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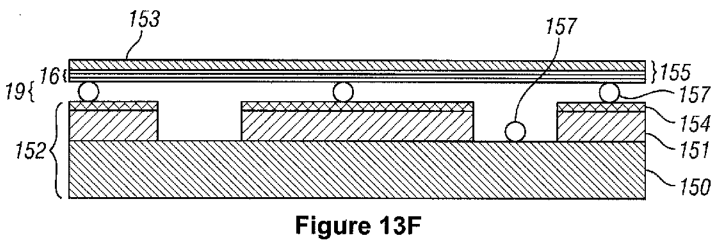

Figure 13F

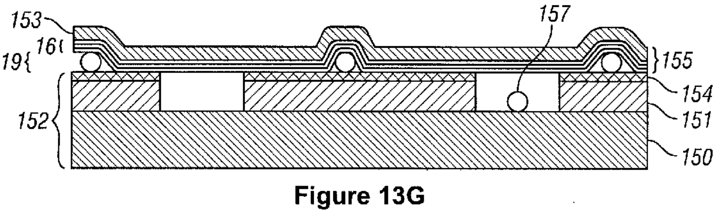

Figure 13G

(57) Abstract: The present disclosure provides systems, methods and apparatus for providing interferometric modulator displays using flexible films. In one aspect, a method of forming an interferometric modulator device includes providing a conductive element, depositing a reflective layer over at least a portion of the conductive element, and depositing a plurality of spacing elements over the conductive element. The absorber layer and the substrate are provided over the conductive element such that the absorber layer is disposed between the substrate and the spacing elements.

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FLEXIBLE FILM INTERFEROMETRIC MODULATOR DEVICES AND METHODS OF FORMING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The disclosure claims priority to U.S. Provisional Patent Application No. 61/379,691 filed September 2, 2010 entitled "INTERFEROMETRIC MODULATOR DEVICES AND METHOD OF FORMING THE SAME," and to U.S. Provisional Patent Application No. 61/379,697 filed September 2, 2010 entitled "INTERFEROMETRIC MODULATOR DEVICES AND METHOD OF FORMING THE SAME," each of which is assigned to the assignee hereof. The disclosures of the prior applications are considered part of, and are incorporated by reference in, this disclosure.

TECHNICAL FIELD

[0002] This disclosure relates to electromechanical systems.

DESCRIPTION OF THE RELATED TECHNOLOGY

[0003] Electromechanical systems (EMS) include devices having electrical and mechanical elements, actuators, transducers, sensors, optical components (including mirrors) and electronics. Electromechanical systems 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.

[0004] One type of EMS device is called an interferometric modulator (IMOD). As used herein, the term interferometric modulator 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 interferometric modulator 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. In an implementation, one plate may include a stationary layer deposited on 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 interferometric modulator. Interferometric modulator 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.

[0005] Some products include segmented displays having segments that can be selectively controlled to display alphanumeric and graphic characters. Segmented displays can include a patterned substrate, such as a printed circuit board ("PCB") patterned to form the segments. The voltage potential of the segments of the PCB can be dynamically adjusted to form segmented images. Segmented displays can be relatively inexpensive to manufacture, and can have relative low dynamic power consumption.

SUMMARY

[0006] The systems, methods and devices of the disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0007] One innovative aspect of the subject matter described in this disclosure can be implemented in a device including a plurality of display elements, each element including a conductive element, a flexible film including a partially reflective and partially transmissive absorber layer, and a reflective layer disposed on the conductive element. The reflective layer is disposed at least partially between the flexible film and the conductive element, and the reflective layer and the absorber layer define a cavity therebetween. The flexible film is configured to move toward the conductive element when a voltage is applied across the flexible film and the conductive element due to an electrostatic force generated between the flexible film and the conductive element.

[0008] Another innovative aspect of the subject matter described in this disclosure can be implemented in a device including a flexible absorber layer, a printed circuit board including at least one conductive trace element, and a reflective layer disposed over the conductive trace element. The absorber layer is partially reflective and partially transmissive, and the flexible absorber layer is configured to move toward the printed circuit board when a voltage is applied between the absorber layer the conductive trace element. Movement of the absorber layer alters the optical characteristics of the display device.

[0009] Another innovative aspect of the subject matter described in this disclosure can be implemented in a device including a display means. The display means includes means for applying a voltage, flexible means for partially reflecting and transmitting light, and means for reflecting light disposed on the voltage applying means. The reflective means is disposed at least partially between the flexible means and the voltage applying means, and the reflective means and the flexible means define a cavity therebetween. The flexible means is configured to move toward the voltage applying means when a voltage is applied between the flexible means and the voltage applying means.

[0010] Another innovative aspect of the subject matter described in this disclosure can be implemented in a method of manufacturing a device. The method includes depositing an absorber layer on a sacrificial material, providing a substrate, depositing a first adhesive layer on the substrate, depositing a second adhesive layer on the substrate, positioning the absorber layer over the first and second adhesive layers such that the absorber layer contacts the first and second adhesive layers, and developing the adhesive layer. The absorber layer includes a partially reflective and transmissive material. The first adhesive layer and the second adhesive layer are substantially co-planar and are spaced apart from one another on a common plane.

[0011] Another innovative aspect of the subject matter described in this disclosure can be implemented in a method of manufacturing a device. The method includes providing a substrate, depositing an adhesive inhibiting material on the substrate, depositing an absorber layer over the adhesive inhibiting material, providing an electrode, and applying a voltage between the absorber layer and the electrode to pull a portion of the absorber layer away from the substrate. The absorber layer includes a partially reflective and transmissive material.

[0012] Details of one or more implementations of the subject matter described in this specification 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

[0013] Figure 1A shows an example of an isometric view depicting two adjacent pixels in a series of pixels of an interferometric modulator (IMOD) display device.

[0014] Figure 1B shows an example of a system block diagram illustrating an electronic device incorporating a 3x3 interferometric modulator display.

[0015] Figures 2–6 show examples of cross-sectional schematics illustrating varying implementations of interferometric modulators.

[0016] Figure 7 shows an example of a flow diagram illustrating a manufacturing process for an interferometric modulator.

[0017] Figures 8A–8E show examples of cross-sectional schematic illustrations of various stages in a method of making an interferometric modulator.

[0018] Figure 9A shows an example of a schematic cross section of an interferometric stack.

[0019] Figure 9B shows a graph of brightness versus gap size for one example of an interferometric stack.

[0020] Figure 9C shows a graph of reflectivity spectrum versus wavelength for three examples of interferometric stacks.

[0021] Figure 10 shows an example of a flow diagram illustrating a manufacturing process for an interferometric modulator.

[0022] Figure 11 shows an example of a schematic plan view of a segmented display.

[0023] Figure 12 shows an example of a flow diagram illustrating a manufacturing process for an interferometric modulator.

[0024] Figures 13A–13G show examples of cross-sectional schematic illustrations of various stages in methods of making interferometric modulators according to various implementations.

[0025] Figure 14 shows an example of a flow diagram illustrating a manufacturing process for an interferometric modulator.

[0026] Figures 15A–15I show examples of cross-sectional schematic illustrations of various stages in methods of making interferometric modulators according to various implementations.

[0027] Figure 16 shows an example of a flow diagram illustrating a manufacturing process for an interferometric modulator.

[0028] Figures 17A–17F show examples of cross-sectional schematic illustrations of various stages in methods of making interferometric modulators according to various implementations.

[0029] Figures 18A and 18B show examples of system block diagrams illustrating a display device that includes a plurality of interferometric modulators.

[0030] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0031] 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 or system that can be configured to display an image, whether in motion (e.g., video) or stationary (e.g., still image), 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, GPS receivers/navigators, cameras, MP3 players, camcorders, game consoles, wrist watches, clocks, calculators, television monitors, flat panel displays, electronic reading devices (i.e., 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), microelectromechanical systems (MEMS) and non-MEMS applications), aesthetic structures (e.g., display of images on a piece of jewelry) 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.

[0032] In some implementations, an interferometric modulator device is disclosed having a relatively large gap height such that the device includes multiple optical resonances and reflects lights appearing to a viewer as substantially white. The device can include an optically resonant cavity having a dielectric of a relatively high index of refraction, thereby broadening optical peaks in the reflectance spectrum and increasing the brightness of the reflected light. The device can have improved tolerance to variation in air gap height, thereby providing improved color consistency across a display and permitting manufacturing of the devices using relatively inexpensive processes, such as printed circuit board (PCB) technology.

[0033] In some implementations, an interferometric modulator device is disclosed having a stationary electrode formed from a patterned conductive layer on a substrate, such as a PCB. A reflective layer can be disposed on the patterned conductive layer, and a flexible film having an optical stack can be spaced from the patterned substrate to define a gap. The resulting interferometric modulator devices can be manufactured inexpensively and can be used in a direct-drive segmented display, thereby eliminating a need for row and column switching and reducing power consumption. In some implementations, the interferometric modulator devices can have multiple optical resonances and can reflect light appearing to a viewer as substantially white. For example, some interferometric modulator devices described herein can include a relatively large gap height, such as gap heights greater than about 1000 nm. By configuring the device in this manner, a display can be provided that includes interferometric modulator devices having improved tolerance to variation in air gap height and having improved color consistency across the display. Additionally, in some implementations, a dielectric layer of the optical stack can have a relatively high index of refraction, such as an index of refraction greater than about 2.0 to aid in enhancing the brightness of the display.

[0034] Particular implementations of the subject matter described in this disclosure can be implemented to realize one or more of the following potential advantages. For examples, some implementations provide displays that are relatively inexpensive to manufacture and can be employed in direct-drive segmented displays. Additionally, some implementations can reduce power consumption. Furthermore, some implementations provide displays that can reflect light appearing to a viewer as substantially white. Moreover, some implementation can be used to enhanced brightness of a display and/or improve a displays tolerance to variation in air gap height.

[0035] An example of a suitable EMS or MEMS device, to which the described implementations may apply, is a reflective display device. Reflective display devices can incorporate interferometric modulators (IMODs) to selectively absorb and/or reflect light incident thereon using principles of optical interference. IMODs can include an absorber, a reflector that is movable with respect to the absorber, and an optical resonant cavity defined between the absorber and the reflector. 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 interferometric modulator. The reflectance spectrums of IMODs can create fairly broad spectral bands which 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.

[0036] Figure 1 shows an example of an isometric view depicting two adjacent pixels in a series of pixels of an interferometric modulator (IMOD) display device. The IMOD display device includes one or more interferometric MEMS display elements. In these devices, the pixels of the MEMS display elements can be in either a bright or dark state. In the bright ("relaxed," "open" or "on") state, the display element reflects a large portion of incident visible light, e.g., to a user. Conversely, in the dark ("actuated," "closed" or "off") state, the display element reflects little incident visible light. MEMS pixels can be configured to reflect predominantly at particular wavelengths allowing for a color display in addition to black and white.

[0037] The IMOD display device can include a row/column array of IMODs. Each IMOD can include a pair of reflective layers, i.e., a movable reflective layer and a fixed partially reflective layer, positioned at a variable and controllable distance from each other to form an air gap (also referred to as an optical gap or cavity). The movable reflective layer may be moved between at least two positions. In a first position, i.e., a relaxed position, the movable reflective layer can be positioned at a relatively large 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 or destructively depending on the position of the movable reflective layer, producing either an overall reflective or non-reflective state for each pixel. In some implementations, the IMOD may be in a reflective state when unactuated, reflecting light within the visible spectrum, and may be in a dark state when unactuated, absorbing and/or destructively interfering light within the visible range. In some other implementations, however, an IMOD 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 pixels to change states. In some other implementations, an applied charge can drive the pixels to change states.

[0038] The depicted portion of the pixel array in Figure 1A includes two adjacent interferometric modulators **12** (i.e., IMOD pixels). In the IMOD pixel **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 IMOD pixel **12** on the left is insufficient to cause actuation of the movable reflective layer **14**. In the IMOD pixel **12** on the right, 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 IMOD **12** on the right is sufficient to move and can maintain the movable reflective layer **14** in the actuated position.

[0039] In Figure 1A, the reflective properties of pixels **12** are generally illustrated with arrows **13** indicating light incident upon the pixels **12**, and light **15** reflecting from the IMOD pixel **12** on the left. A person having ordinary skill in the art will readily recognize that most of the light **13** incident upon the pixels **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 at the movable reflective layer **14**, back toward (and through) the transparent substrate **20**. Interference (constructive 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 the wavelength(s) of light **15** reflected from the pixel **12**.

[0040] 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, such as chromium (Cr), 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, the optical stack **16** can include a single semi-transparent thickness of metal or semiconductor which serves as both an 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 IMOD) can serve to bus signals between IMOD pixels. The optical stack **16** also can include one or more insulating or dielectric layers covering one or more conductive layers or an electrically conductive/optically absorptive layer.

[0041] In some implementations, 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 posts **18** and an intervening sacrificial material deposited 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 um, while the gap **19** may be less than 10,000 Angstroms (Å).

[0042] In some implementations, each pixel of the IMOD, whether in the actuated or relaxed state, is essentially 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 pixel **12** on the left in Figure 1A, with the gap **19** between the movable reflective layer **14** and optical stack **16**. However, when a potential difference, i.e., 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 pixel 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 pixel **12** on the right in Figure 1A. The behavior is the same regardless of the polarity of the applied potential difference. Though a series of pixels 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. 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.

[0043] Figure 1B shows an example of a system block diagram illustrating an electronic device incorporating a 3x3 interferometric modulator display. 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.

[0044] 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 Figure 1A is shown by the lines 1–1 in Figure 1B. Although Figure 1B illustrates a 3x3 array of IMODs for the sake of clarity, the display array **30** may contain a very large number of IMODs, and may have a different number of IMODs in rows than in columns, and vice versa.

[0045] The details of the structure of interferometric modulators that operate in accordance with the principles set forth above may vary widely. For example, Figures 2–6 show examples of cross-sections of varying implementations of interferometric modulators, including the movable reflective layer **14** and its supporting structures. Figure 2 shows an example of a partial cross-section of the interferometric modulator display of Figure 1A, where a strip of metal material, i.e., the movable reflective layer **14** is deposited on supports **18** extending orthogonally from the substrate **20**. In Figure 3, the movable reflective layer **14** of each IMOD is generally square or rectangular in shape and attached to supports at or near the corners, on tethers **32**. In Figure 4, the movable reflective layer **14** is generally square or rectangular in shape and suspended from a deformable layer **34**, which may include a flexible metal. The deformable layer **34** can connect, directly or indirectly, to the substrate **20** around the perimeter of the movable reflective layer **14**. These connections are herein referred to as support posts. The implementation shown in Figure 4 has additional benefits deriving from the decoupling of the optical functions of the movable reflective layer **14** from its mechanical functions, which are carried out by the deformable layer **34**. This decoupling allows the structural design and materials used for the reflective layer **14** and those used for the deformable layer **34** to be optimized independently of one another.

[0046] Figure 5 shows another example of an IMOD, where the movable reflective layer **14** includes a reflective sub-layer **14a**. The movable reflective layer **14** rests on a support structure, such as support posts **18**. The support posts **18** provide separation of the movable reflective layer **14** from the lower stationary electrode (i.e., part of the optical stack **16** in the illustrated IMOD) so that a gap **19** is formed between the movable reflective layer **14** and the optical stack **16**, for example when the movable reflective layer **14** is in a relaxed position. The movable reflective layer **14** also can include a conductive layer **14c**, which may be configured to serve as an electrode, and a support layer **14b**. In this example, the conductive layer **14c** is disposed on one side of the support layer **14b**, distal from the substrate **20**, and the reflective sub-layer **14a** is disposed on the other side of the support layer **14b**, proximal to the substrate **20**. In some implementations, the reflective sub-layer **14a** can be conductive and can be disposed between the support layer **14b** and the optical stack **16**. The support layer **14b** can include one or more layers of a dielectric material, for example, silicon oxynitride (SiON) or silicon dioxide (SiO_2). In some implementations, the support layer **14b** can be a stack of layers, such as, for example, a SiO_2/SiON/SiO_2 tri-layer stack. Either or both of the reflective sub-layer **14a** and the conductive layer **14c** can include, e.g., an aluminum (Al) alloy with about 0.5% copper (Cu), or another reflective metallic material. Employing conductive layers **14a**, **14c** above and below the dielectric support layer **14b** can balance stresses and provide enhanced conduction. In some implementations, the reflective sub-layer 14a and the conductive layer **14c** can be formed of different materials for a variety of design purposes, such as achieving specific stress profiles within the movable reflective layer **14**.

[0047] As illustrated in Figure 5, some implementations also can include a black mask structure **23**. The black mask structure **23** can be formed in optically inactive regions (e.g., between pixels or under posts **18**) to absorb ambient or stray light. The black mask structure **23** also can improve the optical properties of a display device by inhibiting light from being reflected from or transmitted through inactive portions of the display, thereby increasing the contrast ratio. Additionally, the black mask structure **23** can be conductive and be configured to function as an electrical bussing layer. In some implementations, the row electrodes can be connected to the black mask structure **23** to reduce the resistance of the connected row electrode. The black mask structure **23** can be formed using a variety of methods, including deposition and patterning techniques. The black mask structure **23** can include one or more layers. For example, in some implementations, the black mask structure **23** includes a molybdenum-chromium (MoCr) layer that serves as an optical absorber, a silicon dioxide (SiO_2) layer, and an aluminum alloy that serves as a reflector and a bussing layer, with a thickness in the range of about 30–80 Å, 500–1000 Å, and 500–6000 Å, respectively. The one or more layers can be patterned using a variety of techniques, including photolithography and dry etching, including, for example, tetrafluoromethane (CF_4) and/or oxygen (O_2) for the MoCr and SiO_2 layers and chlorine (Cl_2) and/or boron trichloride (BCl_3) for the aluminum alloy layer. In some implementations, the black mask **23** can be an etalon or interferometric stack structure. In such interferometric stack black mask structures **23**, the conductive absorbers can be used to transmit or bus signals between lower, stationary electrodes in the optical stack **16** of each row or column. In some implementations, a spacer layer **35** can serve to generally electrically isolate the absorber layer **16a** from the conductive layers in the black mask **23**.

[0048] Figure 6 shows another example of an IMOD, where the movable reflective layer **14** is self supporting. In contrast with Figure 5, the implementation of Figure 6 does not include support posts **18**. Instead, the movable reflective layer **14** contacts the underlying optical stack **16** at multiple locations, and the curvature of the movable reflective layer **14** provides sufficient support that the movable reflective layer **14** returns to the unactuated position of Figure 6 when the voltage across the interferometric modulator is insufficient to cause actuation. The optical stack **16**, which may contain a plurality of several different layers, is shown here for clarity including an optical absorber **16a**, and a dielectric **16b**. In some implementations, the optical absorber **16a** may serve both as a fixed electrode and as a partially reflective layer.

[0049] In implementations such as those shown in Figures 2–6, the IMODs function as direct-view devices, in which images are viewed from the front side of the transparent substrate **20**, i.e., the side opposite to that upon which the modulator is arranged. In these implementations, the back portions of the device (that is, any portion of the display device behind the movable reflective layer **14**, including, for example, the deformable layer **34** illustrated in Figure 4) can be configured and operated upon without impacting or negatively affecting the image quality of the display device, because the reflective layer **14** optically shields those portions of the device. For example, in some implementations a bus structure (not illustrated) can be included behind the movable reflective layer **14** which provides the ability to separate the optical properties of the modulator from the electromechanical properties of the modulator, such as voltage addressing and the movements that result from such addressing. Additionally, the implementations of Figures 2–6 can simplify processing, such as patterning.

[0050] Figure 7 shows an example of a flow diagram illustrating a manufacturing process **80** for an interferometric modulator, and Figures 8A–8E show examples of cross-sectional schematic illustrations of corresponding stages of such a manufacturing process **80**.

In some implementations, the manufacturing process **80** can be implemented to manufacture, e.g., interferometric modulators of the general type illustrated in Figures 1A and 2–6, in addition to other blocks not shown in Figure 7. With reference to Figures 1A and 2–7, the process **80** begins at block **82** with the formation of the optical stack **16** over the substrate **20**. Figure 8A illustrates such an optical stack **16** formed over the substrate **20**. The substrate **20** may be a transparent substrate such as glass or plastic, it may be flexible or relatively stiff and unbending, and may have been subjected to prior preparation processes, e.g., cleaning, to facilitate efficient formation of the optical stack **16**. As discussed above, the optical stack **16** can be electrically conductive, partially transparent and partially reflective and may be fabricated, for example, by depositing one or more layers having the desired properties onto the transparent substrate **20**. In the implementation illustrated in Figure 8A, 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**, **16b** can be configured with both optically absorptive and conductive properties, such as the combined conductor/absorber sub-layer **16a**. Additionally, one or more of the sub-layers **16a**, **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**, **16b** can be an insulating or dielectric layer, such as sub-layer **16b** that is deposited over one or more metal layers (e.g., 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.

[0051] The process **80** continues at block **84** with the formation of a sacrificial layer **25** over the optical stack **16**. The sacrificial layer **25** is later removed (e.g., at block **90**) to form the cavity **19** and thus the sacrificial layer **25** is not shown in the resulting interferometric modulators **12** illustrated in Figure 1A. Figure 8B 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 (XeF_2)-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

Figures 1A and 8E) having a desired design size. Deposition of the sacrificial material may be carried out using deposition techniques such as physical vapor deposition (PVD, e.g., sputtering), plasma-enhanced chemical vapor deposition (PECVD), thermal chemical vapor deposition (thermal CVD), or spin-coating.

[0052] The process **80** continues at block **86** with the formation of a support structure e.g., a post **18** as illustrated in Figures 1A, 5 and 8C. The formation of the post **18** may include patterning the sacrificial layer **25** to form a support structure aperture, then depositing a material (e.g., a polymer or an inorganic material, e.g., silicon oxide) into the aperture to form the 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 post **18** contacts the substrate **20** as illustrated in Figure 2. Alternatively, as depicted in Figure 8C, the aperture formed in the sacrificial layer **25** can extend through the sacrificial layer **25**, but not through the optical stack **16**. For example, Figure 8E illustrates the lower ends of the support posts **18** in contact with an upper surface of the optical stack **16**. The 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 Figure 8C, but also can, at least partially, extend 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 patterning and etching process, but also may be performed by alternative etching methods.

[0053] 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 Figures 1A, 2–6 and 8D. The movable reflective layer **14** may be formed by employing one or more deposition steps, e.g., reflective layer (e.g., aluminum, aluminum alloy) deposition, along with one or more patterning, masking, and/or etching steps. 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, **14c** as shown in Figure 8D. In some implementations, one or more of the sub-layers, such as sub-layers **14a**, **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. Since the sacrificial layer **25** is still present in the partially fabricated interferometric modulator formed at block **88**, the movable reflective layer **14** is typically not movable at this stage. A partially fabricated IMOD that contains a sacrificial layer **25** also may be referred to herein as an "unreleased" IMOD. As described above in connection with Figure 1A, the movable reflective layer **14** can be patterned into individual and parallel strips that form the columns of the display.

[0054] The process **80** continues at block **90** with the formation of a cavity, e.g., cavity **19** as illustrated in Figures 1A, 2–6 and 8E. 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 molybdenum (Mo) or amorphous silicon (Si) may be removed by dry chemical etching, e.g., by exposing the sacrificial layer **25** to a gaseous or vaporous etchant, such as vapors derived from solid xenon difluoride (XeF_2) for a period of time that is effective to remove the desired amount of material, typically selectively removed relative to the structures surrounding the cavity **19**. Other etching methods, e.g. 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 may be referred to herein as a "released" IMOD.

[0055] In some implementations described herein, a display is provided that includes interferometric modulator devices having improved tolerance to variation in air gap height and having improved color consistency across the display. The interferometric modulator devices can have multiple optical resonances and can reflect light appearing to a viewer as substantially white. In some implementations, the interferometric modulator devices can have enhanced brightness and can be manufactured at reduced cost.

[0056] Figure 9A shows an example of a schematic cross section of an interferometric stack **99**. The interferometric stack **99** can form a portion of an interferometric modulator, and includes an optical stack **16**, a gap **19**, and a reflector **51**. The optical stack **16** can include a dielectric **59** and a partially reflective optical absorber **53**, such as chromium (Cr). By positioning the dielectric **59** and the gap **19** between the optical absorber **53** and the reflector **51**, an optically resonant cavity **54** having a desired thickness or "thickness dimension" can be formed, as will be described below. As used herein in relation to the optical cavity, the term "thickness," and also "thickness dimension," refer to the distance between the two reflective surfaces that are on either side of the optically resonant cavity **54**. In various implementations, the thickness (or thickness dimension) can include the thickness of the dielectric and the thickness of the gap that are included in an optical cavity. For example, in the configuration illustrated in Figure 9A, the thickness dimension is the distance between the absorber **53** and the reflector **51** and includes the thickness of the gap **19** and the dielectric **59**. Although not illustrated in Figure 9A, the optical stack **16** also can include a transparent conductor, such as indium tin oxide (ITO), which can serve as an electrode to pull the reflector **51** and the optical stack **16** together (using electrostatic forces) when the stack is employed in an interferometric modulator device.

[0057] When incident light **55** reaches the interferometric stack **99**, a portion of the light **55** can be reflected off of the partially reflective optical absorber **53**, thereby forming a first reflected portion of light **56**. Additionally, as shown in Figure 9A, some of the light passes through the absorber **53** and the dielectric **59** and can enter the optically resonant cavity **54** and reach the reflector **51**, where it is reflected back to the partially reflective optical absorber **51**. A first portion of light incident upon the optical absorber **51** from within the optically resonant cavity can exit the cavity to form a second portion of reflected light **57**, while some light can remain within the optically resonant cavity **54**. Each time light within the optically resonant cavity **54** reaches the partially reflective optical absorber **53**, a portion of the light can exit the cavity and a portion of the light can remain in the optically resonant cavity and can be reflected by the reflector **51** one or more times thereafter. Depending on the height of the gap **19**, the wavelength of the light **55**, and the thickness and index of refraction of the dielectric **59**, phase differences can exist between the first portion of light **56** and the portions of light exiting the optically resonant cavity, such as the second and third portions of light **57**, **58**. Based on these phase differences, some wavelengths of the light **55** can constructively interfere, while other wavelengths of the light can destructively interfere.

[0058] In some implementations of interferometric modulator devices, the gap height and dielectric **59** are selected so that the interferometric stack **99** has a single optical resonance in the visible band of light. The wavelength of the optical resonance and the brightness of the reflected light can vary significantly with the height of the gap **19**, and thus it can be important to tightly control gap height variation. Control of the gap height can be difficult, for example, in implementations in which the gap **19** is formed by removing a sacrificial layer. For example, mechanical stresses in the reflector **51** can produce unintended variation in the gap size after removal of the sacrificial material. Additionally, temperature changes can cause variation in gap height.

[0059] In some implementations, an interferometric modulator device is configured with a large gap size such that the reflectivity spectrum includes multiple color peaks. Additionally, the optical stack **16** is selected such that the optical resonances of the interferometric stack **99** extend over a relatively wide range of wavelengths in the spectrum of visible light, thereby reflecting light which appears substantially white to a viewer. Furthermore, a dielectric having a relatively high index of refraction, such as an index greater than or equal to about 2.0, can be employed to increase the brightness of the reflected light. Employing a dielectric having a relatively high index of refraction can result in the interferometric stack reflecting light having a relatively greater brightness as compared to an interferometric stack using a dielectric having a relatively low index of refraction. Since the interferometric stack can be configured to have a plurality of optically resonant peaks within the band of visible light, the plurality of optical peaks can reflect light which appears substantially white to a user.

[0060] Accordingly, employing an interferometric modulator device having a relatively large gap height and a dielectric **59** of a relatively high index of refraction can produce a device which can reflect light appearing to be substantially white and which has an increased brightness. Additionally, as will be described in further detail below, the interferometric modulator device can reflect light which appears to be white over a relatively wide range of gap values, thereby increasing the tolerance of the interferometric modulator device to gap variation and permitting the device to be manufactured using relatively low-cost manufacturing processes.

[0061] Figure 9B shows a graph **91** of brightness versus gap size for one example of an interferometric stack. The graph **91** shows simulation results for an interferometric stack including a partially reflective optical absorber of molybdenum chromium (MoCr) having a thickness of about 5 nm, a zirconium dioxide (ZrO_2) dielectric layer having a thickness of about 40 nm, and an aluminum (Al) reflective layer having a thickness of about 300 nm. Although the graph **91** illustrates a configuration in which the substrate is glass, skilled artisans will appreciate that the results can be similar for a variety of substantially transparent substrates, including plastic substrates.

[0062] As shown in the graph **91**, the brightness of the simulated interferometric stack becomes less sensitive to variation in gap height as the magnitude of the height increases. Thus, in contrast to an interferometric modulator device having a gap height of about 200 nm, an interferometric modulator device having a relatively large gap height, including, for example, gap heights greater than about 1000 nm, exhibits substantially less variation in brightness for a particular variation in gap height size. Thus, interferometric modulator devices employing a relatively large gap height can be manufactured using processes having a lower precision. These processes can be cheaper than processes designed for smaller tolerances, resulting in a decreased cost for a display employing these interferometric modulators.

[0063] Figure 9C shows a graph **92** of reflectivity spectrum versus wavelength for three examples of interferometric stacks. The graph **92** shows simulation results for an interferometric stack including a partially reflective optical absorber of MoCr having a thickness of about 5 nm, a ZrO_2 dielectric layer having a thickness of about 40 nm, and an Al reflective layer having a thickness of about 300 nm over a glass substrate.

[0064] The graph **92** illustrates interferometric stacks for three gap heights. In particular, a first plot **93** illustrates an interferometric stack having a gap height of about 10 nm, a second plot **94** illustrates an interferometric stack having a gap height of about 200 nm, and a third plot **95** illustrates an interferometric stack having a gap height of about 1000 nm. As shown by a comparison of the first plot **93**, the second plot **94**, and the third plot **95** increasing the gap height results in the interferometric stack having a plurality of optical resonances and a plurality of reflectivity spectrum peak wavelengths. The multitude of optical resonances over the band of visible light can result in a reflectance spectrum which produces reflected light that can appear to be substantially white to a viewer. Additionally, the variation in perceived color can vary less than that of a display with a single optical resonance positioned at a single wavelength of light. Furthermore, by selecting the index of refraction to be relatively large, the optical peaks can cover a relatively broader range of wavelengths, which can result in improved brightness. Accordingly, using a relatively large gap height and a dielectric having a relatively high index of refraction in an interferometric modulator device can improve tolerance to gap height variation and can improve the brightness of a display employing the devices.

[0065] Figure 10 shows an example of a flow diagram illustrating a manufacturing process for an interferometric modulator. With reference to Figures 2–6, 9A and 10, the process **100** starts at block **102**, in which a stationary electrode such as the optical stack **16** is formed over the substrate **20**. The substrate **20** can be, for example, a transparent substrate including glass or a transparent polymeric material which permits images to be viewed through the substrate. Although the process **100** is illustrated as starting at block **102**, the substrate **20** can be subjected to one or more prior preparation steps such as, for example, a cleaning step to facilitate efficient formation of the optical stack **16**. Additionally, in some implementations one or more layers are provided before forming the optical stack **16** over the substrate **20**. For example, with reference to Figure 6, in some configurations the black mask **23** is provided before forming the optical stack **16**.

[0066] The optical stack **16** can include an optional transparent conductor, a partially reflective optical absorber layer **53**, and a transparent dielectric **59**. In some implementations, the absorber layer **53** can include molybdenum (Mo), chromium (Cr), tungsten (W), vanadium (V), silicon (Si), germanium (Ge), tantalum (Ta), or osmium (Os), and can have, for example, a thickness in the range of about 3 nm to about 20 nm. The transparent dielectric **59** can be configured to include a material having a relatively high index of refraction, such as zirconium dioxide (ZrO_2), titanium dioxide (TiO_2), hafnium dioxide (HfO_2), silicon nitride (Si_3N_4), silicon oxynitride (SiON), yttrium oxide (Y_2O_3), gallium nitride (GaN), gallium phosphide (GaP), and/or nanocrystalline diamond. In some implementations the index of refraction is selected to be greater than or equal to about 2.0, or more particularly, greater than or equal to about 2.4. Inclusion of a dielectric **59** having a relatively high index of refraction can increase the brightness of the display. In some implementations, the thickness (or thickness dimension) of the dielectric **59** can be selected to be in the range of about 20 nm to about 50 nm.

[0067] The process **100** illustrated in Figure 10 continues to a block **103**, in which a sacrificial layer is formed over the optical stack **16**. The sacrificial layer is later removed to form a gap (e.g., **19** of Figure 9A). The formation of the sacrificial layer over the optical stack **16** may include deposition of a fluorine-etchable material such as molybdenum (Mo) or amorphous silicon (a-Si), in a thickness selected to provide, after subsequent removal, a gap **19** having the desired size. In some implementations, the gap size is selected to be in the range of about 1000 nm to about 10 μm.

[0068] The process **100** illustrated in Figure 10 continues at block **104** with the formation of a support structure, such as the support post **18** illustrated in Figure 5. The formation of the support post **18** may include the steps of patterning the sacrificial layer to form a support structure aperture, then depositing a material (such as a polymer or a silicon oxide) into the aperture using a deposition method such as PECVD, thermal CVD, or spin-coating. In some implementations, the support structure aperture formed in the sacrificial layer extends through both the sacrificial layer and the optical stack **16** to the underlying substrate **20**, so that the lower end of the support post **18** contacts the substrate **20**. In some other implementations, the aperture formed in the sacrificial layer extends through the sacrificial layer, but not through the optical stack **16**.

[0069] The process **100** illustrated in Figure 10 continues at block **105** with the formation of a mechanical layer such as the mechanical layer **14** illustrated in Figure 5. The mechanical layer **14** can be formed by employing one or more deposition steps, e.g., reflective layer (such as aluminum, aluminum alloy) deposition, along with one or more patterning, masking, and/or etching steps. As discussed above, the mechanical layer can be electrically conductive, and in some implementations may serve as the movable electrode. Since the sacrificial layer is still present in the partially fabricated interferometric modulator formed at block **105** of the process **100**, the mechanical layer **14** is typically not movable at this stage.

[0070] The process **100** illustrated in Figure 10 continues at block **106** with the formation of a gap, e.g., the gap **19** illustrated in Figure 9A. The gap **19** may be formed by exposing the sacrificial material, such as the sacrificial material deposited at the block **103**, to an etchant. For example, a sacrificial material such as molybdenum (Mo), tungsten (W), tantalum (Ta) or polycrystalline silicon (poly-Si) or amorphous silicon (a-Si) can be removed by etching. The sacrificial layer can be exposed for a period of time that is effective to remove the material, typically selectively relative to the structures surrounding the gap **19**. Since the sacrificial layer is removed during block **106** of the process **100**, the movable reflective layer **14** is released at this stage.

[0071] The process above can be used for manufacturing, for example, interferometric modulators having improved brightness and robustness to gap height variation. The interferometric modulators can be used, for example, in black and white displays, or in analog interferometric modulator implementations. Additional steps may be employed before, in the middle of, or after the illustrated sequence, but are omitted for clarity.

[0072] In some implementations, interferometric modulator devices are provided that can be used in low-power direct-drive segmented displays. The interferometric devices can be manufactured simply and can function in a display without needing to employ hysteresis. The devices can have enhanced robustness to process variation and temperature, and can be manufactured using relatively simple processes, such as printed circuit board (PCB) technology.

[0073] Figure 11 shows an example of a schematic plan view of a segmented display **120**. The segmented display **120** includes segments **122** which can be used to define segmented alphanumeric and graphic characters. The segmented display **120** can include a patterned substrate, such as a PCB, which can be used to in forming images on the display. Segmented displays can be relatively inexpensive to manufacture, and can have reduced dynamic power consumption relative to a comparably sized passive-array, in which significant power can be consumed during row and column switching.

[0074] In some implementations described herein, a segmented display is provided that includes a patterned substrate and a flexible film. For example, the patterned substrate can be a printed circuit board (PCB) including segments that operate as stationary electrodes and the flexible film can include an optical stack that has a movable electrode. By controlling the electrical potential between portions of the patterned substrate relative to the flexible film, images can be formed on the segmented display. For example, in some implementations, the flexible film can be held at a fixed electrical potential and the electrical potential of the segments can be selectively controlled to form an image on the segmented display. For instance, generating a relatively large voltage difference between a segment and the flexible film, such as a voltage difference having a magnitude greater that about 5 V, can create an electrostatic force between the flexible film and the segment that can cause a portion of the flexible film over the segment to collapse. Accordingly, the segmented display can be controlled by selectively controlling the electrical potential of the segments relative to the flexible film.

[0075] Although one example of a drive scheme for a segmented display was described above, the segmented display can be controlled using any suitable drive scheme. For example, in some implementations, the flexible film can be configured to have a relatively high voltage, such as a voltage greater than or equal to about +5 V, and the segments can be configured to have voltages of about 0 V or about +5 V to control the state of the segmented display. However, in other implementations, the flexible film can be configured to have a relatively low voltage, such as a voltage of about 0 V, and the segments can be configured to have voltages of about 0 V or about +5 V to control the state of the segmented display. Additionally, in some implementations, the segments and/or flexible film can be electrically controlled to negative voltages. For example, the flexible film can be controlled to an electrical potential of about 0 V, segments in an unactuated state can be controlled to an electrical potential of about 0 V, and segments in an actuated state can be alternatively controlled between electrical potentials of about +5 V and about -5 V so as to reduce charge build-up on the flexible film over time.

[0076] Figure 12 shows an example of a flow diagram illustrating a manufacturing process **130** for an interferometric modulator. With reference to Figure 12, the process **130** starts at block **134**, in which a substrate having a patterned reflective layer is provided. In some implementations, the patterned substrate is a PCB having a laminated stack of one or more conducting and non-conducting layers. The non-conducting layers can be, for example, FR-4 board or a ceramic. The conductive layers can include copper or a variety of other suitable metals. A patterned reflective layer, such as Al or aluminized copper, can be provided on the surface layer of the PCB.

[0077] The process **130** continues at block **136** with forming an optical stack on a flexible film to produce a flexible interferometric film. The flexible film can include a variety of materials, including, for example polyethylene terephthalate (PET), polyetheretherketone (PEEK), and/or polyimide. The thickness of the flexible film can be selected to achieve a desired flexibility and actuation voltage of the flexible film, as will be described in further detail below. In some implementations, the flexible film has a thickness ranging between about 25um to about 100um.

[0078] The optical stack can include a transparent conductor, a partially reflective optical absorber layer, and a transparent dielectric. The transparent conductor can be configured as an electrode to pull the flexible film toward the substrate. In some implementations, the transparent conductor includes indium tin oxide (ITO), with a thickness selected to be in the range of about 50nm to about 100nm. The absorber layer can include, for example, molybdenum (Mo), chromium (Cr), tungsten (W), vanadium (V), silicon (Si), germanium (Ge), tantalum (Ta), or osmium (Os), and can have, for example, a thickness in the range of about 3 nm to about 20 nm.

[0079] The transparent dielectric can include, for example, a silicon dioxide (SiO_2) layer and/or a material having a relatively high index of refraction, such as zirconium (Zr), titanium dioxide (TiO_2), hafnium dioxide (HfO_2), silicon nitride (Si_3N_4), silicon oxynitride (SiON), yttrium oxide (Y_2O_3), gallium nitride (GaN), gallium phosphide (GaP), or nanocrystalline diamond. The index of refraction can be selected to be greater than or equal to about 2.0, or more particularly, greater than or equal to about 2.4. Inclusion of a dielectric having a relatively high index of refraction can increase the brightness of the segmented display when the gap height is selected to be relatively large so that the optically resonant cavity has a plurality of optical resonances in the visible band of light. The thickness of the dielectric can be selected, for example, to be in the range of about 20 nm to about 50nm.

[0080] A flexible interferometric film can be manufactured in a variety of ways. In some implementations, the film is formed using a sheet process. In some other implementations, the film is formed using a roll-to-roll process. In some implementations, the film is formed using blanket depositions, and does not include patterning, thereby reducing manufacturing complexity and cost.

[0081] The process **130** continues at block **138**, in which spacers are provided. As will be described below, the spacers can be provided to create a gap of an interferometric modulator device through which a mechanical layer moves, thereby changing the reflectance of the interferometric modulator device. In some implementations, the spacers can be positioned in the display region of a segmented interferometric modulator display to support the flexible interferometric film, thereby maintaining a substantially uniform gap between the flexible interferometric film and the patterned reflective layer. The spacers have a density sufficient to support the flexible interferometric film and allow the interferometric modulator film to flex when a desired actuation voltage is applied.

[0082] In some implementations, the spacers include discrete spacers positioned across the surface of the substrate. The spacers can include a resin such as polystyrene or an inorganic material such as silicone, glass or sapphire. The diameter of the spacers can be selected to achieve the desired gap height. In some implementations, the diameter of the spacers is greater than about 200 nm. In some other implementations, the diameter of the spacers is selected to be in the range of about 1000 nm to about 1 µm. The spacers also can include other shapes, such as rods or plates. The spacers can be provided using a variety of processes, including, for example, a spray process in which the spacers are randomly scattered to achieve a desired spacer density. In some implementations, the spacer is coated with an adhesive, such as an epoxy.

[0083] Spacers also can be integrated into the patterned substrate or the flexible film. In some implementations, spacers are provided using integrated posts, rails and/or other protrusions on the patterned substrate. In some implementations, the flexible film is fabricated having posts, rails, and/or protrusions of any other suitable pattern. For example, the flexible film can be patterned using periodically spaced posts before depositing a conformal optical stack, thereby producing post structures in the resulting interferometric modulator device.

[0084] With continuing reference to Figure 12, the process **130** continues at block **140**, in which the flexible film is provided over the patterned substrate to form an interferometric modulator device. In some implementations, the film is machine cut to fit the patterned substrate, and laminated to the patterned substrate. Skilled artisans will appreciate that one or more additional steps can be performed before providing the flexible film over the patterned substrate. For example, a desiccant configured to absorb water molecules that permeate the display package structure once it has been manufactured can be provided. The desiccant can maintain a low humidity environment between the flexible film and the substrate and can prevent water vapor from adversely affecting the operation of the interferometric modulator device. Suitable desiccant materials include, but are not limited to, zeolites, calcium sulfate ($CaSO_4$), calcium oxide (CaO), silica gel, molecular sieves, surface adsorbents, bulk adsorbents, and/or chemical reactants.

[0085] The process above can be used for manufacturing, for example, interferometric modulator devices that can be used in a segmented display, such as the segmented display **120** of Figure 11. The segmented display can be a direct-drive display in which row and column switching is eliminated, thereby reducing power consumption and avoiding a need to use hysteresis. Furthermore, the segmented display can employ a substrate having a patterned reflective layer, such a PCB, to form an interferometric stack. The resulting interferometric modulator devices can be manufactured inexpensively, and can be tolerant to process, voltage, and/or temperature variation. Additional steps may be employed before, in the middle of, or after the illustrated sequence, but are omitted for clarity.

[0086] Figures 13A–13G show examples of cross-sectional schematic illustrations of various stages in methods of making interferometric modulators according to various implementations.

[0087] Figures 13A–13C illustrate forming a substrate having a patterned reflective layer. In Figure 13A, a nonconductive substrate **150** having a conductor **151** has been provided. In some implementations, the nonconductive substrate **150** and a conductor **151** are a blank PCB including a uniform layer of copper (Cu) over a nonconductive substrate, such as FR-4 board.

[0088] In Figure 13B, the conductor **151** has been patterned to form a patterned substrate **152**. The conductor **151** can include a plurality of segments and/or symbols selectively arranged in any suitable configuration. Accordingly, the patterned substrate **152** can be employed in a segmented display, such as the segmented display **120** of Figure 11. The conductor **151** can be patterned using a variety of techniques, including, for example, silk screen printing, photoengraving, and/or milling. Although Figures 13A and 13B illustrate patterning the conductor **151** on the nonconductive substrate **150** to form the patterned substrate **152**, persons having ordinary skill in the art will appreciate that the patterned substrate **152** can be formed by a variety of other methods, such as by depositing traces on the substrate using electroplating.

[0089] In Figure 13C, a reflector **154** has been formed on the conductor **151**. The reflector **154** can include a variety of materials suitable for formation on a conductive surface. In some implementations, the conductor **151** includes Cu and the reflector **154** includes aluminized copper. The aluminized copper reflector can be formed using, for example, an aluminum deposition step followed by a high-temperature anneal. However, skilled artisans will appreciate that a wide variety of method can be employed to form aluminized copper on a copper conductor. In some implementations, the reflector **154** can have a thickness ranging between about 20 nm to about 100 nm.

[0090] Figure 13D illustrates providing a flexible interferometric film **155**. As shown in Figure 13D, the flexible interferometric film **155** includes an optical stack **16** and a flexible film **153**. The illustrated optical stack **16** includes a transparent conductor, a partially reflective optical absorber layer, and a transparent dielectric. The flexible interferometric film **155** can be formed, for example, using uniform conformal depositions in a sheet process.

[0091] In Figure 13E, spacers **157** have been provided over the patterned substrate **152** of Figure 13C. The spacers **157** can be distributed across the surface of the patterned substrate **152**, and can be used to define the gap height of an interferometric modulator device, as will be described below. The spacers **157** can be provided using a variety of processes, including, for example, a spray process in which the spacers are randomly scattered to achieve a desired spacer density. The spacers **157** can be coated with an adhesive, such as an epoxy, either before or after being distributed.

[0092] Spacers also can be integrated into the patterned substrate or the flexible film, rather than by distributing discrete objects. For example, spacers can be provided using integrated posts, rails and/or other protrusions on the patterned substrate **152**. In some implementations, the flexible film **153** is fabricated to have protrusions. For example, the flexible film can be patterned using periodically spaced posts before depositing a conformal optical stack, thereby producing post structures in the film.

[0093] Figures 13F illustrates providing the flexible interferometric film **155** over the patterned substrate **152** to form an interferometric modulator device. The flexible interferometric film **155** can be machine cut to fit the patterned substrate **152**, and thereafter the flexible interferometric film **155** and the patterned substrate **152** can be laminated together. Desiccant can be provided before attaching the flexible interferometric film **155**, to maintain a low humidity environment in the gap **19** to prevent water vapor from adversely affecting the operation of the interferometric modulator device.

[0094] Figures 13F and 13G illustrate the interferometric modulator device in the relaxed and actuated positions, respectively. The spacers **157** support the flexible film **153** and the optical stack **16** over a collapsible gap **19**. The spacers **157** can be used to define the gap height of the interferometric modulator device. Additionally, the density of the spacers **157** can be used to selectively vary the actuation voltage of the interferometric modulator device, which can be based on the flexibility of the flexible interferometric film **155** and the height of the gap **19**. The density of spacers **157** can be varied to control the tension of the flexible interferometric film **155**, thereby controlling the actuation voltage of the interferometric modulator device. For example, the density of spacers can be determined by the stiffness of the film. In some implementations, the density of the spaces is in the range of about 1 spacer per 10,000 μm^2 to about 1 spacer per 1 μm^2.

[0095] The reflective layer **154**, the gap **19**, and the optical stack **16** form an interferometric stack, such as the interferometric stack **99** of Figure 9A. A voltage can be applied between the transparent conductor in the optical stack **16** and the conductor **151** to collapse the gap **19** into the actuated position, as shown in Figure 13G. In some implementations, the gap **19** has a height selected using the spacers **157** to be in the range of about 1000 nm to about 10 μm to form an interferometric modulator device having multiple optical resonances. The multiple optical resonances can be employed to produce reflected light which is substantially white over a relatively wide range of gap sizes. For example, as was described above with reference to Figures 8–10, employing an interferometric modulator device having a relatively large gap height can reduce the sensitivity of the interferometric modulator device to gap height variation and temperature, which can permit the use of manufacturing processes having a relatively low precision. These processes can be cheaper than processes designed for smaller tolerances, resulting in a decreased cost for a display employing these interferometric modulators.

[0096] The interferometric modulator device of Figures 13F and 13G can be used in a segmented display, such as the segmented display **120** of Figure 11. Although the spacers **157** can result in portions of the interferometric modulator device reflecting an undesired color, the density of the spacers **157** can be relatively low, and the segmented display can have a resolution suitable for a wide variety of applications.

[0097] The patterned substrate **152** can be a PCB, and can include vias to allow electrical connection to conductors positioned on the opposite side of the substrate **150**. Thus, the patterned substrate **152** can include one or more additional conductive layers used in selectively controlling the voltage provided to the conductive layer **151**. By varying the voltage provided to portions of the conductor **151**, portions of the flexible interferometric film **155** can be selectively relaxed or actuated, thereby controlling the images displayed on the segmented interferometric display.

[0098] Figure 14 shows an example of a flow diagram illustrating a manufacturing process **170** for an interferometric modulator. With reference to Figure 14, the process **170** starts at block **174**, in which an optical stack is formed on a first substrate. The first substrate can be, for example, a transparent substrate including plastic, or other transparent bendable substrates. Although the process **170** is illustrated as starting at **172**, in some implementations one or more layers are provided before forming the optical stack over the first substrate.

[0099] The process **170** continues at block **176**, in which an adhesive is formed on the first substrate. The adhesive can be, for example, an epoxy, or any other suitable material. The adhesive can be deposited in a variety of ways, including deposition. The adhesive can have a strength and thickness selected to support a flexible reflective layer, as will be described in further detail below. Additionally, the adhesive can be used to provide a thin gap and to maintain tension for a subsequently attached layer, as will be described in detail below. In some implementations, the adhesive is provided randomly across a surface of the first substrate. However, in some other implementations, the adhesive is selectively provided over particular locations of the first substrate.

[0100] The method **170** continues at a block **178**, in which a reflective layer is formed on a sacrificial substrate. The sacrificial substrate can be planar, or may be shaped to have a preformed pattern. Preformed patterns may be provided by, for example, embossing, inscribing, or depositing/etching rails and/or posts such that the reflective layer can be discontinuously deposited thereon. The sacrificial substrate can include, for example, silicon (Si), glass, or a plastic. The reflective layer can be, for example, an Al layer. The reflective layer can be formed using any suitable technique, including, for example, photolithography and etching, or screen printing. The thickness of the reflective layer can be selected to vary the actuation voltage of the interferometric modulator device, as will be described below.

[0101] One or more additional layers can be provided before or after forming the reflective layer on the sacrificial substrate. In some implementations, a nonconductive layer is provided before forming the reflective layer in order to prevent electrical shorts in the resulting interferometric modulator device.

[0102] With continuing reference to Figure 14, the process **170** continues at block **180**, in which the reflective layer is attached to the adhesive. Attaching the reflective layer to the adhesive can include a heating step to aid in curing the adhesive. The method **170** continues at a block **182**, in which the sacrificial substrate is removed. Removal of the sacrificial substrate can be performed using a variety of suitable methods, including an etching step.

[0103] In a block **184**, a second substrate having a patterned conductive layer is provided. In some implementations, the patterned substrate is a printed circuit board (PCB) having a laminated stack of one or more conducting and non-conducting layers. The non-conducting layers can be, for example, FR-4 board or a ceramic. The conductive layers can include Cu and/or a variety of other suitable metals. A patterned conductive layer, such as copper or aluminized copper, can be provided on the surface layer of the PCB.

[0104] The process **170** continues at block **186**, in which spacers are provided over the second substrate. As will be described below, the spacers can be provided to maintain a gap of an interferometric modulator device. The spacers can be positioned in the display region of a segmented interferometric modulator display to support the movable reflective layer and the optical stack, thereby maintaining a substantially uniform gap between the reflective layer and the second substrate. The spacers can have a density sufficient to support the movable reflective layer and which provides a desired actuation voltage.

[0105] In some implementations, the spacers include discrete spacers, such as spherical objects, positioned across the surface of the substrate. Spacers also can be integrated into the second substrate. In some implementations, spacers are provided using integrated posts, rails or other protrusions on the second substrate.

[0106] In a block **188**, the first and second substrates are attached to form an interferometric modulator. Before attaching the first and second substrates, a desiccant can be provided to maintain a low humidity environment between the first and second substrates and can prevent water vapor from adversely affecting the operation of the interferometric modulator device. Suitable desiccant materials can be as described earlier.

[0107] The process **170** above can be used for manufacturing, for example, the interferometric modulators illustrated in Figures 15F–15I below. The interferometric modulator devices can be employed in a segmented display, such as the segmented display **120** of Figure 11. Additional steps may be employed before, in the middle of, or after the illustrated sequence, but are omitted for clarity.

[0108] Figures 15A–15I show examples of cross-sectional schematic illustrations of various stages in methods of making interferometric modulators according to various implementations. **[0108]** Figures 15A and 15B illustrate providing an optical stack **16** and an adhesive **192** over a first substrate **190**. The first substrate **190** can be, for example, a transparent substrate including glass, plastic and/or a film, and the optical stack **16** can include, for example, a partially reflective optical absorber layer, and a transparent dielectric. Although not illustrated, the optical stack also can include an optional transparent conductor.

[0109] In Figure 15C, a nonconductive layer **197** and a reflective layer **199** have been formed over a sacrificial substrate **196**. The sacrificial substrate **196** can be planar, as illustrated, or may be shaped to have preformed patterns, such as posts or rails. The reflective layer **199** can include, for example, an Al layer. The thickness of the reflective layer **199** can be selected to aid in achieving a desired actuation voltage of the interferometric modulator device. In Figure 15C, the nonconductive layer **197** has been provided before forming the reflective layer **199** in order to prevent electrical shorts in the resulting interferometric modulator device, as will be described in further detail below. However, in some implementations, such as those shown in Figures 15H and 15I, formation of the nonconductive layer **197** can be omitted and other schemes for preventing electrical shorts can be used.

[0110] In Figures 15D and 15E, the reflective layer **199** is attached to the adhesive **192**, and the sacrificial substrate **196** is removed. As shown in Figure 15D, after attaching the reflective layer **199** to the adhesive **192**, a thin gap **198** can be formed. The thin gap **198** can server to space the reflective layer **199** from the optical stack **16**, thereby facilitating subsequent actuation of the reflective layer **199**.

[0111] In Figure 15F, the first substrate **190** and the structures disposed thereon have been attached to a patterned substrate **152** having a patterned conductive layer **151** and spacers **157**. The resulting interferometric modulator device includes an optical stack **16** and a reflective layer **199** separated by a collapsible gap **19**. In Figure 15F, the interferometric modulator device is shown in the relaxed position. In Figure 15G, the interferometric modulator device is shown in the actuated position. The nonconductive layer **197** can prevent electrical shorts when the device is actuated. The patterned substrate can be, for example, a PCB. The conductor **151** optionally can be aluminized, as was described above with reference to Figure 13C.

[0112] With reference to Figures 15F and 15G, the spacers **157** support the reflective layer **199** and the optical stack **16** over the collapsible gap **19**. The spacers **157** can be used to define the gap height of the interferometric modulator device. Additionally, the density of the spacers **157** can be used to selectively vary the actuation voltage that is needed to actuate the interferometric modulator device. For example, the density of the spacers can affect the flexibility of the reflective layer **199,** and size or diameter of the spacers can affect the height of the gap **19**. In particular, the density of the spacers **157** can be varied to control the tension of reflective layer **199**, thereby controlling the actuation voltage of the interferometric modulator device. Additionally, the thickness of the reflective layer **199** can be selected to vary the flexibility of the layer. In some implementations, the density of spacers is selected to be in the range of about 1 spacer per 10,000 μm^2 to about 1 spacer per 1 μm^2, and the thickness of the aluminum is selected to be in the range of about 30 nm to about 100 nm.

[0113] The reflective layer **199**, the gap **19**, and the optical stack **16** form an interferometric stack, such as the interferometric stack **99** of Figure 9A. A voltage can be applied between the reflective layer **199** and the conductor **151** to collapse the gap **19** into the actuated position, as shown in Figure 15G. In some implementations, the gap **19** has a height selected using the spacers **157** to be in the range of about 1000 nm to about 10 μm to form an interferometric modulator device having multiple optical resonances.

[0114] Figures 15H and 15I illustrate another example of an interferometric modulator device. In contrast to the interferometric modulator device of Figures 15F and 15G, the illustrated interferometric modulator device includes a nonconductive layer **197** formed on the conductor **151** of the patterned substrate **152**. The nonconductive layer **197** can aid in preventing electrical shorts between the conductor **151** and the reflective layer **199** when the interferometric modulator device is in the relaxed position. Thus, employing the nonconductive layer **197** on the patterned substrate can remove the need for forming a nonconductive layer on a surface of the reflective layer **199**. The nonconductive layer **197** can be formed on the patterned substrate **152** using a variety of techniques, including any suitable coating method.

[0115] Figure 16 shows an example of a flow diagram illustrating a manufacturing process **200** for an interferometric modulator. With reference to Figure 16, the process **200** starts at block **202**, in which an optical stack is formed on a first substrate. Details of this step can be as described above with reference to block **174** of Figure 14.

[0116] In a block **204**, an adhesive inhibitor is formed on the first substrate. The adhesive inhibitor can include, for example, a material suitable to prevent adhesion of a materially subsequently deposited using physical vapor deposition (PVD) or other deposition processes. The adhesive inhibitor can be uniformly deposited, and then selectively removed to permit a subsequently deposited reflective layer to contact the optical stack.

[0117] With continuing reference to Figure 16, the process **200** continues at block **206**, in which a reflective layer is provided over the first substrate and the adhesive inhibitor. Based on the patterning of the adhesive inhibitor, the reflective layer can contact the adhesive inhibitor or the optical stack. Thereafter, the reflective layer can be patterned to produce holes or other perforations to aid in releasing the reflective layer, as will be described below.

[0118] The process **200** continues at block **208**, in which the reflective layer is released. In some implementations, releasing the reflective layer includes providing a superstructure having an electrode, and applying a voltage between the electrode and the reflective layer. The resulting electrostatic forces can pull the reflective layer away from the first substrate, and can create a thin gap between the reflective layer and the adhesion inhibitor. The reflective layer can include holes or other perforations configured to avoid creating a vacuum when the reflective layer is released.

[0119] The process **200** of Figure 16 continues at block **210**, in which a second substrate having a patterned conductive layer is provided. In a block **212**, spacers are provided over the second substrate. The process **200** continues at block **214**, in which the first and second substrates are attached to form an interferometric modulator. Additional details of blocks **210**, **212**, **214** can be as described above with reference to blocks **184**, **186**, **188** of Figure 14.

[0120] The process **200** above can be used for manufacturing, for example, the interferometric modulators illustrated in Figures 17E and 17F below. The interferometric modulator devices can be employed in a segmented display, such as the segmented display **120** of Figure 11. Additional steps may be employed before, in the middle of, or after the illustrated sequence, but are omitted for clarity.

[0121] Figures 17A–17F show examples of cross-sectional schematic illustrations of various stages in methods of making interferometric modulators according to various implementations. It will be understood that not all of the illustrated steps are required, and that this method can be modified without departing from the spirit and scope of the invention.

[0122] In Figures 17A, an optical stack **16** has been formed over a first substrate **190**. Additional details can be similar to those described above with reference to Figure 15A. In Figure 17B, an adhesive inhibitor **219** has been provided over the first substrate **190** and the optical stack **16**. The adhesive inhibitor **219** can be patterned to permit a subsequently deposited layer to selectively contact the optical stack **16**. The adhesive inhibitor **219** can be optically transparent and can be configured to prevent adhesion of a subsequently deposited layer. The adhesive inhibitor can be deposited using any suitable deposition technique, can be selectively patterned using, for example, an etching or micromachining processes.

[0123] In Figure 17C, a reflective layer **199** has been provided over the adhesive inhibitor **219** and the first substrate **190**. The reflective layer **199** can be deposited using a variety of suitable processes, and can include, for example, Al. Additional details of the reflective layer **199** can be as described above with reference to Figures 14–16. After the reflective layer **199** is provided, the reflective layer can be patterned with holes or other perforations to aid in preventing the formation of a vacuum when the reflective layer is subsequently released, as will be described below.

[0124] Figure 17D illustrates providing a superstructure **221** over the first substrate **190**. A voltage can be applied between the superstructure **221** and the reflective layer **199**. The applied voltage can generate electrostatic forces which can pull the reflective layer **199** away from the adhesive inhibitor **219** to define a thin gap **198**. The thin gap **198** can server to space the reflective layer **199** from the first substrate **190**, thereby facilitating subsequent actuation of the reflective layer **199**. In some implementations, the thin gap **198** has a height in the range of about 50 nm to about 1,000 nm.

[0125] After release of the reflective layer **199**, the first substrate **190** and the structures formed thereon can be attached to a patterned substrate **152**. The attachment process and particular configurations of the patterned substrate **152** can be as described above with reference to Figures 13F and 15F.

[0126] The resulting interferometric modulator is shown in the relaxed and actuated positions in Figures 17E and 17F, respectively. As illustrated, the spacers **157** support the reflective layer **199** and the optical stack **16** over the collapsible gap **19**. The spacers **157** can be used to define the gap height of the interferometric modulator device, and the density of the spacers **157** can be used to selectively vary the actuation voltage of the interferometric modulator device, as described above with reference to Figures 15F and 15G. The reflective layer **199**, the gap **19**, and the optical stack **16** form an interferometric stack, such as the interferometric stack **99** of Figure 9A. A voltage can be applied between the reflective layer **199** and the conductor **151** to move the reflective layer **199** into the actuated position, as shown in Figure 15G. A nonconductive layer **197** can be prevented to prevent electrical shorts when the interferometric modulator device is actuated. However, skilled artisans will appreciate that the nonconductive layer can be omitted in favor of using, for example, a nonconductive layer on the reflective layer **197**.

[0127] Figures 18A and 18B show examples of system block diagrams illustrating a display device **40** that includes a plurality of interferometric modulators. 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, tablets, e-readers, hand-held devices and portable media players.

[0128] 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.

[0129] 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 interferometric modulator display, as described herein.

[0130] The components of the display device **40** are schematically illustrated in Figure 18B. 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 is coupled to a transceiver **47**. 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 (e.g., filter a signal). The conditioning hardware **52** is connected to a speaker **45** and a microphone **46**. The processor **21** is also connected to an input device **48** and a driver controller **29**. The driver controller **29** is coupled to a frame buffer **28**, and to an array driver **22**, which in turn is coupled to a display array **30**. In some implementations, a power supply **50** can provide power to substantially all components in the particular display device **40** design.

[0131] 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** is 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 or 4G 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**.

[0132] 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 is 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.

[0133] 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.

[0134] 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**.

[0135] 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 pixels.

[0136] 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 controller). Additionally, the array driver **22** can be a conventional driver or a bi-stable display driver (such as an IMOD display 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 IMODs). 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.

[0137] 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 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**.

[0138] 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.

[0139] 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.

[0140] 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.

[0141] 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.

[0142] 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.

[0143] 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.

[0144] 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. The word "exemplary" is used exclusively herein to mean "serving as an example, instance, or illustration." Any implementation described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other possibilities or implementations. 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 an IMOD as implemented.

[0145] 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.

[0146] 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. A device comprising:

a plurality of display elements, each element including

a conductive element;

a flexible film including a partially reflective and partially transmissive absorber layer; and

a reflective layer disposed on the conductive element, the reflective layer disposed at least partially between the flexible film and the conductive element,

wherein the reflective layer and the absorber layer define a cavity therebetween and wherein the flexible film is configured to move toward the conductive element when a voltage is applied across the flexible film and the conductive element due to an electrostatic force generated between the flexible film and the conductive element.

2. The device of claim 1, wherein the absorber layer has a thickness dimension that is between about 3 nm and about 20 nm.

3. The device of claim 1, wherein the flexible film further includes a dielectric layer.

4. The device of claim 3, wherein the dielectric layer has a thickness dimension that is between about 20 nm and about 50 nm.

5. The device of claim 3, wherein the dielectric layer is disposed between the absorber layer and the reflective layer.

6. The device of claim 5, wherein the dielectric layer is connected to the absorber layer.

7. The device of claim 3, wherein the dielectric layer includes at least one of zirconium dioxide (ZrO_2), titanium dioxide (TiO_2), hafnium dioxide (HfO_2), silicon nitride (Si_3N_4), silicon oxynitride (SiON), yttrium oxide (Y_2O_3), gallium nitride (GaN), gallium phosphide (GaP), and nanocrystalline diamond.

8. The device of claim 3, wherein the dielectric layer includes a material having an index of refraction greater than about 2.0.

9. The device of claim 8, wherein the dielectric layer includes a material having an index of refraction greater than about 2.4.

10. The device of claim 1, wherein the cavity has a height ranging between about 1 μm and about 10 μm.

11. The device of claim 1, wherein the cavity is configured to produce a plurality of reflectivity spectrum peak wavelengths.

12. The device of claim 1, wherein the absorber layer includes at least one of molybdenum (Mo), chromium (Cr), tungsten (W), vanadium (V), silicon (Si), germanium (Ge), tantalum (Ta), and osmium (Os).

13. The device of claim 1, wherein the display device further includes a printed circuit board, and wherein the printed circuit board includes the conductive element.

14. The device of claim 13, wherein the conductive element includes a copper (Cu) trace.

15. The device of claim 14, wherein the reflective layer includes an aluminized copper coating of the copper trace.

16. The device of claim 1, wherein a surface of the conductive element adjacent to the reflective layer is non-planar.

17. The device of claim 1, wherein the reflective layer includes aluminum (Al).

18. The device of claim 1, further comprising:

a processor that is configured to communicate with the conductive element, the processor being configured to process image data; and

a memory device that is configured to communicate with the processor.

19. The device of claim 18, further comprising:

a driver circuit configured to send at least one signal to the conductive element; and

a controller configured to send at least a portion of the image data to the driver circuit.

20. The device of claim 18, further comprising an image source module configured to send the image data to the processor.

21. The device of claim 20, wherein the image source module includes at least one of a receiver, transceiver, and transmitter.

22. The device of claim 18, further comprising an input device configured to receive input data and to communicate the input data to the processor.

23. The device of claim 1, further comprising spacing elements disposed between the flexible film and the conductive element.

24. The device of claim 23, wherein the spacing elements include glass or sapphire.

25. The device of claim 1, further comprising a substrate layer, wherein the flexible film is disposed between the substrate layer and the reflective layer, wherein the flexible film is fixedly attached to the substrate layer at a plurality of points, and wherein at least a portion of the flexible film is configured to move away from the substrate when a voltage is applied between the absorber layer and the conductive element.

26. A device comprising

a flexible absorber layer, wherein the absorber layer is partially reflective and partially transmissive;

a printed circuit board including at least one conductive trace element; and

a reflective layer disposed over the conductive trace element,

wherein the flexible absorber layer is configured to move toward the printed circuit board when a voltage is applied between the absorber layer the conductive trace element, and wherein movement of the absorber layer alters the optical characteristics of the display device.

27. The device of claim 26, wherein the absorber layer includes molybdenum (Mo).

28. The device of claim 27, further comprising a dielectric layer disposed between the absorber layer and the reflective layer.

29. The device of claim 28, wherein the dielectric layer includes zirconium dioxide (ZrO_2).

30. The device of claim 26, further comprising a plurality of spacing elements disposed between the absorber layer and the printed circuit board.

31. The device of claim 26, wherein the dielectric layer includes a material having an index of refraction greater than about 2.0.

32. The device of claim 26, wherein the absorber layer and the printed circuit board are separated by a gap having a height in the range of about 1 μm and about 10 μm.

33. A device comprising:

display means including

means for applying a voltage;

flexible means for partially reflecting and transmitting light; and means for reflecting light disposed on the voltage applying means, wherein the reflective means is disposed at least partially between the flexible means and the voltage applying means,

wherein the reflective means and the flexible means define a cavity therebetween and wherein the flexible means is configured to move toward the voltage applying means when a voltage is applied between the flexible means and the voltage applying means.

34. The device of claim 33, wherein the voltage applying means includes a printed circuit board.

35. The device of claim 33, wherein reflecting means includes a layer of aluminum (Al).

36. The device of claim 33, wherein the flexible means includes a layer of molybdenum (Mo).

37. A method of manufacturing a device, comprising:

depositing an absorber layer on a sacrificial material, wherein the absorber layer includes a partially reflective and transmissive material;

providing a substrate;

depositing a first adhesive layer on the substrate;

depositing a second adhesive layer on the substrate, wherein the first adhesive layer and the second adhesive layer are substantially co-planar and are spaced apart from one another on a common plane;

positioning the absorber layer over the first and second adhesive layers such that the absorber layer contacts the first and second adhesive layers; and

developing the adhesive layer.

38. The method of claim 37, further comprising:

providing a conductive element;

depositing a reflective layer over at least a portion of the conductive element;

depositing a plurality of spacing elements over the conductive element; and

disposing the absorber layer and substrate over the conductive element such that the absorber layer is disposed between the substrate and the spacing elements.

39. The method of claim 38, wherein the spacing elements include glass or sapphire.

40. The method of claim 38, wherein the conductive element includes a printed circuit board.

41. The method of claim 37, further comprising removing the sacrificial substrate.

42. The method of claim 37, wherein the spacing elements have a height in the range of about 1 μm and about 10 μm.

43. The method of claim 37, further comprising providing a dielectric layer adjacent the absorber layer.

44. The method of claim 43, wherein the dielectric layer includes a material having an index of refraction greater than about 2.0.

45. A method of manufacturing a device, the method comprising:

providing a substrate;

depositing an adhesive inhibiting material on the substrate;

depositing an absorber layer over the adhesive inhibiting material, wherein the absorber layer includes a partially reflective and transmissive material;

providing an electrode; and

applying a voltage between the absorber layer and the electrode to pull a portion of the absorber layer away from the substrate.

46. The method of claim 45, wherein the adhesive inhibiting material is deposited using physical vapor deposition.

47. The method of claim 45, further comprising removing the electrode.

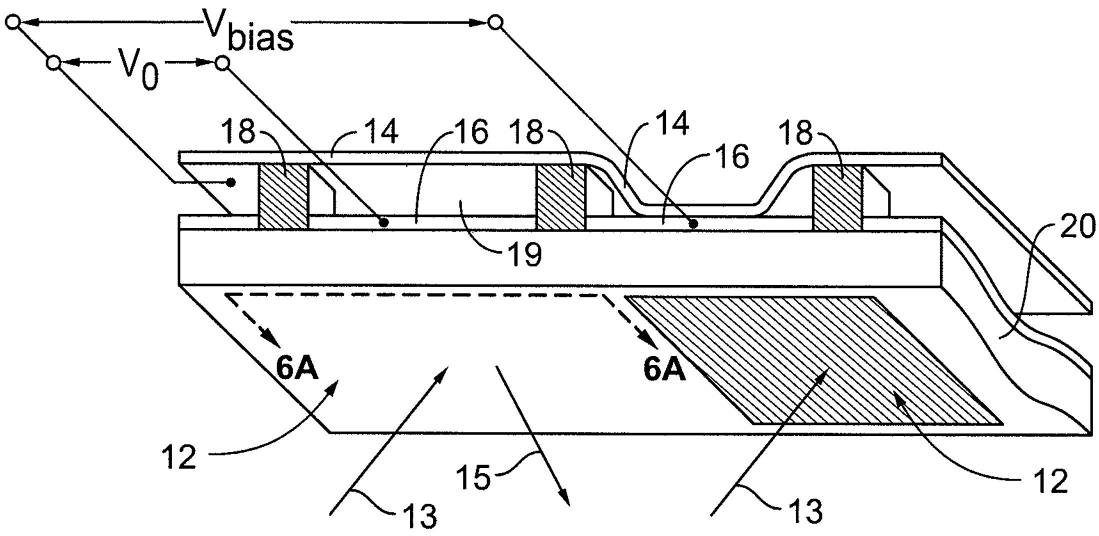
48. The method of claim 45, further comprising:

providing a conductive element;

depositing a reflective layer over at least a portion of the conductive element;

depositing a plurality of spacing elements over the conductive element; and disposing the absorber layer and substrate over the conductive element such that the absorber layer is disposed between the substrate and the spacing elements.

49. The method of claim 45, further comprising removing the adhesive inhibiting material between the substrate and the portion of the absorber that is pulled away from the substrate.



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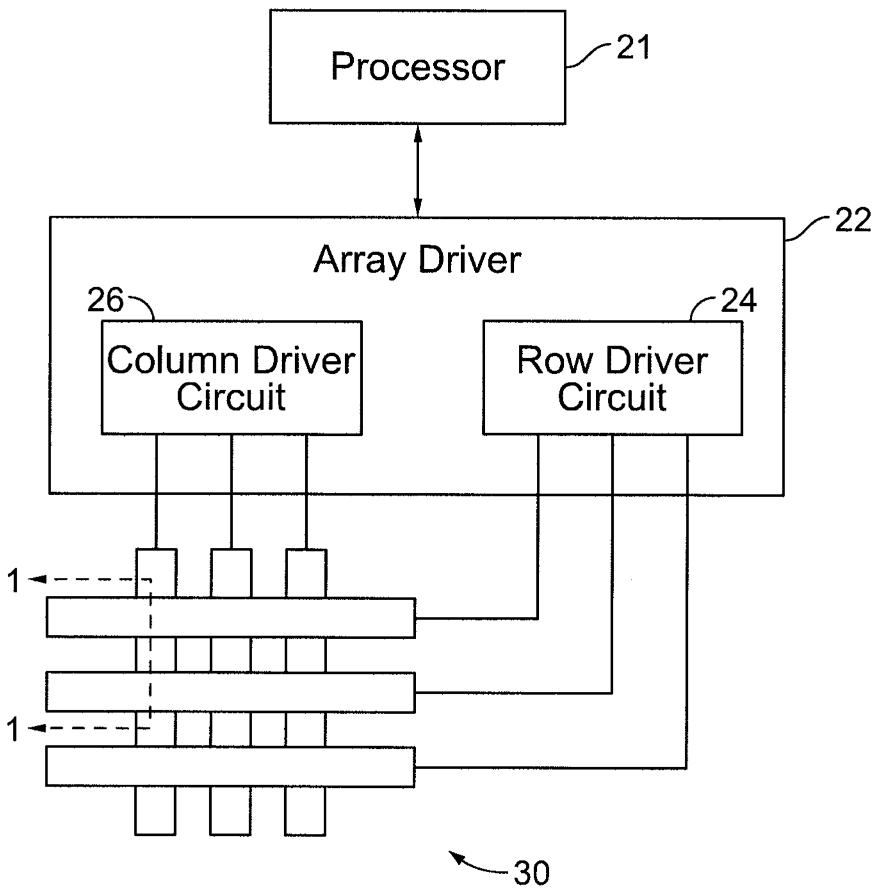

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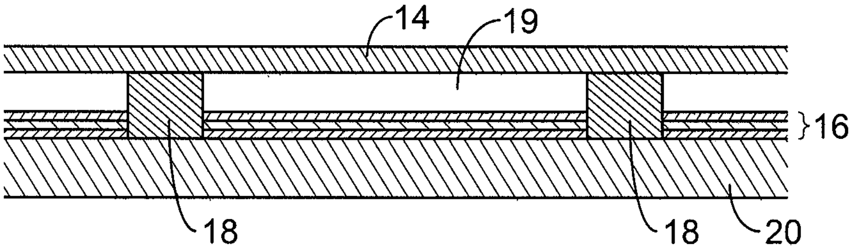


Figure 2

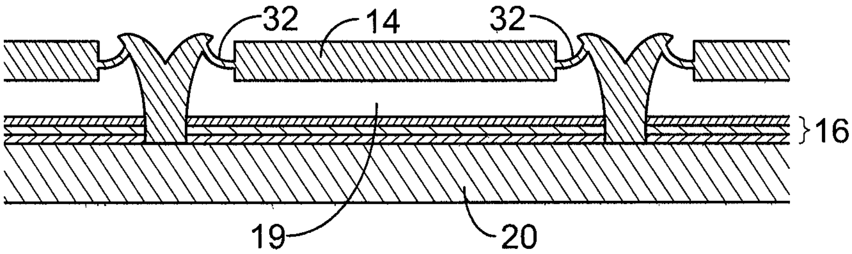


Figure 3

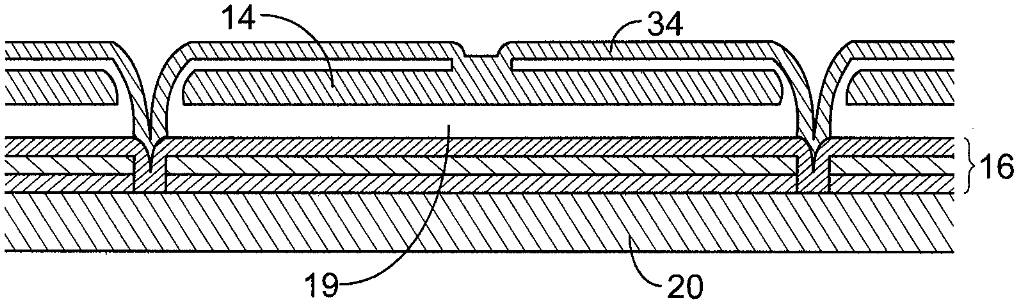


Figure 4

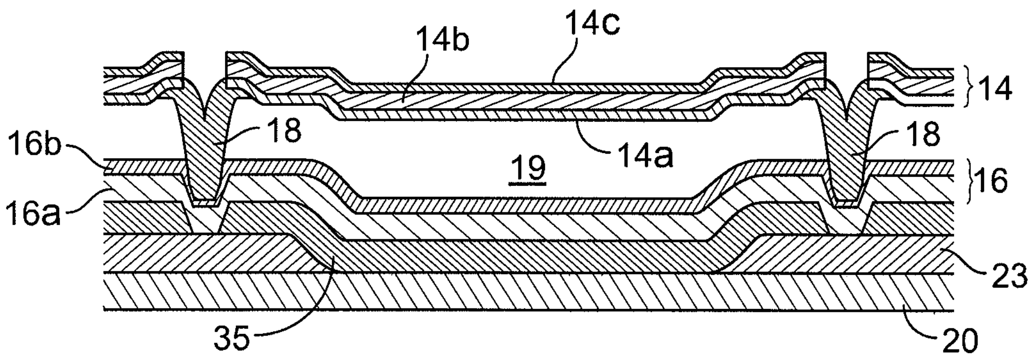


Figure 5

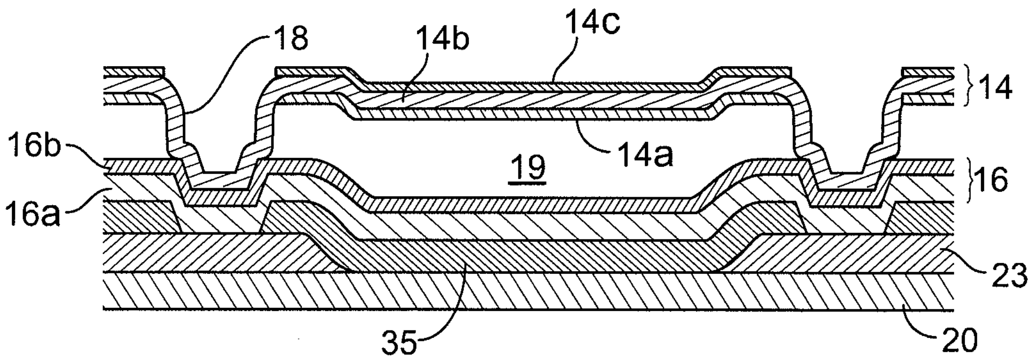


Figure 6

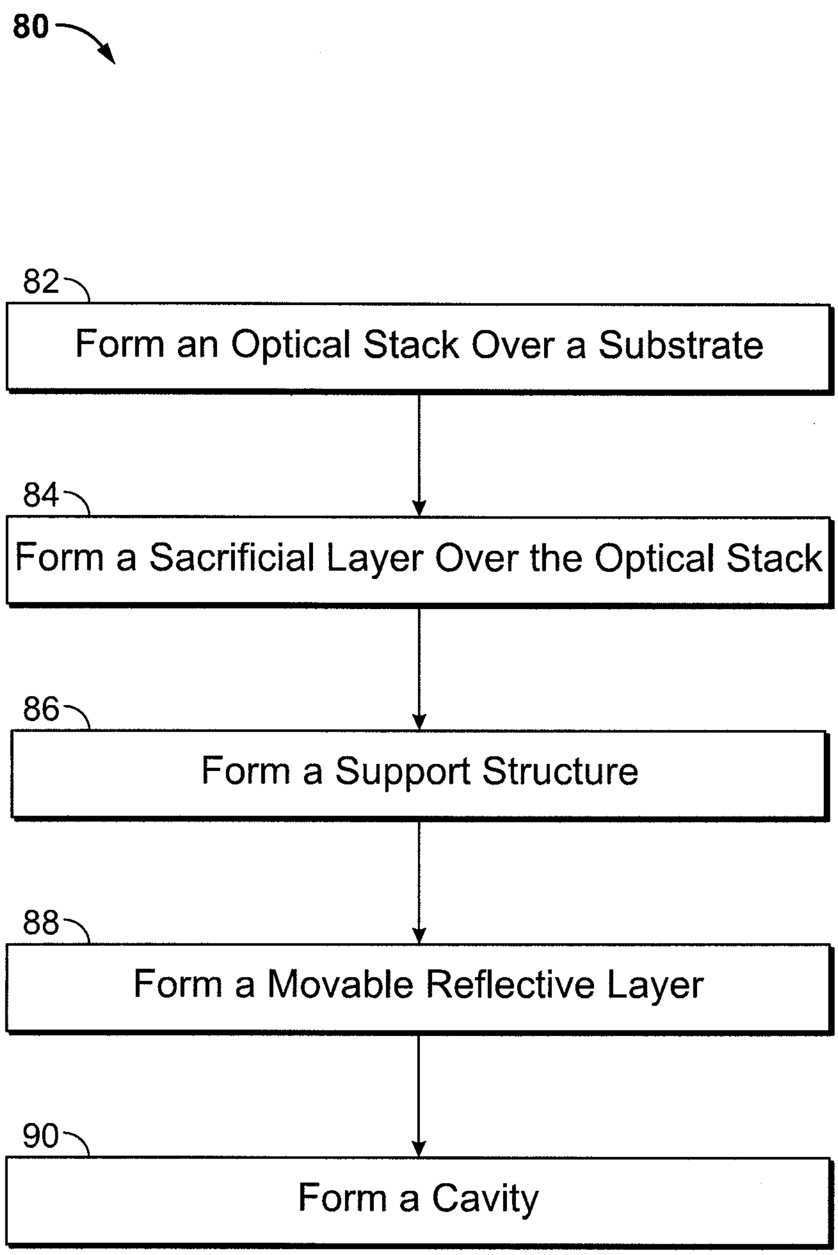

80
82
Form an Optical Stack Over a Substrate
84
Form a Sacrificial Layer Over the Optical Stack
86
Form a Support Structure
88
Form a Movable Reflective Layer
90
Form a Cavity

Figure 7

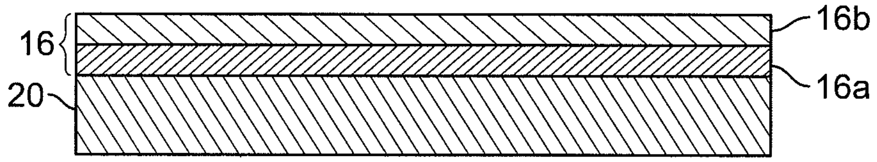


Figure 8A

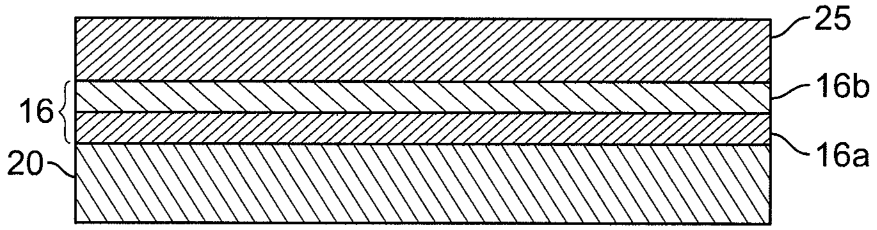


Figure 8B

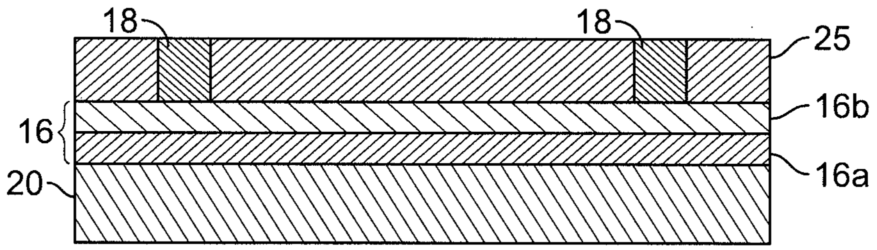


Figure 8C

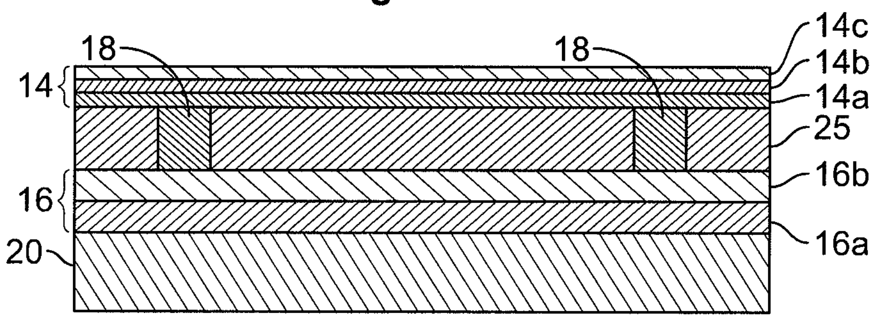


Figure 8D

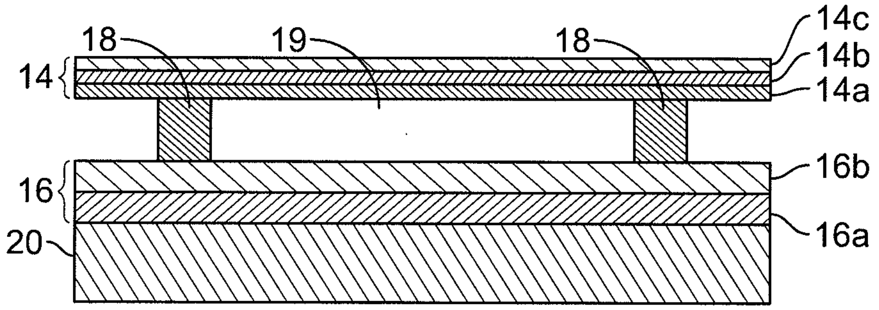


Figure 8E

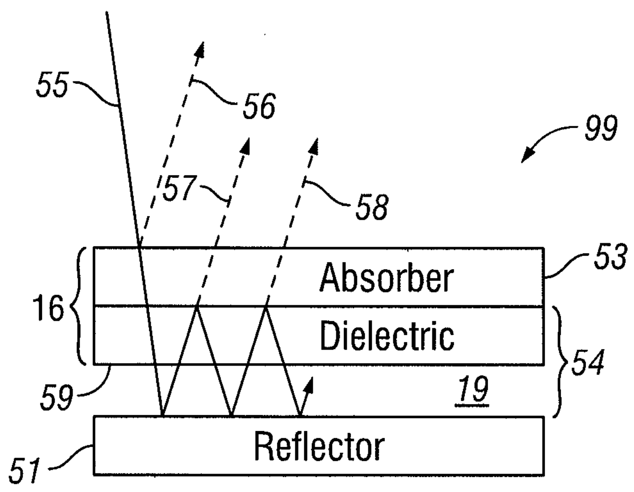


Figure 9A

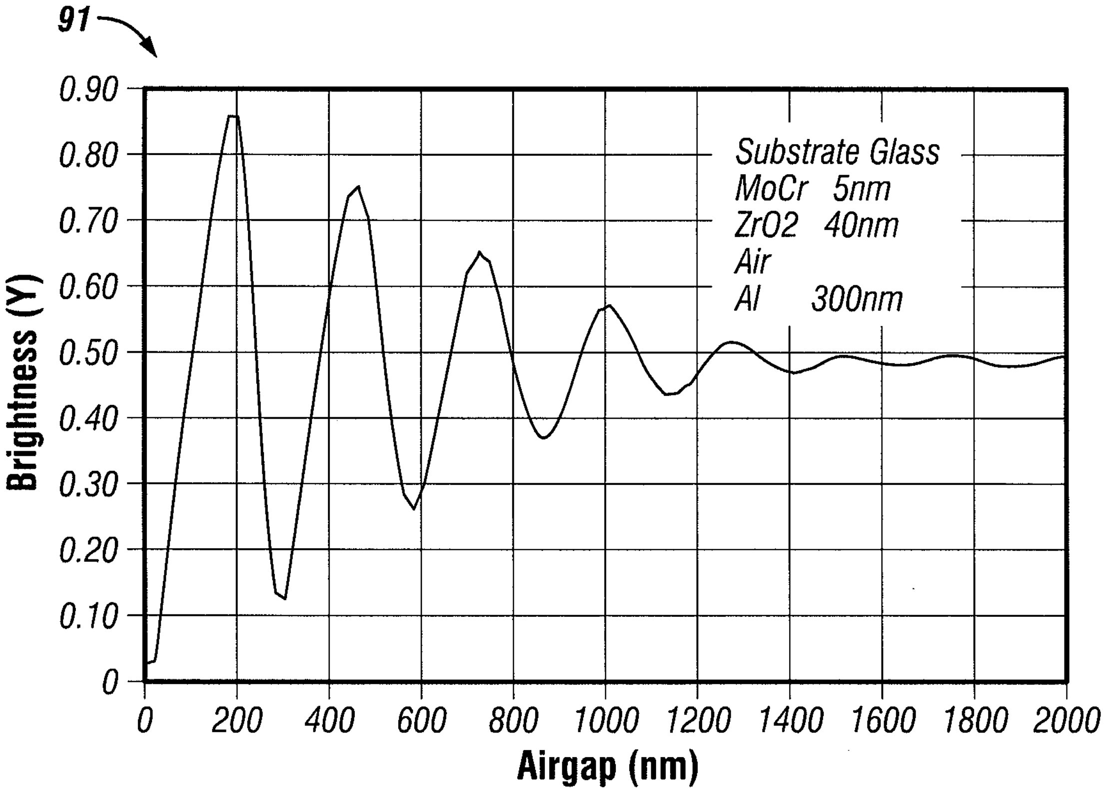


Figure 9B

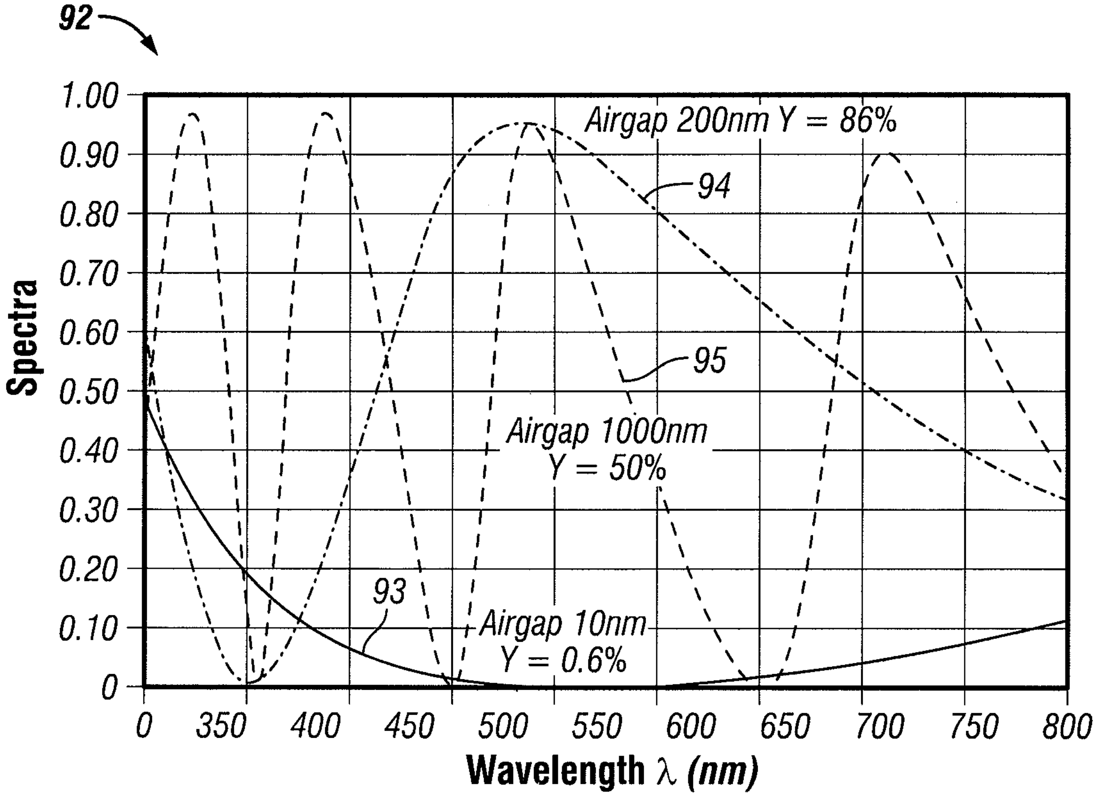


Figure 9C

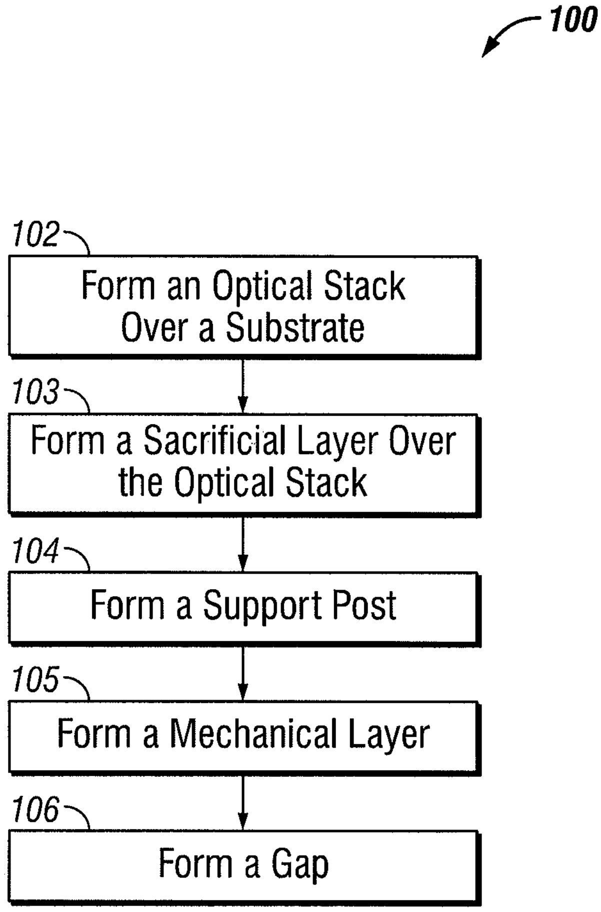

100
102
Form an Optical Stack Over a Substrate
103
Form a Sacrificial Layer Over the Optical Stack
104
Form a Support Post
105
Form a Mechanical Layer
106
Form a Gap

Figure 10

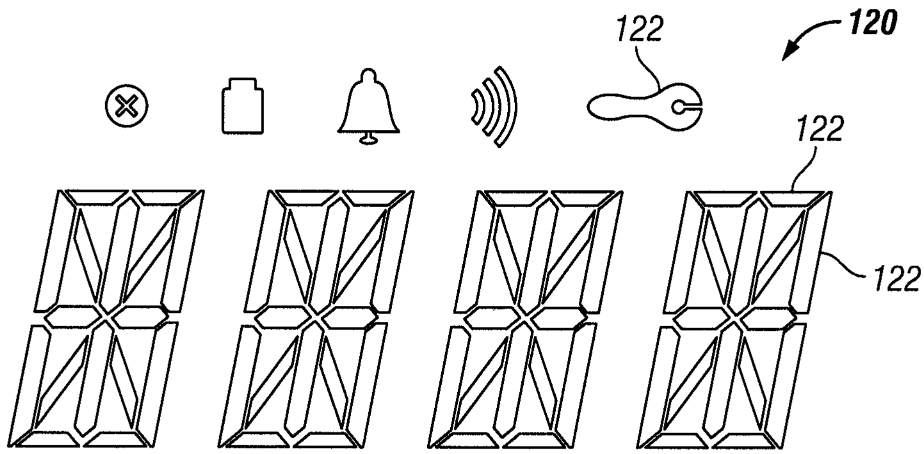


Figure 11

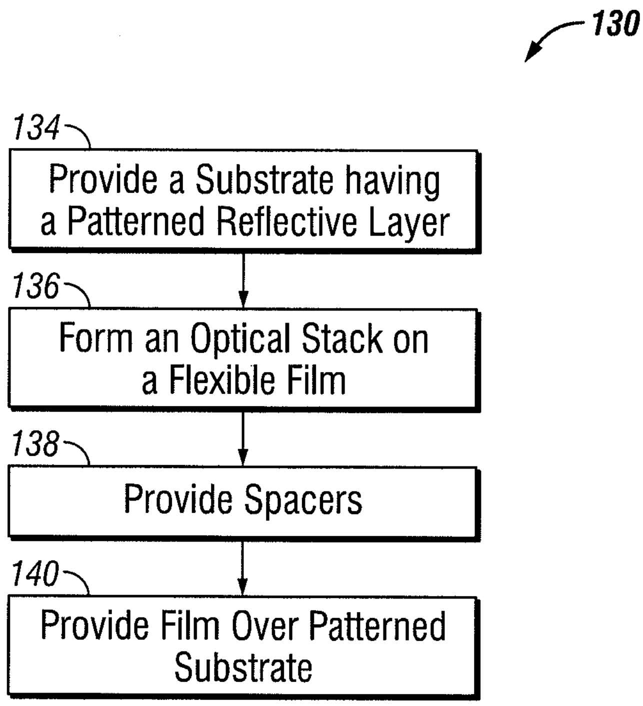


Figure 12

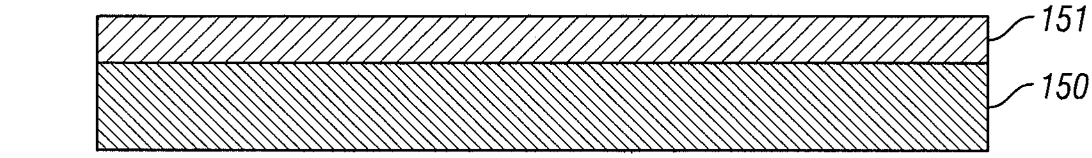


Figure 13A

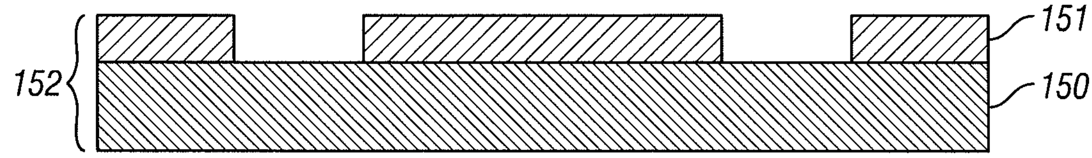


Figure 13B

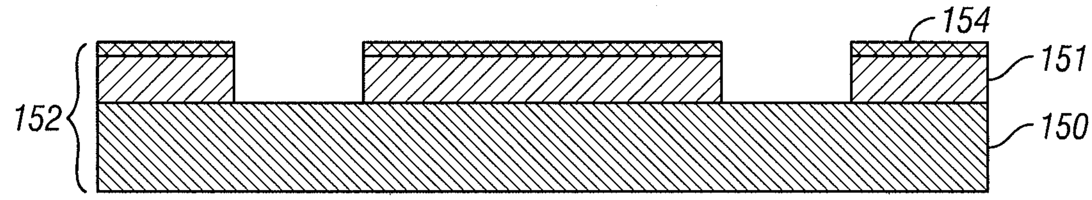


Figure 13C

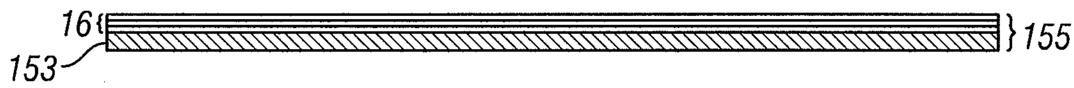


Figure 13D

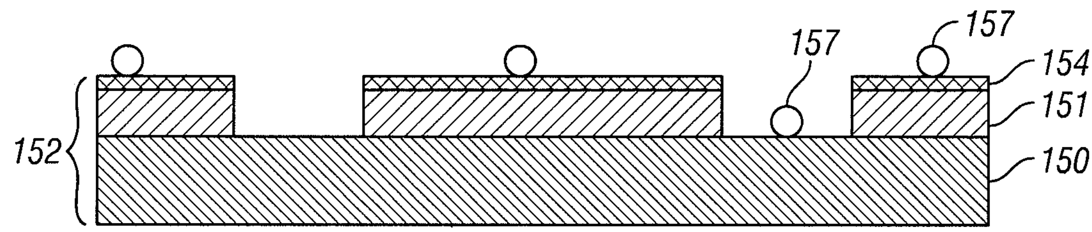


Figure 13E

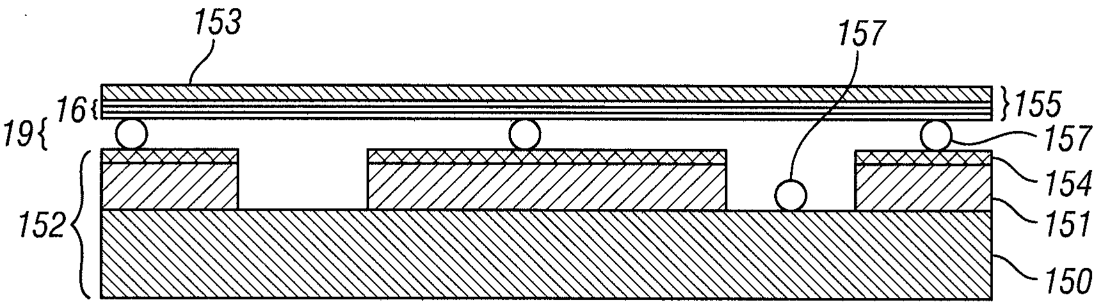


Figure 13F

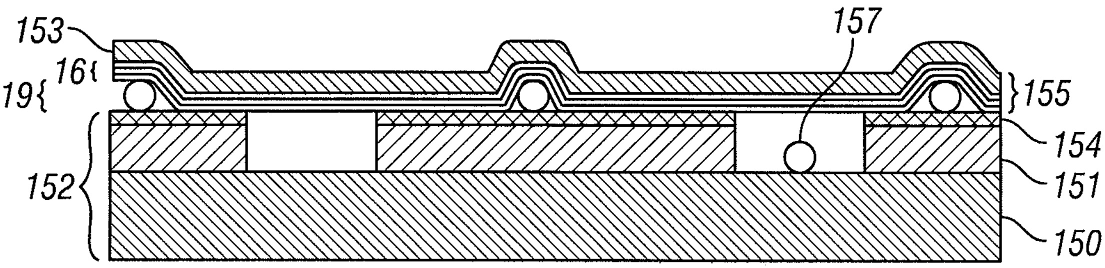


Figure 13G

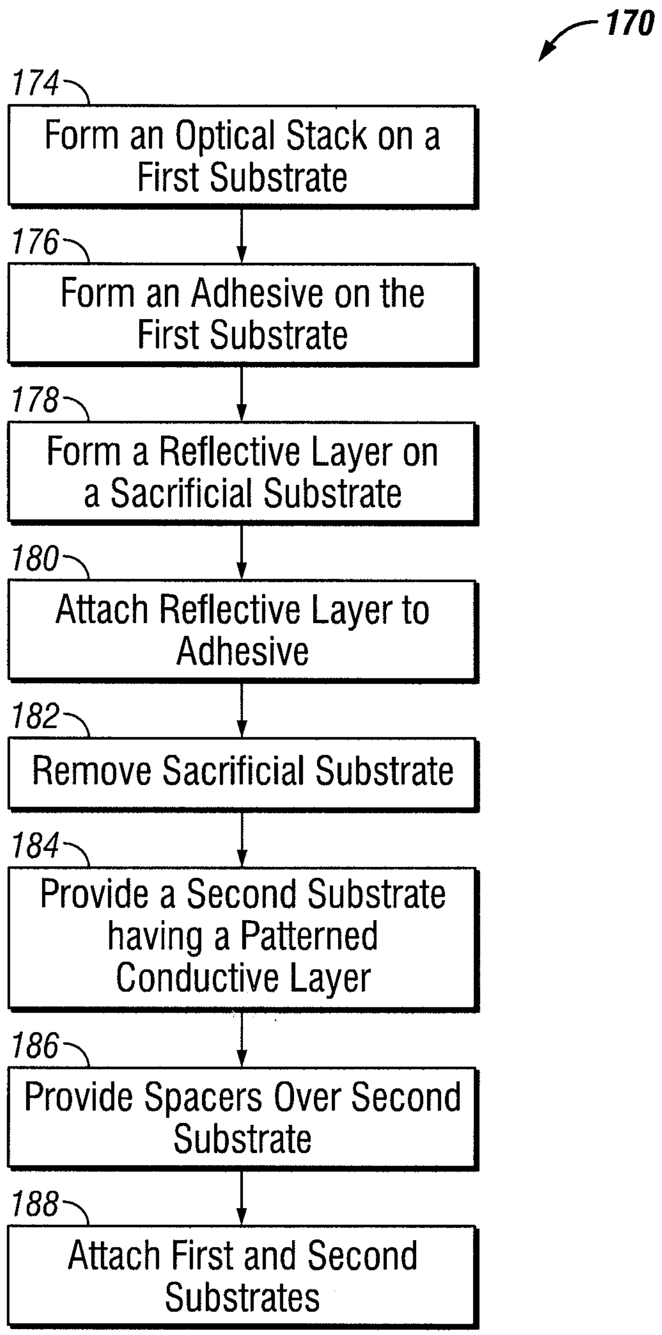

170
174
Form an Optical Stack on a First Substrate
176
Form an Adhesive on the First Substrate
178
Form a Reflective Layer on a Sacrificial Substrate
180
Attach Reflective Layer to Adhesive
182
Remove Sacrificial Substrate
184
Provide a Second Substrate having a Patterned Conductive Layer
186
Provide Spacers Over Second Substrate
188
Attach First and Second Substrates

Figure 14

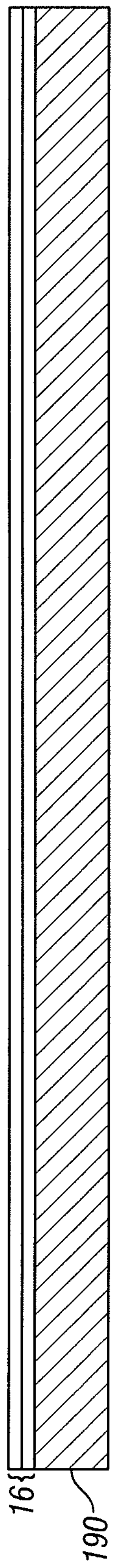


Figure 15A

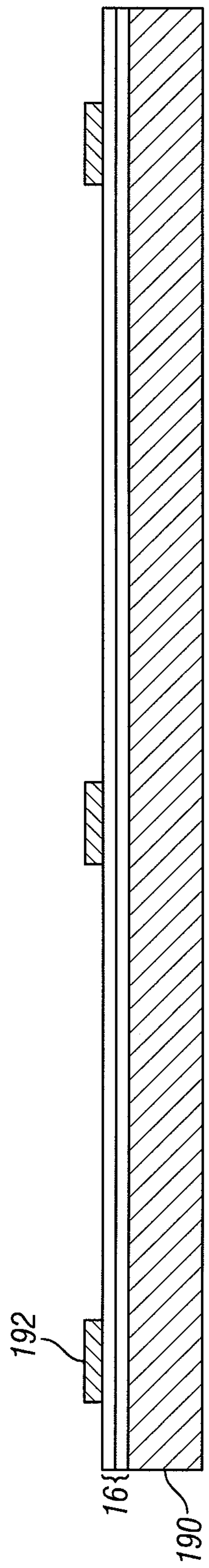


Figure 15B

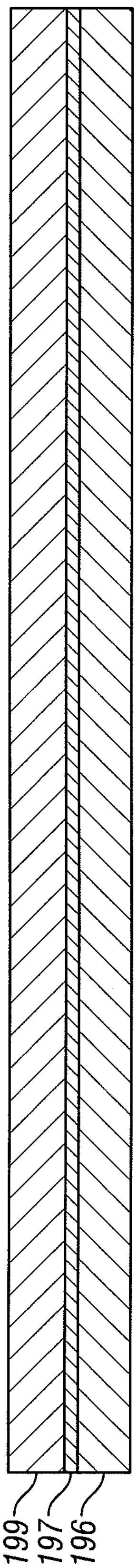


Figure 15C

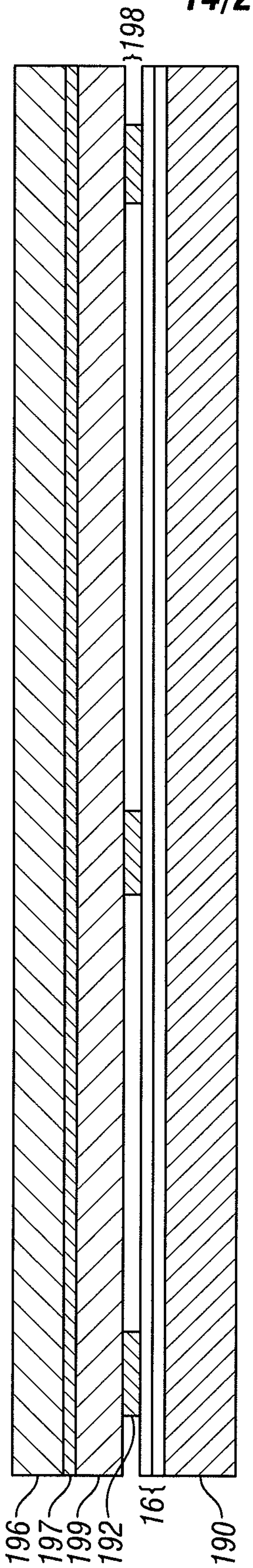


Figure 15D

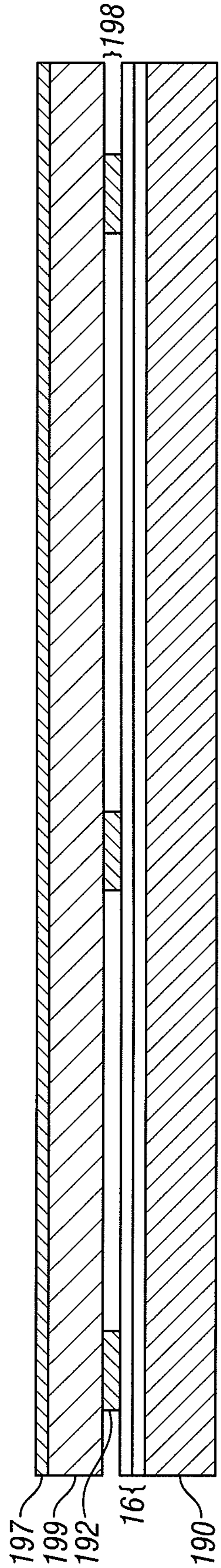


Figure 15E

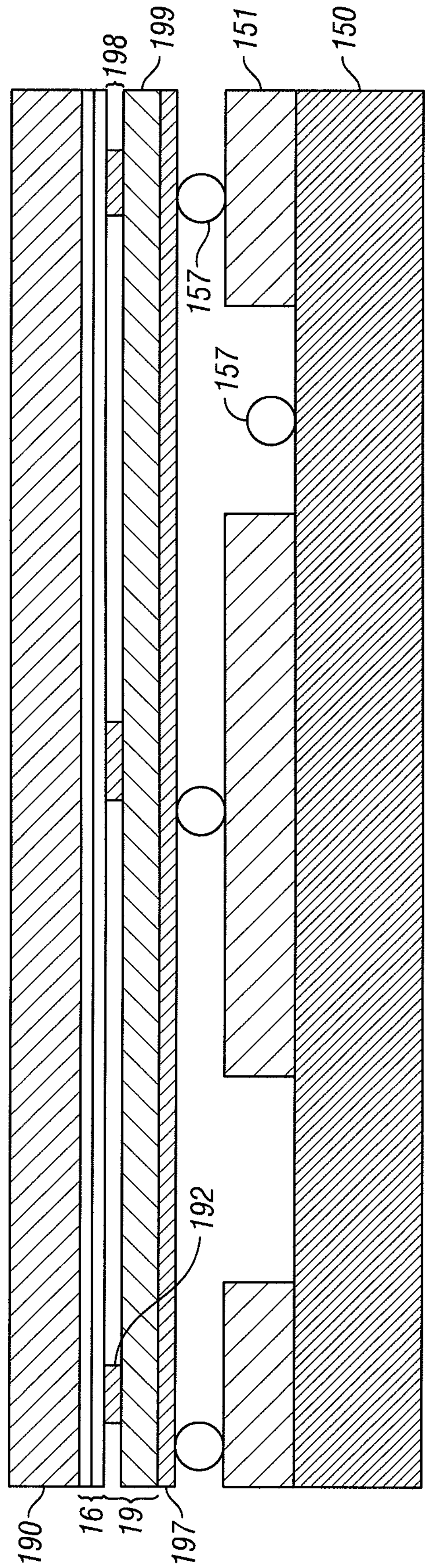


Figure 15F

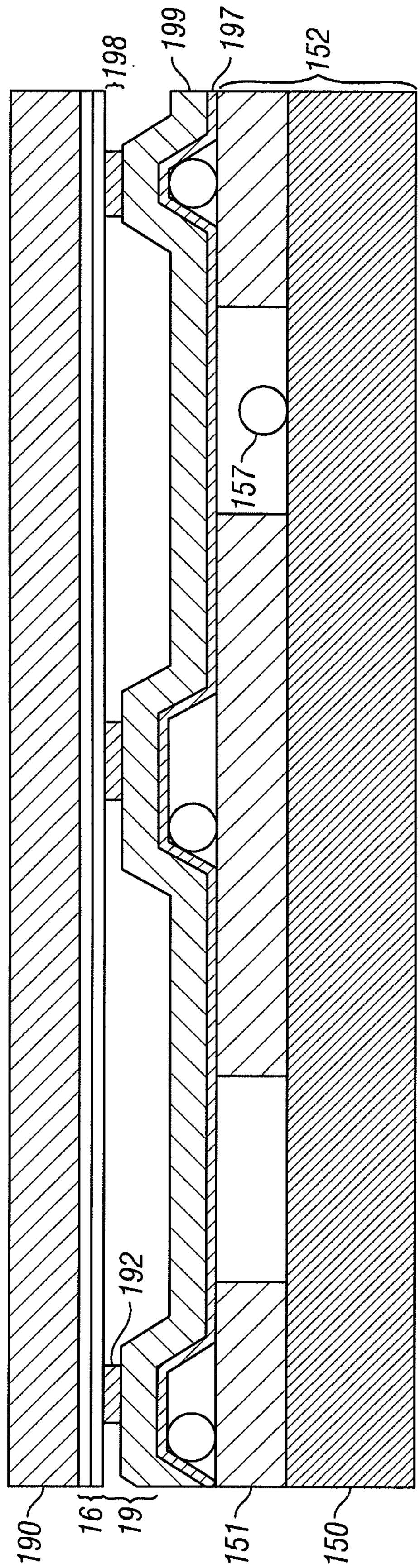


Figure 15G

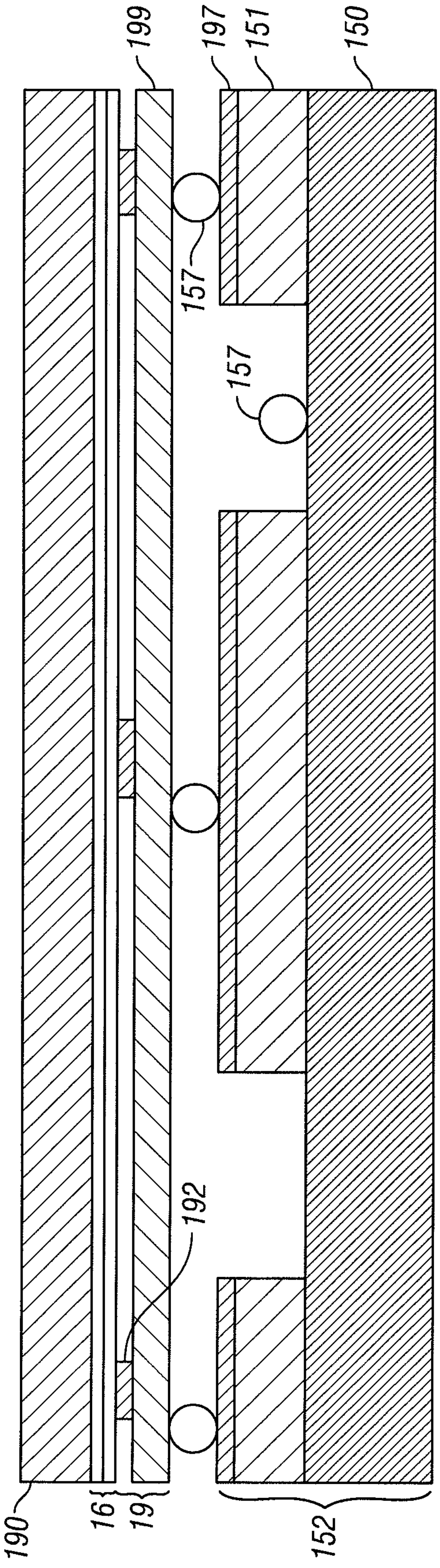


Figure 15H

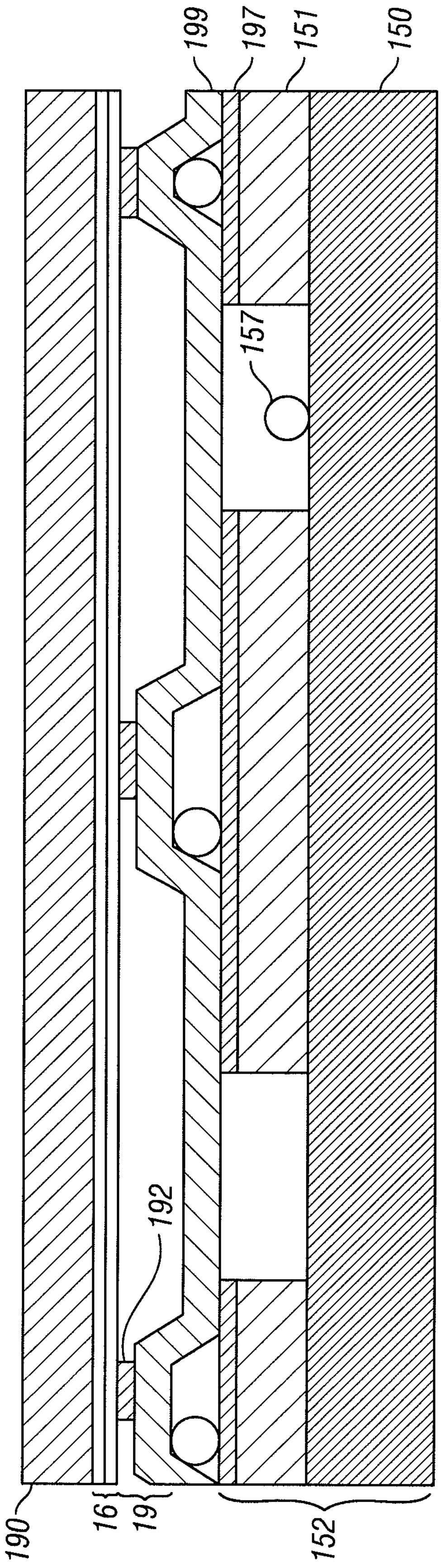


Figure 15I

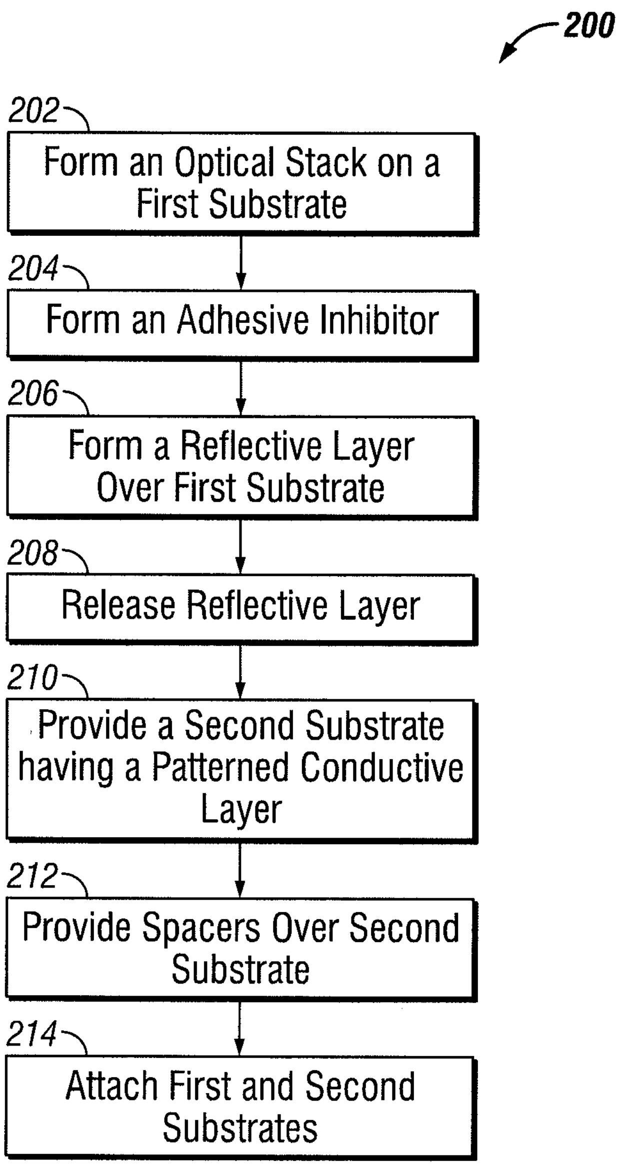

200
202
Form an Optical Stack on a First Substrate
204
Form an Adhesive Inhibitor
206
Form a Reflective Layer Over First Substrate
208
Release Reflective Layer
210
Provide a Second Substrate having a Patterned Conductive Layer
212
Provide Spacers Over Second Substrate
214
Attach First and Second Substrates

Figure 16

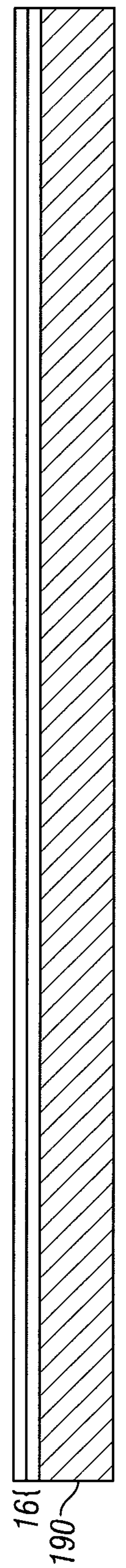


Figure 17A

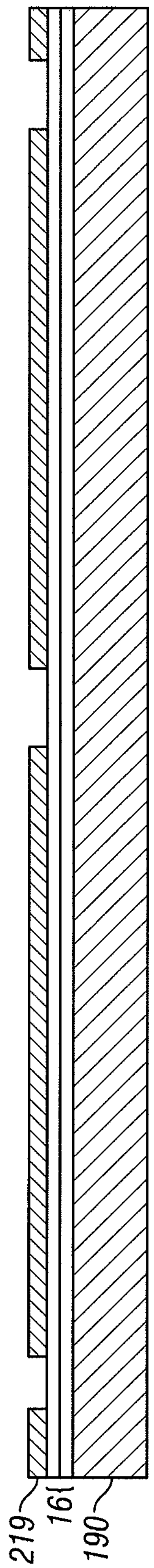


Figure 17B

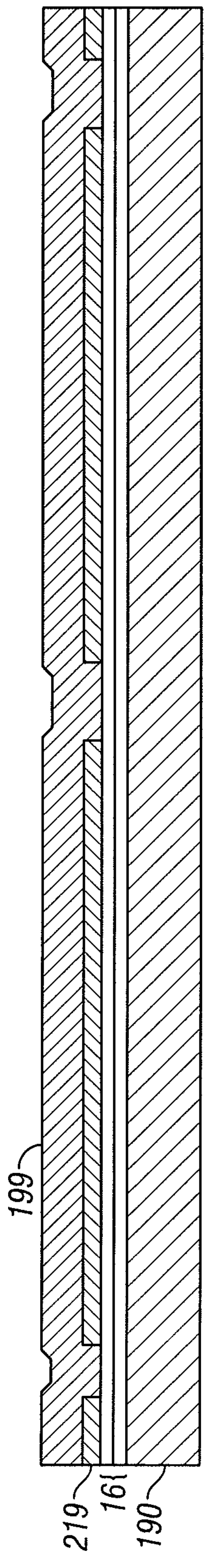
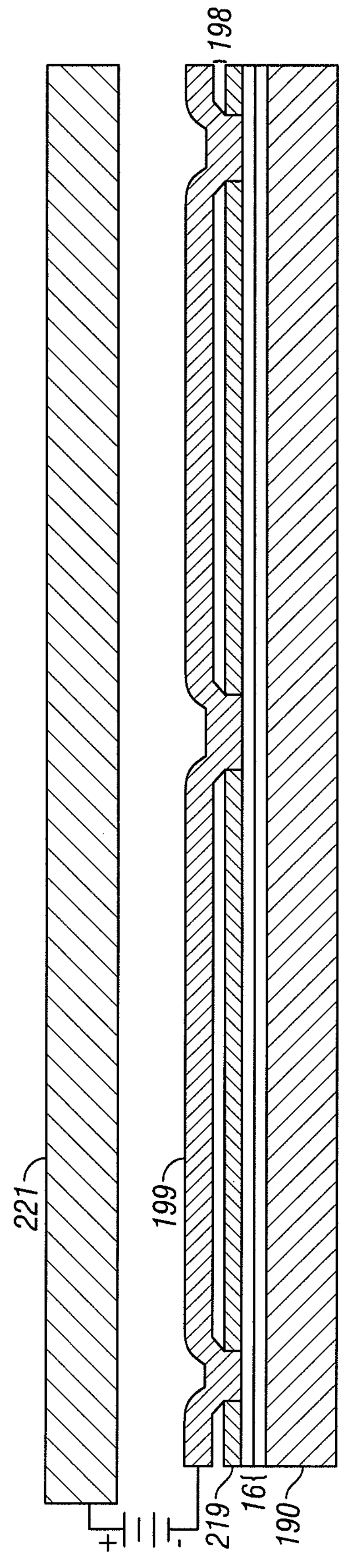


Figure 17C



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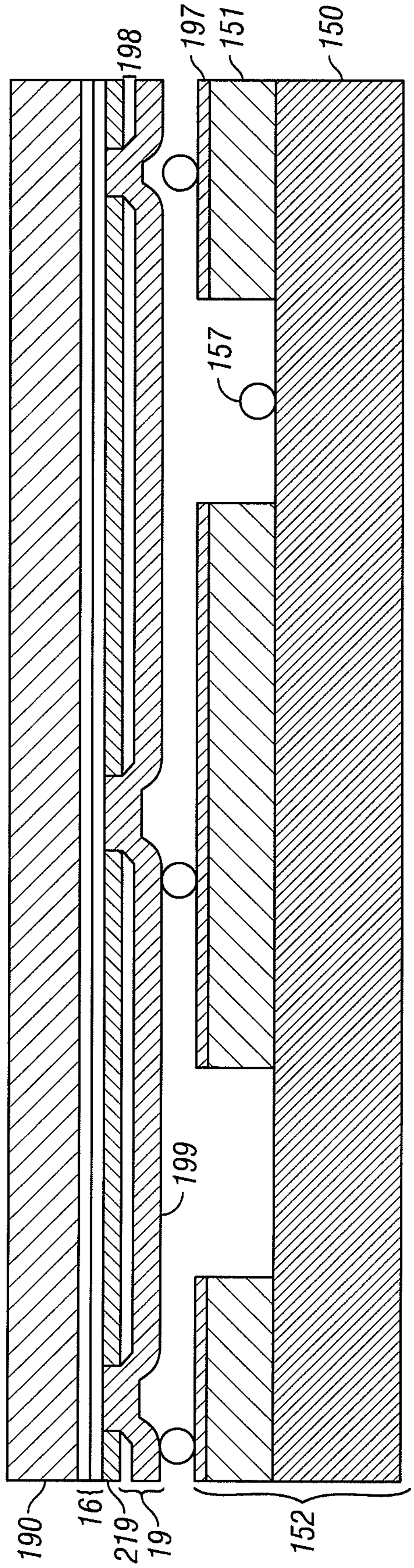

Figure 17E

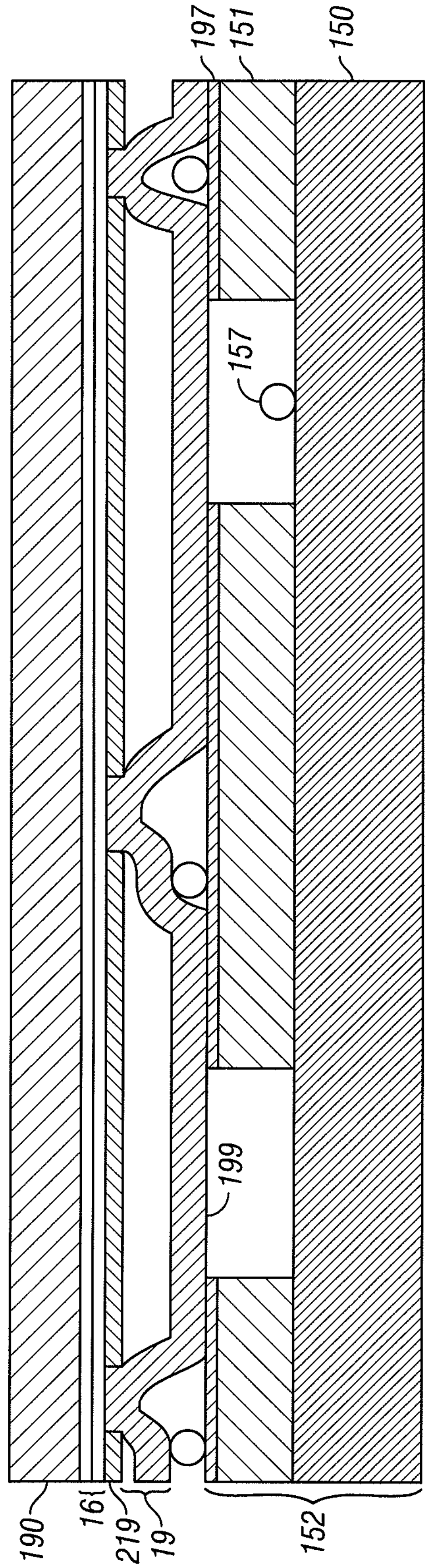

Figure 17F

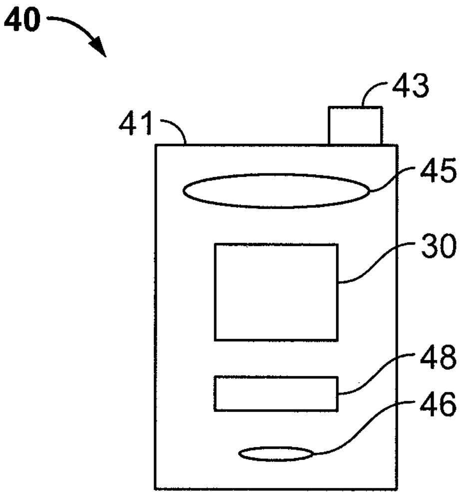

Figure 18A

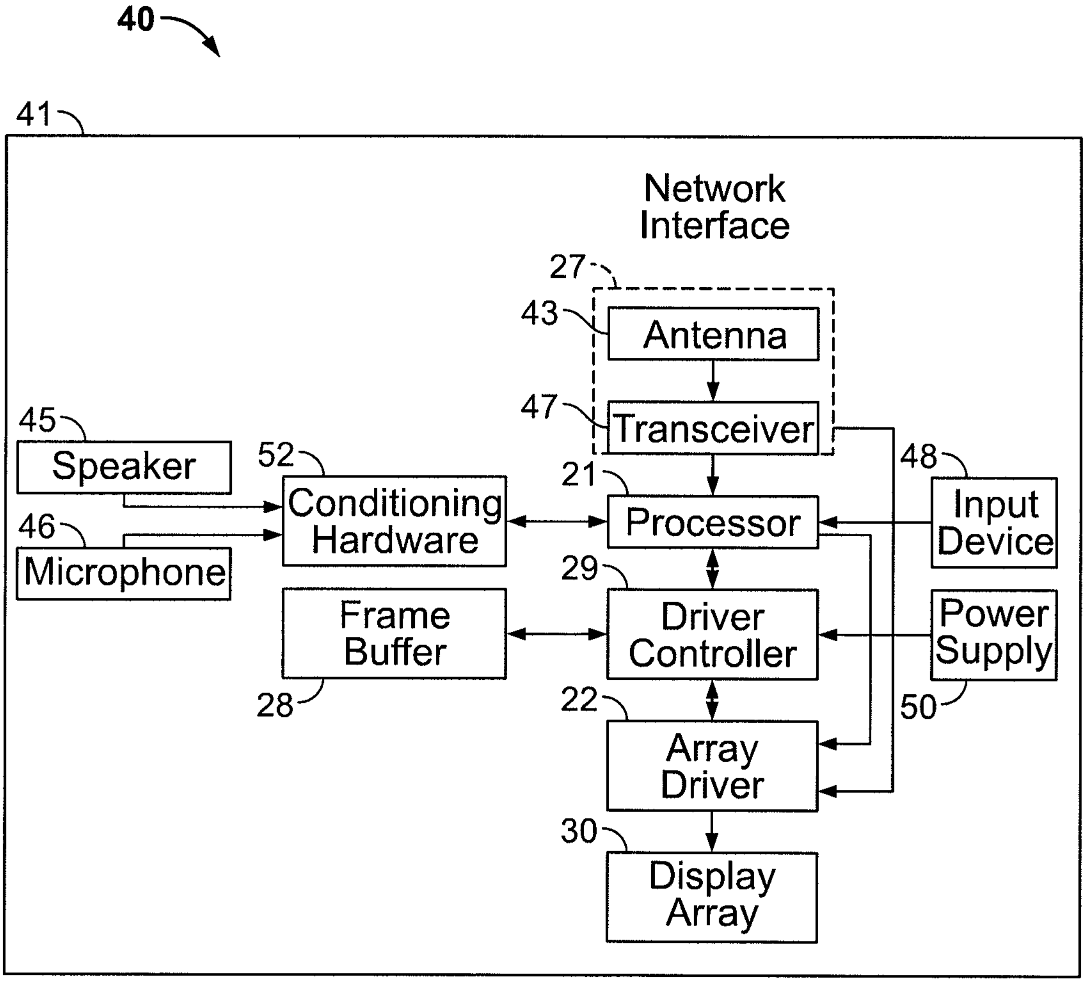

Figure 18B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2011/049407

A. CLASSIFICATION OF SUBJECT MATTER
INV. B81C1/00 G02B26/00
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)
B81C G02B

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/214644 A1 (CHEONG BYOUNG-HO [KR] ET AL) 26 August 2010 (2010-08-26)	1-4, 10-12, 18-24, 33,36
Y	paragraphs [0036] - [0053]; figures 2,12	5-9

X	US 2005/078348 A1 (LIN WEN-JIAN [TW]) 14 April 2005 (2005-04-14)	1
Y	paragraphs [0004], [0040] - [0046]; figure 5	5-9

X	EP 0 139 991 A2 (TEXAS INSTRUMENTS INC [US]) 8 May 1985 (1985-05-08) pages 18-22; figures 9-12	1

A	US 2006/008200 A1 (NAKAMURA RYOSUKE [JP] ET AL) 12 January 2006 (2006-01-12) paragraphs [0062] - [0083]	1

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 November 2011	17/02/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Stemmer, Michael

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2011/049407

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2010/086502 A1 (VALTION TEKNILLINEN [FI]; BLOMBERG MARTTI [FI]; KATTELUS HANNU [FI]; P) 5 August 2010 (2010-08-05) pages 7-13	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2011/049407

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010214644 A1	26-08-2010	CN 101813825 A	25-08-2010
		EP 2224275 A1	01-09-2010
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INTERNATIONAL SEARCH REPORT	International application No. PCT/US2011/049407

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-12, 18-24, 33, 36

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12, 18-24, 33, 36

   a device having layered structures arranged at both sides of a cavity solving the problems of optimizing the optical properties of the cavity

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2. claims: 13-15, 26-32, 34

   interferometric modulation device integrated with a printed circuit board, solving the problem of enhancing process integration between cavity and addressing electronics

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3. claim: 16

   an interferometric modulation device where the conductive element adjacent to the reflective layer is non-planar solving the problem of structuring the addressing line wiring

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4. claims: 17, 35

   an interferometric modulation device wherein the reflective layer includes aluminum solving the problem of providing appropriate refection properties

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5. claim: 25

   an interferometric modulation device wherein the flexible film is disposed between the substrate layer and the reflective layer, solving the problem of protection of the flexible film

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6. claims: 37-44

   a method of manufacturing an interferometric modulation device using adhesive layers solving the problem of adhering the wall constituting elements of the cavity

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7. claims: 45-49

   a method of manufacturing an interferometric modulation device using adhesive inhibiting material solving the problem of providing a cavity without the use of a sacrificial layer

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