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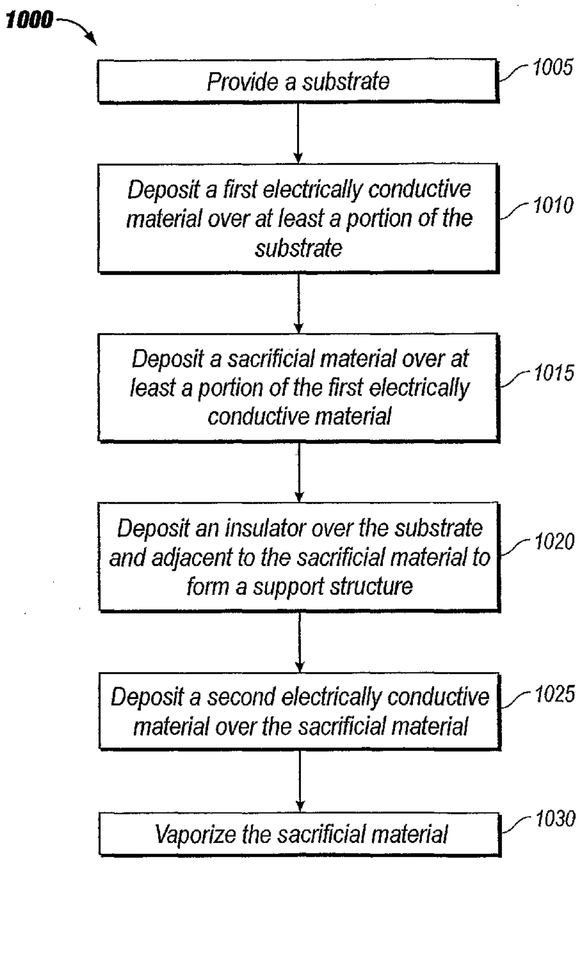
(54) Title: METHOD OF CREATING MEMS DEVICE CAVITIES BY A NON-ETCHING PROCESS



(57) Abstract: MEMS devices (such as interferometric modulators) may be fabricated using a sacrificial layer that contains a heat vaporizable polymer to form a gap between a moveable layer and a substrate. One embodiment provides a method of making a MEMS device that includes depositing a polymer layer over a substrate, forming an electrically conductive layer over the polymer layer, and vaporizing at least a portion of the polymer layer to form a cavity between the substrate and the electrically conductive layer. Another embodiment provides a method for making an interferometric modulator that includes providing a substrate, depositing a first electrically conductive material over at least a portion of the substrate, depositing a sacrificial material over at least a portion of the first electrically conductive material, depositing an insulator over the substrate and adjacent to the sacrificial material to form a support structure, and depositing a second electrically conductive material over at least a portion of the sacrificial material, the sacrificial material being removable by heat-vaporization to thereby form a cavity between the first electrically conductive layer and the second electrically conductive layer.

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METHOD OF CREATING MEMS DEVICE CAVITIES BY A NON-ETCHING PROCESS

BACKGROUND

Field of the Invention

[0001] This invention relates to microelectromechanical systems for use as interferometric modulators. More particularly, this invention relates to systems and methods for improving the manufacture of interferometric modulators.

Description of the Related Technology

[0002] Microelectromechanical systems (MEMS) include micro mechanical elements, actuators, and electronics. Micromechanical elements may be created using deposition, etching, 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. One type of MEMS device is called an interferometric modulator. 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 certain embodiments, an interferometric modulator may comprise a pair of conductive plates, one or both of which may be transparent and/or reflective in whole or part and capable of relative motion upon application of an appropriate electrical signal. In a particular embodiment, one plate may comprise a stationary layer deposited on a substrate and the other plate may comprise a metallic membrane separated from the stationary layer by a gap. As described herein in more detail, the position of one plate in relation to another can change the optical interference of light incident on the interferometric modulator. Such devices have a wide range of applications, and it would be beneficial in the art to utilize and/or modify the characteristics of these types of devices so that their features can be exploited in improving existing products and creating new products that have not yet been developed.

Summary

[0003] The system, method, and devices of the invention each have several aspects, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of this invention, its more prominent features will now be discussed

briefly. After considering this discussion, and particularly after reading the section entitled "Detailed Description of Certain Embodiments" one will understand how the features of this invention provide advantages over other display devices.

[0004] An embodiment provides a method of making a MEMS device that includes depositing a polymer layer over a substrate, forming an electrically conductive layer over the polymer layer, and vaporizing at least a portion of the polymer layer to form a cavity between the substrate and the electrically conductive layer.

[0005] Another embodiment provides an unreleased MEMS device that includes a substrate, a heat-vaporizable polymer over the substrate, and an electrically conductive layer over the heat-vaporizable polymer.

[0006] Another embodiment provides a method for making an interferometric modulator that includes providing a substrate, depositing a first electrically conductive material over at least a portion of the substrate, depositing a sacrificial material over at least a portion of the first electrically conductive material, depositing an insulator over the substrate and adjacent to the sacrificial material to form a support structure, and depositing a second electrically conductive material over at least a portion of the sacrificial material, the sacrificial material being removable by heat-vaporization to thereby form a cavity between the first electrically conductive layer and the second electrically conductive layer. Another embodiment provides an unreleased interferometric modulator made by such a method.

[0007] Another embodiment provides an unreleased interferometric modulator that includes a first means for reflecting light, a second means for reflecting light, a first means for supporting the second reflecting means, and a second means for supporting the second reflecting means, where the first supporting means comprises a sacrificial material, the sacrificial material being removable by heat-vaporization to thereby form a cavity defined by the first reflecting means, the second reflecting means, and the second supporting means.

[0008] Another embodiment provides an interferometric modulator that includes a substrate, a first electrically conductive material over at least a portion of the substrate, a second electrically conductive layer separated from the first electrically conductive layer by a cavity, and a nonconductive support structure arranged over the substrate and configured to support the second electrically conductive layer. In this embodiment, at least one of the first electrically conductive layer, the second electrically conductive layer and the non-conductive support structure comprises a material that is etchable by xenon diflouride. Another embodiment provides an array of interferometric modulators that includes such an interferometric modulator. Another embodiment provides a display device that includes such an array of interferometric modulators. The display device of this embodiment further includes a processor configured to communicate with the array, the processor being configured to process image data, and a memory device configured to communicate with the processor.

[0009] These and other embodiments are described in greater detail below.

Brief Description of the Drawings

[0010] FIG. 1 is an isometric view depicting a portion of one embodiment of an interferometric modulator display in which a movable reflective layer of a first interferometric modulator is in a relaxed position and a movable reflective layer of a second interferometric modulator is in an actuated position.

[0011] FIG. 2 is a system block diagram illustrating one embodiment of an electronic device incorporating a 3x3 interferometric modulator display.

[0012] FIG. 3 is a diagram of movable mirror position versus applied voltage for one exemplary embodiment of an interferometric modulator of FIG. 1.

[0013] FIG. 4 is an illustration of a set of row and column voltages that may be used to drive an interferometric modulator display.

[0014] FIGS. 5A and 5B illustrate one exemplary timing diagram for row and column signals that may be used to write a frame of display data to the 3x3 interferometric modulator display of FIG. 2.

[0015] FIGS. 6A and 6B are system block diagrams illustrating an embodiment of a visual display device comprising a plurality of interferometric modulators.

[0016] FIG. 7A is a cross section of the device of FIG. 1.

[0017] FIG. 7B is a cross section of an alternative embodiment of an interferometric modulator.

[0018] FIG. 7C is a cross section of another alternative embodiment of an interferometric modulator.

[0019] FIG 7D is a cross section of yet another alternative embodiment of an interferometric modulator.

[0020] FIG. 7E is a cross section of an additional alternative embodiment of an interferometric modulator.

[0021] FIG. 8 is a flow diagram illustrating certain steps in an embodiment of a method of making an interferometric modulator.

[0022] FIG. 9 is a flow diagram illustrating an embodiment of a method of making a MEMS device.

[0023] FIGS. 10a through 10c schematically illustrate an embodiment of a method for fabricating a MEMS device.

[0024] FIGS. 11a through 11d schematically illustrate an embodiment of a method for fabricating a MEMS device.

[0025] FIG. 12 is a flow diagram illustrating an embodiment of a method of making an interferometric modulator.

[0026] FIGS. 13a through 13e schematically illustrate an embodiment of a method for fabricating an interferometric modulator.

[0027] Figures 1 to 13 are not to scale.

Detailed Description of Certain Embodiments

[0028] The following detailed description is directed to certain specific embodiments of the invention. However, the invention can be embodied in a multitude of different ways. In this description, reference is made to the drawings wherein like parts are designated with like numerals throughout. As will be apparent from the following description, the embodiments may be implemented in any device that is configured to display an image, whether in motion (e.g., video) or stationary (e.g., still image), and whether textual or pictorial. More particularly, it is contemplated that the embodiments may be implemented in or associated with a variety of electronic devices such as, but not limited to, mobile telephones, wireless devices, personal data assistants (PDAs), hand-held or portable computers, GPS receivers/navigators, cameras, MP3 players, camcorders, game consoles, wrist watches, clocks, calculators, television monitors, flat panel displays, computer monitors, auto displays (e.g., odometer display, etc.), cockpit controls and/or displays, display of camera views (e.g., display of a rear view camera in a vehicle), electronic photographs, electronic billboards or signs, projectors, architectural structures, packaging, and aesthetic structures (e.g., display of images on a piece of jewelry). MEMS devices of similar structure to those described herein can also be used in non-display applications such as in electronic switching devices.

[0029] A preferred embodiment provides methods of making interferometric modulators by using a sacrificial layer that contains a heat vaporizable polymer to form a gap between a moveable layer and a substrate.

[0030] One interferometric modulator display embodiment comprising an interferometric MEMS display element is illustrated in Figure 1. In these devices, the pixels are in either a bright or dark state. In the bright ("on" or "open") state, the display element reflects a large portion of incident visible light to a user. When in the dark ("off" or "closed") state, the display element reflects little incident visible light to the user. Depending on the embodiment, the light reflectance properties of the "on" and "off" states may be reversed. MEMS pixels can be configured to reflect predominantly at selected colors, allowing for a color display in addition to black and white.

[0031] Figure 1 is an isometric view depicting two adjacent pixels in a series of pixels of a visual display, wherein each pixel comprises a MEMS interferometric modulator. In some embodiments, an interferometric modulator display comprises a row/column array of these interferometric modulators. Each interferometric modulator includes a pair of reflective layers positioned at a variable and controllable distance from each other to form a resonant optical cavity with at least one variable dimension. In one embodiment, one of the reflective layers may be moved between two positions. In the first position, referred to herein as the relaxed position, the movable reflective layer is positioned at a relatively large distance from a fixed partially reflective layer. In the second position, referred to herein as the actuated position, the movable reflective layer is positioned more closely adjacent to the partially reflective layer. Incident light that reflects from the two layers interferes constructively or destructively depending on the position of the movable reflective layer, producing either an overall reflective or non-reflective state for each pixel.

[0032] The depicted portion of the pixel array in Figure 1 includes two adjacent interferometric modulators **12a** and **12b**. In the interferometric modulator **12a** on the left, a movable reflective layer **14a** is illustrated in a relaxed position at a predetermined distance from an optical stack **16a**, which includes a partially reflective layer. In the interferometric modulator **12b** on the right, the movable reflective layer **14b** is illustrated in an actuated position adjacent to the optical stack **16b**.

[0033] The optical stacks **16a** and **16b** (collectively referred to as optical stack **16**), as referenced herein, typically comprise of several fused layers, which can include an electrode layer, such as indium tin oxide (ITO), a partially reflective layer, such as chromium, and a transparent dielectric. The optical stack **16** is thus 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**. In some embodiments, the layers are patterned into parallel strips, and may form row electrodes in a display device as described further below. The movable reflective layers **14a, 14b** may be formed as a series of parallel strips of a deposited metal layer or layers (orthogonal to the row electrodes of **16a, 16b**) deposited on top of posts **18** and an intervening sacrificial material deposited between the posts **18**. When the sacrificial material is etched away, the movable reflective layers **14a, 14b** are separated from the optical stacks **16a, 16b** by a defined gap **19**. A highly conductive and reflective material such as aluminum may be used for the reflective layers **14**, and these strips may form column electrodes in a display device.

[0034] With no applied voltage, the cavity **19** remains between the movable reflective layer **14a** and optical stack **16a**, with the movable reflective layer **14a** in a mechanically relaxed state, as illustrated by the pixel **12a** in Figure 1. However, when a potential difference is applied to 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 voltage is high enough, the movable reflective layer **14** is deformed and is forced against the optical stack **16**. A dielectric layer (not illustrated in this Figure) within the optical stack **16** may prevent shorting and control the separation distance between layers **14** and **16**, as illustrated by pixel **12b** on the right in Figure 1. The behavior is the same regardless of the polarity of the applied potential difference. In this way, row/column actuation that can control the reflective vs. non-reflective pixel states is analogous in many ways to that used in conventional LCD and other display technologies.

[0035] Figures 2 through 5 illustrate one exemplary process and system for using an array of interferometric modulators in a display application.

[0036] Figure 2 is a system block diagram illustrating one embodiment of an electronic device that may incorporate aspects of the invention. In the exemplary embodiment, the electronic device includes a processor **21** which may be any general purpose single- or multi-chip microprocessor such as an ARM, Pentium®, Pentium II®, Pentium III®, Pentium IV®, Pentium® Pro, an 8051, a MIPS®, a Power PC®, an ALPHA®, or any special purpose microprocessor such as a digital signal processor, microcontroller, or a programmable gate array. As is conventional in the art, the processor **21** may be configured to execute one or more software modules. In addition to executing an operating system, the processor 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.

[0037] In one embodiment, the processor **21** is also configured to communicate with an array driver **22**. In one embodiment, the array driver **22** includes a row driver circuit **24** and a column driver circuit **26** that provide signals to a panel or display array (display) **30**. The cross section of the array illustrated in Figure 1 is shown by the lines 1-1 in Figure 2. For MEMS interferometric modulators, the row/column actuation protocol may take advantage of a hysteresis property of these devices illustrated in Figure 3. It may require, for example, a 10 volt potential difference to cause a movable layer to deform from the relaxed state to the actuated state. However, when the voltage is reduced from that value, the movable layer maintains its state as the voltage drops back below 10 volts. In the exemplary embodiment of Figure 3, the movable layer does not relax completely until the voltage drops below 2 volts. There is thus a range of voltage, about 3 to 7 V in the example illustrated in Figure 3, where there exists a window of applied voltage within which the device is stable in either the relaxed or actuated state. This is referred to herein as the "hysteresis window" or "stability window." For a display array having the hysteresis characteristics of Figure 3, the row/column actuation protocol can be designed such that during row strobing, pixels in the strobed row that are to be actuated are exposed to a voltage difference of about 10 volts, and pixels that are to be relaxed are exposed to a voltage difference of close to zero volts. After the strobe, the pixels are exposed to a steady state voltage difference of about 5 volts such that they remain in whatever state the row strobe put them in. After being written, each pixel sees a potential difference within the "stability window" of 3-7 volts in this example. This feature makes the pixel design illustrated in Figure 1 stable under the same applied voltage conditions in either an actuated or relaxed pre-existing state. Since each pixel of the interferometric modulator, whether in the actuated or relaxed state, is essentially a capacitor formed by the fixed and moving reflective layers, this stable state can be held at a voltage within the hysteresis window with almost no power dissipation. Essentially no current flows into the pixel if the applied potential is fixed.

[0038] In typical applications, a display frame may be created by asserting the set of column electrodes in accordance with the desired set of actuated pixels in the first row. A row pulse is then applied to the row 1 electrode, actuating the pixels corresponding to the asserted column lines. The asserted set of column electrodes is then changed to correspond to the desired set of actuated pixels in the second row. A pulse is then applied to the row 2 electrode, actuating the appropriate pixels in row 2 in accordance with the asserted column electrodes. The row 1 pixels are unaffected by the row 2 pulse, and remain in the state they were set to during the row 1 pulse. This may be repeated for the entire series of rows in a sequential fashion to produce the frame. Generally, the frames are refreshed and/or updated with new display data by continually repeating this process at some desired number of frames per second. A wide variety of protocols for driving row and column electrodes of pixel arrays to produce display frames are also well known and may be used in conjunction with the present invention.

[0039] Figures 4 and 5 illustrate one possible actuation protocol for creating a display frame on the 3x3 array of Figure 2. Figure 4 illustrates a possible set of column and row voltage levels that may be used for pixels exhibiting the hysteresis curves of Figure 3. In the Figure 4 embodiment, actuating a pixel involves setting the appropriate column to $-V_{bias}$, and the appropriate row to $+\Delta V$, which may correspond to -5 volts and +5 volts respectively. Relaxing the pixel is accomplished by setting the appropriate column to $+V_{bias}$, and the appropriate row to the same $+\Delta V$, producing a zero volt potential difference across the pixel. In those rows where the row voltage is held at zero volts, the pixels are stable in whatever state they were originally in, regardless of whether the column is at $+V_{bias}$, or $-V_{bias}$. As is also illustrated in Figure 4, it will be appreciated that voltages of opposite polarity than those described above can be used, e.g., actuating a pixel can involve setting the appropriate column to $+V_{bias}$, and the appropriate row to $-\Delta V$. In this embodiment, releasing the pixel is accomplished by setting the appropriate column to $-V_{bias}$, and the appropriate row to the same $-\Delta V$, producing a zero volt potential difference across the pixel.

[0040] Figure 5B is a timing diagram showing a series of row and column signals applied to the 3x3 array of Figure 2 which will result in the display arrangement illustrated in Figure 5A, where actuated pixels are non-reflective. Prior to writing the frame illustrated in Figure 5A, the pixels can be in any state, and in this example, all the rows are at 0 volts, and all the columns are at +5 volts. With these applied voltages, all pixels are stable in their existing actuated or relaxed states.

[0041] In the Figure 5A frame, pixels (1,1), (1,2), (2,2), (3,2) and (3,3) are actuated. To accomplish this, during a "line time" for row 1, columns 1 and 2 are set to -5 volts, and column 3 is set to +5 volts. This does not change the state of any pixels, because all the pixels remain in the 3-7 volt stability window. Row 1 is then strobed with a pulse that goes from 0, up to 5 volts, and back to zero. This actuates the (1,1) and (1,2) pixels and relaxes the (1,3) pixel. No other pixels in the array are affected. To set row 2 as desired, column 2 is set to -5 volts, and columns 1 and 3 are set to +5 volts. The same strobe applied to row 2 will then actuate pixel (2,2) and relax pixels (2,1) and (2,3). Again, no other pixels of the array are affected. Row 3 is similarly set by setting columns 2 and 3 to -5 volts, and column 1 to +5 volts. The row 3 strobe sets the row 3 pixels as shown in Figure 5A. After writing the frame, the row potentials are zero, and the column potentials can remain at either +5 or -5 volts, and the display is then stable in the arrangement of Figure 5A. It will be appreciated that the same procedure can be employed for arrays of dozens or hundreds of rows and columns. It will also be appreciated that the timing, sequence, and levels of voltages used to perform row and column actuation can be varied widely within the general principles outlined above, and the above example is exemplary only, and any actuation voltage method can be used with the systems and methods described herein.

[0042] Figures 6A and 6B are system block diagrams illustrating an embodiment of a display device **40**. The display device **40** can be, for example, a cellular or mobile telephone. However, the same components of display device **40** or slight variations thereof are also illustrative of various types of display devices such as televisions and portable media players.

[0043] The display device **40** includes a housing **41**, a display **30**, an antenna **43**, a speaker **45**, a microphone **46** and an input device **48**. The housing **41** is generally formed from any of a variety of manufacturing processes as are well known to those of skill in the art, 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. In one embodiment the housing **41** includes removable portions (not shown) that may be interchanged with other removable portions of different color, or containing different logos, pictures, or symbols.

[0044] The display **30** of the exemplary display device **40** may be any of a variety of displays, including a bi-stable display, as described herein. In other embodiments, the display **30** includes a flat-panel display, such as plasma, EL, OLED, STN LCD, or TFT LCD as described above, or a non-flat-panel display, such as a CRT or other tube device, as is well known to those of skill in the art. However, for purposes of describing the present embodiment, the display **30** includes an interferometric modulator display, as described herein.

[0045] The components of one embodiment of the exemplary display device **40** are schematically illustrated in Figure 6B. The illustrated exemplary display device **40** includes a housing **41** and can include additional components at least partially enclosed therein. For example, in one embodiment, the exemplary 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 the 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 the array driver **22**, which in turn is coupled to a display array **30**. A power supply **50** provides power to all components as required by the particular exemplary display device **40** design.

[0046] The network interface **27** includes the antenna **43** and the transceiver **47** so that the exemplary display device **40** can communicate with one ore more devices over a network. In one embodiment the network interface **27** may also have some processing capabilities to relieve requirements of the processor **21**. The antenna **43** is any antenna known to those of skill in the art for transmitting and receiving signals. In one embodiment, the antenna transmits and receives RF signals according to the IEEE 802.11 standard, including IEEE 802.11(a), (b), or (g). In another embodiment, the antenna transmits and receives RF signals according to the BLUETOOTH standard. In the case of a cellular telephone, the antenna is designed to receive CDMA, GSM, AMPS or other known signals that are used to communicate within a wireless cell phone network. The transceiver **47** pre-processes 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 processes signals received from the processor **21** so that they may be transmitted from the exemplary display device **40** via the antenna **43**.

[0047] In an alternative embodiment, the transceiver **47** can be replaced by a receiver. In yet another alternative embodiment, 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**. For example, the image source can be a memory storage device such as a digital video disc (DVD) or a hard-disc drive that contains image data, or a software module that generates image data.

[0048] The processor **21** generally controls the overall operation of the exemplary 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** then sends 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.

[0049] In one embodiment, the processor **21** includes a microcontroller, CPU, or logic unit to control operation of the exemplary display device **40**. The conditioning hardware **52** generally includes 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 exemplary display device **40**, or may be incorporated within the processor **21** or other components.

[0050] The driver controller **29** takes the raw image data generated by the processor **21** either directly from the processor **21** or from the frame buffer **28** and reformats the raw image data appropriately for high speed transmission to the array driver **22**. Specifically, the driver controller **29** reformats 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 a 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. They 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**.

[0051] Typically, the array driver **22** receives the formatted information from the driver controller **29** and reformats the video data into a parallel set of waveforms that are applied many times per second to the hundreds and sometimes thousands of leads coming from the display's x-y matrix of pixels.

[0052] In one embodiment, the driver controller **29**, array driver **22**, and display array **30** are appropriate for any of the types of displays described herein. For example, in one embodiment, the driver controller **29** is a conventional display controller or a bi-stable display controller (e.g., an interferometric modulator controller). In another embodiment, the array driver **22** is a conventional driver or a bi-stable display driver (e.g., an interferometric modulator display). In one embodiment, the driver controller **29** is integrated with the array driver **22**. Such an embodiment is common in highly integrated systems such as cellular phones, watches, and other small area displays. In yet another embodiment, the display array **30** is a typical display array or a bi-stable display array (e.g., a display including an array of interferometric modulators).

[0053] The input device **48** allows a user to control the operation of the exemplary display device **40**. In one embodiment, the input device **48** includes a keypad, such as a QWERTY keyboard or a telephone keypad, a button, a switch, a touch-sensitive screen, a pressure- or heat-sensitive membrane. In one embodiment, the microphone **46** is an input device for the exemplary display device **40**. When the microphone **46** is used to input data to the device, voice commands may be provided by a user for controlling operations of the exemplary display device **40**.

[0054] The power supply **50** can include a variety of energy storage devices as are well known in the art. For example, in one embodiment, the power supply **50** is a rechargeable battery, such as a nickel-cadmium battery or a lithium ion battery. In another embodiment, the power supply **50** is a renewable energy source, a capacitor, or a solar cell, including a plastic solar cell, and solar-cell paint. In another embodiment, the power supply **50** is configured to receive power from a wall outlet.

[0055] In some implementations control programmability resides, as described above, in a driver controller which can be located in several places in the electronic display system. In some cases control programmability resides in the array driver **22**. Those of skill in the art will recognize that the above-described optimization may be implemented in any number of hardware and/or software components and in various configurations.

[0056] The details of the structure of interferometric modulators that operate in accordance with the principles set forth above may vary widely. For example, Figures 7A-7E illustrate five different embodiments of the movable reflective layer **14** and its supporting structures. Figure 7A is a cross section of the embodiment of Figure 1, where a strip of metal material **14** is deposited on orthogonally extending support structures **18**. In Figure 7B, the movable reflective layer **14** is attached to supports at the corners only, on tethers **32**. In Figure 7C, the movable reflective layer **14** is suspended from a deformable layer **34**, which may comprise a flexible metal. The deformable layer **34**

connects, directly or indirectly, to the substrate **20** around the perimeter of the deformable layer **34**. These connections may be referred to herein as support posts. The embodiment illustrated in Figure 7D has support structures **18** that include support post plugs **42** upon which the deformable layer **34** rests. The movable reflective layer **14** remains suspended over the cavity, as in Figures 7A-7C, but the deformable layer **34** does not form the support posts **18** by filling holes between the deformable layer **34** and the optical stack **16**. Rather, the support posts **18** comprise a planarization material, which is used to form support post plugs **42**. The embodiment illustrated in Figure 7E is based on the embodiment shown in Figure 7D, but may also be adapted to work with any of the embodiments illustrated in Figures 7A-7C as well as additional embodiments not shown. In the embodiment shown in Figure 7E, an extra layer of metal or other conductive material has been used to form a bus structure **44**. This allows signal routing along the back of the interferometric modulators, eliminating a number of electrodes that may otherwise have had to be formed on the substrate **20**.

[0057] In embodiments such as those shown in Figure 7, the interferometric modulators function as direct-view devices, in which images are viewed from the front side of the transparent substrate **20**, the side opposite to that upon which the modulator is arranged. In these embodiments, the reflective layer **14** optically shields some portions of the interferometric modulator on the side of the reflective layer opposite the substrate **20**, including the deformable layer **34** and the bus structure **44** (Figure 7E). This allows the shielded areas to be configured and operated upon without negatively affecting the image quality. This separable modulator architecture allows the structural design and materials used for the electromechanical aspects and the optical aspects of the modulator to be selected and to function independently of each other. Moreover, the embodiments shown in Figures 7C-7E have additional benefits deriving from the decoupling of the optical properties of the reflective layer **14** from its mechanical properties, which are carried out by the deformable layer **34**. This allows the structural design and materials used for the reflective layer **14** to be optimized with respect to the optical properties, and the structural design and materials used for the deformable layer **34** to be optimized with respect to desired mechanical properties.

[0058] Figure 8 illustrates certain steps in an embodiment of a manufacturing process **800** for an interferometric modulator. Such steps may be present in a process for manufacturing, e.g., interferometric modulators of the general type illustrated in Figures 1 and 7, along with other steps not shown in Figure 8. With reference to Figures 1, 7 and 8, the process **800** begins at step **805** with the formation of the optical stack **16** over the substrate **20**. The substrate **20** may be a transparent substrate such as glass or plastic and may have been subjected to prior preparation step(s), e.g., cleaning, to facilitate efficient formation of the optical stack **16**. As discussed above, 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 layers onto the transparent substrate **20**. In some embodiments, the layers are patterned into parallel strips, and may form row electrodes in a display device. In some embodiments, the optical stack **16** includes an insulating or dielectric layer that is deposited over one or more metal layers (e.g., reflective and/or conductive layers).

[0059] The process **800** illustrated in Figure 8 continues at step **810** with the formation of a sacrificial layer over the optical stack **16**. The sacrificial layer is later removed (e.g., at step **825**) to form the cavity **19** as discussed below and thus the sacrificial layer is not shown in the resulting interferometric modulator **12** illustrated in Figures 1 and 7. The formation of the sacrificial layer over the optical stack **16** may include deposition of a XeF_2-etchable material such as molybdenum or amorphous silicon, in a thickness selected to provide, after subsequent removal, a cavity **19** having the desired 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.

[0060] The process **800** illustrated in Figure 8 continues at step **815** with the formation of a support structure e.g., a post **18** as illustrated in Figures 1 and 7. The formation of the post **18** may include the steps of patterning the sacrificial layer to form a support structure aperture, then depositing a material (e.g., a polymer) into the aperture to form the post **18**, using a deposition method such as PECVD, thermal CVD, or spin-coating. In some embodiments, 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 post **18** contacts the substrate **20** as illustrated in Figure 7A. In other embodiments, the aperture formed in the sacrificial layer extends through the sacrificial layer, but not through the optical stack **16**. For example, Figure 7C illustrates the lower end of the support post plugs **42** in contact with the optical stack **16**.

[0061] The process **800** illustrated in Figure 8 continues at step **820** with the formation of a movable reflective layer such as the movable reflective layer **14** illustrated in Figures 1 and 7. 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. As discussed above, the movable reflective layer **14** is typically electrically conductive, and may be referred to herein as an electrically conductive layer. Since the sacrificial layer is still present in the partially fabricated interferometric modulator formed at step **820** of the process **800**, the movable reflective layer **14** is typically not movable at this stage. A partially fabricated interferometric modulator that contains a sacrificial layer may be referred to herein as an "unreleased" interferometric modulator.

[0062] The process **800** illustrated in Figure 8 continues at step **825** with the formation of a cavity, e.g., a cavity **19** as illustrated in Figures 1 and 7. The cavity **19** may be formed by exposing the sacrificial material (deposited at step **810**) to an etchant. For example, an etchable sacrificial material such as molybdenum or amorphous silicon may be removed by dry chemical etching, e.g., by exposing the sacrificial layer 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 relative to the structures surrounding the cavity **19**. Other etching methods, e.g. wet etching and/or plasma etching, may also be used. Since the sacrificial layer is removed during step **825** of the process **800**, the movable reflective layer **14** is typically movable after this stage. After removal of the sacrificial material, the resulting fully or partially fabricated interferometric modulator may be referred to herein as a "released" interferometric modulator.

[0063] While etching methods have been used to successfully remove sacrificial materials such as molybdenum or amorphous silicon to form cavities in MEMS devices such as interferometric modulators, there are drawbacks and disadvantages. One disadvantage of etching is that the size of the substrates that can be etched is usually small due to the environmental control requirements of the etching process including, for example, venting toxic and/or corrosive by-products, e.g., fluorine gas. Another disadvantage is that complete removal of some sacrificial materials may result in over etching and damage to neighboring structures. Such damage may be mitigated, e.g., by using an etch stop, but in some situations such additional structures may undesirably complicate the process. Another disadvantage is that use of materials that are etchable by XeF_2 may be limited in devices that are exposed to a XeF_2 etching process. Another disadvantage is that XeF_2 tends to be relatively expensive.

[0064] A MEMS fabrication method has now been developed that utilizes a heat vaporizable polymer as a sacrificial material. A heat vaporizable material is a solid material that vaporizes upon heating to a vaporization temperature, such that substantially all of the polymer (e.g., >95% by weight) is vaporized. The vaporization temperature range is preferably high enough such that the heat vaporizable material remains intact at normal fabrication temperatures, but low enough to avoid damaging other materials present during vaporization. In an embodiment, the heat vaporizable material is a heat vaporizable polymer. A variety of heat vaporizable polymers may be used. For example, one such heat vaporizable material is a heat-depolymerizable polycarbonate (HDP) such as poly(cyclohexene carbonate), an aliphatic polycarbonate that may be made from CO_2 and an epoxide, see U.S. Patent No. 6,743,570 B2. Other HDP's may also be used.

[0065] Heat vaporization of a material, such as HDP, being used as a sacrificial material in a process for manufacturing interferometric modulators, such as process **800** illustrated in Figure 8, may be advantageous as compared to removal of the sacrificial material using an etchant such as XeF_2. In an embodiment, an advantage is that the vapors given off during heating of HDP are non-toxic or less toxic than vapors given off in an etching process. This simplifies the environmental requirements of the chamber being used for removing the sacrifical material. A simple oven, or even a heated surface such as a heated plate, may be used to heat substrates to a temperature sufficient for vaporization. Use of an oven or heated plate and, in one embodiment, simplified venting requirements afford an advantage of being able to process a substantially larger glass (or temperature resistant plastic) plate than the substrates provided for in etchers. Glass plates up to about 2 meters by about 3 meters, or larger, may be processed. This size of substrate would permit the manufacture of relatively large MEMS devices, e.g., large-screen-TV sized interferometric modulator arrays. In addition, non-uniformity produced by etching may be reduced by heating instead of etching.

[0066] The use of heat vaporization may permit the use of a wider array of materials including those materials that are etchable by XeF_2. For example, one or more of various structures such as the electrically conductive layer, the substrate and the support structure may comprise a material that is etchable by xenon diflouride. In addition, use of etch stops (which may, in the fabrication of MEMS devices, complicate the process and increase costs) may be reduced or eliminated. The use of heat vaporization may also allow for process flexibility, which may result in the elimination of entire steps such as patterning.

[0067] Figure 9 is a flow diagram illustrating certain steps in an embodiment of a method of making a MEMS device. Such steps may be present in a process for manufacturing, e.g., interferometric modulators of the general type illustrated in Figures 1 and 7, along with other steps not shown in Figure 9. Figures 10a through 10c schematically illustrate an embodiment of a method for fabricating a MEMS device. With reference to Figures 9 and 10, the process **900** begins at step **905** with the depositing of a polymer layer **510** over a substrate **500** as depicted in Figure 10a. In one embodiment, the polymer is a heat vaporizable polymer such as an aliphatic polycarbonate, one example being poly(cyclohexene carbonate). Other heat-vaporizable polymers may be used including organic and inorganic polymers. The polymer serves as a sacrificial layer similar to the sacrificial layer formed in step **810** of Figure 8. The substrate **500** may comprise a material that is etchable by xenon diflouride. The deposition in step **905** may take many forms such as spin coating, extrusion coating, spray coating and printing. In one embodiment, inkjet deposition is used. In one embodiment, the heat vaporizable polymer is self planarizing. In one embodiment, the substrate **500** may comprise any transparent material such as glass or a heat resistant plastic that is not unduly affected by temperatures that bring about vaporization of the sacrificial polymer layer **510**. In another embodiment, the substrate **500** can comprise an optical stack **16** as in Figures 1 and 7.

[0068] The process **900** illustrated in Figure 9 continues at step **910** with the formation of an electrically conductive layer **520** over the polymer layer **510** as depicted in Figure 10b. In one embodiment, the electrically conductive layer is part of the movable reflective layer **14** in Figures 1 and 7. Since the sacrificial polymer layer **510** is still present at step **910** of the process **900**, the movable reflective layer **14** is typically not movable at this stage. A partially fabricated MEMS device, e.g. a partially fabricated interferometric modulator, that contains the sacrificial polymer layer **510** may be referred to herein as an "unreleased" MEMS device. The electrically conductive layer **520** may comprise a metal (e.g. aluminum or aluminum alloy). Since process **900** uses vaporization, at step **915**, to remove the polymer layer **510**, materials that are etchable by XeF_2 may also be used for the electrically conductive layer. Such XeF_2-etchable materials comprise titanium, tungsten and tantalum. Forming the electrically conductive layer **520** in step **910** may include one or more deposition steps as well as one or more patterning or masking steps.

[0069] Process **900** continues at step **915** with the vaporization of at least a portion of the heat vaporizable polymer layer **510** resulting in a cavity **530** as depicted in Figure 10c. In one embodiment, the vaporizing step **915** comprises heating. Heating may be done on a heated plate, in an oven, in a kiln or by using any heating device capable of achieving and maintaining a temperature sufficient to vaporize the polymer for a long enough time that substantially all of the polymer vaporizes. In one embodiment, the heat vaporizable polymer is poly(cyclohexene carbonate) which vaporizes at about 300° C. Other heat vaporizable materials may be used. Materials that may be used include those that vaporize in temperature ranges high enough to be in a solid state during steps **905** and **910** and other steps not shown in Figure 9, but vaporize at temperatures low enough such that other materials present during the vaporizing step **915** are not unduly affected. In one embodiment, materials present during step **915** include materials in the movable reflective layer **14**, materials in the optical stack **16**, materials in the substrate **20** and materials in the post **18** as shown in Figures 1 and 7. In one embodiment, a vaporization temperature range of about 200° C to about 350° C is acceptable. In this embodiment, deposition and patterning steps are preferably carried out at temperatures below the 200° C vaporization temperature in order not to vaporize the polymer layer prematurely. In this embodiment, the 350° C temperature may be about the maximum termperature that other materials, such as aluminum and indium tin oxide, can withstand without adverse effects. Adverse effects of heating may include hillocking, transmission and/or electrical resistance change. The heat vaporizable material should be a material that vaporizes within an acceptable temperature range and where substantially all (greater than about 95% by weight) of the heat vaporizable material is removed. Preferably, the heat vaporizable material vaporizes relatively quickly, e.g., within about 10 seconds to about 30 minutes, at the vaporization temperature.

[0070] In one embodiment a patterning step (not shown in Figures 9 or 10) may take place after step **905** and before the formation of the electrically conductive layer **520** in step **910**. This patterning may comprise techniques such as electron beam lithography and image transfer. The patterning may be done to form a support structure aperture in the polymer layer **510**. After the patterning, a depositing step (not shown in Figure 9) may take place. A non-conductive material may be deposited into the support structure aperture formed in the patterning step to form a post **18** as shown in Figures 1 and 7. Step **910** may then form the electrically conductive layer **520** over the polymer layer **510** and over the post such that the post will support the electrically conductive layer after removal of the polymer layer **510** in step **915**. In one embodiment, XeF_2-etchable materials may be used in forming at least part of the post structure. XeF_2-etchable materials suitable for the post structure include molybedenum and silicon-containing materials, such as silicon itself (including amorphous silicon, polysilicon, and crystalline silicon), as well as silicon germanium and silicon nitride. In some embodiments, the process **900** may include additional steps and the steps may be rearranged from the illustrations of Figures 9 and 10.

[0071] Figures 11a through 11d schematically illustrate an embodiment of a method for fabricating a MEMS device. With reference to Figures 9 and 11, a depositing step (not shown in Figure 9) forms post structures **710** on a substrate **700**. This depositing step takes place prior to depositing the polymer layer at step **905**. In one embodiment, a non-conductive material is deposited to form the post structures **710**. In one embodiment, XeF_2-etchable materials may be used in forming at least part of the post structures **710**. XeF_2-etchable materials suitable for the post structure include molybedenum and silicon-containing materials, such as silicon itself (including amorphous silicon, polysilicon, crystalline silicon), as well as silicon germanium and silicon nitride. In one embodiment, the substrate **700** may comprise any transparent material such as glass or a heat resistant plastic that is not unduly affected by temperatures that bring about vaporization of the heat vaporizable polymer layer. In another embodiment, the substrate **700** may comprise an optical stack **16** as in Figures 1 and 7. After depositing post structures **710**, process **900** continues to step **905** with the depositing of a polymer layer **720** next to the post structures **710** and over the substrate **700** as shown in Figure 11b.

[0072] The process **900** continues at step **910** with the formation of an electrically conductive layer **730** over at least a portion of polymer layer **720** and post structures **710** as illustrated in Figure 11c. In one embodiment, electrically conductive layer **730** is part of the movable reflective layer **14** as illustrated in Figures 1 and 7. Since the sacrificial polymer layer **720** is still present at step **910** of the process **900**, the movable reflective layer **14** is typically not movable at this stage. A partially fabricated MEMS device, e.g. a partially fabricated interferometric modulator, that contains the sacrificial polymer layer **720** may be referred to herein as an "unreleased" MEMS device. The electrically conductive layer **730** may comprise a metal (e.g. aluminum or aluminum alloy). Since the process **900** uses vaporization, at step **915**, to remove the polymer layer **720**, materials that are etchable by XeF_2 may also be used for the electrically conductive layer. Such XeF_2-etchable materials comprise titanium, tungsten and tantalum. Forming the electrically conductive layer **730** in step **910** may include one or more deposition steps as well as one or more patterning or masking steps.

[0073] The process **900** continues at step **915** with the vaporization of the sacrificial polymer layer **720** resulting in a cavity **740** as illustrated in Figure 11d. In one embodiment, the vaporizing step **915** comprises heating. Heating may be done on a heated plate or in an oven, kiln or any heating device capable of achieving and maintaining a temperature sufficient to vaporize the polymer for a long enough time that substantially all of the polymer vaporizes. Figure 11d depicts a MEMS device, e.g., an interferometric modulator, in a released state. In some embodiments, the process **900** may include additional steps and the steps may be rearranged from the illustrations of Figures 9 and 11.

[0074] Figure 12 is a flow diagram illustrating certain steps in another embodiment of a method of making an interferometric modulator. Such steps may be present in a process for manufacturing, e.g., interferometric modulators of the general type illustrated in Figures 1 and 7, along with other steps not shown in Figure 12. Figures 13a through 13e schematically illustrate an embodiment of a method for fabricating an interferometric modulator. With reference to Figures 12 and 13, the process **1000** begins at step **1005** with providing a substrate **600** as depicted in Figure 13a. In one embodiment, the substrate **600** may comprise any transparent material such as glass or a heat resistant plastic that is not unduly affected by temperatures that bring about vaporization of a heat vaporizable sacrificial polymer. Process **1000** continues at step **1010** with the deposition of a first electrically conductive material **610** over at least a portion of the substrate **600** as depicted in Figure 13a. The first electrically conductive material **610** can be part of the optical stack **16** depicted in Figures 1 and 7. In one embodiment the first electrically conductive layer comprises indium tin oxide. At step **1015**, a sacrificial layer **620**, comprising a heat vaporizable material, is deposited over at least a portion of the first electrically conductive material **610** as illustrated in Figure 13b. The sacrificial layer **620** may be deposited by techniques such as spin coating, extrusion coating, spray coating and printing. The sacrificial layer **620** is deposited in thicknesses and locations to provide for a cavity of the desired size between the first electrically conductive layer and the second electrically conductive layer deposited in step **1025**. The sacrificial layer may be deposited in select locations by, e.g., printing techniques, one of which is inkjet deposition. In one embodiment the sacrificial layer is printed onto locations adjacent to post structure locations (already deposited post structures or to-be-deposited post structure locations).

[0075] The process **1000** continues at step **1020** with the deposition of an insulator over the substrate **600** and adjacent to the sacrificial material **620** (or adjacent to the location of a to-be-deposited sacrificial material) to form a support structure **630** as depicted in Figure 13c. In one embodiment, step **1020** is performed before step **1015** (similar to the schematic illustration of Figure 11), thereby eliminating a patterning step (not shown in Figure 10) to form a support post aperture. The insulator material may be used, in an embodiment, to form support posts **18** in Figures 1 and 7. The insulator material may include materials etchable by XeF_2 as discussed above. Continuing at step **1025**, a second electrically conductive material **640** is deposited over at least a portion of the sacrificial material **620** as depicted in Figure 13d. The second electrically conductive material **640** may be part of the movable reflective layer **14** of Figures 1 and 7. The movable reflective layer **14** is configured such that the post structure supports the movable reflective layer including the second electrically conductive layer **640**.

[0076] After step **1025**, the partially fabricated interferometric modulater is in an unreleased state. In one embodiment, the unreleased interferometric modulator depicted in Figure 13d includes a first electrically conductive material **610** that is a partially reflective layer, a second electrically conductive material **640** that is a movable reflective layer, a sacrificial material **620**, the sacrificial material being removable by heat-vaporization to thereby form a cavity **650**, and the support structure **630** is a support post. The act of releasing the interferometric modulator is performed at step **1030** by vaporizing the sacrificial material **620** resulting in the cavity **650** as depicted in Figure 13e. In one embodiment, vaporization is accomplished by heating the entire unreleased interferometric modulator to a temperature and for a duration sufficient to remove substantially all of the sacrificial material. After step **1030**, the interferometric modulator is in a released state. In some embodiments, the process **1000** may include additional steps and the steps may be rearranged from the illustrations of Figures 12 and 13.

[0077] An embodiment of an unreleased interferometric modulator includes a first means for reflecting light, a second means for reflecting light, a first means for supporting the second reflecting means, and a second means for supporting the second reflecting means, where the first supporting means comprises a sacrificial material, the sacrificial material being removable by heat-vaporization to thereby form a cavity defined by the first reflecting means, the second reflecting means, and the second supporting means. With reference to Figure 13d, aspects of this embodiment include where the first reflecting means is a partially reflective layer, such as the first electrically conductive material **610**, where the second reflecting means is a movable reflective layer such as the second electrically conductive material **640**, where the first supporting means is a sacrificial layer such as the sacrificial material **620**, and where the second supporting means is a support post such as the support structure **630**.

[0078] In one embodiment, the process **900** in Figure 9 and/or the process **1000** in Figure 12 may include a patterning step that comprises forming vent holes in the other materials, including, e.g., one or more of the substrates, the electrically conductive layers and/or any other structures present in the MEMS device or interferometric modulator. The vent holes, which may be similar to vent holes used in etching processes, serve as exit pathways for the vaporized sacrificial materials.

[0079] In an embodiment, vent holes are eliminated or reduced in number and/or size, and the sacrificial material, in this example a heat vaporizable polymer, escapes to the sides of the moveable reflective layer.

[0080] While the above detailed description has shown, described, and pointed out novel features of the invention as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art without departing from the spirit of the invention. As will be recognized, the present invention may be embodied within a form that does not provide all of the features and benefits set forth herein, as some features may be used or practiced separately from others.

CLAIMS

WHAT IS CLAIMED IS:

1. A method of making a microelectromechanical system (MEMS) device, comprising:

depositing a polymer layer over a substrate;

forming an electrically conductive layer over the polymer layer; and

vaporizing at least a portion of the polymer layer to thereby form a cavity between the substrate and the electrically conductive layer.

2. The method of Claim 1, wherein the substrate comprises a second electrically conductive layer.

3. The method of Claim 2, wherein the second electrically conductive layer comprises indium tin oxide.

4. The method of Claim 1, wherein the electrically conductive layer comprises a movable layer.

5. The method of Claim 1, wherein vaporizing comprises heating.

6. The method of Claim 5, wherein vaporizing comprises heating to a temperature in the range of from about 200 degrees C to about 350 degrees C.

7. The method of Claim 1, wherein the electrically conductive layer comprises a metal.

8. The method of Claim 1, wherein the polymer layer comprises an organic polymer.

9. The method of Claim 1, wherein the substrate comprises a partially reflective layer.

10. The method of Claim 1, further comprising patterning the polymer layer.

11. The method of Claim 10, wherein the patterning comprises at least one of electron beam lithography and image transfer.

12. The method of Claim 10, further comprising:

forming a support structure aperture in the polymer; and

depositing a non-conductive material into the support structure aperture.

13. The method of Claim 1, wherein depositing the polymer layer comprises at least one of spin coating, extrusion coating, spray coating, and printing.

14. The method of Claim 13, wherein printing comprises inkjet deposition.

15. An unreleased microelectromechanical system (MEMS) device, comprising:

a substrate;

a heat-vaporizable polymer over the substrate; and

an electrically conductive layer over the heat-vaporizable polymer.

16. The unreleased MEMS device of Claim 15, wherein the substrate comprises a second electrically conductive layer.

17. The unreleased MEMS device of Claim 16, wherein the second electrically conductive layer comprises indium tin oxide.

18. The unreleased MEMS device of Claim 15, wherein the electrically conductive layer comprises a metal.

19. The unreleased MEMS device of Claim 15, wherein the heat-varporizable polymer comprises an organic polymer.

20. The unreleased MEMS device of Claim 15, wherein the substrate comprises a partially reflective layer.

21. The unreleased MEMS device of Claim 15, further comprising:

a nonconductive support structure arranged over the substrate and configured to support the electrically conductive layer.

22. The unreleased MEMS device of Claim 21 wherein at least one of the electrically conductive layer, the substrate and the support structure comprises a material that is etchable by xenon diflouride.

23. The unreleased MEMS device of Claim 15, wherein the heat vaporizable polymer is configured to vaporize upon heating to a temperature in the range of about 200 degrees C to about 350 degrees C.

24. A method for making an interferometric modulator, comprising:

providing a substrate;

depositing a first electrically conductive material over at least a portion of the substrate;

depositing a sacrificial material over at least a portion of the first electrically conductive material;

depositing an insulator over the substrate and adjacent to the sacrificial material to form a support structure; and

depositing a second electrically conductive material over at least a portion of the sacrificial material;

the sacrificial material being removable by heat-vaporization to thereby form a cavity between the first electrically conductive layer and the second electrically conductive layer.

25. An unreleased interferometric modulator made by the method of Claim 24.

26. The method of Claim 24, further comprising:

vaporizing the sacrificial material thereby removing substantially all of the sacrificial material.

27. A released interferometric modulator made by the method of Claim 26.

28. The method of Claim 24, wherein depositing the insulator precedes depositing the sacrificial material.

29. The method of Claim 24, further comprising:

forming a support structure aperture in a portion of the deposited sacrificial material; and

depositing the insulator into the support structure aperture.

30. An unreleased interferometric modulator, comprising:

a first means for reflecting light;

a second means for reflecting light;

a first means for supporting the second reflecting means; and

a second means for supporting the second reflecting means;

wherein the first supporting means comprises a sacrificial material, the sacrificial material being removable by heat-vaporization to thereby form a cavity defined by the first reflecting means, the second reflecting means, and the second supporting means.

31. The unreleased interferometric modulator of Claim 30, wherein the first reflecting means is a partially reflective layer.

32. The unreleased interferometric modulator of Claim 30, wherein the second reflecting means is a movable reflective layer.

33. The unreleased interferometric modulator of Claim 30, wherein the first supporting means is a sacrificial layer.

34. The unreleased interferometric modulator of Claim 30, wherein the second supporting means is a support post.

35. An interferometric modulator comprising:

a substrate;

a first electrically conductive material over at least a portion of the substrate;

a second electrically conductive layer separated from the first electrically conductive layer by a cavity; and

a nonconductive support structure arranged over the substrate and configured to support the second electrically conductive layer;

wherein at least one of the first electrically conductive layer, the second electrically conductive layer and the non-conductive support structure comprises a material that is etchable by xenon diflouride.

36. The interferometric modulator of Claim 35, wherein the material that is etchable by xenon diflouride comprises at least one of titanium, tungsten, tantalum, molybdenum, silicon nitride, and silicon.

37. An array of interferometric modulators comprising the interferometric modulator of Claim 35.

38. A display device, comprising:

an array of interferometric modulators as claimed in Claim 37;

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

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

39. The display device of Claim 38, further comprising:

a driver circuit configured to send at least one signal to the array.

40. The display device of Claim 39, further comprising:

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

41. The display device of Claim 38, further comprising:

an image source module configured to send the image data to the processor.

42. The display device of Claim 41, wherein the image source module comprises at least one of a receiver, transceiver, and transmitter.

43. The display device of Claim 38, further comprising:

an input device configured to receive input data and to communicate the input data to the processor.

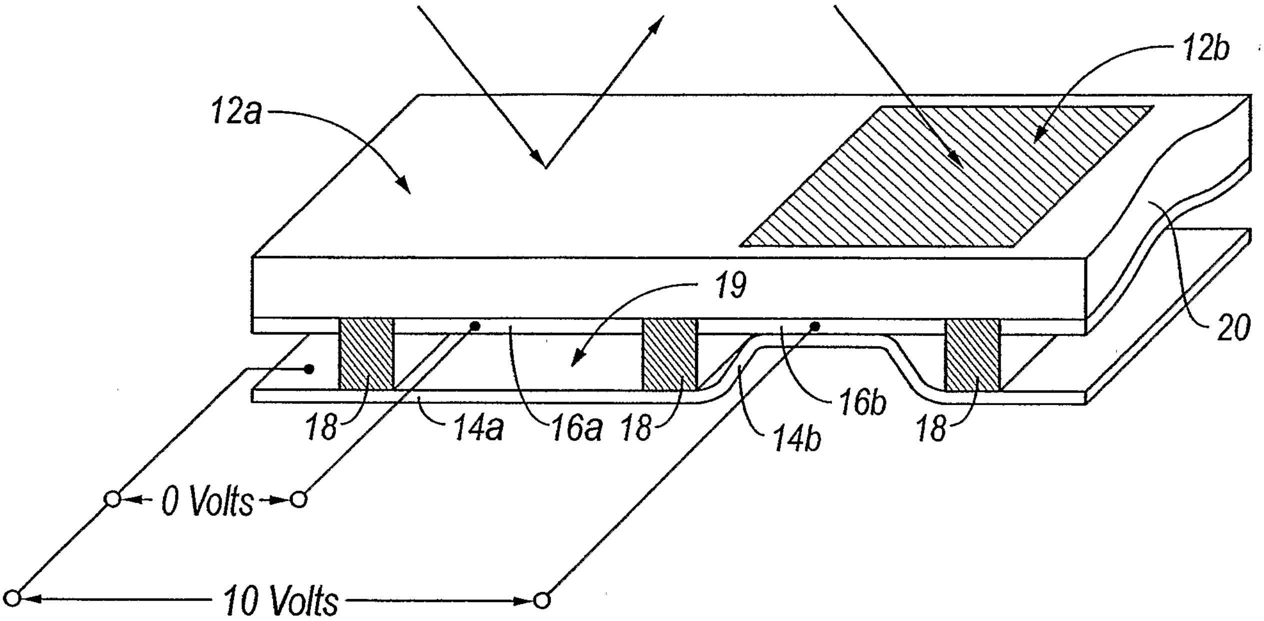
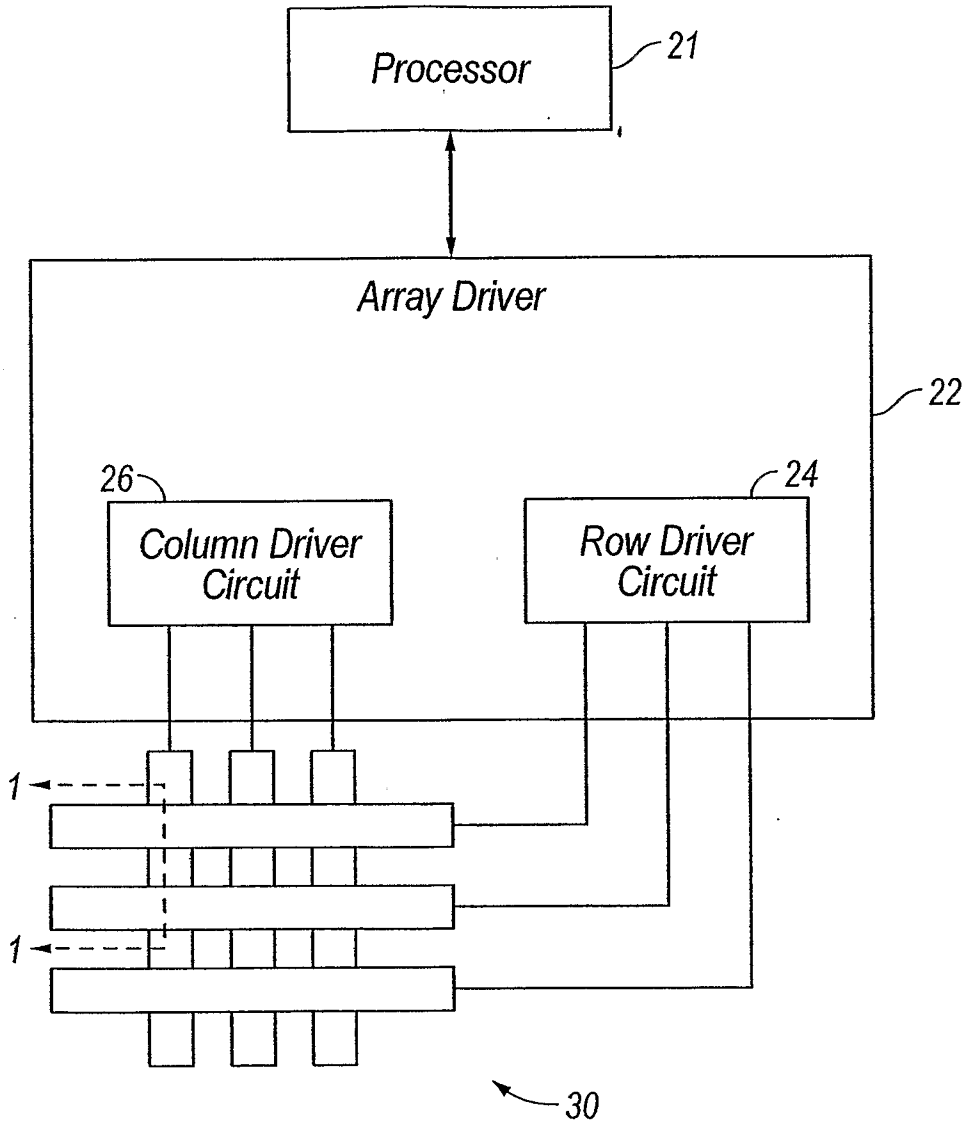


FIG. 1



Processor
21
Array Driver
22
26
Column Driver Circuit
24
Row Driver Circuit
1
1
30

FIG. 2

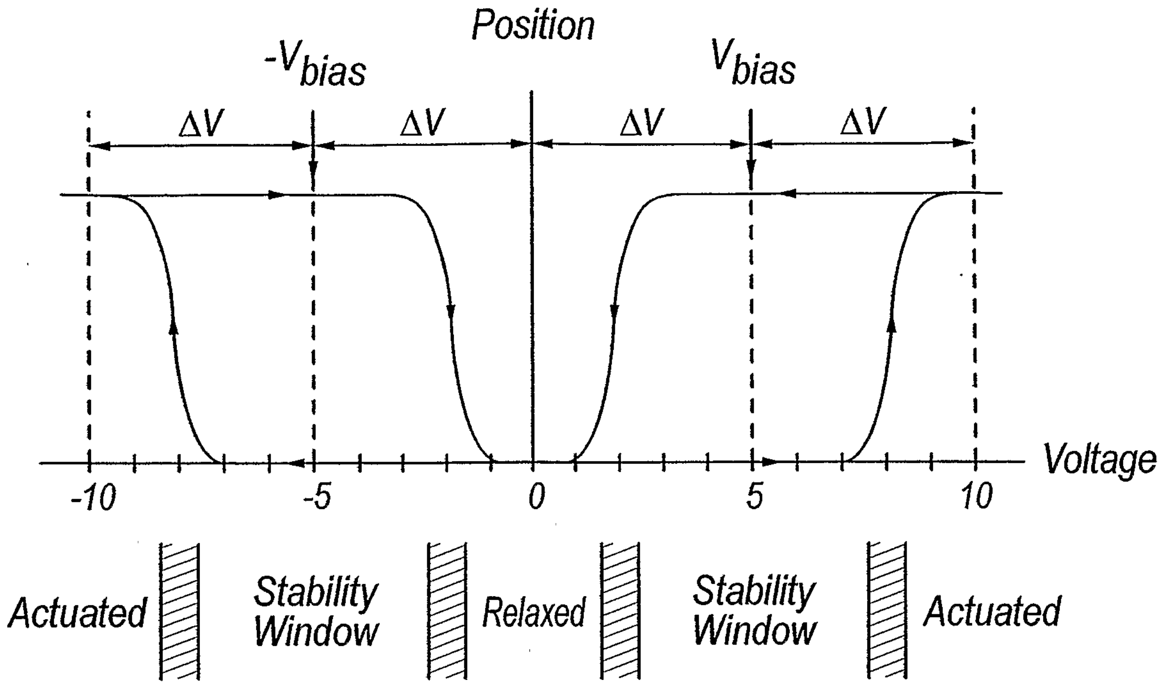


FIG. 3

Column Output Signals

Row Output Signals

	$+V_{bias}$	$-V_{bias}$
0	Stable	Stable
+ΔV	Relax	Actuate
–ΔV	Actuate	Relax

FIG. 4

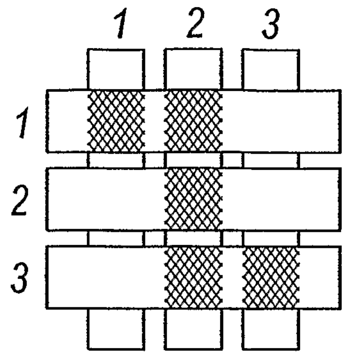

1
2
3
1
2
3

FIG. 5A

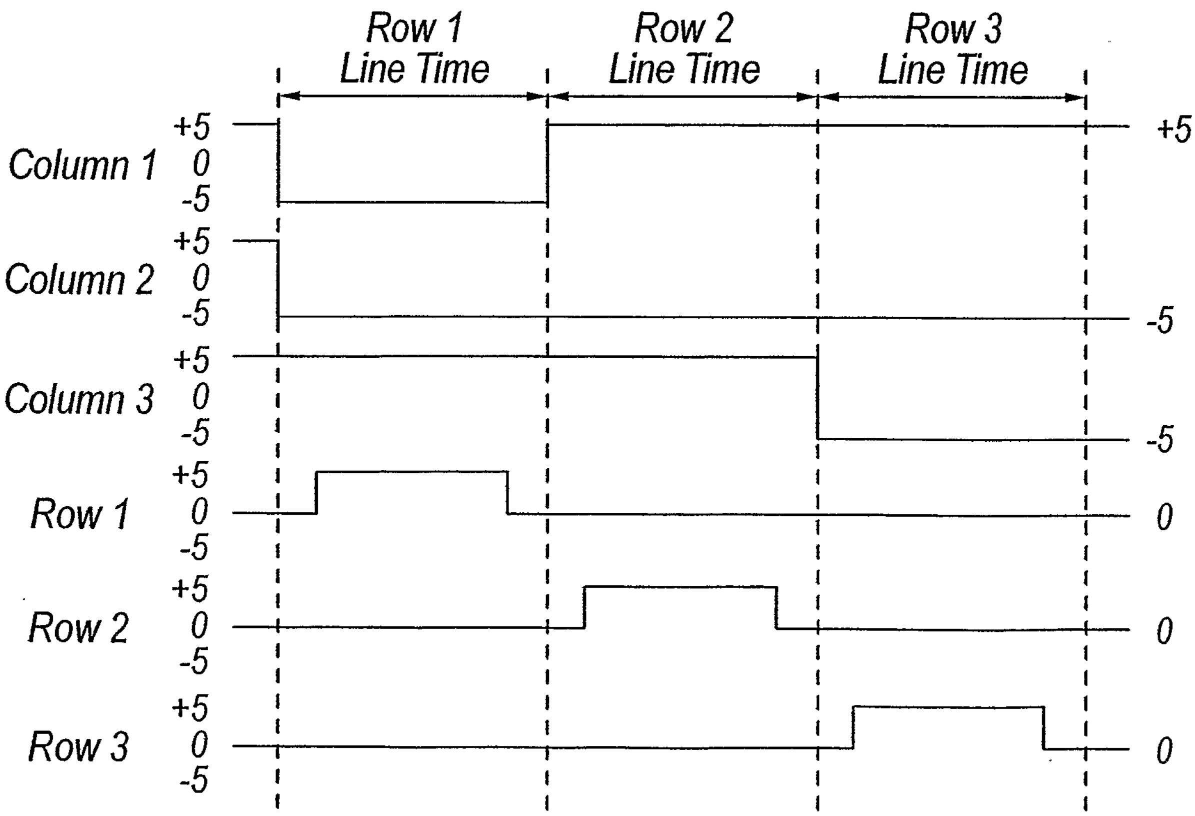

Row 1 Line Time
Row 2 Line Time
Row 3 Line Time
Column 1
Column 2
Column 3
Row 1
Row 2
Row 3
+5
0
-5

FIG. 5B

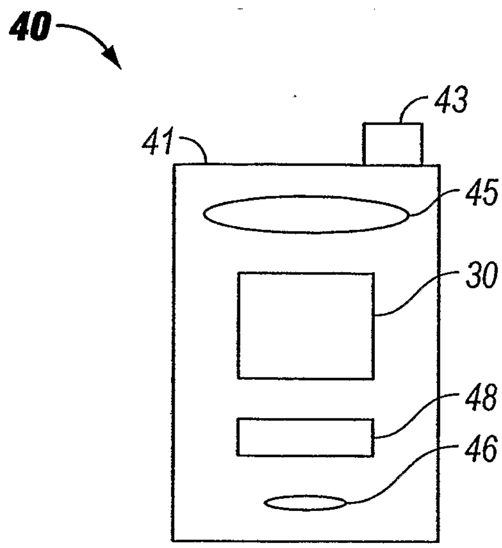

40
43
41
45
30
48
46

FIG. 6A

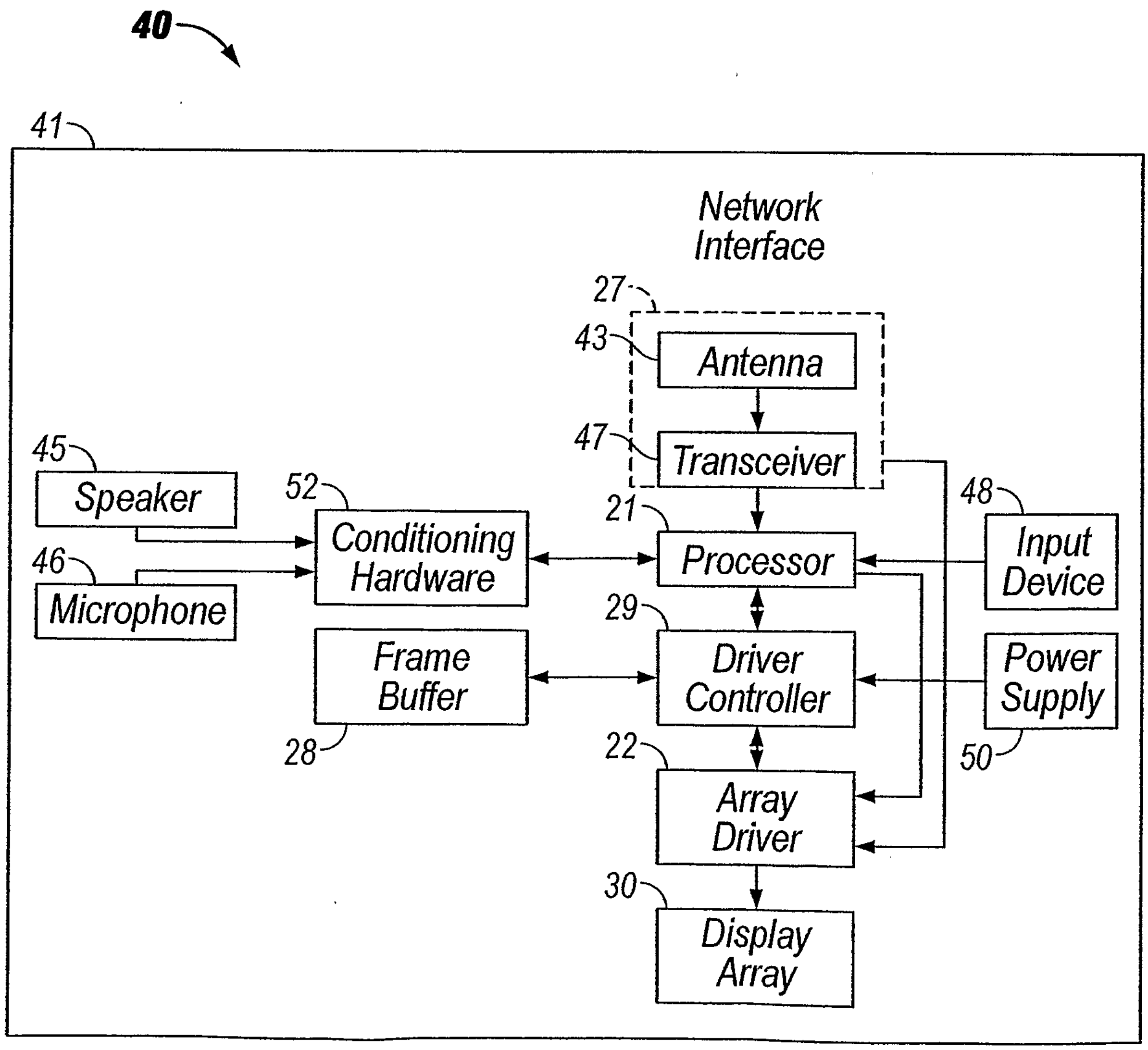

40
41
Network Interface
27
43
Antenna
47
Transceiver
45
Speaker
52
Conditioning Hardware
21
Processor
48
Input Device
46
Microphone
29
Frame Buffer
Driver Controller
Power Supply
28
22
50
Array Driver
30
Display Array

FIG. 6B

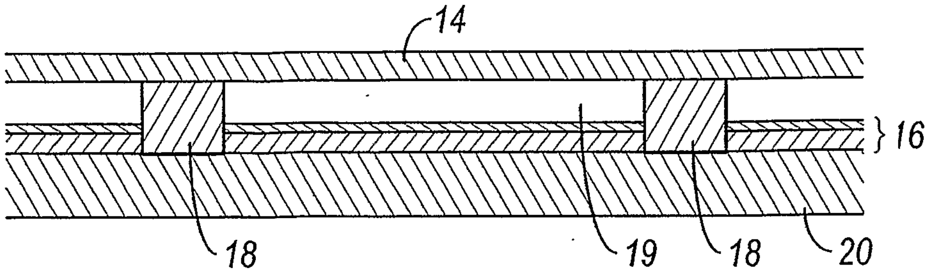


FIG. 7A

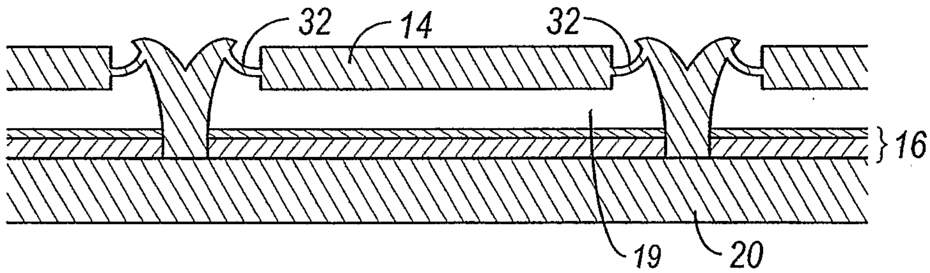


FIG. 7B

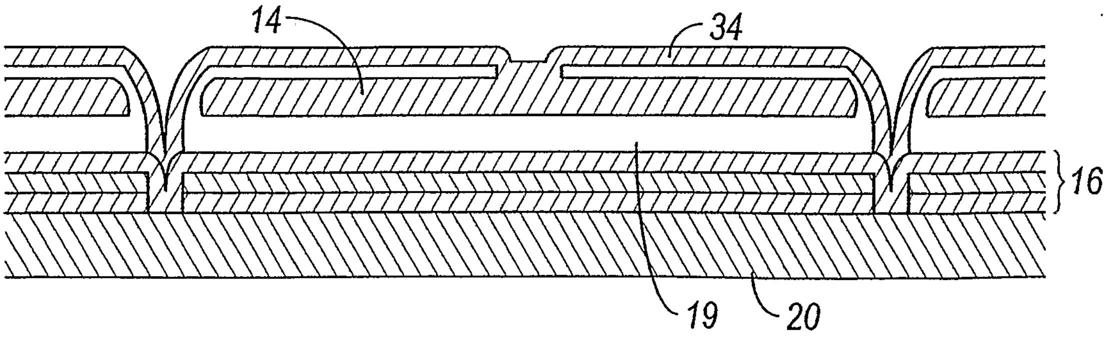


FIG. 7C

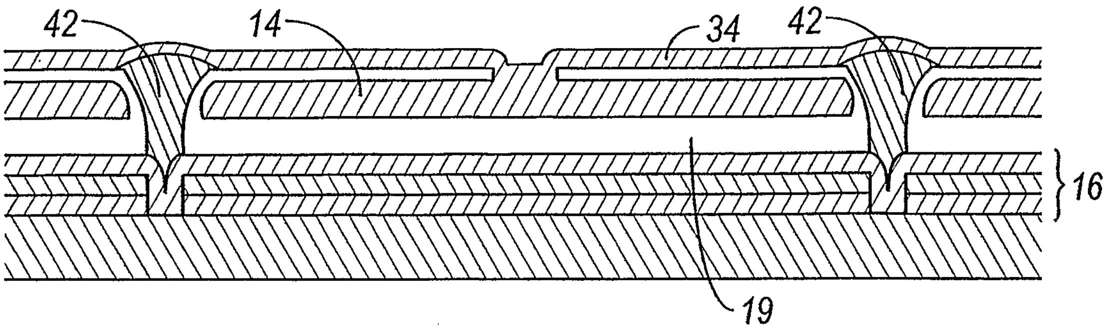


FIG. 7D

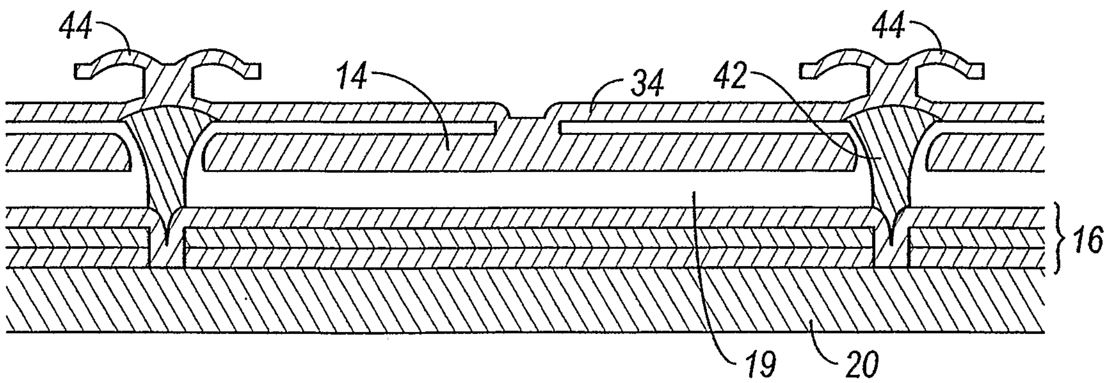


FIG. 7E

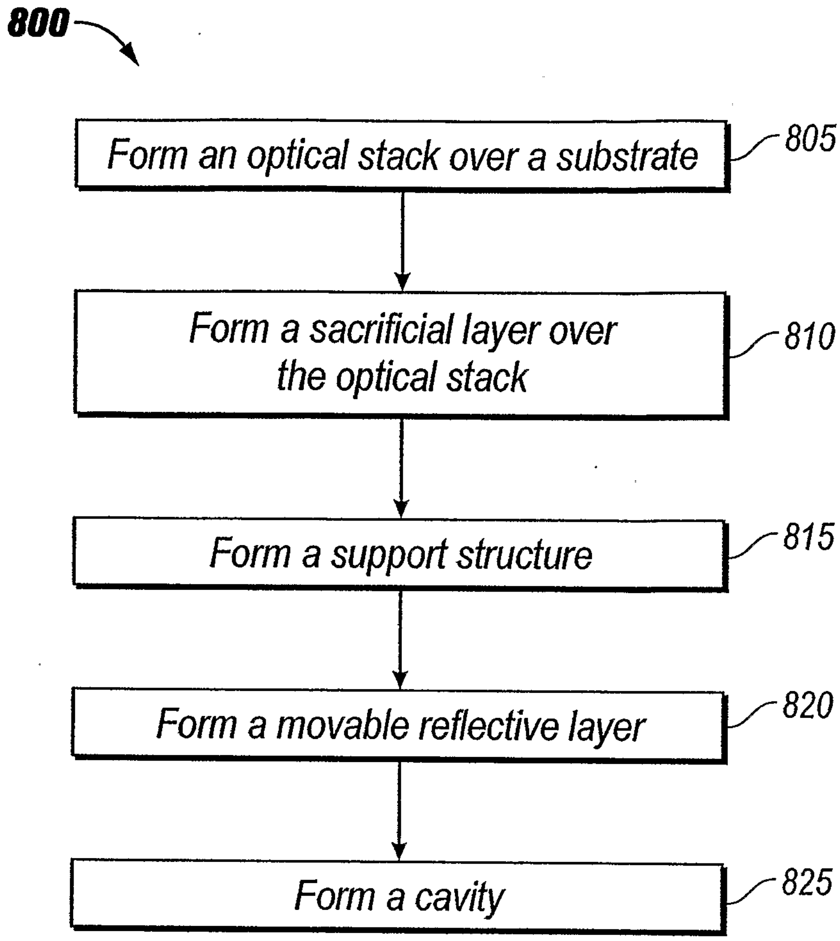

800
Form an optical stack over a substrate
805
Form a sacrificial layer over the optical stack
810
Form a support structure
815
Form a movable reflective layer
820
Form a cavity
825

FIG. 8

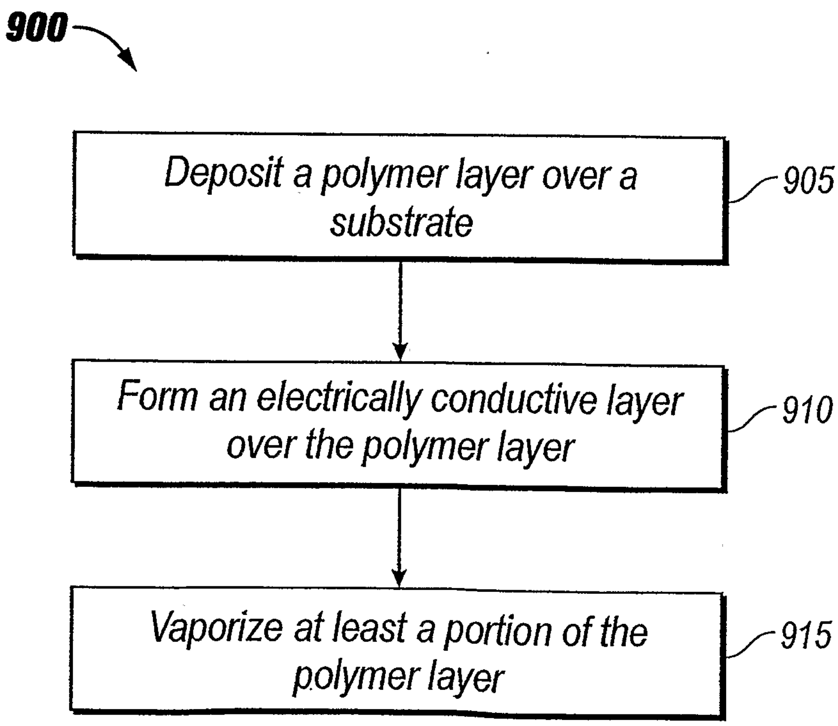

900
Deposit a polymer layer over a substrate
905
Form an electrically conductive layer over the polymer layer
910
Vaporize at least a portion of the polymer layer
915

FIG. 9

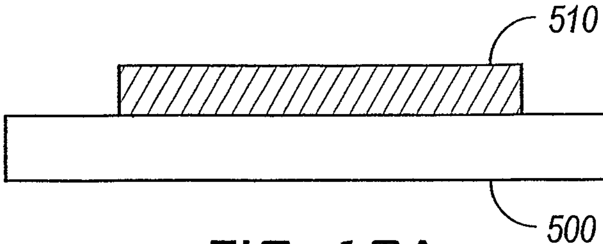


FIG. 10A

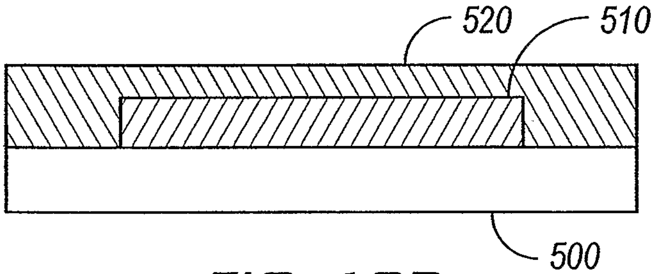


FIG. 10B

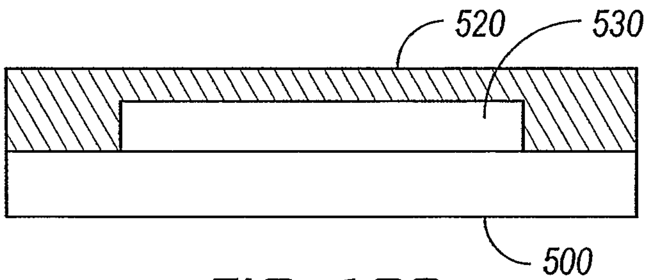


FIG. 10C

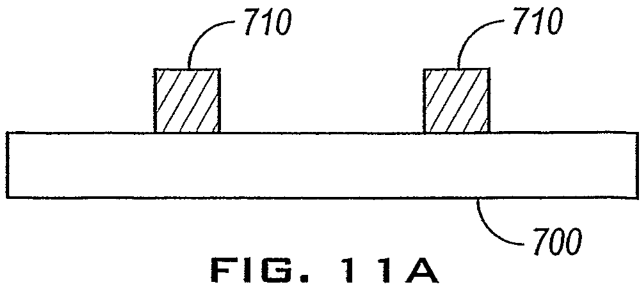


FIG. 11A

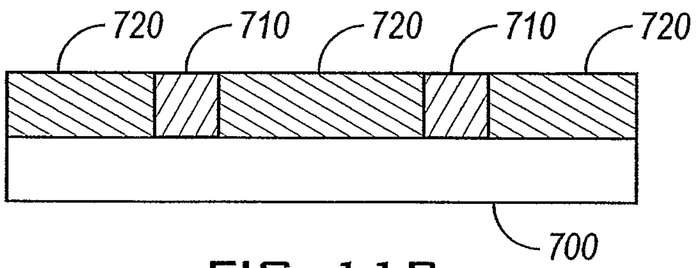


FIG. 11B

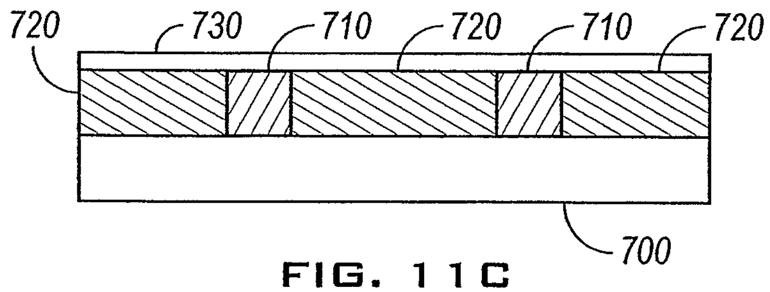


FIG. 11C

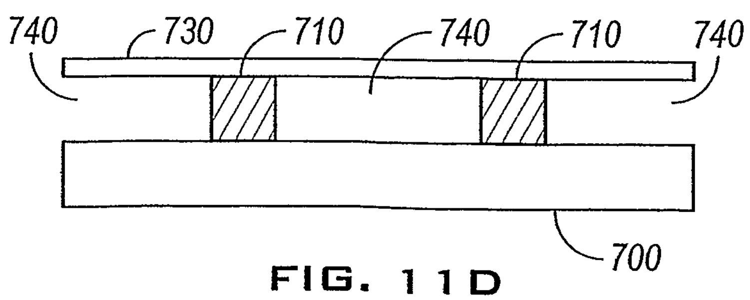


FIG. 11D

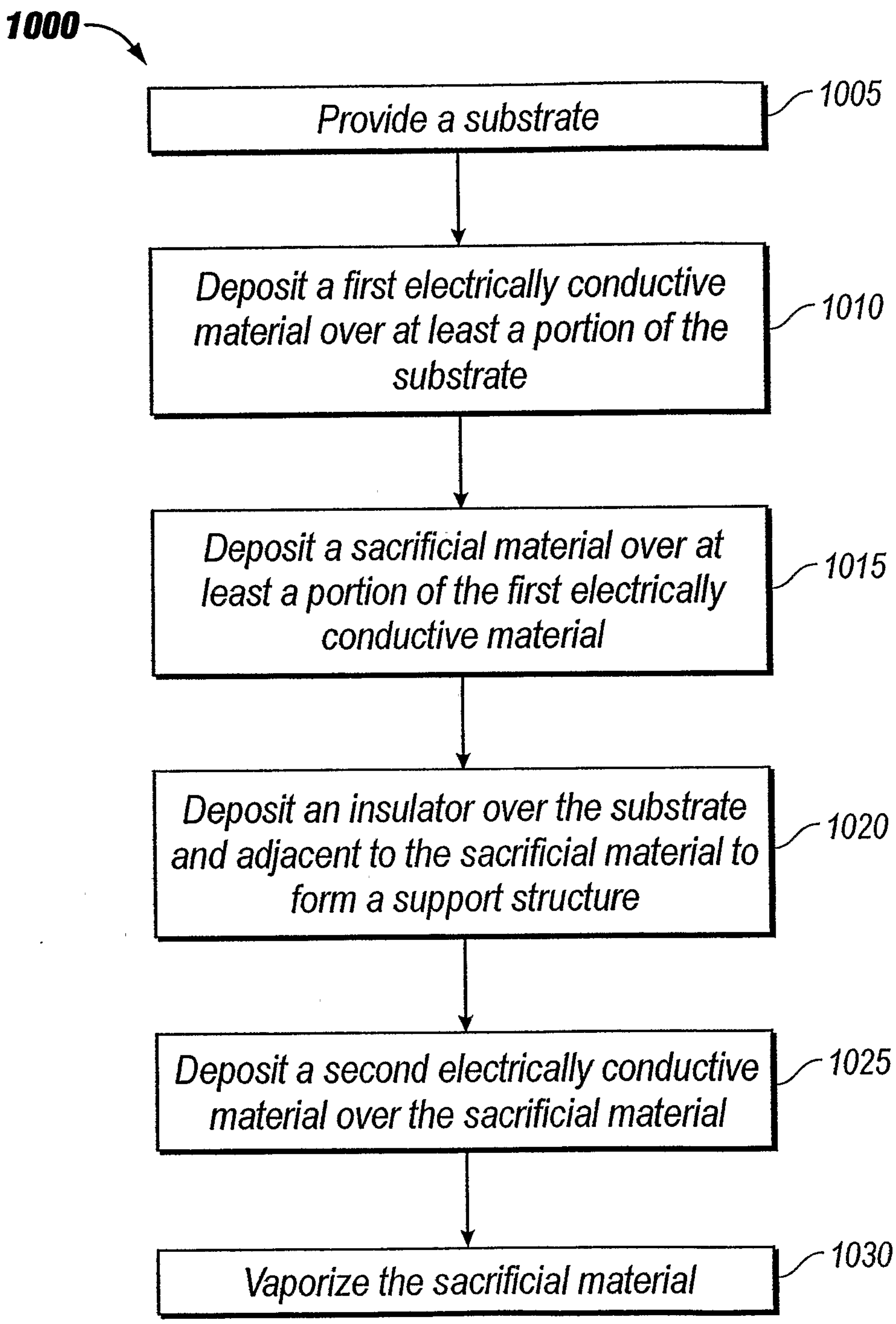

1000
Provide a substrate
1005
Deposit a first electrically conductive material over at least a portion of the substrate
1010
Deposit a sacrificial material over at least a portion of the first electrically conductive material
1015
Deposit an insulator over the substrate and adjacent to the sacrificial material to form a support structure
1020
Deposit a second electrically conductive material over the sacrificial material
1025
Vaporize the sacrificial material
1030

FIG. 12

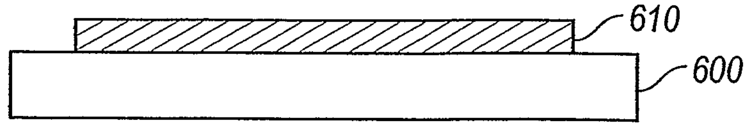


FIG. 13A

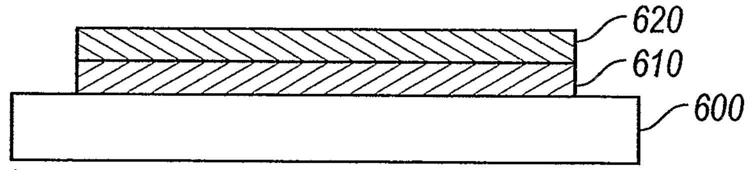


FIG. 13B

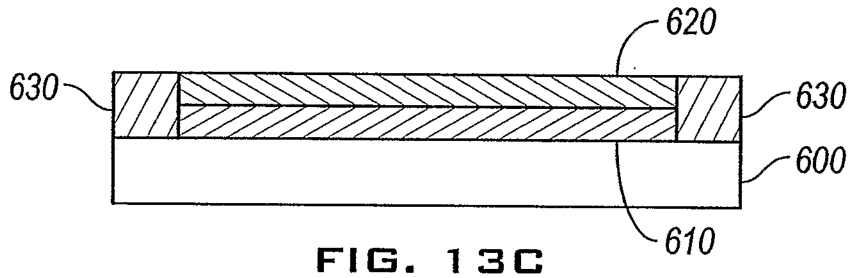


FIG. 13C

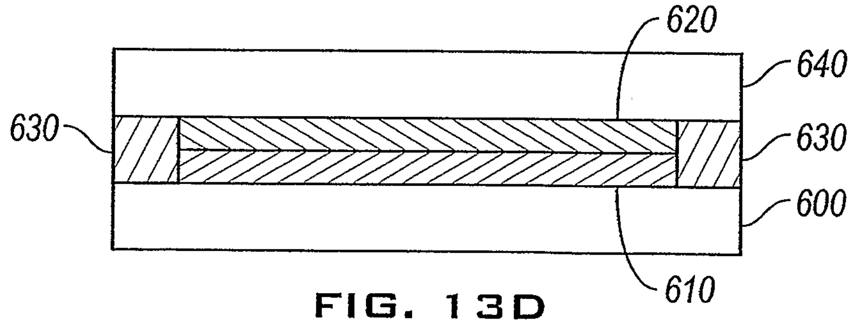


FIG. 13D

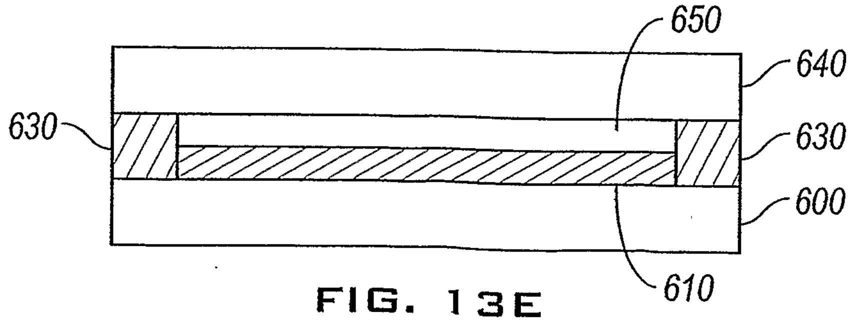


FIG. 13E