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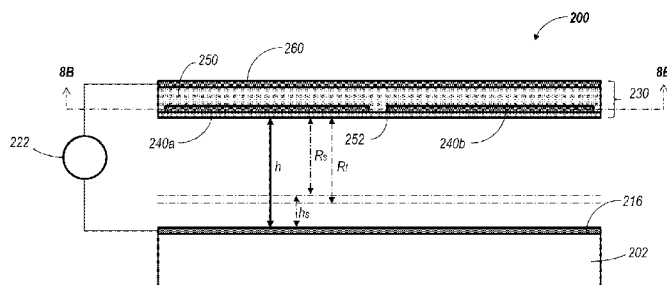


FIG. 8A

(57) Abstract: This disclosure provides systems, methods and apparatus for increasing a range of stable travel positions of a movable layer within electromechanical systems (EMS) devices. In one aspect, an electrically isolated floating electrode can be disposed between a driving electrode within a movable layer and a fixed electrode in order to increase a stable travel range of the movable layer. By segmenting the electrically isolated floating electrode into multiple isolated electrode segments, unbalanced charge accumulation in response to tilting of the movable layer can be constrained to further increase the stable travel range of the movable layer.

ELECTROMECHANICAL SYSTEMS DEVICE WITH SEGMENTED ELECTRODES

TECHNICAL FIELD

[0001] This disclosure relates to electromechanical systems (EMS) devices having segmented electrodes and methods of fabricating the same.

DESCRIPTION OF THE RELATED TECHNOLOGY

[0002] Electromechanical systems (EMS) include devices having electrical and mechanical elements, actuators, transducers, sensors, optical components such as mirrors and optical films, and electronics. EMS devices or elements can be manufactured at a variety of scales including, but not limited to, microscales and nanoscales. For example, microelectromechanical systems (MEMS) devices can include structures having sizes ranging from about a micron to hundreds of microns or more. Nanoelectromechanical systems (NEMS) devices can include structures having sizes smaller than a micron including, for example, sizes smaller than several hundred nanometers. Electromechanical elements may be created using deposition, etching, lithography, and/or other micromachining processes that etch away parts of substrates and/or deposited material layers, or that add layers to form electrical and electromechanical devices.

[0003] One type of EMS device is called an interferometric modulator (IMOD). The term IMOD or interferometric light modulator refers to a device that selectively absorbs and/or reflects light using the principles of optical interference. In some implementations, an IMOD display element may include a pair of conductive plates, one or both of which may be transparent and/or reflective, wholly or in part, and capable of relative motion upon application of an appropriate electrical signal. For example, one plate may include a stationary layer deposited over, on or supported by a substrate and the other plate may include a reflective membrane separated from the stationary layer by an air gap. The position of one plate in relation to another can change the optical interference of light incident on the IMOD display element. IMOD-based display devices have a wide range of applications, and are anticipated to be used in improving existing products and creating new products, especially those with display capabilities.

[0004] When an EMS device includes a movable layer, the range of stable travel positions through which the movable layer can be electrostatically displaced may be limited at least in part by a tendency of the movable layer to tilt. This tilting can be due, at least in part, to variances or imperfections in the manufacture of the EMS device. The rotational stability of a movable layer can affect the stable travel range of the EMS, and rotational instability can limit the performance of the EMS device.

SUMMARY

[0005] The systems, methods and devices of this disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0006] One innovative aspect of the subject matter described in this disclosure can be implemented in an electromechanical systems (EMS) device, including a first electrode supported by a substrate, a movable layer separated from the first electrode by a gap, a second electrode supported by the movable layer, where one of the first or second electrodes is a segmented electrode including a plurality of isolated electrode segments located between the first driving electrode and the second driving electrode, where each of the plurality of isolated electrode segments are electrically isolated both from the first and second driving electrodes and from the other isolated electrode segments, and where the other of the first or second electrodes serves as a first driving electrode, and a second driving electrode, where application of a voltage between the first driving electrode and the second driving electrode electrostatically displaces the movable layer.

[0007] In some implementations, the first driving electrode and the segmented electrode can form a first capacitor, and the second driving electrode and the segmented electrode can form a second capacitor in series with the first capacitor. In some implementations, each individual isolated electrode segment can be surrounded on all sides by dielectric material. In further implementations, the plurality of isolated electrode segments can include four isolated electrical segments separated by two substantially perpendicular sections of dielectric material.

[0008] In some implementations, the device can include an interferometric modulator. In further implementations, the movable layer can be movable over a range of stable positions in which application of a voltage between the first driving electrode and the second driving electrode maintains the movable layer at a position

within the range of stable positions, the interferometric modulator can be capable of reflecting substantially white light when the movable layer is collapsed against the first electrode, and the interferometric modulator can be capable of appearing black when the movable layer is maintained in at least one position within the range of stable positions

[0009] In some implementations, the device can additionally including driving circuitry capable of applying a range of voltages between the first driving electrode and the second driving electrode to move the movable layer through a range of stable positions between a relaxed position where no voltage is applied between the first driving electrode and the second driving electrode and a minimum stable distance from the first electrode. In further implementations, the minimum stable distance can be less than 40% of the distance between the relaxed position and the first electrode.

[0010] In some implementations, the second electrode can be the segmented electrode. In further implementations, the movable layer can include the second driving electrode, where application of a voltage between the driving electrode and the first electrode electrostatically displaces the movable layer, and where the plurality of isolated electrode segments are located between the second driving electrode and the fixed electrode, and a dielectric layer located between the second driving electrode and the first electrode, where each of the plurality of isolated electrode segments are electrically isolated from both the second driving electrode and from the other isolated electrode segments. In further implementations, the first electrode can include an optical absorber, and the isolated electrode segments can include a reflective material.

[0011] In some implementations, the first electrode can be a segmented optical absorber which includes the plurality of isolated electrode segments. In further implementations, the second driving electrode can be electrically isolated from the segmented optical absorber, and where the segmented optical absorber is disposed between the fixed electrode and the second electrode. In further implementations, the second driving electrode can be more transmissive to visible wavelengths of light than the segmented optical absorber. In further implementations, the segmented optical absorber can include at least one gap between segmented optical absorber sections, and the device can additionally include a second optical absorber structure electrically isolated from the segmented optical absorber structure is aligned with the at least one gap between segmented optical absorber sections. In still further implementations, at

least a portion of the second optical absorber structure can be substantially the same size and shape as the at least one gap between segmented optical absorber sections.

[0012] Another innovative aspect of the subject matter described in this disclosure can be implemented in a method of fabricating an electromechanical systems (EMS) device, including forming a first dielectric layer over a substrate, forming a first electrode layer over the first dielectric layer, forming a plurality of isolated electrode segments in the first electrode layer, forming a second dielectric layer over the plurality of isolated electrode segments, and forming a second electrode layer over the second dielectric layer.

[0013] In some implementations, forming a plurality of isolated electrode segments can include patterning the first electrode layer to form a group of four isolated electrical segments separated by two substantially perpendicular cuts extending through the first electrode layer. In some implementations forming a first dielectric layer can include forming a stack of dielectric layers, the stack of dielectric layers including a first dielectric sublayer including a first material having a first index of refraction, and a second dielectric sublayer including a second material having a second index of refraction, where the first index of refraction is greater than the second index of refraction.

[0014] Another innovative aspect of the subject matter described in this disclosure can be implemented in an electromechanical systems (EMS) device, including a first electrode supported by a substrate, a movable layer separated from the first electrode by a gap, a second electrode supported by the movable layer, where one of the first or second electrodes is a floating electrode including means for inhibiting an imbalanced accumulation of charge within the movable layer to increase a range of stable positions of the movable layer, and where the other of the first or second electrodes serves as a first driving electrode, and a second driving electrode, where application of a voltage between the first driving electrode and the second driving electrode electrostatically displaces the movable layer.

[0015] In some implementations, the floating electrode can be a segmented electrode, where the inhibiting means include a plurality of isolated electrode segments located between the first driving electrode and the second driving electrode, and where each of the plurality of isolated electrode segments are electrically isolated both from the first and second driving electrodes and from the other isolated electrode segments. In further implementations, the first driving electrode and the segmented

electrode can form a first capacitor, and the second driving electrode and the segmented electrode can form a second capacitor in series with the first capacitor.

[0016] In some implementations, the second electrode can be the segmented electrode, and the movable layer can include the second driving electrode, where application of a voltage between the driving electrode and the first electrode electrostatically displaces the movable layer, and where the plurality of isolated electrode segments are located between the second driving electrode and the fixed electrode, and a dielectric layer located between the second driving electrode and the first electrode, where each of the plurality of isolated electrode segments are electrically isolated from both the second driving electrode and from the other isolated electrode segments. In some implementations, the first electrode can be a segmented optical absorber which includes the plurality of isolated electrode segments, where the second driving electrode is electrically isolated from the segmented optical absorber, and where the segmented optical absorber is disposed between the fixed electrode and the second electrode.

[0017] Details of one or more implementations of the subject matter described in this disclosure are set forth in the accompanying drawings and the description below. Although the examples provided in this disclosure are primarily described in terms of EMS and MEMS-based displays, the concepts provided herein may apply to other types of displays such as liquid crystal displays, organic light-emitting diode (“OLED”) displays, and field emission displays. Other features, aspects, and advantages will become apparent from the description, the drawings and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] **FIG. 1** is an isometric view illustration depicting two adjacent interferometric modulator (IMOD) display elements in a series or array of display elements of an IMOD display device.

[0019] **FIG. 2** is a system block diagram illustrating an electronic device incorporating an IMOD-based display including a three element by three element array of IMOD display elements.

[0020] **FIG. 3** is a flow diagram illustrating a manufacturing process for an IMOD display or display element.

[0021] FIGS. 4A–4E are cross-sectional illustrations of various stages in a process of making an IMOD display or display element.

[0022] FIGS. 5A and 5B are schematic exploded partial perspective views of a portion of an electromechanical systems (EMS) package including an array of EMS elements and a backplate.

[0023] FIG. 6 is a schematic cross-section showing an example of an IMOD being driven in an analog fashion.

[0024] FIG. 7 is a schematic cross-section showing an example of another example of an analog IMOD including an isolated electrode.

[0025] FIG. 8A is a schematic cross-section showing an example of another example of an analog IMOD in which an isolated electrode is separated into multiple isolated electrode segments.

[0026] FIG. 8B is a cross-sectional view of the movable layer of the analog IMOD of FIG. 8A, taken along the line 8B–8B of FIG. 8A.

[0027] FIGS. 9A–9D are cross-sectional illustrations of various stages in a process of fabricating an analog IMOD having isolated electrode segments.

[0028] FIG. 10 is a flow diagram illustrating a fabrication process for an analog IMOD having isolated electrode segments, which may include the stages illustrated in FIGS. 9A–9D .

[0029] FIG. 11 is a cross-sectional view of an example of a movable layer patterned to include support arms.

[0030] FIG. 12A is a schematic cross-section showing an example of another example of an analog IMOD in which an optical absorber is separated into multiple isolated electrode segments.

[0031] FIG. 12B is a cross-sectional view of the example optical absorber of the analog IMOD of FIG. 12A.

[0032] FIGS. 13A–13C are cross-sectional illustrations of various stages in an example process of fabricating an analog IMOD having an optical absorber including isolated electrode segments.

[0033] FIGS. 14A and 14B are cross-sectional illustrations of additional stages in an example process of fabricating an analog IMOD which increase the fill factor of an optical absorber including isolated electrode segments.

[0034] FIG. 15 is a cross-sectional view of the example optical absorber of the analog IMOD of FIG. 14B.

[0035] **FIG. 16** is a flow diagram illustrating an example fabrication process for an analog IMOD having an optical absorber including isolated electrode segments, which may include the stages illustrated in **FIGS. 13A–13C**.

[0036] **FIGS. 17A** and **17B** are system block diagrams illustrating a display device that includes a plurality of IMOD display elements.

[0037] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0038] The following description is directed to certain implementations for the purposes of describing the innovative aspects of this disclosure. However, a person having ordinary skill in the art will readily recognize that the teachings herein can be applied in a multitude of different ways. The described implementations may be implemented in any device, apparatus, or system that can be configured to display an image, whether in motion (such as video) or stationary (such as still images), and whether textual, graphical or pictorial. More particularly, it is contemplated that the described implementations may be included in or associated with a variety of electronic devices such as, but not limited to: mobile telephones, multimedia Internet enabled cellular telephones, mobile television receivers, wireless devices, smartphones, Bluetooth® devices, personal data assistants (PDAs), wireless electronic mail receivers, hand-held or portable computers, netbooks, notebooks, smartbooks, tablets, printers, copiers, scanners, facsimile devices, global positioning system (GPS) receivers/navigators, cameras, digital media players (such as MP3 players), camcorders, game consoles, wrist watches, clocks, calculators, television monitors, flat panel displays, electronic reading devices (e.g., e-readers), computer monitors, auto displays (including odometer and speedometer displays, etc.), cockpit controls and/or displays, camera view displays (such as the display of a rear view camera in a vehicle), electronic photographs, electronic billboards or signs, projectors, architectural structures, microwaves, refrigerators, stereo systems, cassette recorders or players, DVD players, CD players, VCRs, radios, portable memory chips, washers, dryers, washer/dryers, parking meters, packaging (such as in electromechanical systems (EMS) applications including microelectromechanical systems (MEMS) applications, as well as non-EMS applications), aesthetic structures (such as display of images on a piece of jewelry or clothing) and a variety of EMS devices. The

teachings herein also can be used in non-display applications such as, but not limited to, electronic switching devices, radio frequency filters, sensors, accelerometers, gyroscopes, motion-sensing devices, magnetometers, inertial components for consumer electronics, parts of consumer electronics products, varactors, liquid crystal devices, electrophoretic devices, drive schemes, manufacturing processes and electronic test equipment. Thus, the teachings are not intended to be limited to the implementations depicted solely in the Figures, but instead have wide applicability as will be readily apparent to one having ordinary skill in the art.

[0039] By driving a movable layer of an EMS device over a range of stable positions, additional precision and functionality of the EMS device may be provided. For example, an IMOD having a movable reflective layer may be driven in a multi-state (and when the number of multiple states is sufficiently large, an analog or near-analog) manner to move the movable reflective layer over a range of positions to cause the IMOD to reflect a range of possible colors. The range of stable positions can depend on, for example, the structure and components of the EMS device, but can also be affected by imperfections or variance in the fabrication of the EMS device. In some EMS devices, a slight rotational instability can lead to unintended collapse of an electrostatically displaced movable layer when the movable layer is near the edge of a stable range of positions, due to imbalanced charge accumulation on the movable layer which leads to tilting and subsequent collapse of the movable layer. The practical range of stable positions of such an EMS device may be significantly less than a theoretical range of stable positions for an EMS device of the same design. By separating an electrode in the movable layer into electrically isolated electrode segments, some of the charge accumulation resulting from rotational instability can be constrained to positions where it exerts less of a rotational moment on the movable layer of the EMS device, increasing the range of stable positions of the EMS device.

[0040] Particular implementations of the subject matter described in this disclosure can be implemented to realize one or more of the following potential advantages. In some implementations, dividing a movable electrode along two perpendicular axes provides a significant increase in the stable range of the EMS device without a substantial reduction in the total electrode area. In implementations in which the EMS device is an IMOD configured to be driven in a multi-state manner, extending the stable travel range of the multi-state IMOD can extend the range of colors that can be reflected by the multi-state IMOD.

[0041] An example of a suitable EMS or MEMS device or apparatus, to which the described implementations may apply, is a reflective display device. Reflective display devices can incorporate interferometric modulator (IMOD) display elements that can be implemented to selectively absorb and/or reflect light incident thereon using principles of optical interference. IMOD display elements can include a partial optical absorber, a reflector that is movable with respect to the absorber, and an optical resonant cavity defined between the absorber and the reflector. In some implementations, the reflector can be moved to two or more different positions, which can change the size of the optical resonant cavity and thereby affect the reflectance of the IMOD. The reflectance spectra of IMOD display elements can create fairly broad spectral bands that can be shifted across the visible wavelengths to generate different colors. The position of the spectral band can be adjusted by changing the thickness of the optical resonant cavity. One way of changing the optical resonant cavity is by changing the position of the reflector with respect to the absorber.

[0042] **FIG. 1** is an isometric view illustration depicting two adjacent interferometric modulator (IMOD) display elements in a series or array of display elements of an IMOD display device. The IMOD display device includes one or more interferometric EMS, such as MEMS, display elements. In these devices, the interferometric MEMS display elements can be configured in either a bright or dark state. In the bright (“relaxed,” “open” or “on,” etc.) state, the display element reflects a large portion of incident visible light. Conversely, in the dark (“actuated,” “closed” or “off,” etc.) state, the display element reflects little incident visible light. MEMS display elements can be configured to reflect predominantly at particular wavelengths of light allowing for a color display in addition to black and white. In some implementations, by using multiple display elements, different intensities of color primaries and shades of gray can be achieved.

[0043] The IMOD display device can include an array of IMOD display elements which may be arranged in rows and columns. Each display element in the array can include at least a pair of reflective and semi-reflective layers, such as a movable reflective layer (i.e., a movable layer, also referred to as a mechanical layer) and a fixed partially reflective layer (i.e., a stationary layer), positioned at a variable and controllable distance from each other to form an air gap (also referred to as an optical gap, cavity or optical resonant cavity). The movable reflective layer may be moved between at least two positions. For example, in a first position, i.e., a relaxed

position, the movable reflective layer can be positioned at a distance from the fixed partially reflective layer. In a second position, i.e., an actuated position, the movable reflective layer can be positioned more closely to the partially reflective layer. Incident light that reflects from the two layers can interfere constructively and/or destructively depending on the position of the movable reflective layer and the wavelength(s) of the incident light, producing either an overall reflective or non-reflective state for each display element. In some implementations, the display element may be in a reflective state when unactuated, reflecting light within the visible spectrum, and may be in a dark state when actuated, absorbing and/or destructively interfering light within the visible range. In some other implementations, however, an IMOD display element may be in a dark state when unactuated, and in a reflective state when actuated. In some implementations, the introduction of an applied voltage can drive the display elements to change states. In some other implementations, an applied charge can drive the display elements to change states.

[0044] The depicted portion of the array in **FIG. 1** includes two adjacent interferometric MEMS display elements in the form of IMOD display elements **12**. In the display element **12** on the right (as illustrated), the movable reflective layer **14** is illustrated in an actuated position near, adjacent or touching the optical stack **16**. The voltage V_{bias} applied across the display element **12** on the right is sufficient to move and also maintain the movable reflective layer **14** in the actuated position. In the display element **12** on the left (as illustrated), a movable reflective layer **14** is illustrated in a relaxed position at a distance (which may be predetermined based on design parameters) from an optical stack **16**, which includes a partially reflective layer. The voltage V_0 applied across the display element **12** on the left is insufficient to cause actuation of the movable reflective layer **14** to an actuated position such as that of the display element **12** on the right.

[0045] In **FIG. 1**, the reflective properties of IMOD display elements **12** are generally illustrated with arrows indicating light **13** incident upon the IMOD display elements **12**, and light **15** reflecting from the display element **12** on the left. Most of the light **13** incident upon the display elements **12** may be transmitted through the transparent substrate **20**, toward the optical stack **16**. A portion of the light incident upon the optical stack **16** may be transmitted through the partially reflective layer of the optical stack **16**, and a portion will be reflected back through the transparent

substrate **20**. The portion of light **13** that is transmitted through the optical stack **16** may be reflected from the movable reflective layer **14**, back toward (and through) the transparent substrate **20**. Interference (constructive and/or destructive) between the light reflected from the partially reflective layer of the optical stack **16** and the light reflected from the movable reflective layer **14** will determine in part the intensity of wavelength(s) of light **15** reflected from the display element **12** on the viewing or substrate side of the device. In some implementations, the transparent substrate **20** can be a glass substrate (sometimes referred to as a glass plate or panel). The glass substrate may be or include, for example, a borosilicate glass, a soda lime glass, quartz, Pyrex, or other suitable glass material. In some implementations, the glass substrate may have a thickness of 0.3, 0.5 or 0.7 millimeters, although in some implementations the glass substrate can be thicker (such as tens of millimeters) or thinner (such as less than 0.3 millimeters). In some implementations, a non-glass substrate can be used, such as a polycarbonate, acrylic, polyethylene terephthalate (PET) or polyether ether ketone (PEEK) substrate. In such an implementation, the non-glass substrate will likely have a thickness of less than 0.7 millimeters, although the substrate may be thicker depending on the design considerations. In some implementations, a non-transparent substrate, such as a metal foil or stainless steel-based substrate can be used. For example, a reverse-IMOD-based display, which includes a fixed reflective layer and a movable layer which is partially transmissive and partially reflective, may be configured to be viewed from the opposite side of a substrate as the display elements **12** of FIG. 1 and may be supported by a non-transparent substrate.

[0046] The optical stack **16** can include a single layer or several layers. The layer(s) can include one or more of an electrode layer, a partially reflective and partially transmissive layer, and a transparent dielectric layer. In some implementations, the optical stack **16** is electrically conductive, partially transparent and partially reflective, and may be fabricated, for example, by depositing one or more of the above layers onto a transparent substrate **20**. The electrode layer can be formed from a variety of materials, such as various metals, for example indium tin oxide (ITO). The partially reflective layer can be formed from a variety of materials that are partially reflective, such as various metals (e.g., chromium and/or molybdenum), semiconductors, and dielectrics. The partially reflective layer can be formed of one or more layers of materials, and each of the layers can be formed of a

single material or a combination of materials. In some implementations, certain portions of the optical stack **16** can include a single semi-transparent thickness of metal or semiconductor which serves as both a partial optical absorber and electrical conductor, while different, electrically more conductive layers or portions (e.g., of the optical stack **16** or of other structures of the display element) can serve to bus signals between IMOD display elements. The optical stack **16** also can include one or more insulating or dielectric layers covering one or more conductive layers or an electrically conductive/partially absorptive layer.

[0047] In some implementations, at least some of the layer(s) of the optical stack **16** can be patterned into parallel strips, and may form row electrodes in a display device as described further below. As will be understood by one having ordinary skill in the art, the term “patterned” is used herein to refer to masking as well as etching processes. In some implementations, a highly conductive and reflective material, such as aluminum (Al), may be used for the movable reflective layer **14**, and these strips may form column electrodes in a display device. The movable reflective layer **14** may be formed as a series of parallel strips of a deposited metal layer or layers (orthogonal to the row electrodes of the optical stack **16**) to form columns deposited on top of supports, such as the illustrated posts **18**, and an intervening sacrificial material located between the posts **18**. When the sacrificial material is etched away, a defined gap **19**, or optical cavity, can be formed between the movable reflective layer **14** and the optical stack **16**. In some implementations, the spacing between posts **18** may be approximately 1–1000 μm , while the gap **19** may be approximately less than 10,000 Angstroms ($\text{\AA}$).

[0048] In some implementations, each IMOD display element, whether in the actuated or relaxed state, can be considered as a capacitor formed by the fixed and moving reflective layers. When no voltage is applied, the movable reflective layer **14** remains in a mechanically relaxed state, as illustrated by the display element **12** on the left in **FIG. 1**, with the gap **19** between the movable reflective layer **14** and optical stack **16**. However, when a potential difference, i.e., a voltage, is applied to at least one of a selected row and column, the capacitor formed at the intersection of the row and column electrodes at the corresponding display element becomes charged, and electrostatic forces pull the electrodes together. If the applied voltage exceeds a threshold, the movable reflective layer **14** can deform and move near or against the optical stack **16**. A dielectric layer (not shown) within the optical stack **16** may

prevent shorting and control the separation distance between the layers **14** and **16**, as illustrated by the actuated display element **12** on the right in **FIG. 1**. The behavior can be the same regardless of the polarity of the applied potential difference. Though a series of display elements in an array may be referred to in some instances as “rows” or “columns,” a person having ordinary skill in the art will readily understand that referring to one direction as a “row” and another as a “column” is arbitrary. Restated, in some orientations, the rows can be considered columns, and the columns considered to be rows. In some implementations, the rows may be referred to as “common” lines and the columns may be referred to as “segment” lines, or vice versa. Furthermore, the display elements may be evenly arranged in orthogonal rows and columns (an “array”), or arranged in non-linear configurations, for example, having certain positional offsets with respect to one another (a “mosaic”). The terms “array” and “mosaic” may refer to either configuration. Thus, although the display is referred to as including an “array” or “mosaic,” the elements themselves need not be arranged orthogonally to one another, or disposed in an even distribution, in any instance, but may include arrangements having asymmetric shapes and unevenly distributed elements.

[0049] **FIG. 2** is a system block diagram illustrating an electronic device incorporating an IMOD-based display including a three element by three element array of IMOD display elements. The electronic device includes a processor **21** that may be configured to execute one or more software modules. In addition to executing an operating system, the processor **21** may be configured to execute one or more software applications, including a web browser, a telephone application, an email program, or any other software application.

[0050] The processor **21** can be configured to communicate with an array driver **22**. The array driver **22** can include a row driver circuit **24** and a column driver circuit **26** that provide signals to, for example a display array or panel **30**. The cross section of the IMOD display device illustrated in **FIG. 1** is shown by the lines **1–1** in **FIG. 2**. Although **FIG. 2** illustrates a 3x3 array of IMOD display elements for the sake of clarity, the display array **30** may contain a very large number of IMOD display elements, and may have a different number of IMOD display elements in rows than in columns, and vice versa.

[0051] **FIG. 3** is a flow diagram illustrating a manufacturing process **80** for an IMOD display or display element. **FIGS. 4A–4E** are cross-sectional illustrations of

various stages in the manufacturing process 80 for making an IMOD display or display element. In some implementations, the manufacturing process 80 can be implemented to manufacture one or more EMS devices, such as IMOD displays or display elements. The manufacture of such an EMS device also can include other blocks not shown in FIG. 3. The process 80 begins at block 82 with the formation of the optical stack 16 over the substrate 20. FIG. 4A illustrates such an optical stack 16 formed over the substrate 20. The substrate 20 may be a transparent substrate such as glass or plastic such as the materials discussed above with respect to FIG. 1. The substrate 20 may be flexible or relatively stiff and unbending, and may have been subjected to prior preparation processes, such as cleaning, to facilitate efficient formation of the optical stack 16. As discussed above, the optical stack 16 can be electrically conductive, partially transparent, partially reflective, and partially absorptive, and may be fabricated, for example, by depositing one or more layers having the desired properties onto the transparent substrate 20.

[0052] In FIG. 4A, the optical stack 16 includes a multilayer structure having sub-layers 16a and 16b, although more or fewer sub-layers may be included in some other implementations. In some implementations, one of the sub-layers 16a and 16b can be configured with both optically absorptive and electrically conductive properties, such as the combined conductor/absorber sub-layer 16a. In some implementations, one of the sub-layers 16a and 16b can include molybdenum-chromium (molychrome or MoCr), or other materials with a suitable complex refractive index. Additionally, one or more of the sub-layers 16a and 16b can be patterned into parallel strips, and may form row electrodes in a display device. Such patterning can be performed by a masking and etching process or another suitable process known in the art. In some implementations, one of the sub-layers 16a and 16b can be an insulating or dielectric layer, such as an upper sub-layer 16b that is deposited over one or more underlying metal and/or oxide layers (such as one or more reflective and/or conductive layers). In addition, the optical stack 16 can be patterned into individual and parallel strips that form the rows of the display. In some implementations, at least one of the sub-layers of the optical stack, such as the optically absorptive layer, may be quite thin (e.g., relative to other layers depicted in this disclosure), even though the sub-layers 16a and 16b are shown somewhat thick in FIG. 4A–4E.

[0053] The process 80 continues at block 84 with the formation of a sacrificial layer 25 over the optical stack 16. Because the sacrificial layer 25 is later removed (see block 90) to form the cavity 19, the sacrificial layer 25 is not shown in the resulting IMOD display elements. FIG. 4B illustrates a partially fabricated device including a sacrificial layer 25 formed over the optical stack 16. The formation of the sacrificial layer 25 over the optical stack 16 may include deposition of a xenon difluoride (XeF₂)-etchable material such as molybdenum (Mo) or amorphous silicon (Si), in a thickness selected to provide, after subsequent removal, a gap or cavity 19 (see also FIG. 4E) having a desired design size. Deposition of the sacrificial material may be carried out using deposition techniques such as physical vapor deposition (PVD, which includes many different techniques, such as sputtering), plasma-enhanced chemical vapor deposition (PECVD), thermal chemical vapor deposition (thermal CVD), or spin-coating.

[0054] The process 80 continues at block 86 with the formation of a support structure such as a support post 18. The formation of the support post 18 may include patterning the sacrificial layer 25 to form a support structure aperture, then depositing a material (such as a polymer or an inorganic material, like silicon oxide) into the aperture to form the support post 18, using a deposition method such as PVD, PECVD, thermal CVD, or spin-coating. In some implementations, the support structure aperture formed in the sacrificial layer can extend through both the sacrificial layer 25 and the optical stack 16 to the underlying substrate 20, so that the lower end of the support post 18 contacts the substrate 20. Alternatively, as depicted in FIG. 4C, the aperture formed in the sacrificial layer 25 can extend through the sacrificial layer 25, but not through the optical stack 16. For example, FIG. 4E illustrates the lower ends of the support posts 18 in contact with an upper surface of the optical stack 16. The support post 18, or other support structures, may be formed by depositing a layer of support structure material over the sacrificial layer 25 and patterning portions of the support structure material located away from apertures in the sacrificial layer 25. The support structures may be located within the apertures, as illustrated in FIG. 4C, but also can extend at least partially over a portion of the sacrificial layer 25. As noted above, the patterning of the sacrificial layer 25 and/or the support posts 18 can be performed by a masking and etching process, but also may be performed by alternative patterning methods.

[0055] The process **80** continues at block **88** with the formation of a movable reflective layer or membrane such as the movable reflective layer **14** illustrated in **FIG. 4D**. The movable reflective layer **14** may be formed by employing one or more deposition steps, including, for example, reflective layer (such as aluminum, aluminum alloy, or other reflective materials) deposition, along with one or more patterning, masking and/or etching steps. The movable reflective layer **14** can be patterned into individual and parallel strips that form, for example, the columns of the display. The movable reflective layer **14** can be electrically conductive, and referred to as an electrically conductive layer. In some implementations, the movable reflective layer **14** may include a plurality of sub-layers **14a**, **14b** and **14c** as shown in **FIG. 4D**. In some implementations, one or more of the sub-layers, such as sub-layers **14a** and **14c**, may include highly reflective sub-layers selected for their optical properties, and another sub-layer **14b** may include a mechanical sub-layer selected for its mechanical properties. In some implementations, the mechanical sub-layer may include a dielectric material. Since the sacrificial layer **25** is still present in the partially fabricated IMOD display element formed at block **88**, the movable reflective layer **14** is typically not movable at this stage. A partially fabricated IMOD display element that contains a sacrificial layer **25** also may be referred to herein as an “unreleased” IMOD.

[0056] The process **80** continues at block **90** with the formation of a cavity **19**. The cavity **19** may be formed by exposing the sacrificial material **25** (deposited at block **84**) to an etchant. For example, an etchable sacrificial material such as Mo or amorphous Si may be removed by dry chemical etching by exposing the sacrificial layer **25** to a gaseous or vaporous etchant, such as vapors derived from solid XeF_2 for a period of time that is effective to remove the desired amount of material. The sacrificial material is typically selectively removed relative to the structures surrounding the cavity **19**. Other etching methods, such as wet etching and/or plasma etching, also may be used. Since the sacrificial layer **25** is removed during block **90**, the movable reflective layer **14** is typically movable after this stage. After removal of the sacrificial material **25**, the resulting fully or partially fabricated IMOD display element may be referred to herein as a “released” IMOD.

[0057] In some implementations, the packaging of an EMS component or device, such as an IMOD-based display, can include a backplate (alternatively referred to as a backplane, back glass or recessed glass) which can be configured to protect the EMS

components from damage (such as from mechanical interference or potentially damaging substances). The backplate also can provide structural support for a wide range of components, including but not limited to driver circuitry, processors, memory, interconnect arrays, vapor barriers, product housing, and the like. In some implementations, the use of a backplate can facilitate integration of components and thereby reduce the volume, weight, and/or manufacturing costs of a portable electronic device.

[0058] **FIGS. 5A and 5B** are schematic exploded partial perspective views of a portion of an EMS package 91 including an array 36 of EMS elements and a backplate 92. **FIG. 5A** is shown with two corners of the backplate 92 cut away to better illustrate certain portions of the backplate 92, while **FIG. 5B** is shown without the corners cut away. The EMS array 36 can include a substrate 20, support posts 18, and a movable layer 14. In some implementations, the EMS array 36 can include an array of IMOD display elements with one or more optical stack portions 16 on a transparent substrate, and the movable layer 14 can be implemented as a movable reflective layer.

[0059] The backplate 92 can be essentially planar or can have at least one contoured surface (e.g., the backplate 92 can be formed with recesses and/or protrusions). The backplate 92 may be made of any suitable material, whether transparent or opaque, conductive or insulating. Suitable materials for the backplate 92 include, but are not limited to, glass, plastic, ceramics, polymers, laminates, metals, metal foils, Kovar and plated Kovar.

[0060] As shown in **FIGS. 5A and 5B**, the backplate 92 can include one or more backplate components 94a and 94b, which can be partially or wholly embedded in the backplate 92. As can be seen in **FIG. 5A**, backplate component 94a is embedded in the backplate 92. As can be seen in **FIGS. 5A and 5B**, backplate component 94b is disposed within a recess 93 formed in a surface of the backplate 92. In some implementations, the backplate components 94a and/or 94b can protrude from a surface of the backplate 92. Although backplate component 94b is disposed on the side of the backplate 92 facing the substrate 20, in other implementations, the backplate components can be disposed on the opposite side of the backplate 92.

[0061] The backplate components 94a and/or 94b can include one or more active or passive electrical components, such as transistors, capacitors, inductors, resistors, diodes, switches, and/or integrated circuits (ICs) such as a packaged, standard or

discrete IC. Other examples of backplate components that can be used in various implementations include antennas, batteries, and sensors such as electrical, touch, optical, or chemical sensors, or thin-film deposited devices.

[0062] In some implementations, the backplate components **94a** and/or **94b** can be in electrical communication with portions of the EMS array **36**. Conductive structures such as traces, bumps, posts, or vias may be formed on one or both of the backplate **92** or the substrate **20** and may contact one another or other conductive components to form electrical connections between the EMS array **36** and the backplate components **94a** and/or **94b**. For example, **FIG. 5B** includes one or more conductive vias **96** on the backplate **92** which can be aligned with electrical contacts **98** extending upward from the movable layers **14** within the EMS array **36**. In some implementations, the backplate **92** also can include one or more insulating layers that electrically insulate the backplate components **94a** and/or **94b** from other components of the EMS array **36**. In some implementations in which the backplate **92** is formed from vapor-permeable materials, an interior surface of backplate **92** can be coated with a vapor barrier (not shown).

[0063] The backplate components **94a** and **94b** can include one or more desiccants which act to absorb any moisture that may enter the EMS package **91**. In some implementations, a desiccant (or other moisture absorbing materials, such as a getter) may be provided separately from any other backplate components, for example as a sheet that is mounted to the backplate **92** (or in a recess formed therein) with adhesive. Alternatively, the desiccant may be integrated into the backplate **92**. In some other implementations, the desiccant may be applied directly or indirectly over other backplate components, for example by spray-coating, screen printing, or any other suitable method.

[0064] In some implementations, the EMS array **36** and/or the backplate **92** can include mechanical standoffs **97** to maintain a distance between the backplate components and the display elements and thereby prevent mechanical interference between those components. In the implementation illustrated in **FIGS. 5A** and **5B**, the mechanical standoffs **97** are formed as posts protruding from the backplate **92** in alignment with the support posts **18** of the EMS array **36**. Alternatively or in addition, mechanical standoffs, such as rails or posts, can be provided along the edges of the EMS package **91**.

[0065] Although not illustrated in **FIGS. 5A** and **5B**, a seal can be provided which partially or completely encircles the EMS array **36**. Together with the backplate **92** and the substrate **20**, the seal can form a protective cavity enclosing the EMS array **36**. The seal may be a semi-hermetic seal, such as a conventional epoxy-based adhesive. In some other implementations, the seal may be a hermetic seal, such as a thin film metal weld or a glass frit. In some other implementations, the seal may include polyisobutylene (PIB), polyurethane, liquid spin-on glass, solder, polymers, plastics, or other materials. In some implementations, a reinforced sealant can be used to form mechanical standoffs.

[0066] In alternate implementations, a seal ring may include an extension of either one or both of the backplate **92** or the substrate **20**. For example, the seal ring may include a mechanical extension (not shown) of the backplate **92**. In some implementations, the seal ring may include a separate member, such as an O-ring or other annular member.

[0067] In some implementations, the EMS array **36** and the backplate **92** are separately formed before being attached or coupled together. For example, the edge of the substrate **20** can be attached and sealed to the edge of the backplate **92** as discussed above. Alternatively, the EMS array **36** and the backplate **92** can be formed and joined together as the EMS package **91**. In some other implementations, the EMS package **91** can be fabricated in any other suitable manner, such as by forming components of the backplate **92** over the EMS array **36** by deposition.

[0068] The IMODs **12** of **FIG. 1** are illustrated in only two positions, a relaxed position in which no voltage is applied between the movable layer **14** and the conductive absorber layer **16**, and an actuated state in which a voltage sufficient to collapse the movable layer **14** against the conductive absorber layer **16** has been applied. However, an IMOD **12** may also be driven in a multi-state, or an analog or near-analog, manner. An EMS device such as IMOD **12** may function essentially as a parallel plate capacitor in which one of the electrodes is movable relative to another electrode. A movable electrode such as the movable layer **14** will move to an equilibrium position between the electrostatic force resulting from a voltage difference between the movable electrode and a fixed electrode such as the conductive absorber **16** and a restoring force due to the displacement of the movable layer **14** from a resting position. In some implementations, the movable layer **14** or similar movable electrode may include a reflective layer, and may be referred to

interchangeably herein as a mirror or a movable mirror. However, even though certain implementations may refer to a mirror or a movable mirror, it will be understood that the description of those implementations is not necessarily intended to exclude other limitations in which a movable layer may be less reflective or otherwise less suitable as a mirror, unless explicitly noted otherwise.

[0069] **FIG. 6** is a schematic cross-section showing an example of an IMOD being driven in a multi-state fashion. It is understood that the term multi-state may also include the idea of driving an IMOD in an analog fashion, particularly as the number of possible states that the IMOD can be driven to becomes very large. Array driver **22** or another voltage source can be used to apply a voltage less than an actuation voltage of the IMOD **12** between the movable layer **14** and the conductive absorber **16** in order to move the movable layer **14** within a stable travel range R_S of the IMOD **12** between a maximum height h of the cavity **19** and a minimum stability height h_S at the end of the stable travel range R_S . In the illustrated implementation, in which the voltage is applied directly between movable layer **14** and conductive absorber **16**, the stable travel range R_S will be roughly one-third of the height of the maximum gap height h . Upon application of a voltage which is equal to or exceeds the actuation voltage of the IMOD **12**, the movable layer **14** will collapse against the conductive absorber layer **16**.

[0070] As the movable mirror **14** is moved relative to the conductive absorber layer **16**, the height of gap **19** between the mirror **14** and the optical absorber **16** will change, and the color reflected by the IMOD **12** will vary. An IMOD **12** driven in a multi-state manner can therefore provide a particular color response in response to application of a particular voltage. This color response can be controlled in part through the selection of particular materials for the components of IMOD **12**, as well as the inclusion of intervening layers between the movable mirror **14** and the optical absorber **16** to maintain a desired spacing between the mirror **14** and the optical absorber **16** when the mirror **14** is in a collapsed state.

[0071] However, the limited stable travel range of IMOD **12** places constraints on the range of possible colors within the stable travel range of the IMOD **12** when driven in a multi-state manner. In some implementations, for example, design of the IMOD **12** to have a white state in the collapsed position places the black state of the IMOD **12** near the bottom of the gap, outside of the stable travel range of the IMOD **12**. More generally, the stable travel range of the IMOD **12** may constrain the colors

that can be reflected by the IMOD **12**, and positions of the mirror **14** outside the stable travel range of the IMOD **12** may correspond to additional colors that could be reflected by the IMOD **12** if the stable travel range were larger. Even when the IMOD **12** is designed to have a stable travel range large enough to reflect a desired range of colors, imperfections in the fabrication of the IMOD **12** may reduce the actual stable travel range of the IMOD **12** in practice, and a larger stable travel range would provide increased reliability. In some implementations, the structure of an IMOD or similar EMS device may be modified to provide an increased stable travel range for a movable layer such as a movable mirror.

[0072] **FIG. 7** is a schematic cross-section showing an example of another example of a multi-state IMOD including an isolated electrode. The IMOD **100** includes an optical absorber **116** supported by a substrate **120**. As described above, the optical absorber **116** may serve as a fixed electrode as shown, or may be formed adjacent another conductive layer which forms part of a fixed electrode. A movable layer **130** is separated from the optical absorber **116** by a gap **119** having a maximum height h . The movable layer **130** includes a driving electrode **160** disposed on the side of the movable layer **130** opposite the optical absorber **116**, a dielectric layer **150**, and an isolated electrode **140** disposed on the opposite side of the dielectric layer **150** from the driving electrode **160**. The isolated electrode **140** can serve as a mirror or reflective layer in the IMOD **100**, similar to the reflector **14** of the IMOD **12** of **FIGS. 1 and 6**.

[0073] A voltage source **122** which can be in some implementations an array driver and associated circuitry is in electrical communication with both the driving electrode **160** and the optical absorber **116** and can apply a voltage between the driving electrode **130** and the optical absorber **116** to control the position of the movable layer **130** relative to the optical absorber **116** and change the color reflected by the IMOD **100**. Unlike the reflector **14** of the IMOD **12** of **FIGS. 1 and 6**, the isolated electrode **140** is not in electrical communication with the voltage source **122** or other array driver circuitry. The voltage source **122** and associated circuitry are configured to apply multiple discrete driving voltages to drive the IMOD **100** in a multi-state, near-analog, or analog fashion, in contrast to the bi-stable operation described above.

[0074] Because the isolated or “floating” electrode **140** is disposed between the driving electrode **160** and the optical absorber **116**, the IMOD **100** no longer behaves

as a single capacitor with the driving electrode **160** and the optical absorber **116** as the capacitor plates, but rather as two capacitors in series with one another. Because of this, the stable travel range of the mirror is increased substantially, significantly increasing the range of colors that can be reflected by the IMOD **100** when driven in a multi-state manner. In some implementations, the thickness of the dielectric layer **150** is chosen such that the effective stable travel range of the movable layer **130** is roughly $1/3$ of the electrical distance between the driving electrode **160** and the optical absorber **116**. When the thickness of the dielectric layer **150** is sufficiently large, the stable travel range of the movable layer **130** may be increased to roughly 60% of the initial gap distance. However, variations or imperfections in the movable layer **130** may limit the stable travel range of the movable layer **130** before a theoretical end of an ideal stable travel range R_I is reached. In other implementations, the series capacitor can be implemented in a driving thin film transistor within circuitry associated with the array driver **122**, rather than being implemented within the movable layer **130** itself.

[0075] In some implementations, as mentioned above, the stable range of the IMOD **100** may terminate not with the collapse of the movable layer **130** against the optical absorber **116** at a theoretical end of an ideal stable travel range R_I due to a lack of stable positions within the remainder of the gap **119**, but rather due to tilting or rotational instability of the movable layer **130**. Due to manufacturing imperfections, the movable layer **130** may be slightly asymmetrically supported, with the restoring force at one side of the movable layer **130** being greater than the restoring force at the other side of the movable layer **130**. As the movable layer **130** travels beyond a point roughly 60% of the way through the gap, where the gap **119** is reduced to the minimum stability height h_s , this imbalance of the restoring force causes an initial tilt in the mirror. The minimum stability height h_s is within an ideal stable travel range R_I , but the actual stable travel range R_S in practice is less than the ideal stable travel range R_I . This tilt in the movable layer **130** induces additional charge accumulation on the portion of the isolated electrode **140** closest to the optical absorber **116**, collapsing that edge of the movable layer **130** against the optical absorber **116**.

[0076] In some implementation, the cumulative effect of charge accumulation can be minimized or controlled by constraining the accumulation of charge within the movable layer. In particular, by segmenting the floating electrode into a plurality of

isolated electrode segments, the flow of charge between those segments can be inhibited, increasing the stable travel range of an EMS device such as an IMOD.

[0077] **FIG. 8A** is a schematic cross-section showing an example of another example of a multi-state IMOD in which an isolated electrode is separated into multiple isolated electrode segments. The IMOD **200** of **Figure 8A** is similar to the IMOD **100** of **Figure 1**, and includes an optical absorber **216** supported by a substrate **202** and spaced apart from a movable layer such as mirror **230** by a gap **219** having a maximum height h . The mirror **230** includes multiple isolated electrode segments **240a** and **240b** and a driving electrode **260** located on the opposite side of a dielectric layer **250** as the isolated electrode segments **240a** and **240b**. Additional dielectric material such as underlying dielectric layer **252** may extend underneath and between the electrode segments **240a** and **240b**, in order to ensure that the electrode segments **240a** and **240b** remain electrically isolated from one another and from other conductive components of the IMOD **200**. A voltage source **222** such as an array driver and associated circuitry can be used to apply a voltage between the driving electrode **260** and the optical absorber **216**. As discussed above, an array driver and associated circuitry can be in communication with a processor, allowing the processor to communicate with each of the driving electrode **260** and the optical absorber **216** via the array driver and associated circuitry.

[0078] **FIG. 8B** is cross-sectional view of the movable layer of the multi-state IMOD of **FIG. 8A**, taken along the line **8B–8B** of **FIG. 8A**. It can be seen that the mirror **230** includes four symmetrical electrode segments **240a–240d**, separated by one another by portions of the dielectric material **250**. In particular, the electrode segments are segmented along two perpendicular axes of rotation of the mirror **220**. A strip **254** of the dielectric material **252** isolates electrode segments **240a** and **240b** from electrode segments **240c** and **240d**, respectively. Similarly, a strip **256** of the dielectric material **252** isolates electrode segments **240a** and **240c** from electrode segments **240b** and **240d**, respectively. The strips **254** and **256** are generally perpendicular to one another as illustrated in order to segment the floating electrodes along two perpendicular axes of rotation. An outer section **245** of dielectric material extends around the outer edges of electrode segments **240a–240d** to fully encapsulate the electrode segments **240a–240d**.

[0079] The segmentation of a floating electrode into the multiple electrode segments **240a–240d** of IMOD **200** illustrated **Figures 2A** and **2B** increases the stable

travel range R_S of the mirror **230**. The minimum stability height h_S at which tilting instability causes collapse of the mirror **230** is closer to the optical absorber **216** when compared to minimum stability height h_S of the IMOD **100** shown in FIG. 7. As noted above, this increase in stable travel range R_S of the mirror **230** is due to the isolation of the electrode segments **240a–240d** from one another. It can be seen in FIG. 8A that the actual stable travel range R_S of the mirror **230** is closer to the ideal stable travel range R_I than the stable travel range of the mirror **130** of IMOD **100** (see FIG. 7).

[0080] When the mirror **230** begins to tilt, two of the isolated electrode segments **240a–240d** will be located closer to the optical absorber **216**, and two of the isolated electrode segments **240a–240d** will be located more distant from the optical absorber **216**. The amount of charge which will shift to the outer edges of the electrode segments **240a–240d** closest to the optical absorber **216** is less than the amount of charge that would shift to the outer edge of an isolated electrode if the isolated electrode was a single electrode. In some implementations, the amount of charge that will shift to the outer edges of the electrode segments **240a–240d** closest to the optical absorber **216** may be on the order of half the charge that would shift to the outer edge of an isolated electrode if the isolated electrode was a single electrode. The exact amount of charge that will shift to the outer edges of a segmented electrode may vary in different implementations, and may be slightly more than half due to non-linear capacitive distribution of charge in a tilted electrode, but will nevertheless be significantly less than in a non-segmented electrode. This division of the charge accumulation occurs because the charge on the more distant electrode segments on the side of the mirror **230** not tilted downward cannot move through the separating dielectric material **254** or **256**. Rather, the charge in the electrode segments on the side of the mirror **230** not tilted downward will accumulate on an inner edge of these more distant electrode segments adjacent the separating dielectric material **254** or **256**. The electrode segments **240a–240d** thus provide a means for inhibiting an imbalanced accumulation of charge within the mirror **230** to increase a range of stable positions of the mirror **230**.

[0081] Because these inner edges are offset from the edge of the mirror **230** tilted downward and towards the optical absorber **216**, the rotational moment induced by electrostatic attraction due to the charge accumulation on the edge of the more distant electrode segments will not be as large as the rotational moment induced if the

isolated electrode were a contiguous structure. The smaller rotational moment is due to the shorter distance between the location of charge accumulation on the more distant electrode segments and the axis of tilting or rotation of the mirror **250**. In the illustrated implementation, in which the floating electrode is divided into four generally symmetrical electrode segments **240a–240d**, the charge accumulation on the pair of more distant electrode segments may exert a force which acts at points very close to the axis of rotation of the mirror **230**, and therefore exert almost no rotational moment on the mirror **230**.

[0082] Because the charge that can be shifted due to tilting the mirror **230** is constrained by the segmentation of the electrode segments **240a–240d**, the stable travel range R_s of the mirror **230** of IMOD **200** is increased to roughly 80% of the maximum gap height h . For a given IMOD design, the segmentation of a floating electrode can significantly increasing the range of colors which can be reflected by the IMOD **200** when compared to the same design including contiguous floating electrode such as the electrode **140** of IMOD **100** shown in **FIG. 7**.

[0083] The isolated electrode segments and the surrounding dielectric material are designed and fabricated to ensure electrical isolation of the electrode segments. If the electrode segments are not well-insulated, and charge accumulates on the electrode segments over time, the operation of the EMS device will be affected. Due to the isolation of the electrode segments, in some implementations accumulated charge may be difficult or impossible to remove.

[0084] **FIGS. 9A–9E** are cross-sectional illustrations of various stages in a process of fabricating a multi-state IMOD having isolated electrode segments. **FIG. 10** is a flow diagram illustrating a fabrication process for a multi-state IMOD having isolated electrode segments, which may include the stages illustrated in **FIGS. 9A–9E**. In some implementations, the fabrication process may also include the stages illustrated and described with respect to **FIGS. 4A–4C**.

[0085] The fabrication process **400** begins at a block **405** where at least a first dielectric layer is formed over a sacrificial layer. As can be seen in **FIG. 9A**, a conductive absorber layer **316** is formed over a substrate **302**, a sacrificial layer **325** is formed over the conductive absorber layer **316**, and a first dielectric layer **352** is formed over the sacrificial layer **325**.

[0086] As discussed above with respect to **FIGS. 4A–4C**, the conductive absorber layer **316** need not be a single layer, but may instead include an optical absorber layer

and a conductive layer, and additional optical layers may be formed over the conductive absorber layer **316** prior to formation of the sacrificial layer **325**. Additional components not shown in **FIG. 9A** may also be formed prior to formation of the sacrificial layer **325**, such as conductive bussing structures or masking or shielding structures. The conductive absorber layer **316** may be patterned to form strip electrodes prior to formation of the sacrificial material **325**, and the sacrificial layer may be similarly patterned to form apertures for support structures (not shown in **FIG. 9A**) prior to deposition of overlying layers, as described with respect to **FIG. 4C**, for example.

[0087] In some implementations, the first dielectric layer **352** may include more than one layer, and the material and thickness of the layer or layers in the dielectric layer **352** may be selected for their optical properties. In other implementations, such as when a non-optical EMS device is formed, the conductive absorber layer **316** may be replaced with an opaque material, and the optical properties of the dielectric layer **352** may not be important.

[0088] In some implementations of IMODs or other optical EMS devices, the first dielectric layer **352** may be a stack of discrete dielectric layers formed over the sacrificial layer **325**, despite being referred to for convenience as a “layer” and illustrated as a single layer in **FIG. 8A**, **FIG. 9A**, and elsewhere throughout the specification. For example, the first dielectric layer **352** can in some implementations be a stack which includes a first dielectric sublayer formed over sacrificial layer **325** and including a material with a high index of refraction, followed by a second dielectric sublayer formed over the first dielectric sublayer and including another material with a lower index of refraction than the material forming the first dielectric sublayer. The lower index dielectric sublayer may have a lower chromatic dispersion than that of the higher index dielectric sublayer. In some implementations, the higher index dielectric sublayer may include a material such as titanium dioxide (TiO_2), zirconium dioxide (ZrO_2), or niobium pentoxide (Nb_2O_5), although other dielectric materials may also be used. Similarly, in some implementation, the lower index dielectric sublayer may include a material such as silicon dioxide (SiO_2) or silicon oxynitride (SiON).

[0089] In some implementations, the first dielectric layer **352** may include a dielectric stack configured such that the interferometric modulator is capable of reflecting a white color when a movable layer including the first dielectric layer **352** is

collapsed against a stationary electrode such as the conductive absorber layer **316**, and the interferometric modulator is configured to appear black when the movable layer is maintained in at least one position within the range of stable positions.

[0090] In one specific implementation, the first dielectric layer **352** may include a first dielectric sublayer formed over the sacrificial layer **325** and including a layer of TiO₂ roughly 21 nm in thickness, and a second dielectric sublayer formed over the first dielectric sublayer and including a layer of SiON roughly 80 nm in thickness. In another specific implementation, the first dielectric layer **352** may include a first dielectric sublayer formed over the sacrificial layer **325** and including a layer of TiO₂ roughly 31 nm in thickness, and a second dielectric sublayer formed over the first dielectric sublayer and including a layer of SiON roughly 72 nm in thickness. In other particular implementations, other materials and/or other thicknesses may be used to form dielectric sublayers within the first dielectric layer **352**, and any appropriate number of sublayers may included in the first dielectric layer **352**.

[0091] In other implementations, the order of the dielectric sublayers in the stack of layers forming first dielectric layer **352** can be reversed, such that the dielectric sublayer formed from the higher index material can be formed after and over the dielectric sublayer formed from the lower index material, so that the higher index material will be closer to a subsequently deposited segmented electrode and/or reflector.

[0092] The fabrication process **400** then moves to a block **410** where a first electrode layer is formed over the first dielectric layer. As can also be seen in **FIG. 9A**, a first electrode layer **340** is formed over the first dielectric layer **352**. The first electrode layer **340** may serve as the mirror in a multi-state IMOD, and the material and thickness of the first electrode layer **340** may be chosen in part on the reflectivity of the electrode layer **340**. In some implementation, the electrode layer **340** may include a layer of aluminum (Al) or an aluminum alloy. However, as noted above, in a non-optical EMS device, the reflectivity of the electrode layer **340** may not be relevant, and a less reflective material may be used.

[0093] The fabrication process **400** then moves to a block **415** where the first electrode layer is patterned to form a plurality of isolated electrode segments. As can be seen in **FIG. 9B**, the first electrode layer **340** has been patterned to form at least isolated electrical segments **340a** and **340b**. In some implementations, the first electrode layer **340** is patterned to form four symmetrical isolated electrode segments

such as isolated electrical segments **340a** and **340b** for each multi-state IMOD element being fabricated. In other implementations, however, other numbers and shapes of isolated electrical segments can be formed. Increasing the number of isolated electrical segments beyond four may increase the stable travel range of the movable layer in the finished IMOD. However, further increases in the number of isolated electrical segments will reduce the total area covered by the isolated electrical segments due to additional cuts between the isolated electrical segments, increasing the actuation voltage of the IMOD and decreasing the fill factor of the mirror.

[0094] The fabrication process **400** then moves to a block **420** where a second dielectric layer is formed over the plurality of isolated electrode segments. As can also be seen in **FIG. 9B**, the second dielectric layer **350** extends over the isolated electrical segments **340a** and **340b** and, in conjunction with the first dielectric layer **352**, surrounds the isolated electrical segments **340a** and **340b**. The isolated electrical segments **340a** and **340b** are therefore surrounded on all sides by dielectric material, which fills the regions such as region **356** between the isolated electrical segments **340a** and **340b**. In the illustrated implementation, the upper surface of the second dielectric layer **350** is shown as planar, but in some implementations the second dielectric layer **350** may be conformal over the underlying isolated electrical segments **340a** and **340b**. The shape of the second dielectric layer **350** and any overlying layers may vary based on the material and deposition processes used to form the second dielectric layer **350**. As discussed above with respect to the first dielectric layer **352**, the second dielectric layer **350** may in some implementations also include a stack of layers, and are illustrated and described as a single layer for convenience and clarity.

[0095] The fabrication process **400** then moves to a block **425** where a second electrode layer is formed over the second dielectric layer. As can be seen in **FIG. 9B**, the second electrode layer **360** may be similar in thickness to the first electrode layer **340** patterned to form the isolated electrical segments **340a** and **340b**. By forming the second electrode layer **360** from the same material and in roughly the same thickness as the first electrode layer **340**, stresses within the electrode layers **340** and **360**, which may be due to deposition conditions or changes in temperature, may generally balance one another out and prevent undesirable flexure of the movable layer. In some implementations, additional layers (not shown) which are the same thickness and formed from the same material as the layer or layers used to form

dielectric layer **352** may be formed over the second electrode layer **360**, to provide additional symmetry and stress balancing.

[0096] Subsequent to the blocks illustrated in **FIG. 10**, a release etch may be performed to remove the sacrificial layer and release the IMOD. **FIG. 9D** shows the IMOD **300** after a release etch is performed to remove the sacrificial layer **325** (see **FIG. 9C**) to form a cavity **319**.

[0097] The first dielectric layer **352**, second dielectric layer **350**, and second electrode layer **360** may have previously been patterned (not shown) to facilitate movement of the movable layer or mirror **330** towards the conductive absorber **316**, and to electrically isolate adjacent IMODs **300** from one another. In some implementations, one or more of these layers may be patterned prior to deposition of any overlying layers, while in other implementations, these layers may be patterned via one or more etching processes after formation of the second electrode layer **360** and any overlying layers. In some implementations, the movable layer **330** may be patterned to form strips extending along connecting a row or column of IMODs **300**, and may include additional widthwise cuts to facilitate at least the isolated electrical segments **340a** and **340b** of the movable layer **330** remaining in a position substantially parallel to the conductive absorber layer **316** when the movable layer **330** is electrostatically pulled downwards. In other implementations, the movable layer **330** may be patterned to form tethers or strips of material supporting the portion of the movable layer **330** including the isolated electrical segments **340a** and **340b**.

[0098] **FIG. 11** is a cross-sectional view of an example of a movable layer patterned to include support arms. It can be seen that the movable layer **530**, shown in a cross-section extending through the isolated electrode segments **540a–540d**, has been patterned to include a support arm **570** extending from each side of a central region **542** including the isolated electrode segments **540a–540d**. Each support arm **570** is in contact with the central region **542** along one side of the central region **542** via a connecting region **572**. Each support arm **570** also extends generally parallel to the side of the central region **542** to which the support arm **570** is attached. The ends **574** of the support arms **570** may be, for example, in contact with support structures (not shown) to suspend the movable layer **530** over a conductive absorber layer. Although not visible in the cross-sectional view of **FIG. 11**, the movable layer **530** also includes a driving electrode electrically isolated from the isolated electrode segments. The driving electrode may be in electrical connection with an array driver

and associated circuitry via, for example, a contiguous portion of the same metal layer used to form the driving electrode extending along at least one of the support arms 570.

[0099] In some implementations, the structure of the EMS device structure may be modified in other ways in conjunction with the implementations discussed above to increase the stable travel range of the EMS device. In other implementations, the area of a fixed electrode underlying a movable layer may be reduced in order to minimize the tilting moment that can be induced by accumulation of charge at one end of the movable layer. If the fixed electrode is made smaller while still remaining substantially centered, the magnitude of a tilting moment induced by the charge accumulation can be reduced by ensuring that the force acts at a point on the movable layer closer to the tilting axis. However, this reduction in electrode size may increase the voltage necessary to actuate the mirror, as discussed above, and thus represents a tradeoff between increased stability range and increased power consumption required to drive the device.

[0100] The segmentation of an electrode can be used to increase a stable travel range of that electrode, or a movable layer including such an electrode, whenever that electrode is being brought towards another conductive layer. In other implementations, for example, a three-terminal EMS device may be provided, which may include, for example, two electrodes configured to electrostatically displace the movable layer of an EMS device in opposite directions, which may increase the stable travel range of the EMS device at the cost of increased complexity in the design and/or operation of the EMS device. In a three-terminal EMS device, segmentation of a floating electrode which is within an electric field created by the other electrodes can therefore similarly prevent tilting due to imbalanced charge accumulation on the floating electrode.

[0101] Other modifications to and combinations of the implementations described herein are also possible. For example, some implementations may include a segmented floating electrode as well as a smaller fixed electrode to further increase the stable travel range of an EMS device. In some implementations, reducing the size of the fixed electrode may reduce the size of the optical absorber, which in turn reducing may reduce the size of the optically active area of the EMS device when the EMS device is a display element such as an interferometric modulator. In a further implementation, the size of the fixed electrode may be reduced without substantially

reducing the optically active area of the display by segmenting the optical absorber into an electrically active interior area in electrical communication with driving circuitry and components and an electrically inactive outer area which is electrically isolated from the electrically active interior area. By providing a segmented optical absorber, the size of the fixed electrode may be reduced to reduce a tilting moment at the cost of increased actuation voltages, while the total area of the optical absorber may be substantially the same size as the total area of the segmented electrode to minimize a reduction in the optically active area of the display element. In other such implementations, the fixed electrode may be a separate component from the optical absorber, and may be arranged over or under the optical absorber layer and electrically isolated from the optical absorber.

[0102] For example, **FIG. 12A** is a schematic cross-section showing an example of another example of an analog IMOD in which an optical absorber is separated into multiple isolated electrode segments. The analog IMOD **600** of **FIG. 12A** includes an optical stack **610** supported by a substrate **602** and including a first driving electrode **612** and a segmented optical absorber which includes isolated optical absorber segments **618a** and **618b**. A first dielectric layer **615** electrically isolates the first driving electrode **612** from the isolated optical absorber segments **618a** and **618b**, and a second dielectric layer **620** overlying the isolated optical absorber segments **618a** and **618b** covers the top and sides of the isolated optical absorber segments **618a** and **618b**, ensuring electrical isolation of the isolated optical absorber segments **618a** and **618b**.

[0103] The analog IMOD **600** of **FIG. 12A** also includes a movable layer **630**. As illustrated, the movable layer **630** includes a second driving electrode **640**, a supporting layer **650** which may be formed from a dielectric material as discussed above, and an additional layer **660** on the opposite side of the supporting layer **650** as the driving electrode. In contrast to the implementation depicted in **FIG. 7**, for example, the second driving electrode **640** need not be electrically isolated from the additional layer **660**, which may serve a primarily mechanical function in the analog IMOD **600**. In some implementations, the additional layer **660** may include substantially the same material and thickness as the second driving electrode **640**, and may serve to balance stresses in the movable layer **630** to control deformation of the movable layer **630**.

[0104] The analog IMOD **600** of **FIG. 12A** also includes a movable layer **630**. As illustrated, the movable layer **630** includes a second driving electrode **640**, a supporting layer **650** which may be formed from a dielectric material as discussed above, and an additional layer **660** on the opposite side of the supporting layer **650** as the driving electrode. In contrast to the implementation of **FIG. 7**, for example, the driving electrode **640** need not be electrically isolated from the additional layer **660**, which may serve a primarily mechanical function in the analog IMOD **600**. In some implementations, the additional layer **660** may comprise substantially the same material and thickness as the driving electrode **640**, and may serve to balance stresses in the movable layer **630** to control deformation of the movable layer **630**.

[0105] In some implementations, an array driver **622** applies a voltage between the first driving electrode **612** and the second driving electrode **640**. As discussed with respect to the previous implementations, the inclusion of a floating electrode in the form of the optical absorber increases the stable travel range of the movable layer, and the patterning of the floating electrode to form the isolated optical absorber segments **618a** and **618b** further increases the stable travel range of the movable layer **630** to a stable travel range R_s which is even closer to the ideal stable travel range R_i . In particular, by patterning the floating electrode into isolated optical absorber segments **618a** and **618b**, the amount of charge that can accumulate at the edges of the floating electrode is reduced. This in turn minimizes the local increase in electrostatic force that can act on the edges of the movable layer **630**, increasing the stable travel range before tilting instability results in collapse of the movable layer against the optical stack **610**.

[0106] **FIG. 12B** is a cross-sectional view of the example optical absorber of the analog IMOD of **FIG. 12A**. It can be seen in **FIG. 12B** that the optical absorber has been patterned to form four electrically isolated optical absorber segments **618a**, **618b**, **618c** and **618d**. A gap **617a** filled with dielectric material from second dielectric layer **620** isolates electrode segments **240a** and **240b** from electrode segments **240c** and **240d**, respectively. Similarly, a gap **617b** filled with dielectric material from second dielectric layer **620** isolates electrode segments **240a** and **240c** from electrode segments **240b** and **240d**. In order to maintain as large of a fill factor as possible, the width of the gaps **617a** and **617b** may be made as small as possible while still maintaining electrical isolation between isolated optical absorber segments **618a**, **618b**, **618c** and **618d**. In some implementations, the gaps **617a** and **617b** may

be 3 μm wide, although gaps having larger or smaller widths also may be used, depending on the fabrication process and materials used. The dielectric material from second dielectric layer **620** also extends around the edges of the isolated optical absorber segments **618a**, **618b**, **618c** and **618d**, to increase the electrical isolation of the isolated optical absorber segments **618a**, **618b**, **618c** and **618d**.

[0107] **FIGS. 13A–13C** are cross-sectional illustrations of various stages in an example process of fabricating an analog IMOD having an optical absorber including isolated electrode segments. In **FIG. 13A** a first driving electrode layer has been formed on a substrate **602** and patterned to form one or more driving electrodes **612**. As discussed above, the driving electrode **612** may in some implementations include a substantially transparent thickness of a conductive oxide, such as ITO, although other materials also may be used.

[0108] In **FIG. 13B**, a first dielectric layer **615** has been formed over the driving electrode **612**, and an optical absorber layer **616** has been formed over the first dielectric layer **615**. Because the first dielectric layer **615** is located between the driving electrode **612** and the optical absorber layer **616**, the optical absorber layer **616** will be electrically isolated from the driving electrode **612** and can serve as a floating electrode. In an alternative implementation (not shown), the first driving electrode **612** may be formed on the opposite side of the substrate **602** from the optical absorber layer **616**, and the substrate **602** itself may be used to electrically isolate the optical absorber layer **616** from the first driving electrode **612**.

[0109] In **FIG. 13C**, the optical absorber layer **616** has been patterned to form isolated optical absorber segments **618a** and **618b**. In the illustrated implementation, the optical absorber layer **616** has been patterned to form four isolated optical absorber segments by forming one gap **617b** extending into the page and separating isolated optical absorber segment **618a** from isolated optical absorber segment **618b**, and a second gap (not shown, see gap **617a** of **FIG. 12B**) extending generally perpendicular to the gap **617b**. As discussed above, the optical absorber layer **616** may in other implementations be patterned to form other patterns, with greater or fewer numbers of isolated optical absorber segments. After patterning the optical absorber layer **616**, a second dielectric layer **620** has been formed over the isolated optical absorber segments **618a** and **618b**, filling the gap **617b** therebetween and extending over the top and outer edges of the isolated optical absorber segments **618a**

and **618b** to provide electrical isolation from adjacent or overlying components (not shown) of an EMS device.

[0110] As discussed above, if the gaps **617a** and **617b** are made as narrow as possible, the aggregate size of the optical absorber segments **618a**, **618b**, **618c** and **618d** can be made as large as possible, increasing the optically active area of the analog IMOD **600** in which a reflective layer is spaced apart from an optical absorber. **FIGS. 14A** and **14B** are cross-sectional illustrations of additional stages in an example process of fabricating an analog IMOD which increase the fill factor of an optical absorber including isolated electrode segments. The process depicted in **FIGS. 14A** and **14B** may continue after the stages illustrated in **FIGS. 13A–13C**. In **FIG. 14A** it can be seen that a layer **724** of optical absorber material has been deposited over the second dielectric layer **620**. The layer **724** may include the same material used in the optical absorber layer **616**.

[0111] In **FIG. 14B**, the layer **724** of optical absorber material has been patterned to form a strip **726b** of optical absorber material extending into the page and a strip **726a** (not shown, see **FIG. 15**) extending generally perpendicular to the optical absorber strip **726b** to form a cross-shaped optical absorber **726** (see **FIG. 15**).

[0112] **FIG. 15** is a cross-sectional view of the example optical absorber of the analog IMOD of **FIG. 14B**. It can be seen in **FIG. 15** that the optical absorber strip **726a** overlies and is aligned with gap **617a** which isolates electrode segments **240a** and **240b** from electrode segments **240c** and **240d**, and the optical absorber strip **726b** overlies and is aligned with gap **617b** which isolates electrode segments **240a** and **240c** from electrode segments **240b** and **240d**. Although the optical absorber strips **726a** and **726b** are illustrated in **FIGS. 14B** and **15** as being wider than the gaps **617a** and **617b** that they overlie, the optical absorber strips **726a** and **726b** may in some implementations be substantially the same width as the gaps **617a** and **617b**, or may have a width that is thinner than the gaps **617a** and **617b**.

[0113] By forming the second dielectric layer **620** between the isolated optical absorber segments **618a**, **618b**, **618c** and **618d** and the additional isolated optical absorber section **726**, an optical absorber layer which appears substantially contiguous can be provided while maintaining electrical isolation between the various optical absorber components. In particular, the gaps **617a** and **617b** between the isolated optical absorber segments **618a**, **618b**, **618c** and **618d** can be partially or completely masked by the additional isolated optical absorber section **726**, so that the various

optical absorber portions appear to be a single optical absorber when viewed from a direction generally orthogonal to the substrate **602**.

[0114] **FIG. 16** is a flow diagram illustrating a fabrication process for an analog IMOD having an optical absorber including isolated electrode segments, which may include the stages illustrated in **FIGS. 13A–13C**. In some implementations, the fabrication process also may include the stages illustrated and described with respect to **FIGS. 13A–14B**.

[0115] In block **805** of the fabrication process **800**, at least a first electrode is formed over a substrate. As discussed above with respect to **FIG. 13A**, the first electrode may in some implementations include a transparent conductor, such as ITO, or another transparent conductive oxide.

[0116] In block **810** of the fabrication process **800**, a first dielectric layer is formed over the first electrode. In block **815** of the fabrication process **800**, an optical absorber layer is formed over the first dielectric layer. As discussed with respect to **FIG. 13B**, the first dielectric layer provides electrical isolation between the first electrode and the optical absorber material, so that the optical absorber material can form part of a floating electrode.

[0117] In block **820** of the fabrication process **800**, the optical absorber layer is patterned to form isolated electrode segments. In some implementations, two perpendicular gaps may be formed, forming four generally rectangular isolated electrode segments of similar size and shape. However, in some other implementations, other patterns of isolated electrode segments may be formed, as greater numbers of isolated electrode segments may provide further increases to tilting stability of a movable layer, increasing the stable travel range of the movable layer while reducing the fill factor of the display.

[0118] In block **825** of the fabrication process **800**, a second dielectric layer is formed over the isolated electrode segments formed by the patterned optical absorber material. As discussed with respect to **FIG. 13C**, the second dielectric layer can cover the isolated electrode segments and fill the gaps between the isolated electrode segments, electrically isolating them both from external components and from each other.

[0119] As noted above, the fabrication process **800** may include additional processing stages not depicted in the flow diagram of **FIG. 16**. For example, an additional optical absorber structure dimensioned to overlie the gaps between the

isolated electrode segments formed at block **820** may be formed over the second dielectric layer, and a third dielectric layer may be formed over the additional optical absorber structure.

[0120] **FIGS. 17A and 17B** are system block diagrams illustrating a display device **40** that includes a plurality of IMOD display elements. The display device **40** can be, for example, a smart phone, a cellular or mobile telephone. However, the same components of the display device **40** or slight variations thereof are also illustrative of various types of display devices such as televisions, computers, tablets, e-readers, hand-held devices and portable media devices.

[0121] The display device **40** includes a housing **41**, a display **30**, an antenna **43**, a speaker **45**, an input device **48** and a microphone **46**. The housing **41** can be formed from any of a variety of manufacturing processes, including injection molding, and vacuum forming. In addition, the housing **41** may be made from any of a variety of materials, including, but not limited to: plastic, metal, glass, rubber and ceramic, or a combination thereof. The housing **41** can include removable portions (not shown) that may be interchanged with other removable portions of different color, or containing different logos, pictures, or symbols.

[0122] The display **30** may be any of a variety of displays, including a bi-stable or analog display, as described herein. The display **30** also can be configured to include a flat-panel display, such as plasma, EL, OLED, STN LCD, or TFT LCD, or a non-flat-panel display, such as a CRT or other tube device. In addition, the display **30** can include an IMOD-based display, as described herein.

[0123] The components of the display device **40** are schematically illustrated in **FIG. 17B**. The display device **40** includes a housing **41** and can include additional components at least partially enclosed therein. For example, the display device **40** includes a network interface **27** that includes an antenna **43** which can be coupled to a transceiver **47**. The network interface **27** may be a source for image data that could be displayed on the display device **40**. Accordingly, the network interface **27** is one example of an image source module, but the processor **21** and the input device **48** also may serve as an image source module. The transceiver **47** is connected to a processor **21**, which is connected to conditioning hardware **52**. The conditioning hardware **52** may be configured to condition a signal (such as filter or otherwise manipulate a signal). The conditioning hardware **52** can be connected to a speaker **45** and a microphone **46**. The processor **21** also can be connected to an input device **48** and a

driver controller **29**. The driver controller **29** can be coupled to a frame buffer **28**, and to an array driver **22**, which in turn can be coupled to a display array **30**. One or more elements in the display device **40**, including elements not specifically depicted in **FIG. 17A**, can be configured to function as a memory device and be configured to communicate with the processor **21**. In some implementations, a power supply **50** can provide power to substantially all components in the particular display device **40** design.

[0124] The network interface **27** includes the antenna **43** and the transceiver **47** so that the display device **40** can communicate with one or more devices over a network. The network interface **27** also may have some processing capabilities to relieve, for example, data processing requirements of the processor **21**. The antenna **43** can transmit and receive signals. In some implementations, the antenna **43** transmits and receives RF signals according to the IEEE 16.11 standard, including IEEE 16.11(a), (b), or (g), or the IEEE 802.11 standard, including IEEE 802.11a, b, g, n, and further implementations thereof. In some other implementations, the antenna **43** transmits and receives RF signals according to the Bluetooth® standard. In the case of a cellular telephone, the antenna **43** can be designed to receive code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA), Global System for Mobile communications (GSM), GSM/General Packet Radio Service (GPRS), Enhanced Data GSM Environment (EDGE), Terrestrial Trunked Radio (TETRA), Wideband-CDMA (W-CDMA), Evolution Data Optimized (EV-DO), 1xEV-DO, EV-DO Rev A, EV-DO Rev B, High Speed Packet Access (HSPA), High Speed Downlink Packet Access (HSDPA), High Speed Uplink Packet Access (HSUPA), Evolved High Speed Packet Access (HSPA+), Long Term Evolution (LTE), AMPS, or other known signals that are used to communicate within a wireless network, such as a system utilizing 3G, 4G or 5G technology. The transceiver **47** can pre-process the signals received from the antenna **43** so that they may be received by and further manipulated by the processor **21**. The transceiver **47** also can process signals received from the processor **21** so that they may be transmitted from the display device **40** via the antenna **43**.

[0125] In some implementations, the transceiver **47** can be replaced by a receiver. In addition, in some implementations, the network interface **27** can be replaced by an image source, which can store or generate image data to be sent to the processor **21**. The processor **21** can control the overall operation of the display device **40**. The

processor **21** receives data, such as compressed image data from the network interface **27** or an image source, and processes the data into raw image data or into a format that can be readily processed into raw image data. The processor **21** can send the processed data to the driver controller **29** or to the frame buffer **28** for storage. Raw data typically refers to the information that identifies the image characteristics at each location within an image. For example, such image characteristics can include color, saturation and gray-scale level.

[0126] The processor **21** can include a microcontroller, CPU, or logic unit to control operation of the display device **40**. The conditioning hardware **52** may include amplifiers and filters for transmitting signals to the speaker **45**, and for receiving signals from the microphone **46**. The conditioning hardware **52** may be discrete components within the display device **40**, or may be incorporated within the processor **21** or other components.

[0127] The driver controller **29** can take the raw image data generated by the processor **21** either directly from the processor **21** or from the frame buffer **28** and can re-format the raw image data appropriately for high speed transmission to the array driver **22**. In some implementations, the driver controller **29** can re-format the raw image data into a data flow having a raster-like format, such that it has a time order suitable for scanning across the display array **30**. Then the driver controller **29** sends the formatted information to the array driver **22**. Although a driver controller **29**, such as an LCD controller, is often associated with the system processor **21** as a stand-alone Integrated Circuit (IC), such controllers may be implemented in many ways. For example, controllers may be embedded in the processor **21** as hardware, embedded in the processor **21** as software, or fully integrated in hardware with the array driver **22**.

[0128] The array driver **22** can receive the formatted information from the driver controller **29** and can re-format the video data into a parallel set of waveforms that are applied many times per second to the hundreds, and sometimes thousands (or more), of leads coming from the display's x-y matrix of display elements.

[0129] In some implementations, the driver controller **29**, the array driver **22**, and the display array **30** are appropriate for any of the types of displays described herein. For example, the driver controller **29** can be a conventional display controller or a bi-stable display controller (such as an IMOD display element controller). Additionally, the array driver **22** can be a conventional driver or a bi-stable display driver (such as

an IMOD display element driver). Moreover, the display array **30** can be a conventional display array or a bi-stable display array (such as a display including an array of IMOD display elements). In some implementations, the driver controller **29** can be integrated with the array driver **22**. Such an implementation can be useful in highly integrated systems, for example, mobile phones, portable-electronic devices, watches or small-area displays.

[0130] In some implementations, the input device **48** can be configured to allow, for example, a user to control the operation of the display device **40**. The input device **48** can include a keypad, such as a QWERTY keyboard or a telephone keypad, a button, a switch, a rocker, a touch-sensitive screen, a touch-sensitive screen integrated with the display array **30**, or a pressure- or heat-sensitive membrane. The microphone **46** can be configured as an input device for the display device **40**. In some implementations, voice commands through the microphone **46** can be used for controlling operations of the display device **40**.

[0131] The power supply **50** can include a variety of energy storage devices. For example, the power supply **50** can be a rechargeable battery, such as a nickel-cadmium battery or a lithium-ion battery. In implementations using a rechargeable battery, the rechargeable battery may be chargeable using power coming from, for example, a wall socket or a photovoltaic device or array. Alternatively, the rechargeable battery can be wirelessly chargeable. The power supply **50** also can be a renewable energy source, a capacitor, or a solar cell, including a plastic solar cell or solar-cell paint. The power supply **50** also can be configured to receive power from a wall outlet.

[0132] In some implementations, control programmability resides in the driver controller **29** which can be located in several places in the electronic display system. In some other implementations, control programmability resides in the array driver **22**. The above-described optimization may be implemented in any number of hardware and/or software components and in various configurations.

[0133] As used herein, a phrase referring to “at least one of” a list of items refers to any combination of those items, including single members. As an example, “at least one of: a, b, or c” is intended to cover: a, b, c, a-b, a-c, b-c, and a-b-c.

[0134] The various illustrative logics, logical blocks, modules, circuits and algorithm steps described in connection with the implementations disclosed herein may be implemented as electronic hardware, computer software, or combinations of

both. The interchangeability of hardware and software has been described generally, in terms of functionality, and illustrated in the various illustrative components, blocks, modules, circuits and steps described above. Whether such functionality is implemented in hardware or software depends upon the particular application and design constraints imposed on the overall system.

[0135] The hardware and data processing apparatus used to implement the various illustrative logics, logical blocks, modules and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose single- or multi-chip processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, or, any conventional processor, controller, microcontroller, or state machine. A processor also may be implemented as a combination of computing devices, such as a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some implementations, particular steps and methods may be performed by circuitry that is specific to a given function.

[0136] In one or more aspects, the functions described may be implemented in hardware, digital electronic circuitry, computer software, firmware, including the structures disclosed in this specification and their structural equivalents thereof, or in any combination thereof. Implementations of the subject matter described in this specification also can be implemented as one or more computer programs, i.e., one or more modules of computer program instructions, encoded on a computer storage media for execution by, or to control the operation of, data processing apparatus.

[0137] If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. The steps of a method or algorithm disclosed herein may be implemented in a processor-executable software module which may reside on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that can be enabled to transfer a computer program from one place to another. A storage media may be any available media that may be accessed by a computer. By way of example, and not limitation, such computer-

readable media may include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Also, any connection can be properly termed a computer-readable medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above also may be included within the scope of computer-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and instructions on a machine readable medium and computer-readable medium, which may be incorporated into a computer program product.

[0138] Various modifications to the implementations described in this disclosure may be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown herein, but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein. Additionally, a person having ordinary skill in the art will readily appreciate, the terms “upper” and “lower” are sometimes used for ease of describing the figures, and indicate relative positions corresponding to the orientation of the figure on a properly oriented page, and may not reflect the proper orientation of, e.g., an IMOD display element as implemented.

[0139] Certain features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0140] Similarly, while operations are depicted in the drawings in a particular order, a person having ordinary skill in the art will readily recognize that such

operations need not be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one more example processes in the form of a flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the illustrated operations. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

CLAIMS

What is claimed is:

1. An electromechanical systems (EMS) device, comprising:
 - a first electrode supported by a substrate;
 - a movable layer separated from the first electrode by a gap;
 - a second electrode supported by the movable layer, wherein one of the first or second electrodes is a segmented electrode including a plurality of isolated electrode segments located between the first driving electrode and the second driving electrode, wherein each of the plurality of isolated electrode segments are electrically isolated both from the first and second driving electrodes and from the other isolated electrode segments, and wherein the other of the first or second electrodes serves as a first driving electrode; and
 - a second driving electrode, wherein application of a voltage between the first driving electrode and the second driving electrode electrostatically displaces the movable layer.
2. The EMS device of claim 1, wherein the first driving electrode and the segmented electrode form a first capacitor, and wherein the second driving electrode and the segmented electrode form a second capacitor in series with the first capacitor.
3. The EMS device of any of claims 1 or 2, wherein the device includes an interferometric modulator.
4. The EMS device of claim 3, wherein:
 - the movable layer is movable over a range of stable positions in which application of a voltage between the first driving electrode and the second driving electrode maintains the movable layer at a position within the range of stable positions;
 - the interferometric modulator is capable of reflecting substantially white light when the movable layer is collapsed against the first electrode; and
 - the interferometric modulator is capable of appearing black when the movable layer is maintained in at least one position within the range of stable positions
5. The EMS device of any of claims 1 to 4, additionally including driving circuitry capable of applying a range of voltages between the first driving electrode

and the second driving electrode to move the movable layer through a range of stable positions between a relaxed position where no voltage is applied between the first driving electrode and the second driving electrode and a minimum stable distance from the first electrode.

6. The EMS device of claim 5, wherein the minimum stable distance is less than 40% of the distance between the relaxed position and the first electrode.

7. The EMS device of any of claims 1 or 2, wherein the second electrode is the segmented electrode.

8. The EMS device of claim 7, wherein the movable layer includes:

the second driving electrode, wherein application of a voltage between the driving electrode and the first electrode electrostatically displaces the movable layer, and wherein the plurality of isolated electrode segments are located between the second driving electrode and the fixed electrode, and

a dielectric layer located between the second driving electrode and the first electrode, wherein each of the plurality of isolated electrode segments are electrically isolated from both the second driving electrode and from the other isolated electrode segments.

9. The EMS device of claim 7 or 8, wherein the plurality of isolated electrode segments are recessed from the edges of the movable layer.

10. The EMS device of any of claims 7 to 9, wherein the first electrode includes an optical absorber, and wherein the isolated electrode segments include a reflective material.

11. The EMS device of any of claims 1 or 2, wherein the first electrode is a segmented optical absorber which includes the plurality of isolated electrode segments.

12. The EMS device of claim 11, wherein the second driving electrode is electrically isolated from the segmented optical absorber, and wherein the segmented optical absorber is disposed between the fixed electrode and the second electrode.

13. The EMS device of claim 12, wherein the second driving electrode is more transmissive to visible wavelengths of light than the segmented optical absorber.

14. The EMS device of claim 12, wherein the second driving electrode includes a substantially transparent thickness of a conductive oxide.

15. The EMS device of any of claims 12 to 14, wherein the substrate is located between the first driving electrode and the segmented optical absorber.

16. The EMS device of any of claims 12 to 14, wherein the first driving electrode is located between the substrate and the segmented optical absorber.

17. The EMS device of any of claims 12 to 16, wherein the segmented optical absorber includes at least one gap between segmented optical absorber sections, the device additionally including a second optical absorber structure electrically isolated from the segmented optical absorber structure is aligned with the at least one gap between segmented optical absorber sections.

18. The EMS device of claim 17, wherein at least a portion of the second optical absorber structure is substantially the same size and shape as the at least one gap between segmented optical absorber sections.

19. The EMS device of any of claims 1 to 18, wherein each individual isolated electrode segment is surrounded on all sides by dielectric material.

20. The EMS device of claim 19, wherein the plurality of isolated electrode segments include four isolated electrical segments separated by two substantially perpendicular sections of dielectric material.

21. The EMS device of any of claims 1 to 20, wherein a surface area of the fixed electrode is less than a surface area of the isolated electrode segments.

22. The EMS device of any of claims 1 to 21, further including

- a processor capable of communicating with at least one of the first driving electrode and the second driving electrode, the processor being capable of processing image data; and

- a memory device capable of communicating with the processor.

23. The EMS device of claim 22, further including:

- a driver circuit capable of sending at least one signal to at least one of the first electrode and the driving electrode; and

- a controller capable of sending at least a portion of the image data to the driver circuit.

24. The EMS device of any of claims 22 or 23, further including an image source module capable of sending the image data to the processor, wherein the image source module includes at least one of a receiver, transceiver, and transmitter.

25. The EMS device of any of claims 22 to 24, further including an input device configured to receive input data and to communicate the input data to the processor.

26. A method of fabricating an electromechanical systems (EMS) device, comprising:

- forming a first dielectric layer over a substrate;
- forming a first electrode layer over the first dielectric layer;
- forming a plurality of isolated electrode segments in the first electrode layer;
- forming a second dielectric layer over the plurality of isolated electrode segments; and
- forming a second electrode layer over the second dielectric layer.

27. The method of claim 26, wherein forming a plurality of isolated electrode segments includes patterning the first electrode layer to form a group of four isolated electrical segments separated by two substantially perpendicular cuts extending through the first electrode layer.

28. The method of claim 26, wherein forming a first dielectric layer includes forming a stack of dielectric layers, the stack of dielectric layers including:

- a first dielectric sublayer including a first material having a first index of refraction; and
- a second dielectric sublayer including a second material having a second index of refraction, wherein the first index of refraction is greater than the second index of refraction.

29. The method of claim 28, wherein forming the stack of dielectric layers includes:

- forming the first dielectric sublayer over the sacrificial layer; and
- forming the second dielectric sublayer over the first dielectric sublayer.

30. The method of claim 26, wherein the first dielectric layer is formed over a sacrificial layer located over a third electrode layer, additionally including performing an etch to remove the sacrificial layer after formation of the second electrode layer to form a gap between the first dielectric layer and the third electrode.

31. The method of claim 26, wherein the first dielectric layer is formed over a third electrode layer, the method additionally including:

- forming a sacrificial layer over the second dielectric layer, wherein the second electrode layer is formed over the sacrificial layer; and

performing an etch to remove the second sacrificial layer after formation of the second sacrificial layer to form a gap between the second dielectric layer and the second electrode.

32. An electromechanical systems (EMS) device, comprising:

a first electrode supported by a substrate;

a movable layer separated from the first electrode by a gap;

a second electrode supported by the movable layer, wherein one of the first or second electrodes is a floating electrode including means for inhibiting an imbalanced accumulation of charge within the movable layer to increase a range of stable positions of the movable layer, and wherein the other of the first or second electrodes serves as a first driving electrode; and

a second driving electrode, wherein application of a voltage between the first driving electrode and the second driving electrode electrostatically displaces the movable layer.

33. The EMS device of claim 32, wherein the floating electrode is a segmented electrode, wherein the inhibiting means include a plurality of isolated electrode segments located between the first driving electrode and the second driving electrode, and wherein each of the plurality of isolated electrode segments are electrically isolated both from the first and second driving electrodes and from the other isolated electrode segments.

34. The EMS device of claim 33, wherein the first driving electrode and the segmented electrode form a first capacitor, and wherein the second driving electrode and the segmented electrode form a second capacitor in series with the first capacitor.

35. The EMS device of any of claims 33 or 34, wherein the second electrode is the segmented electrode, and wherein the movable layer includes:

the second driving electrode, wherein application of a voltage between the driving electrode and the first electrode electrostatically displaces the movable layer, and wherein the plurality of isolated electrode segments are located between the second driving electrode and the fixed electrode, and

a dielectric layer located between the second driving electrode and the first electrode, wherein each of the plurality of isolated electrode segments are electrically isolated from both the second driving electrode and from the other isolated electrode segments.

36. The EMS device of any of claims 33 or 34, wherein the first electrode is a segmented optical absorber which includes the plurality of isolated electrode segments, wherein the second driving electrode is electrically isolated from the segmented optical absorber, and wherein the segmented optical absorber is disposed between the fixed electrode and the second electrode.

37. The EMS device of claim 36, wherein the second driving electrode is more transmissive to visible wavelengths of light than the segmented optical absorber.

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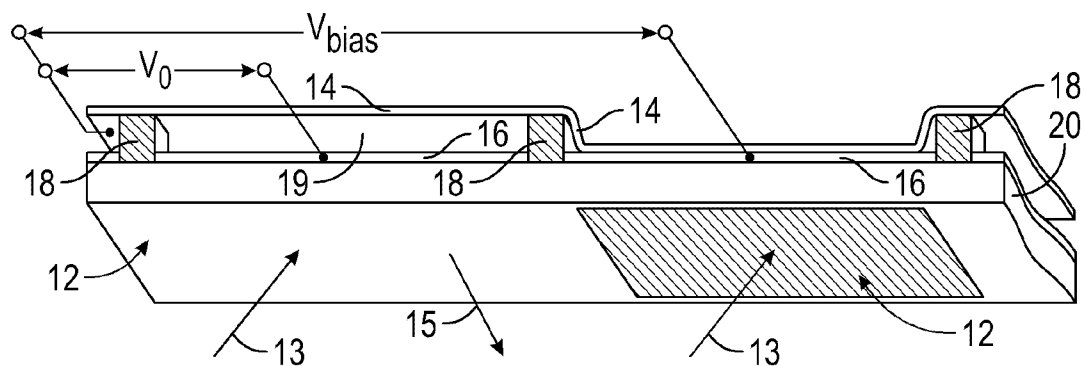


FIG. 1

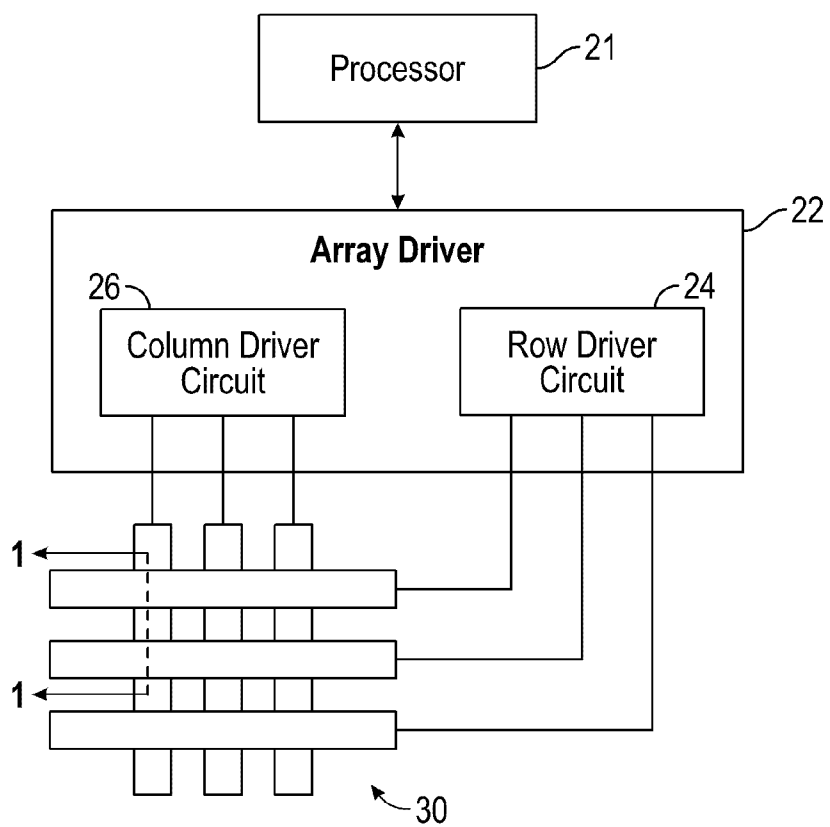


FIG. 2

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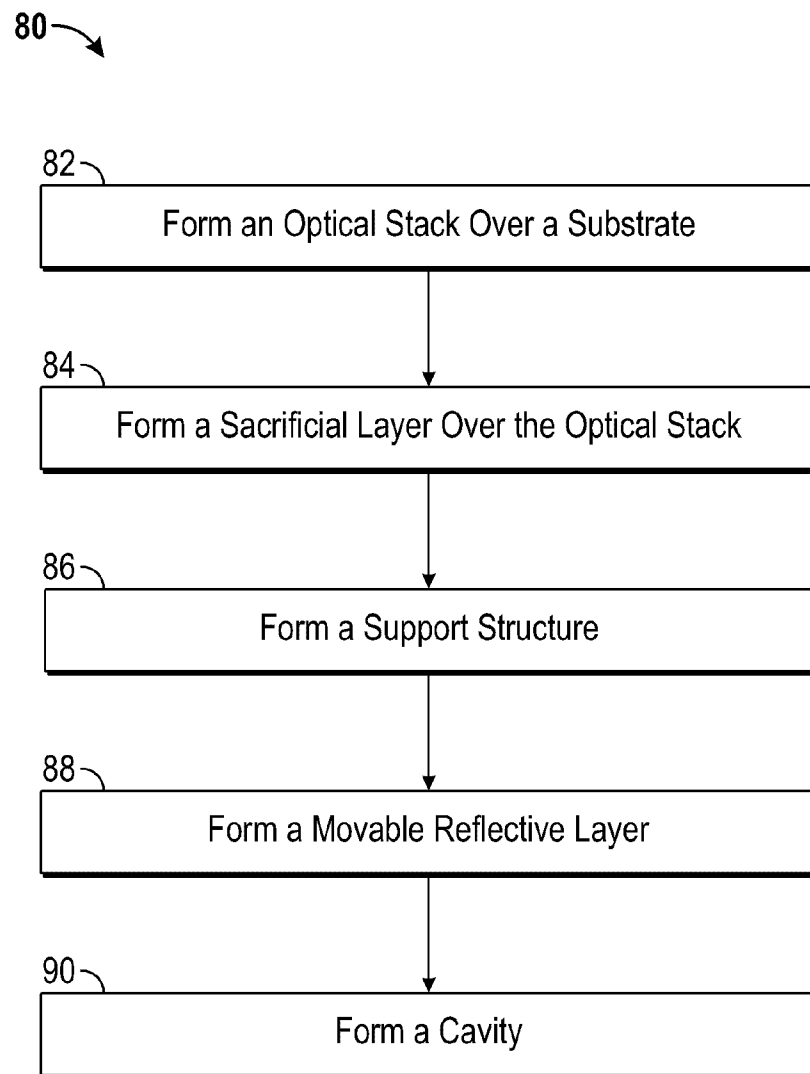


FIG. 3

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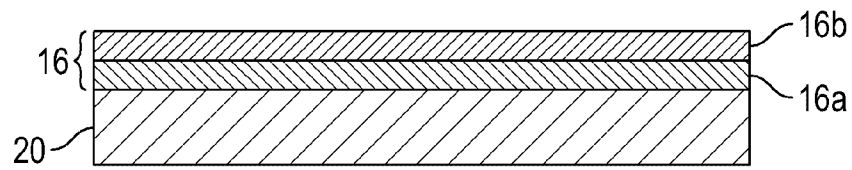


FIG. 4A

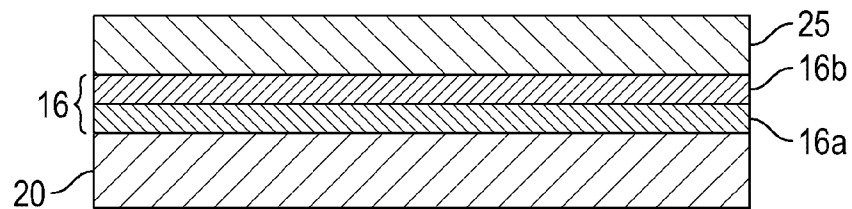


FIG. 4B

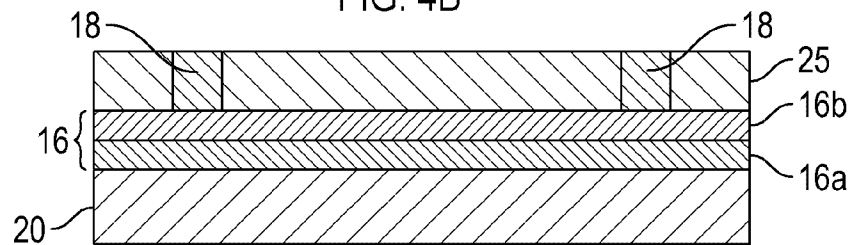


FIG. 4C

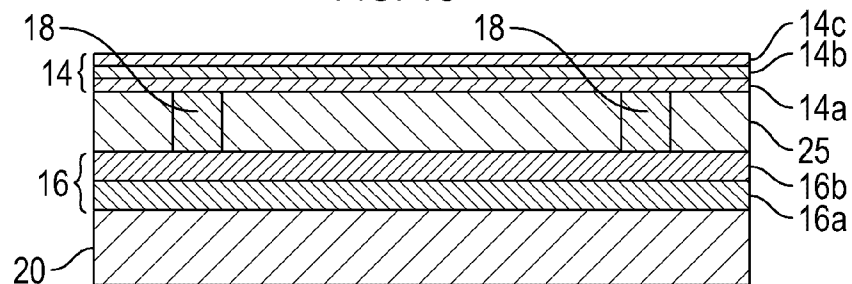


FIG. 4D

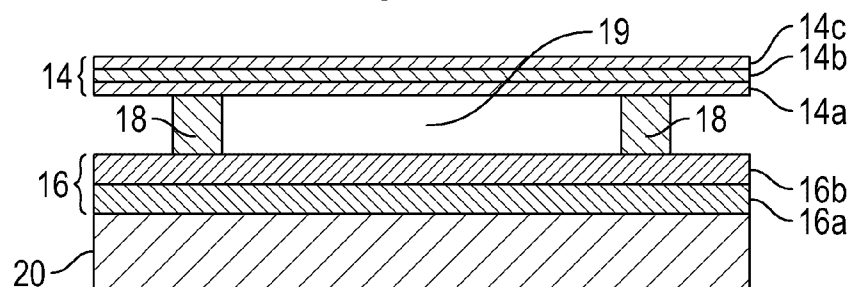


FIG. 4E

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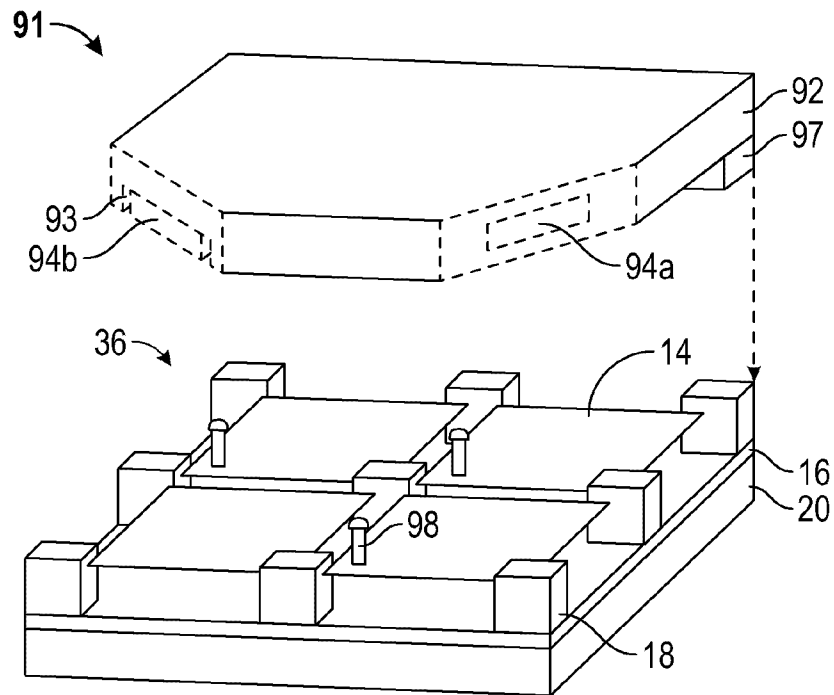


FIG. 5A

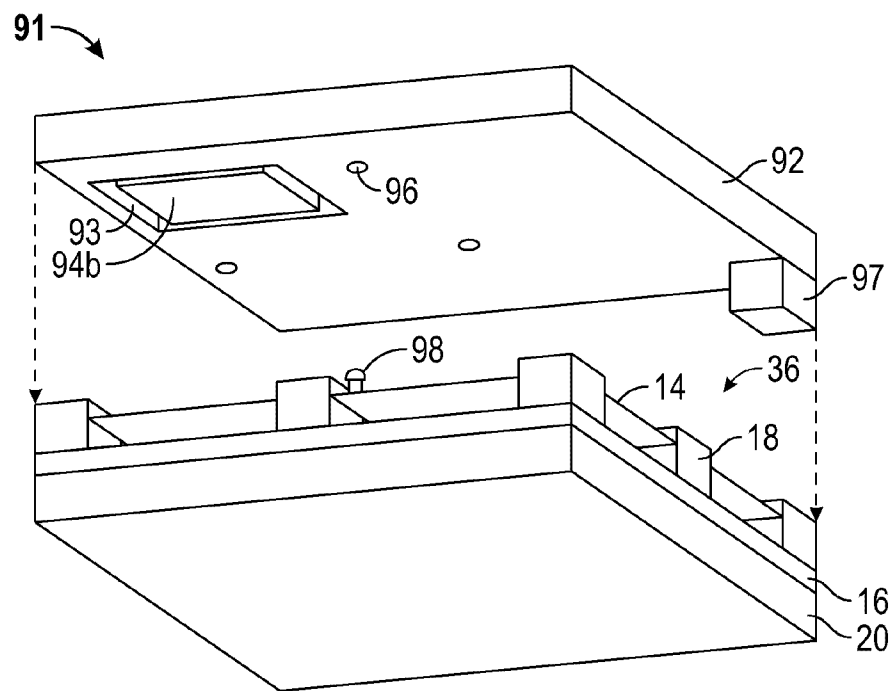


FIG. 5B

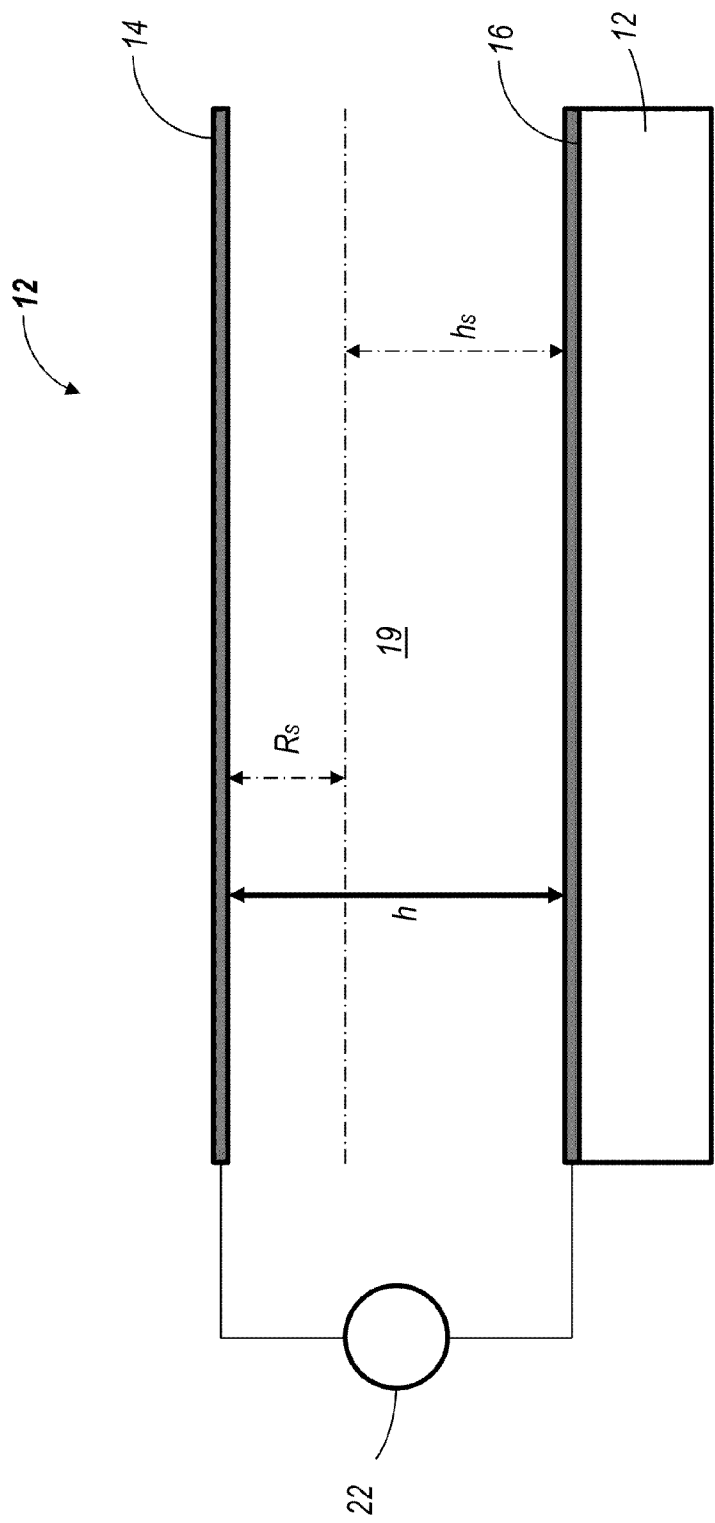


FIG. 6

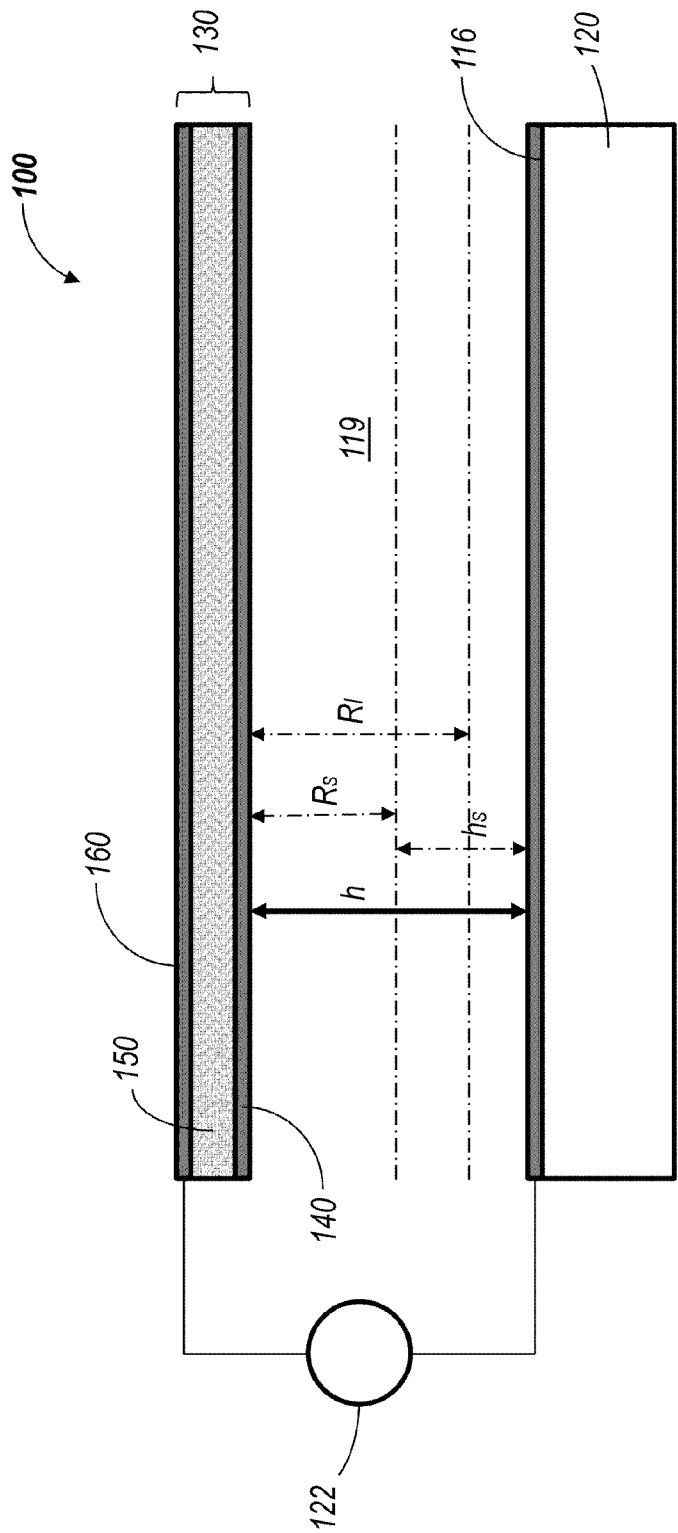


FIG. 7

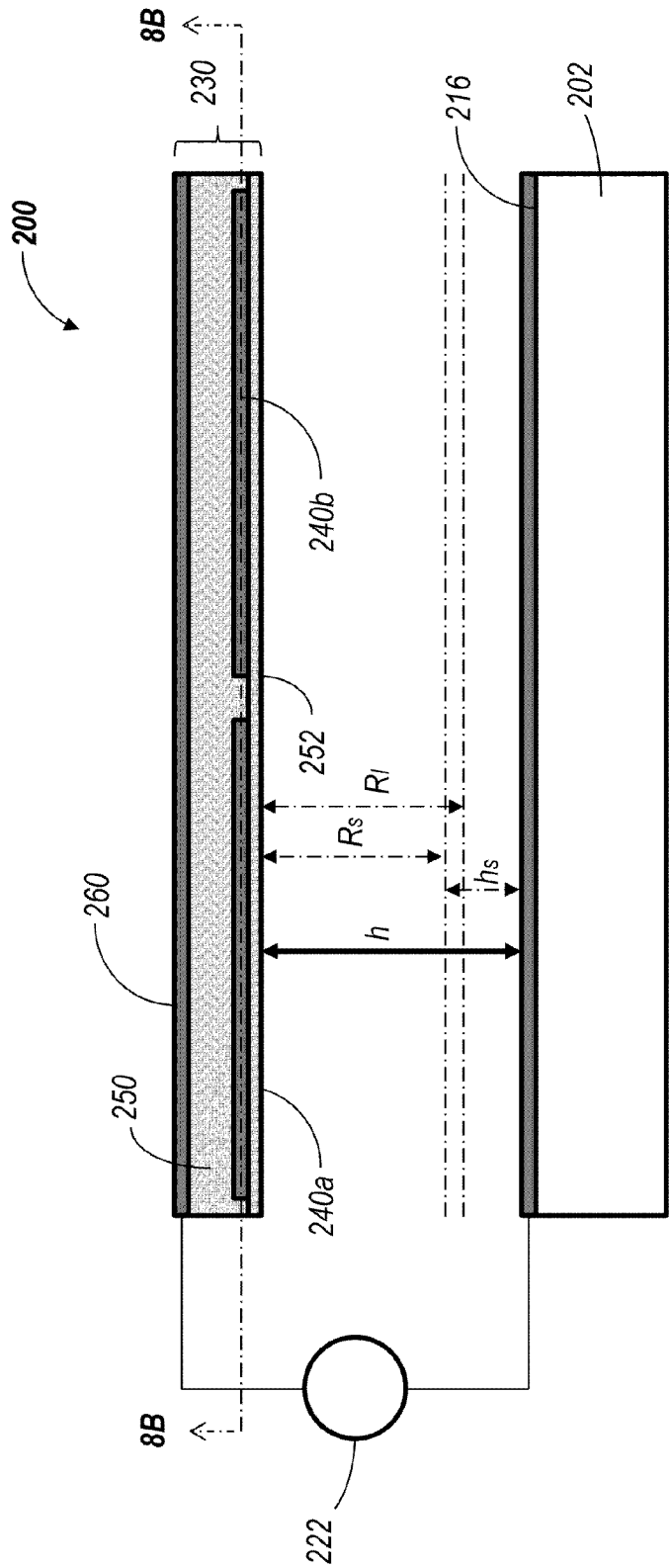


FIG. 8A

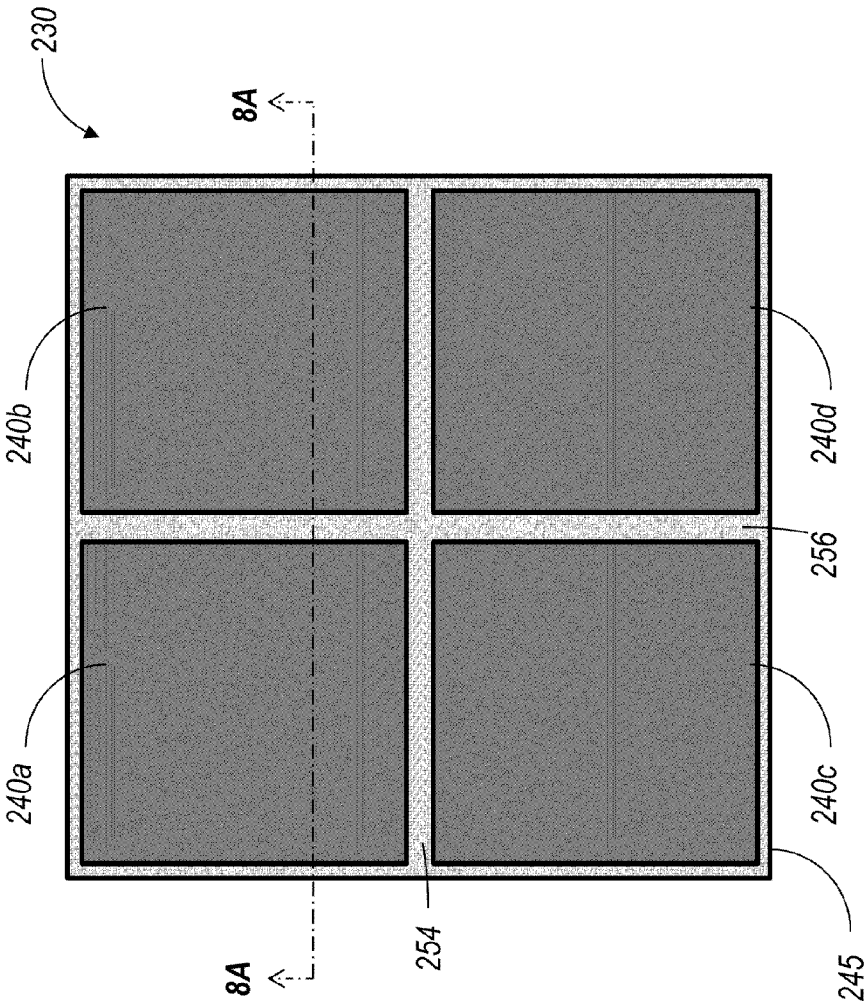


FIG. 8B

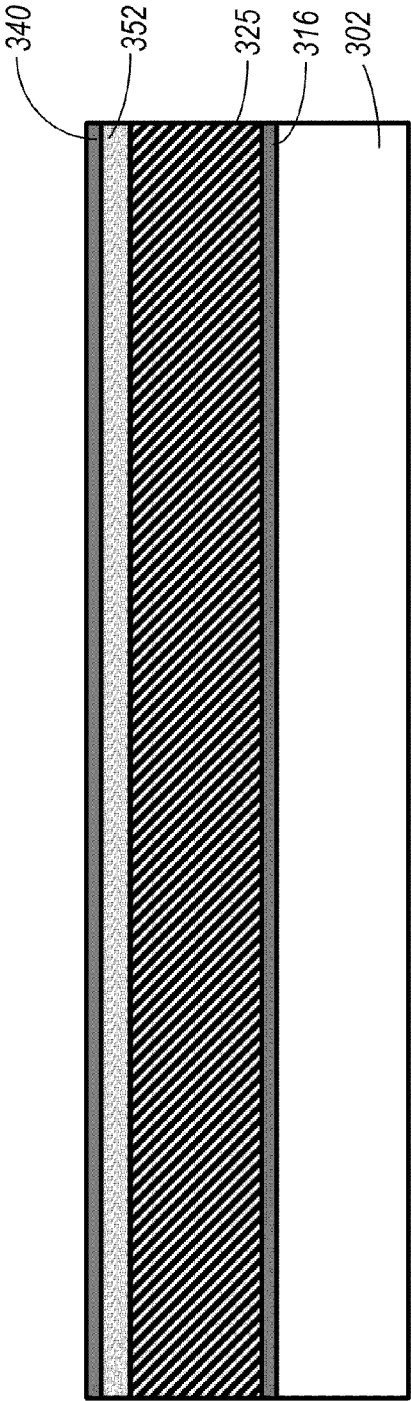


FIG. 9A

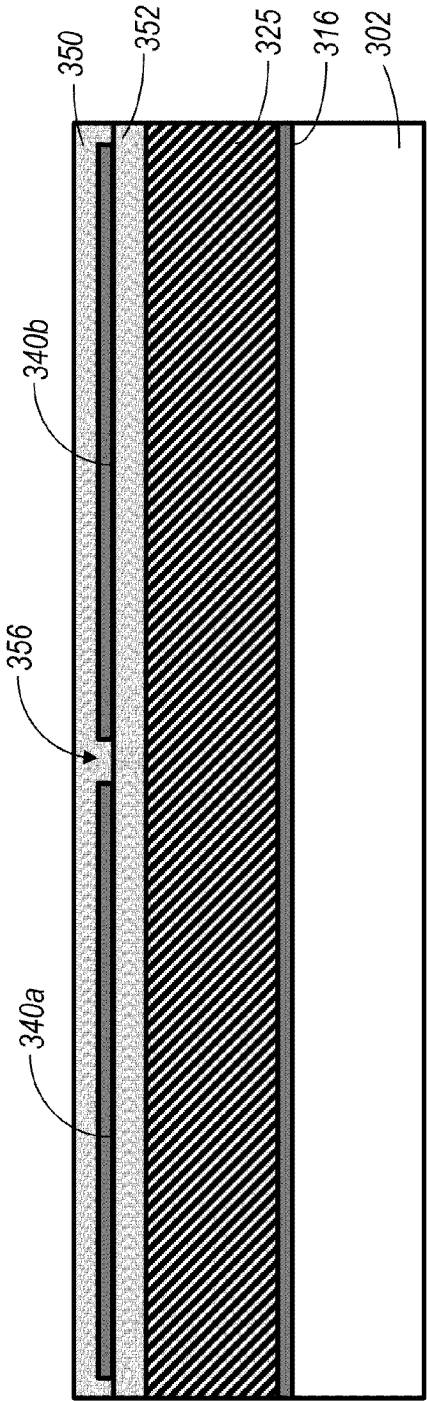


FIG. 9B

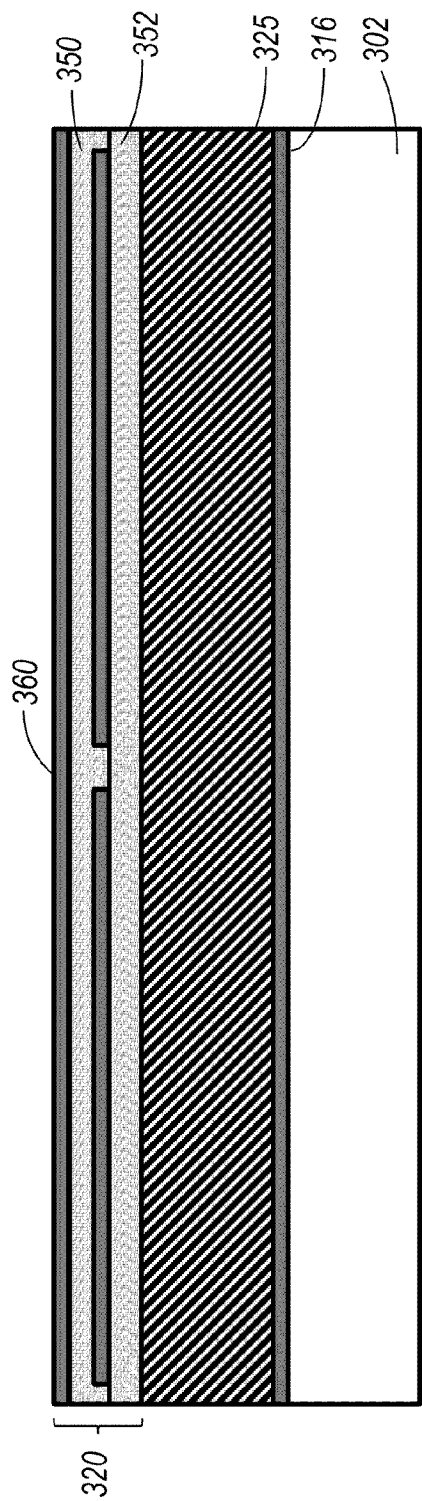
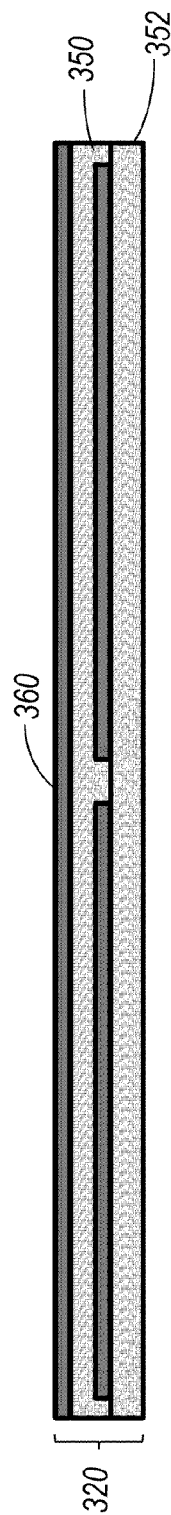


FIG. 9C



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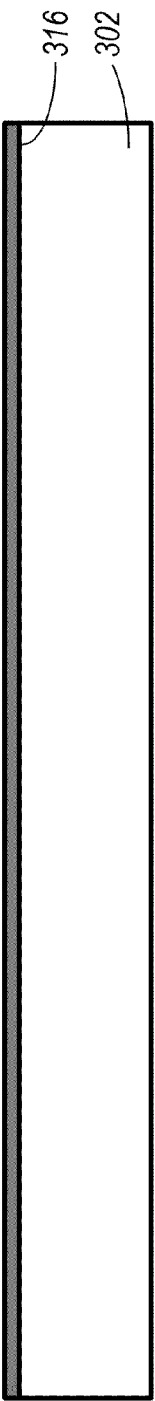


FIG. 9D

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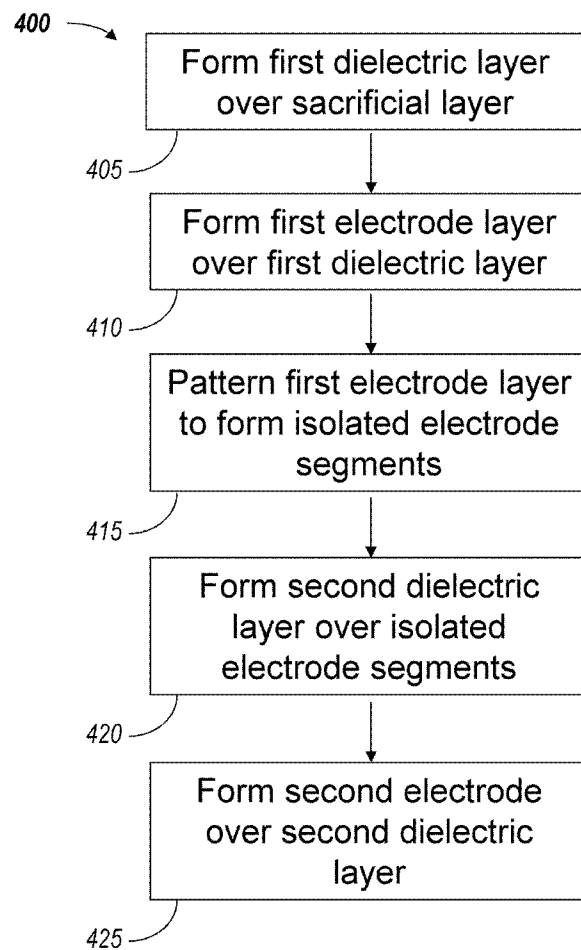
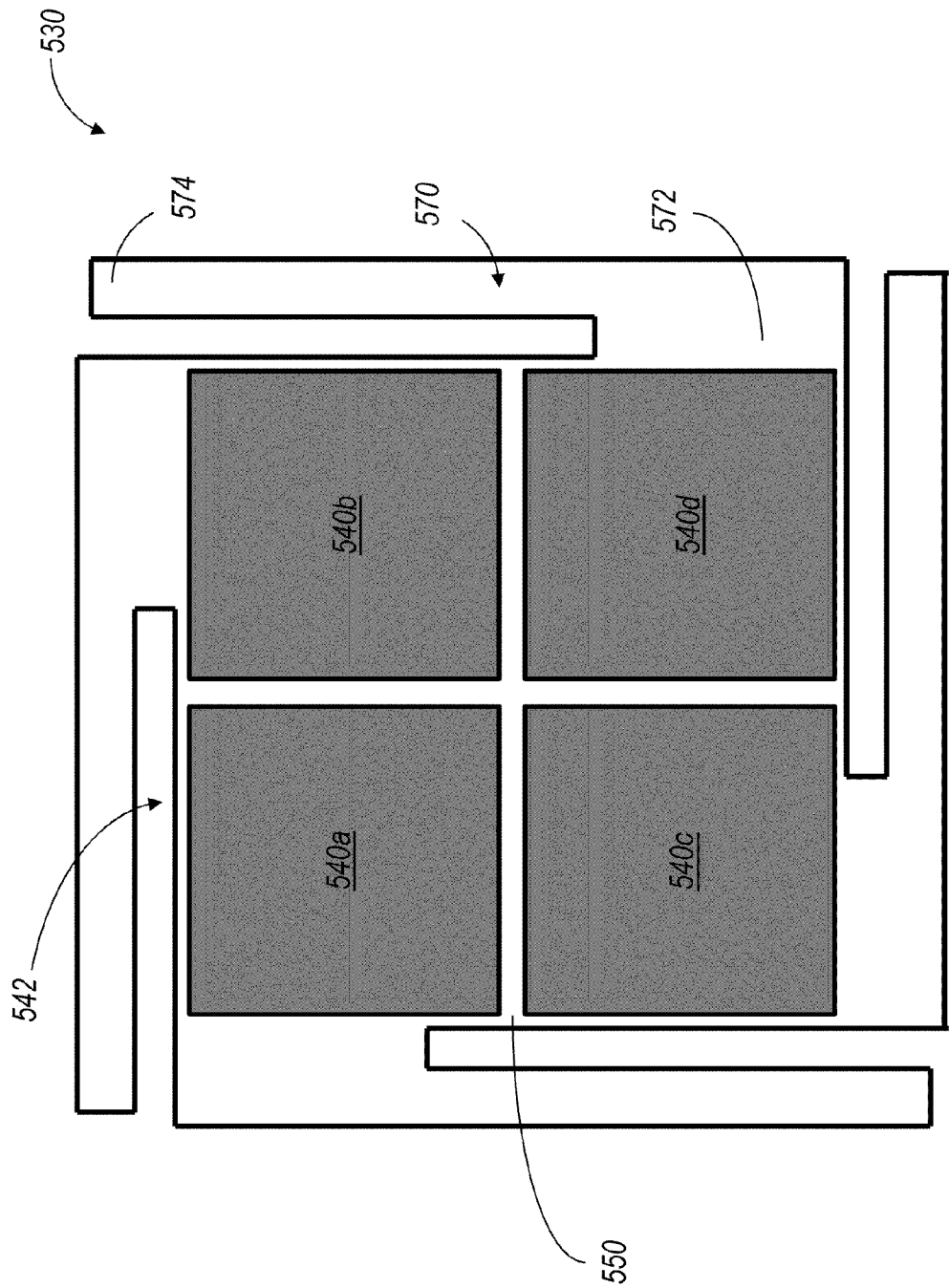


FIG. 10

FIG. 11



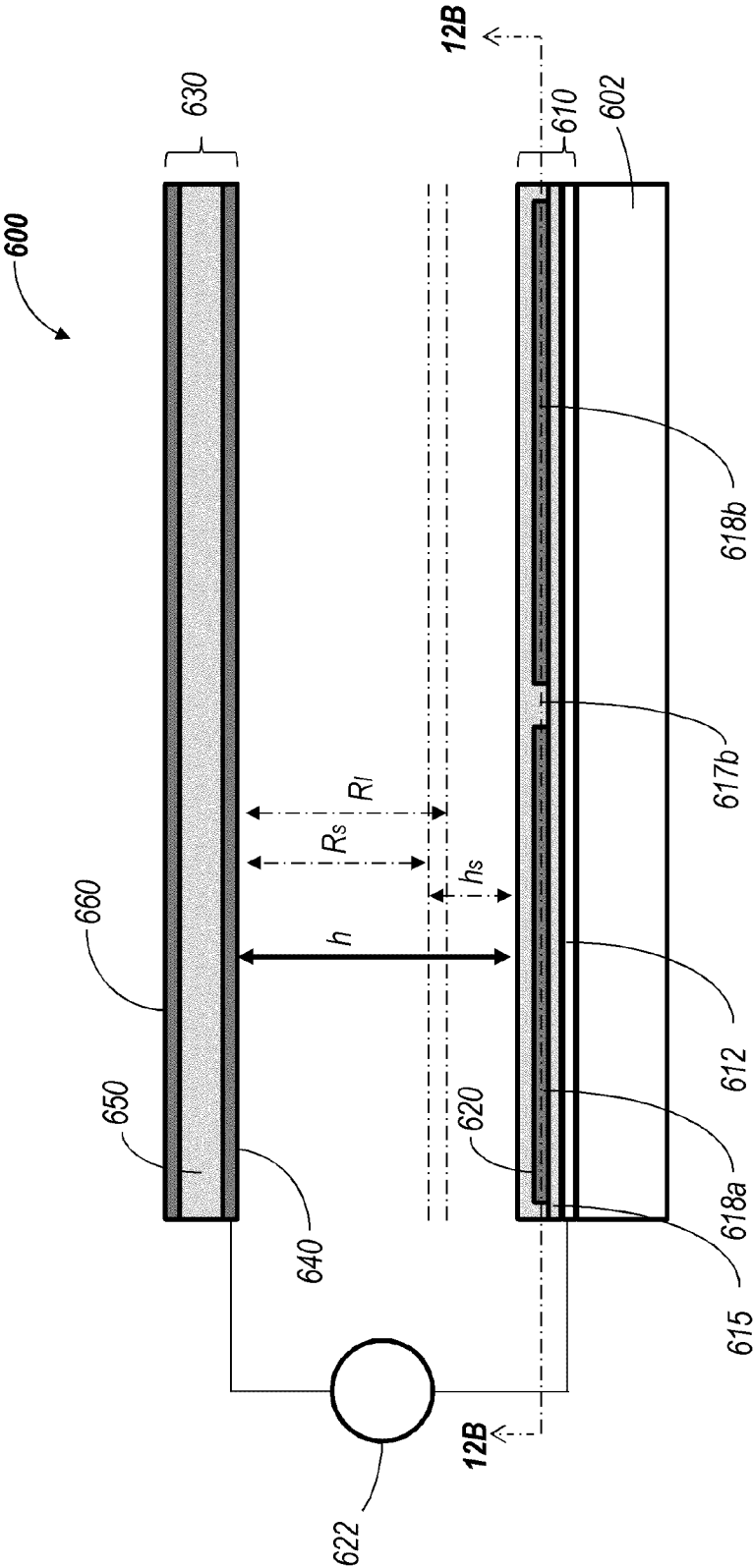


FIG. 12A

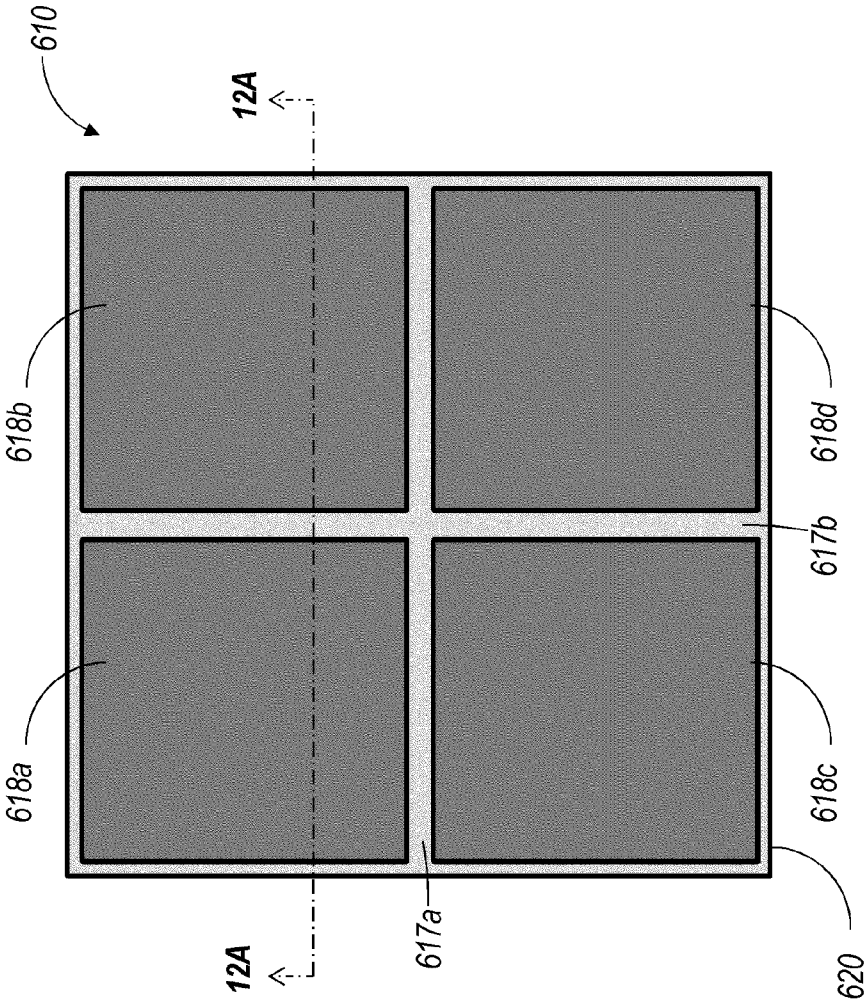


FIG. 12B

FIG. 13A

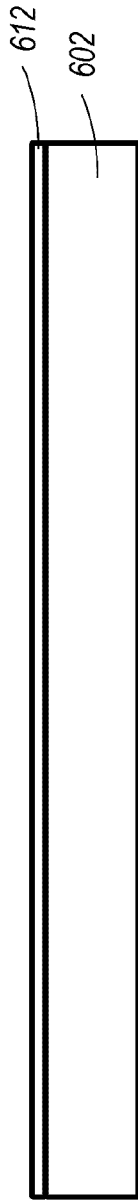


FIG. 13B

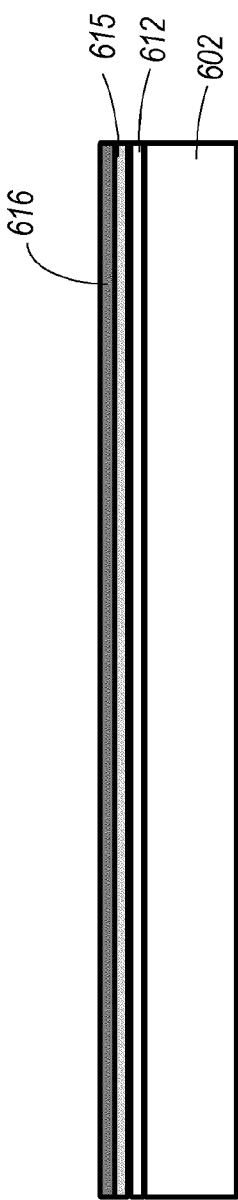
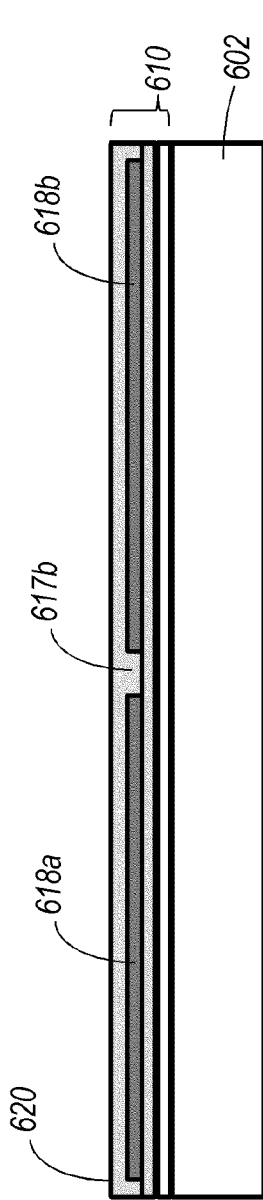


FIG. 13C



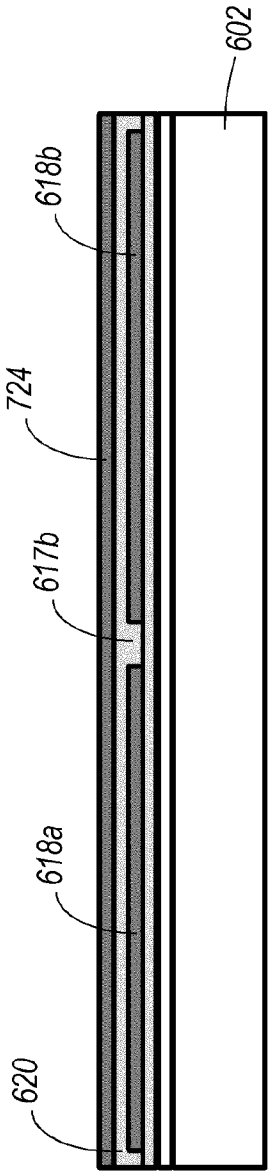


FIG. 14A

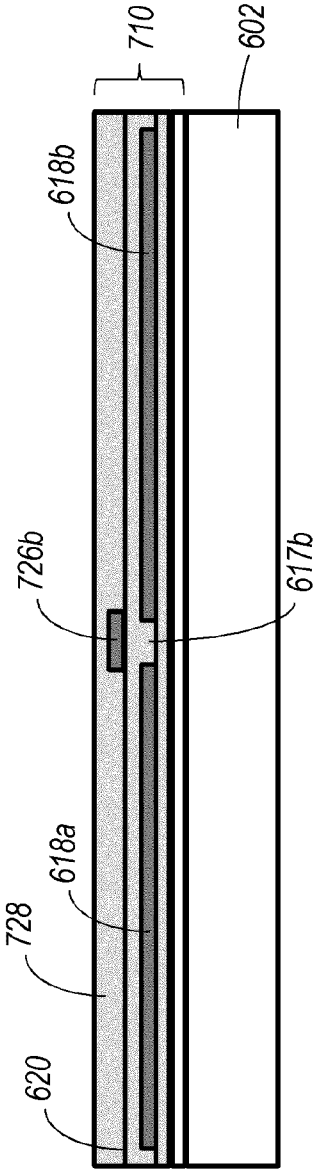


FIG. 14B

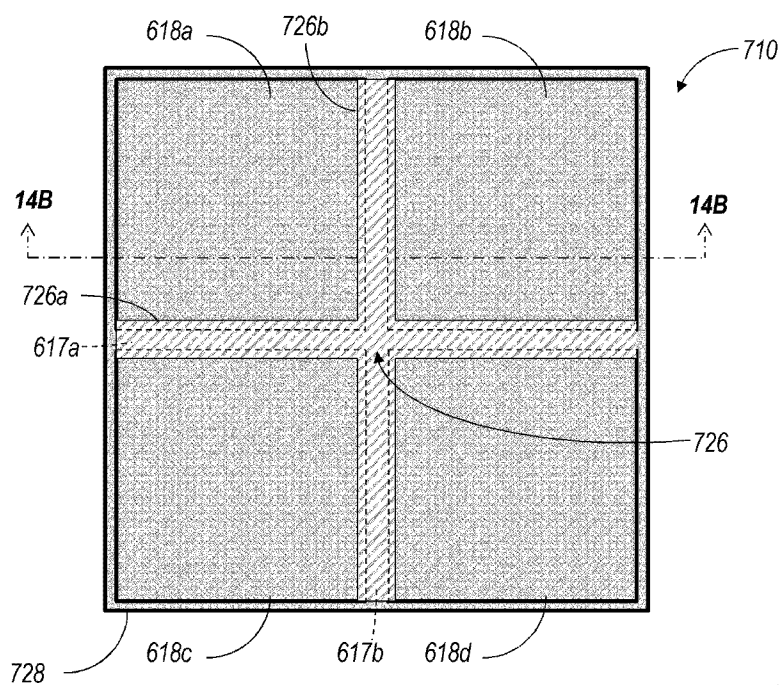
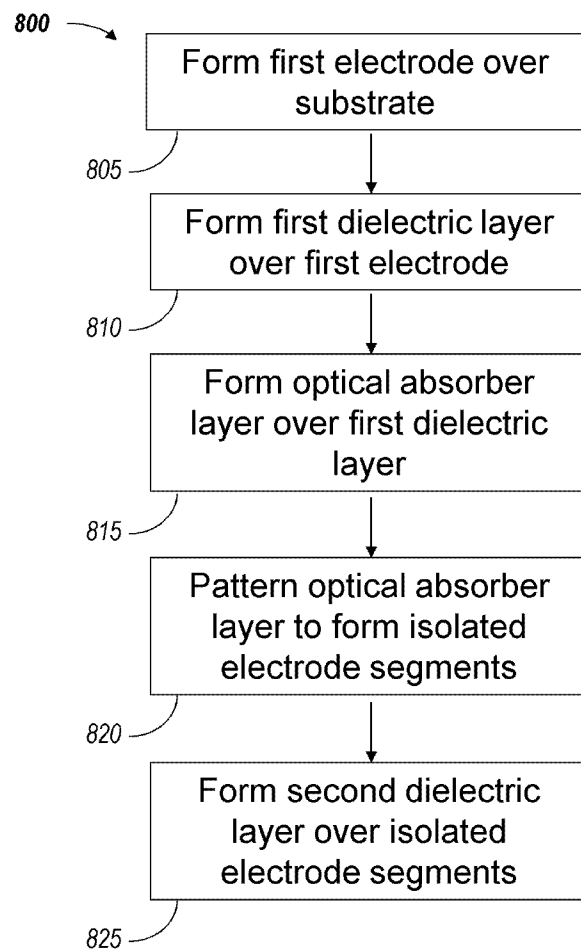


FIG. 15

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**FIG. 16**

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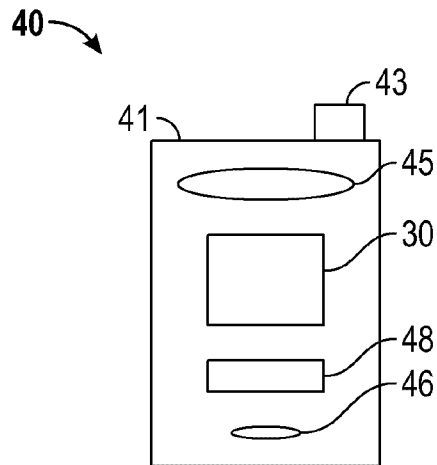


FIG. 17A

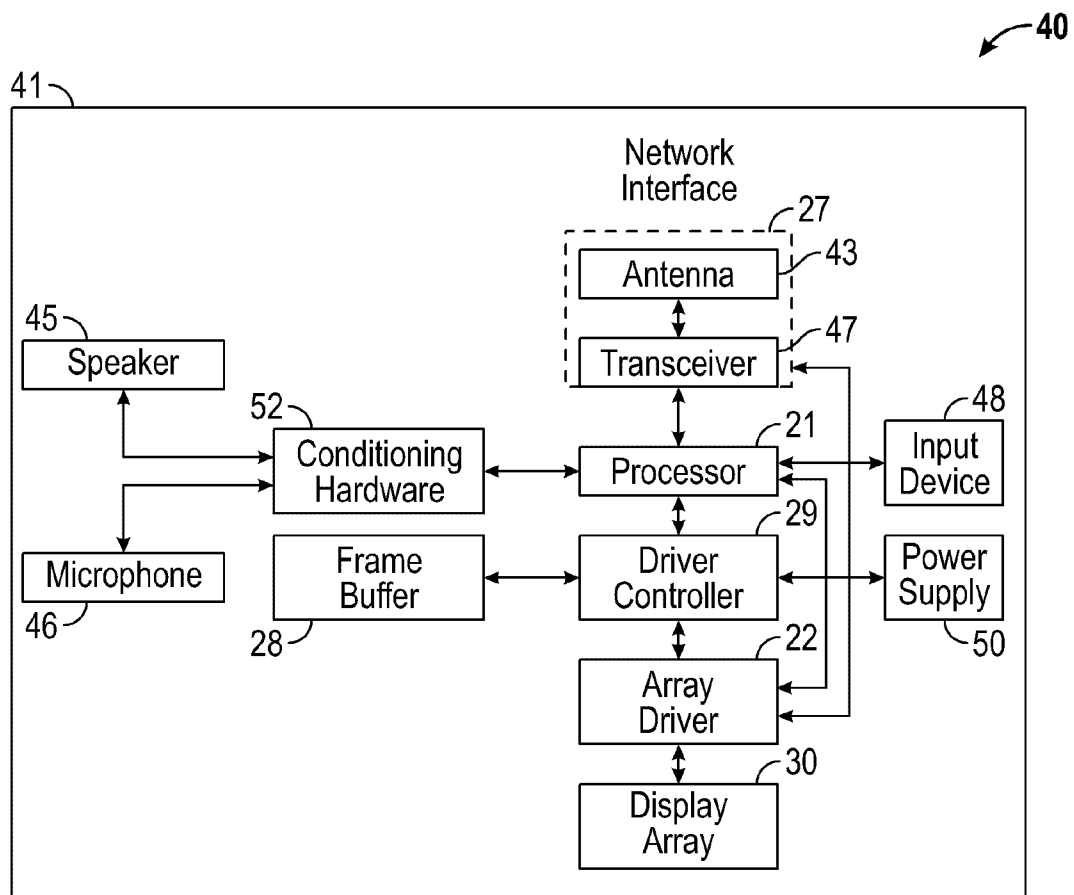


FIG. 17B

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/022770

A. CLASSIFICATION OF SUBJECT MATTER
 INV. G02B26/00 B81B3/00
 ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B G09G B81B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/147343 A1 (KOGUT LIOR [IL] ET AL) 11 June 2009 (2009-06-11)	26-37
A	paragraphs [0086] - [0091]; figures 17,18 -----	1-25
X	US 2011/235154 A1 (JI ZHONG [US]) 29 September 2011 (2011-09-29)	26-32
A	paragraphs [0066] - [0095]; figures 1-15 -----	1-25, 33-37
X	US 2012/044237 A1 (HONG JOHN H [US] ET AL) 23 February 2012 (2012-02-23)	26-32
A	figures 12-30 -----	1-25
A	US 2010/315696 A1 (LEE CHONG U [US] ET AL) 16 December 2010 (2010-12-16)	1-37
	figures 12-14 -----	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

"&" document member of the same patent family

Date of the actual completion of the international search

20 May 2014

Date of mailing of the international search report

10/06/2014

Name and mailing address of the ISA/

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 Fax: (+31-70) 340-3016

Authorized officer

Baur, Christoph

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/022770

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