-optical elements, can be compared with the area of the array of electro-optical elements. In some abovementioned preferred embodiments, the ratio of local encapsulation seal area to the area of the array of electro-optical elements will be less than or equal to 4%, preferably less than or equal to 1%, commonly less than or equal to 0.11%, and often less than 0.01%. Additionally, in some preferred embodiments, the local encapsulation seals will have an aspect ratio less than 3:1, preferably less than 2:1, more preferably less than 1.5:1, and commonly less than 1.2:1. The "aspect ratio" is understood to mean the ratio of (1) the longest dimension of a local encapsulation seal measured parallel to the plane of the substrate, to (2) the shortest dimension of the same local encapsulation seal measured in the same plane.

Panel **300** may be part of a commercial product such as a phone. FIG. **21**A shows a phone **2110**, which incorporates a display having an active light-emitting region **2117** comprising a two-dimensional array of electro-optical elements. Panel **300** may be part of a commercial product incorporating an information display monitor. FIG. **21**B shows information display monitor **2126** that is an integral part of laptop computer **2128**. The information display monitor **2126** has an active light-emitting region comprising a two-dimensional array **2127** of light-emitting elements. Panel **300** may be part of a television set. FIG. **21**C shows a curved television **2130** incorporating an active display region **2137** having a two-dimensional array of pixels. Panel **300** may be part of a wearable electronics product such as a wristwatch. FIG. **21**D shows a wristwatch **2140** in which an active display region comprises a two-dimensional array **2147** of pixels.

Turning now to FIG. **4**A, panel **400** is a preferred second embodiment of a lighting panel comprising light emitting elements separated by banks **303**. The lighting panel may be part of a lighting fixture or other lighting product, either as a removable part or as an integrally fabricated component. FIG. **21**F, adapted from U.S. Pat. No. 7,638,941 shows a ceiling-mount OLED chandelier **2160**; each OLED panel **2167** is a removable unit.

Each light emitting element has a respective local seal **405**. As shown, the local seals **405** are hexagonal and are arranged in a hexagonal pattern forming a two-dimensional array. Although not visible in this view, it can be inferred that the light emitting elements underneath the local seals **405** are also arranged in a similar hexagonal pattern forming a two-dimensional array. Of course, other patterns are possible. For example, FIG. **21**E, adapted from U.S. Pat. No. 6,870,196, shows an OLED lighting panel **2150** comprising a rectangular array of polygonal lighting elements **2154** formed on a common substrate **2151**.

Section AA' is shown in cross-sectional view in FIG. **4**B. Each local seal **405** covers a respective light emitting element **304** formed over substrate **301**. Between lower substrate **301** and light-emitting elements **304** there may be intermediate layers variously including one or more of buffer layers, planarization layers, dielectric layers, banks, passive wiring layers, and active TFT layers: these are collectively represented in FIG. **4**B by structure **302**. The banks **303** may be formed integrally with structure **302** or separately.

In a preferred embodiment, each of light emitting elements **304** may be an organic electroluminescent element such as OLED (organic light emitting diode), as described above. However, the present invention is not limited to organic electroluminescent elements.

Lighting panel **400** may emit fixed white light, temperature tunable white light, fixed colored light, programmable colored light, or a combination of any of these. Lighting panel **400** may also combine a lighting function with other functions including but not limited to a window, a mirror, a display, and signage.

Lighting panel **400** may emit light from the top in some embodiments, in which case light from elements **304** emerges through local seals **405**. In other embodiments, lighting panel **400** may emit light from the bottom, in which case light from elements **304** emerges through transparent portions of structure **302** and a transparent lower substrate **301**. Additionally, some embodiments of lighting panel **400** may emit light from both top and bottom.

Element **304** in FIG. **4**B is encapsulated by local seal **405**, bank **303**, structure **302**, and lower substrate **301**. Similar to panel **300** described above, panel **400** may also have top electrode interconnections (not shown) between light emitting elements **304**, and may also have additional upper elements (not shown) between light emitting elements **304** and local seals **405**. A top electrode interconnection and/or these additional upper elements may also form part of the encapsulation surrounding light emitting element **304**.

As previously described, satisfactory encapsulation of light emitting element **304** can be achieved with a combination of the various components forming encapsulation around the element **304**, despite considerable variation in the permeation rates through the materials constituting the various encapsulating components.

It is not necessary for each individual electro-optical element or light emitting element to have its own independent local seal in order to realize the benefits of the present invention. FIG. **5** shows a third embodiment of a panel **500** wherein local seals **505**A, **505**B cover respective groups of electro-optical elements **504**A, **504**B. The individual elements **504**A are mutually separated by banks **506**, while a group of elements **504**A and its associated local seal **505**A is separated from a neighboring group of elements **504**B and its associated local seal **505**B by bank **503**. In preferred embodiments, the height of bank **506** is less than the height of bank **503**, but this is not necessary. Between lower substrate **301** and elements **504**A, **504**B lies structure **302**, providing the same or similar functions as described above.

FIG. **18** shows a curved or flexed panel **1800** utilizing local seals **1805** over electro-optical elements (not shown) formed on substrate **1801**. Panel **1800** may be part of a display product, a lighting product, or any other product including but not limited to those described above in context of panels **300** and **400**. It should be emphasized that FIG. **18** is not drawn to scale, because of the widely disparate dimensions of the features shown. At the time of writing, OLED displays are known with pixel sizes on the order of tens of microns. By comparison, requirements for bending radius may be on the order of hundreds of microns for an unbreakable display, centimeters for a bendable display, and meters for a curved television set. In some embodiments, the ratio of the largest transverse dimension of a local seal **1805** to the required bend radius will preferably not exceed 10%, or more preferably 5%. Thus, depending on the bending requirements of a product, and the size and spacing of electro-optical elements, it may be possible to accommodate varying numbers of electro-optical elements underneath each local seal **1805**.

In some embodiments, local seals **1805** are made of glass, or another rigid material, while flexible substrate **1801** is less rigid and is able to flex. When a sheet of material is bent, there may be elastic deformation: one surface of the sheet experiences tension and is stretched, while an opposite surface of the sheet experiences compression and is compressed. (Between the surfaces lies a neutral plane, which by definition experiences neither tension nor compression as the sheet is bent.) The bending can be represented in geometrical terms as the local strain in the sheet. In the context of FIG. **18**, the areas of panel **1800** where rigid local seals **1805** are located are stiff and undergo minimal deformation, and consequently have a low value of strain when the panel **1800** is flexed. In comparison, areas between neighboring local seals **1805** are flexible and undergo more deformation, leading to higher values of strain when the panel **1800** is flexed. In embodiments of this invention having local seals **1805** made of glass, it is expected under flexion that the ratio of strain midway between a first and a second neighboring local seals **1805** to the strain at a position of the substrate lying beneath the center of either the first or the second neighboring local seals is at least 2:1, usually at least 5:1, commonly at least 10:1, and sometimes greater than 20:1. In order to maximize the flexibility of such an embodiment, it will be clear to the skilled practitioner that gaps between pixels should be left free to flex. That is to say, it is usually preferable to have separate local encapsulation seals for each electro-optical element in order to maximize flexibility. Exceptions may occur in cases where pixels are of different sizes: grouping of smaller pixels under one encapsulation seal may sometimes be performed without compromising the overall flexibility of the two-dimensional array. The array **2250** shown in FIG. **23**E provides one such example.

Returning to FIG. **5**, panel **500** may be part of a display product, a lighting product, or any other product including but not limited to those described above in context of panels **300** and **400**. As an example, in a display product, the three elements **504**A may comprise a red pixel, a green pixel, and a blue pixel. In a display product having four-element pixel groups, such as RGBG or RGBW—where the letters R, G, B, and W respectively denote red, green, blue, and white elements—elements of **504**A may comprise two, four, or some other number of elements, from the same or different pixel groups. In a lighting product having a hexagonal layout of lighting elements similar to the layout shown in FIG. **4**A, groups of elements **504**A to be covered by a common local seal may be diamond-shaped groups of four elements, or hexagonal-shaped groups of seven elements. Many other groupings of elements are also possible within the scope of this third embodiment.

FIG. **22** shows some possible arrangements of electro-optical elements in a two-dimensional array. FIG. **22** is only a conceptual representation of electro-optical elements; the other features of product embodiments such as a substrate, local seals, and banks are not shown. The full extent of a typical two-dimensional array is not shown either. FIG. **22**A shows a rectangular array **2210** of stripe elements **2214**. FIG. **22**B shows a rectangular array **2220** of circular elements

2224. FIG. **22**C shows an rotated rectangular pattern **2230** of rectangular- and oval-shaped elements **2234**A, **2234**B, **2234**C, **2234**D similar to the pattern found in some Samsung Galaxy™ phones.

FIG. **22**D shows a hexagonal pattern **2240** of circular elements **2244**. FIG. **22**E shows a rectangular pattern **2250** of different shaped elements **2254**A, **2254**B, **2254**C arranged in blocks. It will be understood by a skilled practitioner that the various features of these patterns may be combined in numerous combinations, and that many other patterns are also possible. The elements in FIGS. **22**A-**22**E may be OLED elements, display pixels, electrophoretic elements, or other such electro-optical elements as are described elsewhere in this disclosure.

FIGS. **23**A-**23**E show some possible arrangements of local encapsulation seals for the patterns of FIG. **22**. Dotted lines represent electro-optical elements that lie beneath these seals. Once again, FIG. **23** contains conceptual representations only; local encapsulation seals of different shapes and sizes are shown together as a matter of convenience. As the skilled practitioner will recognize, it is to be expected that within one embodiment, substantially all of the local encapsulation seals will be the same size and shape, with possible exceptions near edges of the underlying two-dimensional array of electro-optical elements. Likewise, it is to be expected that all electro-optical elements of the two-dimensional array will be covered with a local encapsulation seal. Of course, it is usually possible to arrange local encapsulation seals so that each local seal covers exactly one electro-optical element, as shown by local encapsulation seals **2315**C, **2325**A, **2335**A-**2335**D, **2345**A, and **2355**A-**2355**C in corresponding FIGS. **23**A-**23**E. As discussed above, for embodiments having rigid local seals, embodiments having distinct local seals for each electro-optical element of the two-dimensional array will generally maximize the flexibility of the sealed array.

The other encapsulation seals **2315**A-**2315**B, **2325**B-**2325**C, **2335**E-**2335**F, and **2345**B-**2345**D indicate some possible configurations whereby electro-optical elements can be grouped in the corresponding two-dimensional arrays of FIGS. **23**A-**23**E, with one local encapsulation seal over each group. These configurations are suitable for embodiments in which the substrate and local seals have comparable stiffness, or embodiments in which flexibility does not need to be maximized. Because there are lateral permeation pathways from the edge of a local seal to an underlying electro-optical element, configurations with grouped local seals provide less total seal perimeter and, on average, longer permeation pathways compared to configurations having distinct local seals for each pixel. That is to say, grouping electro-optical elements under a common local encapsulation seal is effective to achieve lower permeation rates.

FIGS. **6**A-**6**D depict sequential manufacture of the local seals of a representative embodiment of this invention. FIG. **6**A shows an unfinished panel **600** prior to formation of any local seal. Electro-optical element **304**, which is an OLED element in certain preferred embodiments, has been formed over a lower substrate **301** and intermediate structure **302**, described above. Banks **303** surround electro-optical element **304** and separate this element from neighboring electro-optical elements (not shown in FIG. **6**A-**6**D).

FIG. **6**B shows deposition of a mass of glass powder paste **602** onto element **304** by a nozzle **601**. This deposition technique is often referred to informally as inkjet material deposition, or inkjet printing. While the mass of paste **602** is shown having an uneven top surface, in practice this top surface will be more or less smooth according to the viscosity and surface tension of the deposited formulation, and the force of ejection from nozzle **601**. Nozzle **601** is part of an inkjet dispenser. In some embodiments, a plurality of inkjet dispensers may be used. The skilled practitioner will recognize that a glass powder suspension may equivalently be used as an alternative to glass powder paste.

The mass of paste **602** shown may be deposited as a single drop, or as multiple drops. Multiple drops may be deposited sequentially by a single nozzle **601**, that is, without any intervening deposition of drops over other electro-optical elements. Alternatively, one or more inkjet dispensers may make one or more passes over unfinished panel **600** and the multiple drops of glass powder paste may be deposited onto element **304** during different passes, either by a single inkjet dispenser, or by multiple inkjet dispensers.

FIG. **6**C shows curing of the glass powder paste by irradiation **606** from a laser beam source **604**. At this stage, the mass of glass powder paste **602** has melted, the carrier material of the glass powder paste has volatilized, and the glass powder particles have fused into a liquid mass **607** that is adhered to the adjacent banks **303** and the top surface of the underlying electro-optical element **304**. The liquid mass **607** has a smooth surface as shown.

Finally, FIG. **6**D shows the cured local glass seal **605** after it has cooled and hardened. It will be recognized that the structure of FIG. **6**D resembles the structures previously shown in FIGS. **3**-**5**, and that this manufacturing method is generally applicable to a wide variety of embodiments of this invention including but not limited to those described above.

It will further be recognized that the manufacturing method described is exemplary, and numerous variations are possible without departing from the spirit and scope of this invention. Depending on the size of local seal being formed and the construction of element **304**, techniques such as screen printing and electrophoretic deposition may particularly be suitable. Further, after completion of manufacture, unfinished panel **600** may result in a finished product that could be a display product, a lighting product, or any other product including but not limited to those described above in context of panels **300** and **400**.

While, in preferred embodiments, the local seals are formed of glass using a glass powder paste or suspension, the invention is not so limited. In other embodiments, local seals may be formed from organic resins, inorganic compounds, eutectic metal alloys, or other metals.

The seal material may be deposited as a powder, paste, suspension, solution, or in integral form (that is, as a preformed solid seal to be fused to one or more underlying structures) over the electro-optical elements **304**. The deposition process may use inkjet technology, physical vapor deposition, chemical vapor deposition, printing, sputtering, powder coating, electroplating, electroless plating, and plasma coating. Patterning of the deposited material according to the desired local seals may be done at the time of deposition or subsequently.

Curing of the seal material may be performed by thermal means, such as hot gas, convection, or electrical heating. Electrical heating may take forms including but not limited to induction, resistive, dielectric, RF, and microwave heating. Curing may be performed by external radiation, including infrared lamps, ultraviolet lamps, or laser. Curing may be performed chemically, as in the case of two-part epoxies. For embodiments using heat in the curing process and having organic constituents within electro-optical elements **304**, and particularly for preferred embodiments having elements **304** that are OLED elements, the temperature of the local encapsulation seals, the elements **304**, and the substrate may be controlled to be less than or equal to 300° C., preferably less than or equal to 275° C., commonly less than or equal to 250° C., and sometimes less than or equal to 225° C.

FIGS. **7**A-**7**C show some configurations for curing the local seals **607** using heat and radiation. FIG. **7**A shows a furnace **701** in which the entire unfinished panel **600** is being heated. In some embodiments the space **702** inside the furnace **701** is filled with a gas such as dry nitrogen. In other embodiments, the space **702** is evacuated to a pressure lower than atmospheric pressure, or a vacuum, and unfinished panel **600** is heated by infrared radiation from hot walls of the furnace **701** or from heat lamps (not shown) installed in the furnace **701**. Transport of the unfinished panel **600** in and out of the furnace **701** may be accomplished in some embodiments by continuous transport, in a form of a conveyor belt or in an equivalent form. Transport may also be accomplished on a cyclical basis as sequence of discrete steps: open furnace door, introduce unfinished panel **600** with uncured local sealing material, close furnace door, apply heat to cure the local sealing material, open furnace door, extract panel **600** with cured local seals.

FIG. **7**B shows an embodiment for heating just the top of unfinished panel **600**. The unfinished panel **600** is mounted on a conveyor platform **705** which is transported through a heating zone by rollers **706**. One or more radiation sources **703** provide irradiation **704** of only the top surface of unfinished panel **600**, which results in curing of the seal material **607**. It will be recognized that heating of just the top surface need not be performed using continuous transport, but can also be performed in a heating chamber similar to furnace **701** having, for example, heat lamps installed in a top wall only.

FIG. **7**C shows an embodiment for sequential heat curing of local seals **305**, **607**, **602** using irradiation from laser source **707**. Unfinished panel **600** is located beneath the laser source **707**. Irradiation **708** from the laser is in the form of a conical beam **709** and irradiates a spot **710** that encompasses a single local seal **607**, causing this seal to be heated and cured. Arrows **711** indicate that the laser is scanned in two dimensions (preferably in steps, from one local seal to another) to successively heat and cure all the local seals being formed on unfinished panel **600**. As indicated, some local seals labeled **602** have yet to be cured. Other local seals labeled **305** have already been cured. It will be recognized that although arrows **711** are shown next to the laser source **707**, the translation can alternatively be applied to the unfinished panel **600**. In some embodiments, one axis of translation is performed by moving the laser beam, while another axis of translation is performed by moving the unfinished panel **600**.

The embodiments described above in context of FIGS. **7**B and **7**C have an advantage of using less total heat energy compared to the embodiment described above in context of FIG. **7**A. This has numerous benefits, including but not limited to less energy cost, less cooling time, lower TACT time, higher manufacturing throughput, and reduced heat damage to the unfinished product **600**.

It will be recognized that laser beams can have a variety of tailored beam profiles, some of which are shown in FIGS. **8**A-**8**C. FIG. **8**A shows a spot beam profile illuminating a local seal **607**. Graph **801** represents the beam profile along cross-section AA'. The axes of the graph are I, the intensity of irradiation, a quantity which may be measured in W/cm^2, and x, which is the distance coordinate along the AA' section. Graph **802** represents the beam profile along cross-section BB'. I is the intensity of irradiation, and y is the distance coordinate along the BB' section.

FIG. **8**B shows a multi-spot beam illuminating several of the local seals **607**. Graphs **803** and **804** show the beam profiles along cross-sections AA' and BB'. In the example shown, the laser beam has two spots, each of which illuminates two neighboring local seals **607**. Of course, other combinations are possible, such as five spots illuminating one local seal each, or one spot illuminating four neighboring local seals: two in each of two neighboring rows.

FIG. **8**C shows a linear beam illuminating a row of local seals **607**. Graphs **805** and **806** show the beam profiles along cross-sections AA' and BB'. Of course, other arrangements are possible, such as a beam illuminating two rows of local seals, or a beam having width along the BB' cross-section that is narrower than the width of the local seals **607**. In the latter arrangement, the laser beam is scanned back and forth in the y direction to provide irradiation and heating of the entire area of the local seals **607**.

Microwaves are another form of radiation suitable for curing a local seal. Microwaves are commonly understood in the art to comprise electromagnetic radiation having a free-space wavelength ranging from one millimeter to one meter inclusive, or equivalently frequencies from approximately 300 MHz to approximately 300 GHz. In applications requiring absorption, microwave radiation between 1 and 20 GHz is preferably used, commonly between 3 and 13 GHz, and often between 3 and 4.5 GHz or between 8 and 12 GHz.

U.S. 2013/0015180 by Godard et al. describes the use of microwaves to heat an inner layer of a glass laminate. The same principles can be applied to selectively a glass paste or suspension during manufacture of a local encapsulation seal, without damaging nearby delicate organic materials.

Like laser energy and unlike oven heating, microwave radiation can be used to provide selective absorption of energy inside a target object, component, or material. This provides a temporal advantage since heating energy can be instantaneously available at a distal portion of a local encapsulation seal, without having to wait for conductive transport of heat through the seal material from a surface of the local encapsulation seal proximate to an energy source. Furthermore, microwave energy can be deposited nearly uniformly over the volume of seal material, allowing the entire volume of seal material to attain fusing temperature together. Whereas, with a surface heating technology, it is customary for the proximate surface of the seal material to reach an elevated temperature above the fusing temperature before the distal portion of sealing material fuses. Also, surface heating technologies may not be able to discriminate between the seal material and portions of a substrate between seals. For both these reasons, the surface heating technology results in considerably greater energy deposition in the target panel, as compared to microwave heating. The lower energy burden of microwave heating reduces the risk of damage to sensitive organic materials that are in close proximity to the local encapsulation seals, allowing the use of seal materials with higher fusing temperatures, and/or the use of organic materials with lower thermal damage thresholds, as compared to a surface heating technology. The lower energy burden of microwave heating also reduces the time required to cool the target panel before a subsequent process step, thereby also reducings the TACT time.

Selective microwave absorption can be enhanced by incorporation of a microwave absorbing component within the target glass paste or suspension. The manufacture and use of ferrite nanoparticles for microwave absorption has been described in the art, with demonstrated absorption bands in the range from 3 to 13 GHz. Particular materials include iron-rich ferrites and a substituted barium ferrite $BaFe_9(Mn_{0.5}Co_{0.5}Sn)_{3/2}O_{19}$, but are not limited to these materials. See, for example, Ghasemi et al., IEEE Trans. Magnetics, vol. 45, no. 6, pp. 2456-2459, 2009 and McCauley et al., pp. 359-360, in Proc. 2nd and 3rd Annual Conf. on Composites and Advanced Materials, American Ceramic Society, 1980. The latter describes fine grain powders having particle size about 50 nm. An advantage of using nanoparticles having size much less than the wavelengths of visible light (which covers about 400 to 700 nm) is that the nanoparticles have little impact on transmission of visible light through a finished local encapsulation seal.

The principle of loading the target glass paste or suspension with a component that facilitates energy absorption can also be applied to laser curing of the local encapsulation seal. In particular, plasmonic nanoparticles are known to couple with electromagnetic radiation far greater than the particle size, and can thereby provide increased absorbance. Plasmonic nanoparticles of gold, silver, or platinum are particularly efficient at coupling with and absorbing light. Fabrication and use of plasmonic nanoparticles is described, for example, in U.S. 2015/0017433, U.S. 2012/0271293, and U.S. 2009/0072161. In the art, nanoparticles are understood to be particles between 1 nm and 100 nm in size, inclusive.

Of course, conventional materials such as carbon (including soot or black carbon), other carbonaceous materials, dyes, and pigments, may also be used to enhance absorption of laser light. Some light absorption materials, including plasmonic nanoparticles, dyes, and pigments have wavelength-selective absorption properties. Likewise, an emissive electro-optical element—even a broadband OLED—will have one or more peaks and zero or more valleys in its emission spectrum, with substantially emission-free tails on both the long- and short-wavelength sides of its emission spectrum. In some embodiments, a light absorption material is chosen to have an absorption peak at a wavelength matching or close to a spectral minimum of emission (or a spectral region of low emission) from an emissive element in the target panel, and an irradiation light source is chosen correspondingly with an emission peak at this same wavelength. Thereby light absorption in the sealing material during manufacture can be maximized, while light absorption during normal operation can be kept to a minimum. More precisely, the light absorption material and the irradiation light source are chosen such that the absorption peak of the former lies within the full-width half-maximum (FWHM) wavelength range of the latter.

In other embodiments, light absorption is facilitated during manufacture and light absorption is minimized during normal usage by selecting a dye or pigment having an absorption peak in the near infrared or the near ultraviolet spectrum, for use as a light absorbing material. Such dyes are available from a number of companies, including H. W. Sands Corp. (Jupiter, Fla.), QCR Solutions Corp (Port St. Lucie, Fla.), Eastman Kodak (Rochester, N.Y.), and Epolin (Newark, N.J.). Correspondingly, near infrared and near ultraviolet lasers are available for use as an irradiation source, for example from Coherent Inc. (Santa Clara, Calif.). Near infrared is commonly understood to extend from electromagnetic free-space wavelengths 700 nm to 5 um inclusive, while near ultraviolet is commonly understood to extend from electromagnetic free-space wavelengths 300 to 400 nm inclusive.

As described above, the encapsulation of an electro-optical element such as **304**, **304**R, **304**G, **304**B, **504**A, **504**B is comprised of a number of components having varying material composition and varying permeation rates for moisture, oxygen, and/or other detrimental materials. Although a local seal such as a local glass seal may provide adequate sealing over the top surface of an underlying electro-optical element, side paths through other encapsulating components may adversely affect product performance and lifetime. For this reason, it may be desirable in some applications to combine a local seal with a thin film encapsulation structure.

FIG. **9** shows a fourth embodiment of the present invention. Lower substrate **301**, intermediate layer structure **302**, banks **303**, electro-optical elements **304**, and local seals **305** are substantially similar to the corresponding elements described in context of FIG. **3** above, and may be manufactured by similar processes. The fourth embodiment adds a thin film encapsulation structure **901** above the local seals **305**. The thin film encapsulation structure **901** may be a single layer, or may be a composite of multiple layers. Panel **900** may be part of a display product, a lighting product, or any other product including but not limited to those described above in context of panels **300** and **400**.

Some embodiments may include additional upper elements between the local seal **305** and the thin film encapsulation structure **901**. Such elements may variously include one or more of: a protection layer, color filters, a black matrix, desiccant, and a scattering layer, according to the needs and design of a particular embodiment. In some embodiments, one or more of these additional upper elements may extend beyond a single local seal **305** and therefore form part of the encapsulation surrounding a corresponding electro-optical element **304**.

FIG. **10** is a flow chart showing manufacturing steps for an embodiment of FIG. **9** that is an electroluminescent panel. At steps **1001** and **1002**, the electroluminescent layers and top electrode of element **304** are respectively formed. At step **1003**, local seal **305** is formed. Step **1003** may be performed by a variety of methods including but not limited to those described in context of FIGS. **6**-**7** above. At step **1004**, thin film encapsulation structure **901** is formed.

While FIG. **10** is directed to manufacture of an electroluminescent panel, it is straightforward to see that steps **1001** and optionally **1002** can be replaced by steps suitable to other forms of electro-optical element **304** to manufacture embodiments of panel **900** that are not electroluminescent panels.

FIG. **13**A shows how the combination of a local seal **305**C, **305**D with a thin film encapsulation structure **901** provides advantages. Panel **900** has structure substantially similar to that shown in FIG. **9**. In this figure, dotted line **1301** denotes a pinhole defect in the thin film encapsulation structure **901**. Were it not for the local seal **305**C, oxygen, moisture, and/or other detrimental materials could penetrate through pinhole defect **1301** and damage the electro-optical element **304**C underneath. In the present embodiment, penetration through the thin film encapsulation structure **901** can proceed as shown by arrow **1302**. However seal **305**C prevents further penetration as indicated by the X on arrow **1303**.

Turning now to electro-optical element **304**D, it may be noted that arrow **1305** shows a path for migration of moisture, oxygen, and/or other detrimental materials through a bank **303** that may have higher permeability compared to the local seal **305**D. Were it not for thin film encapsulation structure **901**, the path indicated by arrow **1305** may lead to degradation of the electro-optical element **304**D over time. In the present embodiment, however, thin film encapsulation structure **901** blocks penetration of moisture, oxygen, and/or other detrimental materials into bank **303**, and degradation of electro-optical element **304**D is prevented, as indicated by the X on arrow **1304**. Even in the instance where thin film encapsulation structure **901** has a pinhole defect over bank **303**, considerable reduction in permeation through bank **303** can be achieved.

FIG. **11** shows a fifth embodiment of the present invention. Like the fourth embodiment described above in context of FIG. **9**, the fifth embodiment adds a thin film encapsulation structure **1101** to the basic structure described in context of FIG. **3**. However, in this case, the thin film encapsulation structure **1101** lies beneath the local seal **305**. In other respects thin film encapsulation structure **1101** is similar to previously described thin film encapsulation structure **901**. Otherwise, panel **1100** is substantially similar to panel **900**.

It will be recognized that there are pathways for permeation that go through encapsulation structure **1101** but do not pass through any of local seals **305**. However, as with other figures, FIG. **11** is not to scale. In particular, the thicknesses of the features shown is greatly magnified in comparison to the transverse extents. Therefore, a pathway through encapsulation structure **1101** that bypasses **305** is very narrow and relatively long. By comparison, in the absence of local seals **305**, a pathway directly through encapsulation structure **1101** and into the top of electro-optical element **304** would be very wide (essentially the full-width of element of **304**) and very short (simply the thickness of encapsulation structure **1101**). By blocking a short, wide permeation pathway, the local seals **305** thus greatly improve the encapsulation of panel **1100**.

It is not necessary for the local seal **305** to lie within a recess above electro-optical element **304**. FIG. **19** shows panel **1900**, which is a sixth embodiment. As in FIG. **11**, thin film encapsulation structure **1901** is formed above elements **304**J, **304**K, **304**L, and lies beneath local seals **305**J, **305**K. However, in the sixth embodiment, structure **1901** acts as a planarization layer, and the locals seals **305**J, **305**K are formed on top of structure **1901**. Local seal **305**J is shown formed over a single electro-optical element **304**J. Alternatively, **305**K is shown formed over a group of electro-optical elements **304**K, **304**L. In other respects, panel **1900** is substantially similar to panel **1100**.

FIG. **12** is a flow chart showing manufacturing steps for an embodiment of FIG. **11** that is an electroluminescent panel. At steps **1201** and **1202**, the electroluminescent layers and top electrode of element **304** are respectively formed. At step **1203**, thin film encapsulation structure **1101** is formed. At step **1204**, local seals are formed. Step **1204** may be performed by a variety of methods including but not limited to those described in context of FIGS. **6**-**7** above.

While FIG. **12** is directed to manufacture of an electroluminescent panel, it is straightforward to see that steps **1201** and optionally **1202** can be replaced by steps suitable to other forms of electro-optical element **304** to manufacture embodiments of panel **1100** that are not electroluminescent panels. It will be readily understood that each step shown in FIGS. **10** and **12** may in practice involve a plurality of smaller steps.

FIG. **13**B shows how the combination of a local seal **305** with a thin film encapsulation structure **1101** provides advantages. Panel **1100** has structure substantially similar to that shown in FIG. **11**. In this figure, dotted line **1301** denotes a pinhole defect in the thin film encapsulation structure **1101**. Were it not for the local seal **305**C, oxygen, moisture, and/or other detrimental materials could penetrate through pinhole defect **1301**, as shown by arrow **1307**, and damage the electro-optical element **304**B underneath. However, in the present embodiment, seal **305**B prevents access to the pinhole defect, as shown by the X on arrow **1306**.

Turning now to electro-optical element **304**D, it may be noted that arrow **1305** shows a path for migration of moisture, oxygen, and/or other detrimental materials through a bank **303** that may have higher permeability compared to the local seal **305**D. In a manner substantially similar to that discussed above in context of FIG. **13**A, thin film encapsulation structure **1101** blocks penetration of moisture, oxygen, and/or other detrimental materials into bank **303**, and degradation of electro-optical element **304**D is prevented, as indicated by the

X on arrow **1304**. Even in the instance where thin film encapsulation structure **1101** has a pinhole defect over bank **303**, considerable reduction in permeation through bank **303** can be achieved.

In some embodiments of the present invention, light emerges through a bottom substrate such as **301**, and light emerging through the local seals is not desired. In such embodiments, the optical properties of the local seals are unimportant, and materials may be used for the local seals that result in the local seals being opaque or turbid. The term "opaque" as applied to an object is understood to mean that less than 10% of white light incident on a surface of the object is transmitted through the object. In such embodiments, it may also be desirable to incorporate a reflecting top layer, either integral to respective elements such as **304**, or as part of an upper structure (similar to **203**) formed between elements **304** and seals **305**.

In other embodiments, light emerges from electro-optical elements through the corresponding local seals. As such, optical properties of the local seals can affect the emitted light. Therefore it may be advantageous to customize optical properties of the local seals to achieve desired properties of emitted light. Optical functions that can be designed into a local seal include but are not limited to a lens function, a filter function, and a scattering function.

FIG. **14**A shows a panel **300** which in most respects is unchanged from the panel previously described in context of FIG. **3**. In this figure, local seals **305**A, **305**C, **305**D cover electro-optical elements **304**A, **304**C, **304**D respectively. However the shapes of the local seals **305**A, **305**C, **305**D are varied, and consequently different lens functions are achieved. Local seal **305**A has top and bottom surfaces that are substantially plane and parallel, ray **1402** exits the top surface of local seal **305**A at the same angle that it would have in the absence of local seal **305**A. Thus, no lens function is obtained, which may be desirable for some products. Note that there may be a small lateral shift of ray **1402** with respect to its direction of propagation, this is not consequential to the lens function and is not shown for ray **1402**.

Turning now to local seal **305**C, it can be seen to have a plano-convex shape, and an optical axis **1401**. In the usual case where the medium (such as glass) inside local seal **305**C has a higher refractive index than the medium (such as air) above the convex upper surface of the local seal **305**C, the plano-convex local seal **305**C acts as a converging lens. In comparison to ray **1403** incident at the top surface of local seal **305**C, the emergent ray **1404** is bent away from the normal to the surface, which produces the converging effect shown. The converging effect may be beneficial in display embodiments with regard to privacy. It will be recognized that such a lens function is not limited to display embodiments. Particularly, the converging effect may be beneficial in lighting embodiments where spotlight illumination is desired.

Local seal **305**D is seen to have a plano-concave shape. In the usual case where the medium (such as glass) inside local seal **305**D has a higher refractive index than the medium (such as air) above the convex upper surface of the local seal **305**D, the plano-concave local seal **305**D acts as a diverging lens. In comparison to ray **1405** incident at the top surface of local seal **305**D, the emergent ray **1406** is bent away from the normal to the surface, which for the concave surface produces the diverging effect shown. The diverging effect may be beneficial in display embodiments where wide viewing angle is desired. The diverging effect may be beneficial in lighting embodiments where omni-directional illumination is sought.

FIG. **14**B shows an alternate construction for lensed embodiments, in which plano-convex local seals **305** are covered with a planarization layer **1407**. In this figure, local seals **305**E, **305**F, **305**H cover electro-optical elements **304**E, **304**F, **304**H respectively. The diagram for local seal **305**F shows a case where the refractive index of the local seal **305**F is greater than the refractive index of the planarization layer **1407**. In this situation, local seal **305**F provides a converging effect substantially similar to the converging effect seen for local seal **305**B in FIG. **14**A. In contrast, the diagram for local seal **305**H shows a case where the refractive index of the planarization layer is greater than the refractive index of the local seal **305**H. In this case, the diverging effect of a plano-concave lens defined by the top and bottom surfaces of the planarization layer is stronger than the converging effect of the plano-convex lens defined by the top and bottom surfaces of the local seal **305**H. In terms of rays, ray **1408** is incident on the curved upper surface of local seal **305**H, and emergent ray **1409** is bent closer to the normal to this curved surface compared to ray **1408**. Ray **1409** is subsequently incident on the plane upper surface of planarization layer **1407**, and emergent ray **1410** is bent away from the normal to this plane surface, compared to ray **1409**. The net effect for this configuration is a diverging effect as shown.

FIG. **15** shows an embodiment of the present invention in which local seal **1505** is impregnated with pigment particles to achieve an optical filter function. Panel **1500** may be part of any of a variety of product types among those described above, and in particular may be part of a flat panel display in some preferred embodiments and an illumination source in other preferred embodiments. As shown in FIG. **15**, **304**W is a white light emitting element, which may be fabricated as a tandem OLED structure. The other elements **301-303** shown in FIG. **15** are substantially similar to those described above in context of FIG. **3**. Red light ray **1501**R and green light ray **1501**G are absorbed by pigment particles, as indicated by the respective X marks on which **1501**R and **1501**G terminate, while blue light ray **1501**B emerges without absorption. Thus, a blue filter function is achieved, which may be desirable to obtain a blue pixel in a flat panel display built using a uniform white electroluminescent structure. Of course, red and green pixels may similarly be obtained by impregnating the local seal **1505** with suitable pigments or mixtures of pigments.

The filtering function may also be desirable in lighting products. As an example, a uniform white electroluminescent structure may be built using blue and yellow-orange emissive layers. Filtering of the electroluminescent light can be used to adjust the color temperature, or to otherwise tune the emergent emission spectrum for more pleasant appearance. In particular, the same electroluminescent formulation can be used to produce lighting panels of different color temperature, by varying the filtering properties of local seals **1505**.

Closely related to filtering is the optical color shift function. FIG. **16** shows an embodiment of the present invention in which local seal **1605** is impregnated with particles of a fluorescent or other color shifting material, to achieve an optical color shift function. Panel **1600** may be part of any of a variety of product types among those described above, and in particular may be an illumination source in preferred embodiments. As shown in FIG. **16**, **304** is a light emitting element. The other elements **301-303** shown in FIG. **16** are substantially similar to those described above in context of FIG. **3**. Light ray **1601** excites a fluorescent material particle **1602**. The re-radiated ray **1603** emerges at a longer wavelength. Thus, a color shift function is achieved, which may be desirable to convert blue light to warmer red, orange, or yellow light, decreasing the color temperature of a lighting panel **1600** to produce a more pleasant hue.

Finally, FIG. **17** shows an embodiment in which local seal **1705** incorporates scattering particles **1701** and performs a scattering function. Scattering is recognized as important for increasing light extraction efficiency for display and lighting products alike. Panel **1700** may be part of any of a variety of product types among those described above, and in particular may be a display panel in some preferred embodiments and a lighting panel in other preferred embodiments. As shown in FIG. **17**, **304** is a light emitting element, which may be fabricated as an OLED. The other elements **301-303** shown in FIG. **15** are substantially similar to those described above in context of FIG. **3**. Scattering particles **1701** which may be provided in the form of a powder of a refractory material mixed with a glass powder paste or suspension during deposition of local seal material, as shown for example in FIG. **6**B. During fusing of the glass material, as shown for example in FIG. **6**C or FIG. **7**A-**7**C, the refractory material powder particles remain in situ, and can act as scattering particles **1701** in the finished panel **1700**. Light ray **1702** is scattered by a scattering particle **1701** and emerges at a different angle as shown by ray **1703**. Other light rays, such as **1704**, may emerge without interacting with any scattering particles. A wide variety of inorganic and metal materials are available and suitable for use with a low melting temperature glass. Some well-known materials are aluminum oxide, zinc oxide, and silicon.

While specific embodiments have been described in detail in the foregoing detailed description and illustrated in the accompanying drawings, it will be appreciated by those skilled in the art that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure and the broad inventive concepts thereof. It is understood, therefore, that the scope of the present invention is not limited to the particular examples and implementations disclosed herein, but is intended to cover modifications within the spirit and scope thereof as defined by the appended claims and any and all equivalents thereof.

All U.S. patents and patent application publications referenced above are hereby incorporated by reference as if set forth in full.

I claim:

1. A method of manufacturing local encapsulation seals over a two-dimensional array of organic electro-optical elements, the method comprising:

a) depositing one or more first drops of a glass powder formulation over a first electro-optical element, to form a first mass;
   wherein the formulation is selected from the group consisting of a paste and a suspension;

b) depositing one or more second drops of the same glass powder formulation over a second electro-optical element, to form a second mass;
   wherein the first and second electro-optical elements are neighbors, and the first mass is not in direct contact with the second mass; and

c) fusing the first and second masses, thereby to form respective first and second local encapsulation seals of fused glass;
   wherein an area between the first and second local encapsulation seals remains uncovered by fused glass;

and further wherein

the fusing step is performed by application of laser energy,

the glass powder suspension comprises a light absorbing component,

the organic electro-optical elements are emissive,

the light absorbing component has an absorption peak at a first wavelength selected to be spaced apart from all wavelengths at which the electro-optical elements have peaks in their emissive spectra, and

the laser energy is provided with a spectrum having full width at half maximum extending from a second wavelength to a third wavelength, and the first wavelength lies between the second wavelength and the third wavelength, inclusive.

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