Title: INTERFEROMETRIC MODULATOR WITH REDUCED SLIPAGE BETWEEN STRUCTURES AND METHOD OF MAKING THE INTERFEROMETRIC MODULATOR

Abstract: A support structure (18) within an interferometric modulator device may contact various other structures within the device. Increased bond strengths between the support structure (18) and the other structures may be achieved in various ways, such as by providing roughened surfaces and/or adhesive materials at the interfaces between the support structures and the other structures. In an embodiment, increased adhesion is achieved between a support structure (18) and a substrate layer (20). In another embodiment, increased adhesion is achieved between a support structure (18) and a movable layer (14). Increased adhesion may reduce undesirable slippage between the support structures and the other structures to which they are attached within the interferometric modulator.
APPARATUS AND METHOD FOR REDUCING SLIPPAGE BETWEEN STRUCTURES IN AN INTERFEROMETRIC MODULATOR

BACKGROUND

Field of the Invention

This invention relates to microelectromechanical systems for use as interferometric modulators. More particularly, this invention relates to systems and methods for improving the micro-electromechanical operation of interferometric modulators.

Description of the Related Technology

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 an air 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

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.
An embodiment provides an interferometric modulator that includes a substrate layer and a moveable layer. The substrate layer includes a first reflective surface and the movable layer includes a second reflective surface. The second reflective surface is spaced from the first reflective surface to thereby define a cavity. The interferometric modulator further includes a support structure positioned at a side of the cavity between the substrate layer and the moveable layer. The interferometric modulator further includes a bond between the support structure and at least one of the substrate layer and the moveable layer. The bond is configured to increase adhesion between the support structure and at least one of the substrate layer and the moveable layer.

Another embodiment provides an interferometric modulator that includes means for supporting a moveable layer over a fixed layer. The interferometric modulator further includes means for bonding the support means to at least one of the fixed layer and the moveable layer. The bonding means is configured to provide improved adhesion between the support means and at least one of the fixed layer and the moveable layer.

Another embodiment provides a method of making an interferometric modulator. The method includes forming a substrate layer. The substrate layer comprises a first reflective surface. The method further includes treating at least a portion of a support region of the substrate layer to form a treated support region. The method further includes forming a support structure on the treated support region. The treated support region is configured to increase adhesion between the substrate layer and the support structure.

Another embodiment provides a method of making an interferometric modulator. The method includes forming a substrate layer. The method further includes forming a support structure on the substrate layer. The method further includes treating the support structure to form a treated support structure. The method further includes forming a moveable layer on the treated support structure.

These and other embodiments are described in greater detail below.

**Brief Description of the Drawings**

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.

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

FIG. 3 is a diagram of movable mirror position versus applied voltage for one exemplary embodiment of an interferometric modulator of FIG. 1.
FIG. 4 is an illustration of a set of row and column voltages that may be used to drive an interferometric modulator display.

FIG. 5A illustrates one exemplary frame of display data in the 3x3 interferometric modulator display of FIG. 2.

FIG. 5B illustrates one exemplary timing diagram for row and column signals that may be used to write the frame of FIG. 5A.

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

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

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

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

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

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

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

FIG. 9 is a cross section of an embodiment of an interferometric modulator.

FIGS. 10A – 10E are partial cross sections of an embodiment of an interferometric modulator illustrating bonds to a post structure.

FIG. 11 is a flow diagram illustrating certain steps in an embodiment of a method of making an interferometric modulator.

FIG. 12 is a flow diagram illustrating certain steps in an embodiment of a method of making an interferometric modulator.

**Detailed Description of Preferred Embodiments**

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.

An embodiment provides increased bond strengths between post structures and other
structures (such as the substrate and/or the moveable layer) in an interferometric modulator. In
certain embodiments, the increased bond strengths are achieved by providing a roughened
surface and/or an adhesive layer at the interface between the post structure and the structures to
which it is attached (such as the substrate and/or the moveable layer).

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.

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.

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.
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.

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.

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

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.
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.

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.
Figures 4, 5A, and 5B 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 $-V_{\text{bias}}$, 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 $+V_{\text{bias}}$, 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 $+V_{\text{bias}}$ or $-V_{\text{bias}}$. 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 $+V_{\text{bias}}$, and the appropriate row to $-\Delta V$. In this embodiment, releasing the pixel is accomplished by setting the appropriate column to $-V_{\text{bias}}$, and the appropriate row to the same $-\Delta V$, producing a zero volt potential difference across the pixel.

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.

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.

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.

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 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.

The display 30 of 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.

The components of one embodiment of 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.

The network interface 27 includes the antenna 43 and the transceiver 47 so that the exemplary display device 40 can communicate with one or 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.

In an alternative embodiment, the transceiver 47 can be replaced by a receiver. In yet another alternative embodiment, 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 digital video disc (DVD) or a hard-disc drive that contains image data, or a software module that generates image data.

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 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.

In one embodiment, the processor 21 includes a microcontroller, CPU, or logic unit to control operation of the exemplary display device 40. Conditioning hardware 52 generally includes amplifiers and filters for transmitting signals to the speaker 45, and for receiving signals from the microphone 46. Conditioning hardware 52 may be discrete components within the exemplary display device 40, or may be incorporated within the processor 21 or other components.

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.

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.

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,
driver controller 29 is a conventional display controller or a bi-stable display controller (e.g., an interferometric modulator controller). In another embodiment, array driver 22 is a conventional driver or a bi-stable display driver (e.g., an interferometric modulator display). In one embodiment, a 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, display array 30 is a typical display array or a bi-stable display array (e.g., a display including an array of interferometric modulators).

The input device 48 allows a user to control the operation of the exemplary display device 40. In one embodiment, 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.

Power supply 50 can include a variety of energy storage devices as are well known in the art. For example, in one embodiment, power supply 50 is a rechargeable battery, such as a nickel-cadmium battery or a lithium ion battery. In another embodiment, 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, power supply 50 is configured to receive power from a wall outlet.

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 an 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.

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 supports 18. In Figure 7B, the moveable reflective layer 14 is attached to supports at the corners only, on tethers 32. In Figure 7C, the moveable 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 are herein referred to as support posts. The embodiment illustrated in Figure 7D has 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 by filling holes between the deformable layer 34 and the optical stack 16. Rather, the support posts are formed of 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.

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. 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.

Figure 8 illustrates certain steps in an embodiment of a manufacturing process 800 for a MEMS, e.g., 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. The optical stack 16 may be formed by employing one or more deposition steps, e.g., conductive layer (e.g., indium tin oxide) deposition, reflective layer (e.g., chromium) deposition, and dielectric layer deposition, along with one or more patterning, masking, and/or etching steps.

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 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.

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 an aperture, then depositing a material (e.g., a polymer, metal or oxide) into the aperture to form the post 18, using a deposition method such as PECVD, thermal CVD, or spin-coating. In some embodiments, the 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.

The process 800 illustrated in Figure 8 continues at step 820 with the formation of a moveable reflective layer such as the moveable reflective layer 14 illustrated in Figures 1 and 7. The moveable 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 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 a selective etchant. For example, a 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 xenon difluoride (XeF₂) for a period of time that is effective to remove the desired amount of material. Other etching methods, e.g. wet etching and/or plasma etching, may be also be used.

Interferometric modulators may be manufactured in accordance with various sets of processing parameters, and thus it will be understood that Figure 8 shows only a few of the more common steps for the purposes of illustration. It will be also be understood that not all processes for manufacturing interferometric modulators include all the steps illustrated in Figure 8; that the steps illustrated in Figure 8 need not necessarily be carried out in the order shown, and that various additional manufacturing steps may be carried out, e.g., testing, back-end processing, and incorporating the interferometric modulator into a display device 40 as illustrated in Figure 6.

Figure 9 illustrates a cross-sectional view of an embodiment of a moveable interferometric modulator. In this embodiment, the support structure 18 interacts with the moveable reflective layer 14 at an interface 905 between the upper end of the support structure 18 and the lower surface of the layer 14. Likewise, the support structure 18 interacts with the substrate 20 at an interface 910 between the lower end of the support 18 and the upper surface of the substrate 20.
In certain situations, sliding or slippage between the support 18 and one or both of the moveable reflective layer 14 and the substrate 20 may occur. It has now been found that this movement may be decreased or eliminated in a number of ways. For example, in one embodiment, the movement is decreased by forming a bond at one or both of the interfaces 905, 910. The bond is preferably configured to increase adhesion between the support structure 18 and at least one of the substrate layer 20 and the moveable layer 14. The increased adhesion may provide other benefits, instead of or in addition to decreasing and/or preventing relative movement between the support structure 18 and the layer(s) with which it is in contact.

Figure 10A illustrates an embodiment of a bond 1005 formed at the interface between the upper end of the support structure 18 and the lower surface of the moveable layer 14, and a bond 1010 at the interface between the lower end of the support structure 18 and the upper surface of a transparent substrate layer 20. In the illustrated embodiment, the bonds 1005, 1010 both comprise a roughened interface between the support structure 18 and each of the moveable layer 14 and the substrate layer 20, respectively. This invention is not bound by theory, but it is believed that roughening increases the surface area at the interface and/or provides mechanical interlocking between the two surfaces, thereby increasing adhesion between the support structure 18 and each of the layers 14, 20. Adhesion tends to increase as the degree of roughness increases, and thus the degree of roughness for each of the bonds 1005, 1010 is preferably selected to provide the desired degree of adhesion, as determined by routine experimentation. The bond 1010 at the interface between the lower end of the support structure 18 and the upper surface of a transparent substrate layer 20 may be formed during fabrication of the interferometric modulator, preferably by roughening a region 1040 of the surface of the substrate 20 prior to formation of the support structure, as described in greater detail below. The bond 1005 at the interface between the upper end of the support structure 18 and the lower surface of the moveable layer 14 may also be formed during fabrication of the interferometric modulator, preferably by roughening the support structure prior to formation of the moveable layer 14, as described in greater detail below. Roughening of the substrate and/or support structure may be carried out in various ways, e.g., by etching techniques known to those skilled in the art. For example, the substrate may be etched by oxygen plasma burn down and/or by sputter etching. The degree of roughening for each of the bonds 1005, 1010, may be the same or different. In some embodiments (not shown in Figure 10A), only one of the interfaces 905, 910 is treated to increase adhesion between the support structure 18 and the layers 14, 20, respectively.

Figure 10B illustrates an embodiment of a bond 1015 formed at the interface between the upper end of the support structure 18 and the lower surface of the moveable layer 14, and a bond 1020 at the interface between the lower end of the support structure 18 and the upper surface of a transparent substrate layer 20. In the illustrated embodiment, the bonds 1015, 1020 both comprise an adhesive layer between the support structure 18 and each of the moveable layer 14 and the
substrate layer 20, respectively. The adhesive layer preferably comprises a material that adheres more strongly to both of the surfaces at the interface than either of the interfacial surfaces adhere to one another in the absence of the adhesive material. For example, the bond 1015 preferably comprises a material that adheres better to both the support structure 18 and the moveable layer 14, than the support structure 18 adheres to the moveable layer 14 in the absence of the bond 1015. Likewise, the bond 1020 preferably comprises a material that adheres better to both the support structure 18 and the substrate layer 20, than the support structure 18 adheres to the substrate layer 20 in the absence of the bond 1020. Adhesive materials may be selected by routine experimentation. Preferably, one or both of the adhesive bond 1015 and the adhesive bond 1020 comprise aluminum, e.g., the bonds 1015, 1020 contain aluminum or an aluminum alloy. The bond 1020 at the interface between the lower end of the support structure 18 and the upper surface of a transparent substrate layer 20 may be formed during fabrication of the interferometric modulator, preferably by depositing an adhesive material onto the substrate 20 prior to formation of the support structure, as described in greater detail below. Likewise, the bond 1015 at the interface between the upper end of the support structure 18 and the lower surface of the moveable layer 14 may also be formed during fabrication of the interferometric modulator, preferably by depositing an adhesive material onto the support structure prior to formation of the moveable layer 14, as described in greater detail below.

Figure 10C illustrates that a bond between the support structure and at least one of the substrate layer and the moveable layer may comprise both a roughened interface and an adhesive layer. The bond 1035 between the upper end of the support structure 18 and the lower surface of the moveable layer 14 shown in Figure 10C comprises a bond 1005 that comprises a roughened surface on the upper end of the support structure 18, and an adhesive layer 1015 between the roughened interface and the lower surface of the moveable layer 14. This invention is not bound by theory, but it is believed that the surface roughening increases the surface area of the upper end of the support structure 18 that is available for bonding, thus increasing adhesion between the upper end of the support structure 18 and the adhesive layer in the bond 1015. Figure 10C also illustrates an interferometric modulator in which the upper end of the support structure 18 is bonded to the lower surface of the moveable layer 14 in a different manner (via the bond 1035) than the lower end of the support structure 18 is bonded to the upper surface of the substrate layer 20 (via a bond 1010 that comprises a roughened interface, without an adhesive layer).

Figure 10D illustrates an embodiment of a bond 1025 formed at the interface between the lower end of the support structure 18 and the upper surface of a transparent substrate layer 20, where the upper surface of the substrate 20 comprises an optical stack 16. In the illustrated embodiment, the bond 1015 is formed by roughening the optical stack 16, rather than the transparent substrate 20 as illustrated in Figure 10A. Likewise, Figure 10E illustrates an embodiment of a bond 1030 formed at the interface between the lower end of the support
structure 18 and the upper surface of a transparent substrate layer 20, where the upper surface of the substrate 20 comprises an optical stack 16. In the illustrated embodiment, the bond 1030 is formed by depositing an adhesive layer onto the optical stack 16, rather than onto the transparent substrate 20 as illustrated in Figure 10B.

The various bonds 1005, 1010, 1015, 1020, 1025, 1030 are illustrated in Figure 10 for an interferometric modulator of the general type shown in Figure 7A. It will be understood that similar bonds may be formed between the support structures and the layers to which the support structures are attached in other types of interferometric modulators, including but not limited to the interferometric modulators illustrated in Figures 7B-E. For example, in an embodiment (not illustrated in Figure 10), a bond is formed between a support structure and a moveable layer, and a reflective surface is suspended from the moveable layer, e.g., in the general manner illustrated in Figure 7C. It will also be appreciated that the support structure 18 (e.g., a post) is an example of a means for supporting a moveable layer (e.g., the moveable layer 14) over a fixed layer (e.g., the substrate layer 20 comprising the optical stack 16). It will also be appreciated that the bonds formed by surface roughening (e.g., the bonds 1005, 1010) and by the use of an adhesive layer (e.g., the bonds 1015, 1020) are examples of means for bonding the support means to at least one of the fixed layer and the moveable layer.

Figure 11 is a flow chart illustrating an embodiment of a method of making an interferometric modulator. The method 1100 begins at step 1105 by forming a substrate layer. Preferably, the substrate layer comprises a first reflective surface. The substrate layer may include a transparent substrate 20 and the first reflective surface may include an optical stack 16 as illustrated in Figures 1 and 7. The optical stack 16 may be formed on the substrate 20 by employing one or more deposition steps, e.g., reflective layer (e.g., chromium) deposition, conductive layer (e.g., indium tin oxide) deposition, and dielectric layer deposition, along with one or more patterning, masking, and/or etching steps.

The method 1100 continues at step 1110 by treating at least a portion of a support region of the substrate layer to form a treated support region. The support region of the substrate layer is typically the area that will underlie a support structure that will be formed in a subsequent step. The substrate layer may comprise the first reflective surface, and thus treatment of the support region of the substrate layer may include treatment of the support region of the substrate, e.g., treatment of the support region 1040 of the substrate 20 as illustrated in Figure 10A, and/or treatment of the first reflective surface, e.g., the support region 1045 of the optical stack 16 as illustrated in Figure 10. Treating the support region to form a treated support region may include, for example, roughening the support region and/or applying an adhesive layer. Thus, the resulting treated support region may include, for example, a roughened surface (such as the roughened surfaces included in the bonds 1010, 1025 illustrated in Figures 10A and 10D, respectively) and/or a adhesive layer such as the adhesive layers included in the bonds 1020, 1030 illustrated in
Figures 10B and 10E, respectively. Treating the support region may include exposing the support region to a roughening treatment such as a wet chemical etch, a dry chemical etch, and/or a plasma etch. Examples of roughening treatments include oxygen plasma burn down and sputter etching. In addition to or instead of roughening, treating the support region may include depositing an adhesive layer by a deposition process such as, e.g., spin-on, PECVD, thermal CVD, and/or PVD (e.g., sputtering). In an embodiment, deposition of an adhesive layer comprises depositing a metal, wherein the metal comprises aluminum (e.g., an aluminum alloy). Treatment is preferably carried out to an extent that is effective to provide increased adhesion between the substrate layer and the subsequently-formed support structure, e.g., between the substrate 20 and the support structure 18 as illustrated in Figure 10.

The method 1100 continues at step 1115 by forming a support structure on the treated support region. The support structure may be formed in various ways. For example, in an embodiment, a configuration such as that illustrated in Figures 10A and 10B may be fabricated by depositing a first reflective layer (e.g., the optical stack 16) and a sacrificial layer on a substrate (e.g., the substrate 20), forming an aperture (e.g., a hole) through the sacrificial layer and the first reflective layer to expose a portion of the underlying substrate (e.g., to expose the underlying substrate 20), treating the exposed substrate to form a treated support region (e.g., the treated support region 1040) as described above, and depositing a support structure material into the aperture to form a support structure (e.g., the support structure 18) in contact with the treated support region. In another embodiment, a configuration such as that illustrated in Figures 10D and 10E may be fabricated by depositing a first reflective layer (e.g., the optical stack 16) and a sacrificial layer on a substrate (e.g., the substrate 20), forming an aperture (e.g., a hole) through the sacrificial layer to expose a portion of the underlying first reflective layer (e.g., to expose the optical stack 16), treating the exposed optical stack 16 to form a treated support region (e.g., the treated support region 1045) as described above, and depositing a support structure material into the aperture to form a support structure (e.g., the support structure 18) in contact with the treated support region. The support structure may be formed in various ways, e.g., by spin-in deposition of a polymer or by chemical vapor deposition (e.g., PECVD or thermal CVD) of an oxide such as a silicon oxide.

It will be understood that additional steps (not illustrated in Figure 11) in the fabrication of the interferometric modulator may also be conducted in accordance with the method 1100, e.g., deposition of the sacrificial layer over the substrate layer, deposition of a moveable layer over the sacrificial layer, deposition of a second reflective layer over the sacrificial layer, removal of the sacrificial layer to form a cavity positioned between the first reflective layer and the second reflective layer, and/or removal of the sacrificial layer to form a cavity positioned between the first reflective layer and the moveable layer.
Figure 12 is a flow chart illustrating another embodiment of a method of making an interferometric modulator. The method 1200 begins at step 1205 by forming a substrate layer. Preferably, the substrate layer comprises a first reflective surface. The substrate layer may include a transparent substrate 20 and the first reflective surface may include an optical stack 16 as illustrated in Figures 1 and 7. The optical stack 16 may be formed on the substrate 20 by employing one or more deposition steps, e.g., reflective layer (e.g., chromium) deposition, conductive layer (e.g., indium tin oxide) deposition, and dielectric layer deposition, along with one or more patterning, masking, and/or etching steps.

The method 1200 continues at step 1210 by forming a support structure on the substrate layer. The support structure may be formed in various ways. For example, in an embodiment, a configuration such as that illustrated in Figures 10A and 10B may be fabricated by depositing a first reflective layer (e.g., the optical stack 16) and a sacrificial layer on a substrate (e.g., the substrate 20), forming an aperture (e.g., a hole) through the sacrificial layer and the first reflective layer to expose a portion of the underlying substrate (e.g., to expose the underlying substrate 20), and depositing a support structure material into the aperture to form a support structure (e.g., the support structure 18) in contact with the substrate (e.g., the substrate 20). Optionally, the exposed substrate may be treated to form a treated support region (e.g., the treated support region 1040) as described above. In another embodiment, a configuration such as that illustrated in Figures 10D and 10E may be fabricated by depositing a first reflective layer (e.g., the optical stack 16) and a sacrificial layer on a substrate (e.g., the substrate 20), forming an aperture (e.g., a hole) through the sacrificial layer to expose a portion of the underlying first reflective layer (e.g., to expose the optical stack 16), and depositing a support structure material into the aperture to form a support structure (e.g., the support structure 18) in contact with the first reflective layer (e.g., the optical stack 16). Optionally, the exposed optical stack 16 may be treated to form a treated support region (e.g., the treated support region 1045) as described above. The support structure may be formed in various ways as described above, e.g., by spin-in deposition of a polymer or by chemical vapor deposition (e.g., PECVD or thermal CVD) of an oxide such as a silicon oxide.

The method 1200 continues at step 1215 by treating the support structure to form a treated support structure. Preferably, the upper end of the support structure is treated to increase adhesion to a subsequently-formed moveable layer. Treating the support structure to form a treated support structure may include, for example, roughening the upper end of the support structure and/or applying an adhesive layer over the upper end of the support structure. Thus, the resulting treated support structure may include, for example, a roughened surface (such as the roughened surface included in the bond 1005 illustrated in Figure 10A) and/or a adhesive layer such as the adhesive layer included in the bond 1015 illustrated in Figure 10B. Treating the support structure may include exposing the support structure to a roughening treatment such as a wet chemical etch, a dry chemical etch, and/or a plasma etch. Examples of roughening treatments include oxygen
plasma burn down and sputter etching. In addition to or instead of roughening, treating the support structure may include depositing an adhesive layer by a deposition process such as, e.g., spin-on, plasma-enhanced chemical vapor deposition (PECVD), thermal chemical vapor deposition (thermal CVD), and/or PVD. In an embodiment, deposition of an adhesive layer comprises depositing a metal, wherein the metal comprises aluminum (e.g., an aluminum alloy). Treatment is preferably carried out to an extent that is effective to provide increased adhesion between the support structure and the subsequently-formed moveable layer, e.g., between the support structure 18 and the moveable layer 14 as illustrated in Figure 10.

The method 1200 continues at step 1220 by forming a moveable layer on the treated support structure. The moveable reflective layer (e.g., the layer 14 as illustrated in Figures 1 and 7) 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. In an embodiment, formation of the moveable layer on a roughened surface at the upper end of the support structure forms a bond, e.g., the bond 1005 as illustrated in Figure 10. In another embodiment, formation of the moveable layer on an adhesive layer at the upper end of the support structure forms a bond, e.g., the bonds 1015, 1035 as illustrated in Figure 10.

It will be understood that additional steps (not illustrated in Figure 12) in the fabrication of the interferometric modulator may also be conducted in accordance with the method 1200, e.g., deposition of a first reflective layer over the substrate, deposition of a sacrificial layer over the substrate and/or over the first reflective layer, deposition of a second reflective layer over the sacrificial layer, removal of the sacrificial layer to form a cavity positioned between the first reflective layer and the second reflective layer, and/or removal of the sacrificial layer to form a cavity positioned between the first reflective layer and the moveable layer.

The methods 1100, 1200 discussed above make reference in certain embodiments to forming bonds to the support structure 18 of an interferometric modulator of the general type shown in Figure 7A. It will be understood that the illustrated methods may also be employed to form similar bonds between the support structures and the layers to which the support structures are attached in other types of interferometric modulators, including but not limited to the interferometric modulators illustrated in Figures 7B-E. For example, in an embodiment (not illustrated in Figure 10), the method 1200 is employed to form a bond between a support structure and a moveable layer, and a reflective surface is formed that is suspended from the moveable layer, e.g., in the general manner illustrated in Figure 7C. It will be appreciated that the methods 1100, 1200 may each be carried out individually, or combined into a single method. For example, the method 1100 may be conducted to form a bond between the substrate layer (e.g., the substrate 20 or the optical stack 16) and the support structure 18; the method 1200 may be conducted to form a bond between the support structure 18 and the moveable layer 14; and/or the methods 1100 and 1200 may be carried out together, e.g., to form bonds between the support structure 18.
and both of the substrate layer (e.g., the substrate 20 or the optical stack 16) and the moveable layer 14.

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 microelectromechanical systems (MEMS) device, comprising:
   a substrate layer comprising a first reflective surface;
   a movable layer comprising a second reflective surface, the second reflective
   surface being spaced from the first reflective surface to thereby define a cavity;
   a support structure positioned at a side of the cavity between the substrate layer
   and the movable layer; and
   a bond between the support structure and at least one of the substrate layer and
   the movable layer;
   the bond being configured to increase adhesion between the support structure and
   at least one of the substrate layer and the movable layer.

2. The MEMS device of Claim 1, comprising an interferometric modulator.

3. The MEMS device of Claim 1, wherein the bond comprises a roughened interface
   between the support structure and at least one of the substrate layer and the movable layer.

4. The MEMS device of Claim 3, wherein the bond is between the support structure
   and the substrate layer.

5. The MEMS device of Claim 4, wherein the substrate layer comprises a
   transparent substrate underlying the first reflective surface.

6. The MEMS device of Claim 5, wherein the roughened interface is between the
   support structure and the transparent substrate.

7. The MEMS device of Claim 5, wherein the roughened interface is between the
   support structure and the first reflective surface.

8. The MEMS device of Claim 3, wherein the bond is between the support structure
   and the movable layer.

9. The MEMS device of Claim 8, wherein the second reflective surface is suspended
   from the movable layer.

10. The MEMS device of Claim 1, wherein the bond comprises an adhesive layer
    between the support structure and at least one of the substrate layer and the movable layer.

11. The MEMS device of Claim 10, wherein the adhesive layer comprises aluminum.

12. The MEMS device of Claim 10, wherein the adhesive layer is between the
    support structure and the substrate layer.

13. The MEMS device of Claim 12, wherein the substrate layer comprises a
    transparent substrate underlying the first reflective surface.

14. The MEMS device of Claim 13, wherein the adhesive layer is between the
    support structure and the transparent substrate.
15. The MEMS device of Claim 13, wherein adhesive layer is between the support structure and the first reflective surface.

16. The MEMS device of Claim 10, wherein the adhesive layer is between the support structure and the moveable layer.

17. The MEMS device of Claim 16, wherein the second reflective surface is suspended from the moveable layer.

18. The MEMS device of Claim 1, further comprising:
   a processor that is in electrical communication with at least the movable layer, the processor being configured to process image data; and
   a memory device in electrical communication with the processor.

19. The display device of Claim 18, further comprising a driver circuit configured to send at least one signal to at least the movable layer.

20. The display device of Claim 19, further comprising a controller configured to send at least a portion of the image data to the driver circuit.

21. The display device of Claim 18, further comprising an image source module configured to send the image data to the processor.

22. The display device of Claim 21, wherein the image source module comprises at least one of a receiver, transceiver, and transmitter.

23. The display device of Claim 18, further comprising an input device configured to receive input data and to communicate the input data to the processor.

24. An interferometric modulator comprising:
   means for supporting a moveable layer over a fixed layer; and
   means for bonding the support means to at least one of the fixed layer and the moveable layer, wherein the bonding means is configured to provide improved adhesion between the support means and at least one of the fixed layer and the moveable layer.

25. The interferometric modulator of Claim 24, wherein the bonding means comprises an adhesive.

26. The interferometric modulator of Claim 24, wherein the bonding means comprises a roughened interface between the support means and at least one of the fixed layer and the moveable layer.

27. The interferometric modulator of Claim 24, 25, or 26, wherein the support means comprises a post.

28. A method of making an interferometric modulator, comprising:
   forming a substrate layer, the substrate layer comprising a first reflective surface;
   treating at least a portion of a support region of the substrate layer to form a treated support region; and
   forming a support structure on the treated support region;
the treated support region being configured to increase adhesion between the substrate layer and the support structure.

29. The method of Claim 28, wherein treating comprises roughening at least a portion of the support region of the substrate layer.

30. The method of Claim 29, wherein roughening comprises etching the support region of the substrate layer.

31. The method of Claim 29, wherein roughening comprises roughening a portion of the first reflective surface.

32. The method of Claim 28, wherein treating comprises depositing an adhesive over at least a portion of the support region of the substrate layer.

33. The method of Claim 28, further comprising depositing a sacrificial layer over the substrate layer.

34. The method of Claim 33, further comprising depositing a second reflective layer over the sacrificial layer.

35. The method of Claim 34, further comprising removing the sacrificial layer to form a cavity positioned between the first reflective layer and the second reflective layer.


37. A method of making an interferometric modulator, comprising:
   forming a substrate layer;
   forming a support structure on the substrate layer;
   treating the support structure to form a treated support structure; and
   forming a moveable layer on the treated support structure.

38. The method of Claim 37, wherein treating comprises roughening at least a portion of the support structure.

39. The method of Claim 37, wherein treating comprises depositing an adhesive over at least a portion of the support structure.

40. The method of Claim 37, further comprising forming a reflective layer on the substrate layer.

41. The method of Claim 40, further comprising depositing a sacrificial layer over the first reflective layer.

42. The method of Claim 41, further comprising removing the sacrificial layer to form a cavity positioned between the reflective layer and the moveable layer.

43. An interferometric modulator made by the method of Claim 37.
FIG. 2
**FIG. 3**

![Graph showing voltage vs. position with stability windows and actuated regions.]

- **Actuated**
- **Stability Window**
- **Relaxed**
- **Stability Window**
- **Actuated**

**FIG. 4**

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FIG. 6A

FIG. 6B

5/13
Form an optical stack over a substrate

Form a sacrificial layer over the optical stack

Form a support structure

Form a moveable reflective layer

Form a cavity
Form a substrate layer having a reflective surface

Treat a support region of the substrate layer to form a treated support region

Form a support structure on the treated support region

FIG. 11
Form a substrate layer

Form a support structure on the substrate layer

Treat the support structure to form a treated support structure

Form a moveable layer on the treated support structure

FIG. 12
**A. CLASSIFICATION OF SUBJECT MATTER**

602B26/00

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)

602B

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, PAJ

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>X</td>
<td>WO 03/069413 A (IRIDIGM DISPLAY CORPORATION; MILES, MARK, W) 21 August 2003 (2003-08-21) abstract paragraph ‘0006!’ - paragraph ‘0014!’ figures</td>
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Further documents are listed in the continuation of box C.

* Patent family members are listed in annex.

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*A* document defining the general state of the art which is not considered to be of particular relevance

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

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**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**

4 January 2006

**Date of mailing of the international search report**

19/01/2006

**Name and mailing address of the ISA**

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk
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**Authorized officer**

Seibert, J
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# INTERNATIONAL SEARCH REPORT

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