

DEVICE HAVING A CONDUCTIVE LIGHT ABSORBING MASK AND METHOD FOR FABRICATING SAME

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Background

Field of the Invention

The field of the invention relates to microelectromechanical systems (MEMS).

Description of the Related Technology

Microelectromechanical systems (MEMS) include micro mechanical elements, actuators,
10 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. 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
15 and capable of relative motion upon application of an appropriate electrical signal. One plate may
comprise a stationary layer deposited on a substrate, the other plate may comprise a metallic
membrane separated from the stationary layer by an air gap. 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
20 creating new products that have not yet been developed.

Summary of Certain Embodiments

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
25 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.

In certain embodiments, an optical device comprises a substrate. The optical device
further comprises an interferometric light modulating element disposed on the substrate. The
30 modulating element has an optical characteristic which changes in response to a voltage applied to
the modulating element. The optical device further comprises an electrically-conductive optical
mask disposed on the substrate and spaced from the modulating element. The optical mask is
electrically coupled to the modulating element to provide one or more electrical paths for
application of voltages to the modulating element.

35 In certain embodiments, a method provides an electrical signal to a plurality of
interferometric optical elements of a display. The interferometric optical elements are

individually actuatable by applying a voltage thereto. The method comprises electrically coupling an electrically-conductive optical mask to one or more interferometric optical elements. The method further comprises applying a voltage to the optical mask to activate the one or more interferometric optical elements.

5 In certain embodiments, a method fabricates an interferometric optical device. The method comprises forming an electrically-conductive optical mask on a substrate. The optical mask absorbs light. The method further comprises forming an interferometric optical component on the substrate spaced from the optical mask. The interferometric optical component has a driven state and an undriven state. The interferometric optical component changes between the
10 driven state and the undriven state in response to an applied voltage. Each state has a characteristic optical response to incident light. The method further comprises electrically connecting the optical mask to the interferometric optical component so at least a portion of the optical mask provides a bus for applying the voltage to the interferometric optical component.

 In certain embodiments, a method fabricates an optical device comprising at least one
15 active interferometric optical component formed on a transparent substrate. The method comprises identifying an area on the substrate that is to be light-absorbing. The identified area is laterally offset from the at least one active interferometric optical component. The method further comprises fabricating a conductive light-absorbing optical mask on the identified area prior to fabricating the at least one active interferometric optical component. The mask is connected to
20 the active optical component.

 In certain embodiments, an optical device comprises means for supporting an optical device. The optical device further comprises means for interferometrically modulating light. The modulating means is disposed on the supporting means. The modulating means has an optical characteristic which changes in response to a voltage applied to the modulating means. The
25 optical device further comprises means for absorbing light. The absorbing means is disposed on the supporting means and is spaced from the modulating means. The absorbing means is electrically coupled to the modulating means to provide one or more electrical paths for application of voltages to the modulating means.

Brief Description of the Drawings

30 Figure 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 released position and a movable reflective layer of a second interferometric modulator is in an actuated position.

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

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

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

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

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

Figure 6A is a cross section of the device of Figure 1.

Figure 6B is a cross section of an alternative embodiment of an interferometric modulator.

10 Figure 6C is a cross section of another alternative embodiment of an interferometric modulator.

Figure 7A is a cross-sectional side elevational view of a first exemplary interferometric modulator in a first state.

15 Figure 7B is a cross-sectional side elevational view of the interferometric modulator of Figure 7A in a second state.

Figure 7C is a cross-sectional side elevational view of second exemplary interferometric modulator in a first state.

Figure 7D is a cross-sectional side elevational view of the interferometric modulator of Figure 7C in a second state.

20 Figure 8A is a top view of a portion of an interferometric modulator array illustrating non-active areas containing structures included in a plurality of pixels.

Figure 8B is a top elevational view of a portion of an interferometric modulator array illustrating non-active areas containing structures included in a plurality of pixels.

25 Figure 9 shows a cross-section through a MEMS device having a mask or light-absorbing region in accordance with one embodiment of the invention.

Figure 10 shows a cross-section of another embodiment of a MEMS device having a mask or light-absorbing region in accordance with another embodiment of the invention.

Figure 11 is a cross-sectional view illustrating various layers that can be included in a MEMS device having a conductive mask.

30 Figures 12 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask illustrating a reflective chrome layer deposited on a substrate.

Figure 13 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask illustrating the reflective chrome layer of Figure 12 with portions of the chrome layer removed.

35 Figure 14 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask illustrating additional layers applied to the embodiment shown in Figure 13.

Figure 15 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask illustrating a patterning and etch step performed to form recesses for supports.

5 Figure 16 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask illustrating forming supports in the recesses shown in Figure 15.

Figure 17 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask, illustrating the result of depositing a mechanical membrane onto the embodiment shown in Figure 16 and removing a sacrificial layer to form an air gap.

10 Figure 18 is a cross-sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between both layers of the mask and a movable mechanical membrane.

Figure 19 is a cross-sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between both layers of the mask and a non-movable electrode layer.

15 Figure 20 is a cross-sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between a first reflective layer of the mask and a movable mechanical membrane.

Figure 21 is a cross-sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between a first and second
20 reflective layer of the mask and a movable mechanical membrane.

Figure 22 is a cross-sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between a first reflective layer of the mask and a non-movable electrode layer and another electrically parallel connection is formed between a second reflective layer of the mask and a movable mechanical membrane.

25 Figures 23A and 23B are system block diagrams illustrating an embodiment of a visual display device comprising a plurality of interferometric modulators.

Detailed Description of Certain Embodiments

The following detailed description is directed to certain specific embodiments of the invention. In this description, reference is made to the drawings wherein like parts are designated
30 with like numerals throughout.

Reference in this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same
35 embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. Moreover, various features are described which may be exhibited by some

embodiments and not by others. Similarly, various requirements are described which may be requirements for some embodiments but not other embodiments.

5 The desire to view video data on high resolution mobile device displays while meeting power limitations is facilitated by minimizing the resistance of the display control lines. For these and other reasons, it is desirable to increase the conductance of the signal lines while minimizing the amount of additional passive or non-active optical contents in a display. The present invention discloses, in one embodiment, a multi-purpose optical component that acts as a conductive optical mask, e.g., a "black mask," to absorb ambient or stray light and to improve the optical response of a display device by increasing the contrast ratio, and to also function as an electrical bussing layer. In some applications, the conductive mask can reflect light of a predetermined wavelength to appear as a color other than black. The conductive mask, also referred to herein simply as a "mask," can be electrically coupled to one or more of the elements on the display to provide one or more electrical paths for voltages applied to one or more of the display elements. For example, depending on the configuration desired, one or more of the row or column electrodes can be connected to the conductive mask to reduce the resistance of the connected row or column electrode. In one embodiment, a MEMS display device, for example, an array of interferometric modulators, comprises a dynamic optical component (e.g., a dynamic interferometric modulator) and a static optical component (e.g., a static interferometric modulator) laterally offset from the dynamic optical component. The static optical component functions as the "black mask" to absorb ambient or stray light in non-active areas of a display to improve the optical response of the dynamic optical component, and acts as an electrical bus for either a row or a column electrode of the array of interferometric modulators. For example, non-active areas can include one or more areas of a MEMS display device other than the area corresponding to a movable reflective layer. A non-active area can also include an area of a display device that is not used to display an image or data rendered on the display device.

Although a MEMS device, which includes an interferometric modulator, will be used to illustrate one embodiment, it is to be understood that the invention covers other optical devices such as various imaging display and optoelectronic devices in general, which have non-active areas which are required to be light-absorbing, but which do not include interferometric modulators (e.g., LED and plasma displays). As will be apparent from the following description, the invention 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 invention 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.

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 released state, the movable layer is positioned at a relatively large distance from a fixed partially reflective layer. In the second position, the movable 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 and highly reflective layer 14a is illustrated in a released position at a predetermined distance from a fixed partially reflective layer 16a. In the interferometric modulator 12b on the right, the movable highly reflective layer 14b is illustrated in an actuated position adjacent to the fixed partially reflective layer 16b.

The fixed layers 16a, 16b are electrically conductive, partially transparent and partially reflective, and may be fabricated, for example, by depositing one or more layers each of chromium and indium-tin-oxide onto a transparent substrate 20. The layers are patterned into parallel strips, and may form row electrodes in a display device as described further below. The movable layers 14a, 14b may be formed as a series of parallel strips of a deposited metal layer or layers (orthogonal to the row electrodes 16a, 16b) deposited on top of supports 18 and an

intervening sacrificial material deposited between the supports 18. When the sacrificial material is etched away, the deformable metal layers are separated from the fixed metal layers by a defined air gap 19. A highly conductive and reflective material such as aluminum may be used for the deformable layers, and these strips may form column electrodes in a display device.

5 With no applied voltage, the cavity 19 remains between the layers 14a, 16a and the deformable layer is 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
10 movable layer is deformed and is forced against the fixed layer (a dielectric material which is not illustrated in this Figure may be deposited on the fixed layer to prevent shorting and control the separation distance) as illustrated by the 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
15 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
20 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
25 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 controller 22. In one embodiment, the array controller 22 includes a row driver circuit 24 and a column driver circuit 26 that provide signals to a pixel array 30. The cross section of the array
30 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 released 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
35 below 10 volts. In the exemplary embodiment of Figure 3, the movable layer does not release 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 released 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 released 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 released pre-existing state. Since each pixel of the interferometric modulator, whether in the actuated or released 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. 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. 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 $-V_{\text{bias}}$.

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 released 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 releases 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 release 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 present invention.

The details of the structure of interferometric modulators that operate in accordance with the principles set forth above may vary widely. For example, Figures 6A-6C illustrate three different embodiments of the moving mirror structure. Figure 6A 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 6B, the moveable reflective material 14 is attached to supports at the corners only, on tethers 32. In Figure 6C, the moveable reflective material 14 is suspended from a deformable layer 34. This embodiment has benefits because the structural design and materials used for the reflective material 14 can be optimized with respect to the optical properties, and the structural design and materials used for the deformable layer 34 can be optimized with respect to desired mechanical properties. The production of various types of interferometric devices is described in a variety of published documents, including, for example, U.S. Published Application 2004/0051929. A wide variety of well known techniques may be used to produce the above described structures involving a series of material deposition, patterning, and etching steps.

Figures 7A-7D illustrate certain aspects of the two interferometric modulator structures described above. Figure 7A illustrates a simplified functional diagram of an interferometric modulator 50 in one exemplary embodiment. The interferometric modulator 50 comprises a substrate 20, an optical dielectric 16 upon the substrate 20, two supports 18 and a mirror 14

connected to the supports 18 so as to orient its face in a plane that is parallel to and laterally aligned with the plane of an upper face of the dielectric 16. The mirror 14 in Figure 7A is shown in a mechanically relaxed first state so that it reflects incident light when the interferometric modulator is seen, e.g., from a viewing position 110. The distance between the optical dielectric 16 and the mirror 14 is tuned such that only light at a selected wavelength is reflected. The details of the method of selecting the geometries and materials are described in detail in the
5 aforementioned U.S. Patent No. 5,835,255 and the aforementioned U.S. Patent Application No. 09/966,843. In Figure 7A, the supports 18, mirror 14, and optical dielectric 16 define an optical cavity 55.

10 Figure 7B illustrates a simplified functional diagram of the interferometric modulator 50 shown in Figure 6A where the mirror 14 is in a second state. In Figure 7B, the mirror 14 is moved towards the optical dielectric layer 16 collapsing the optical cavity 55. The mirror 14 is moved by providing a voltage potential between electrodes coupled to the mirror 14 and the optical dielectric 16. By moving the mirror 14 to a second state that is in contact with or in close
15 proximity to the optical dielectric 16, the optical properties of the interferometric modulator 50 in the second state are altered from in the first state. Light reflected from the interferometric modulator 50 in the second state (Figure 7B) is a different color than light reflected from the interferometric modulator 50 in the first state. In one configuration, in the second state the interference of the light is such so that from the viewing position 110 the interferometric
20 modulator appears black.

 Figures 7C and 7D illustrate another embodiment of an interferometric modulator 60 in a first "open" and a second "closed" state, respectively. This embodiment of the interferometric modulator 60 provides an increased usable mirror size as compared to the embodiment shown in Figures 7A and 7B. Referring back to Figure 7B, there are areas of the mirror 14 which are not
25 providing maximum reflectivity towards viewing position 110 because they are bending into the collapsed optical cavity 55. Comparing the mirror 34 in Figure 7D to the mirror 14 in Figure 7B, it can be seen that the mirror 34 in Figure 7D occupies substantially the entire area corresponding to surface area of the optical dielectric 16 in the optical cavity 66. In the embodiment shown in Figure 7D, the reflecting surface of the mirror 34 can be used for the reflection of light because it
30 is not needed to bend the mirror into the collapsed optical cavity 66 when the interferometric modulator 60 is actuated. In Figures 7C and 7D, the substrate optical dielectric 16, two supports 18 and the substrate 20 remain unchanged from the interferometric modulator 50 shown in Figures 7A and 7B. Details of the structure and fabrication of this improved structure can be found in the aforementioned U.S. Patent Application No. 09/966,843.

35 Figures 8A and 8B illustrate an example of a portion of a display with display elements that can incorporate a conductive mask. Figures 8A and 8B illustrate an exemplary portion of a display that includes an array of interferometric modulators. A conductive mask can be used in

the array shown in Figures 8A and 8B, and in any type of display where it is useful to mask off certain areas of the display from ambient light and form an electrically parallel connection of an electrical circuit in the display. Figure 8A shows a plurality of pixels 12 of the array. Figure 8B shows an example of supports 18 located on the plurality of pixels of the array of interferometric modulators that can be masked to improve the optical response of the display. To improve an optical response (e.g., contrast) of the display, it can be desirable to minimize light reflected from certain areas of the array. Any area of an interferometric modulator that increases the reflectance of the display in the dark state can be masked off (e.g., disposing a mask between the structure and light entering the interferometric modulator) using a black mask in order to increase the contrast ratio between an actuated pixel and an unactuated pixel. Some of the areas that can be masked to advantageously affect the display include, but are not limited to, row cuts between interferometric modulators 72 (Figure 8A), the supports 18, bending areas of the movable mirror layers connecting to and/or around the supports 18, and areas between movable mirror layers of adjacent interferometric modulators 76 (Figure 8A). The mask can be disposed in such areas so that it is spaced apart from the movable mirror of the interferometric modulators, e.g., so that ambient light can propagate to and reflect from the movable mirror but the areas other than the movable mirror are masked inhibiting ambient light from reflecting from any structures in the masked areas. These areas that are masked can be referred to as "non-active areas" because they are static, e.g., the areas do not include the movable mirror. In some embodiment, the mask can be conductive to minimize reflected light and provide one or more electrical paths that can be used for the optical element. In some embodiments, the mask can be disposed so that light entering the interferometric modulator falls onto either the masked area or the movable mirror. In other embodiments, at least a portion of the non-active areas are masked.

"The rate at which display elements can respond to drive signals can depend on the resistance and capacitance of the control lines (e.g., row and column electrodes) carrying the drive signals to the display elements. The desire to view video on large displays and for high resolution displays demands that the resistance of the control lines be minimized. For these reasons, it is desirable to increase the conductance of the signal lines while minimizing the amount of additional passive optical contents in a display. One way to decrease the resistance is to provide one or more electrically parallel connections to the control lines. A dual-purpose mask can be provided that increases contrast ratio, and at the same time, acts as a bussing layer for the driving signals. For example, in one embodiment the conductive mask can be used to form an electrically parallel connection to one or more row or column electrodes of an array of display elements, for example, interferometric modulators. It will be appreciated that the electrically parallel connections can be designed in many ways, depending on the application and the type of display elements.

Figure 9 shows a cross-sectional view of a simplified representation of a display 100, according to one embodiment. The display comprises two optical components which are, in this embodiment, interferometric modulators 104. As described above, interferometric modulator devices 104 comprise an arrangement of reflective films that produce a desired optical response when the movable active area is driven towards a substrate 202 in a direction indicated by arrows 106. The general operation of the interferometric modulator devices 104 has been described in U.S. Pat. No. 5,835,255. In Figure 9, reference numerals 108 indicate non-active areas of the interferometric modulators 104. Typically, it is desirable that the non-active areas 108 be light-absorbing or to function as a black mask so that when a viewer looks at the display 100 from a direction indicated by the viewing arrow 110, the optical response produced by the interferometric modulator devices 104 is not degraded by the reflection of ambient light from the non-active areas 108. In other embodiments, it can be desirable to mask the non-active areas 108 with a colored mask (for example, green, red, blue, yellow, etc.) other than black. To gain additional functionality from the mask, the mask can comprise one or more conductive materials which can be connected to circuitry in the display 100 and used in whole or in part to provide one or more electrical busses.

A mask for a non-active area 108 may be fabricated from materials selected to have an optical response which absorbs or attenuates light. One or more of the materials used to fabricate the mask are electrically conductive. According to embodiments of the invention, a mask for each non-active area 108 can be fabricated as a stack of thin films. For example, in one embodiment, the stack of thin films may comprise a non-light-absorbing dielectric layer sandwiched between two light reflecting chrome layers, as will be more fully described below. In other embodiments, the non-active areas 108 may comprise a single layer of organic or inorganic materials which attenuates or absorbs light, and a layer of a conductive material such as chrome or aluminum.

Figure 10 of the drawings shows a cross section through an interferometric modulator device 200 in accordance with one embodiment of the invention. The interferometric modulator device 200 includes an active component comprising an electrode reflective layer 204, an oxide layer 206, an air gap 208, and a mechanical membrane 210 disposed on a substrate 202. As used herein, the phrase "disposed on a substrate" is a broad phrase, and it indicates, for example that a referenced structure, layer, optical device, interferometric modulator, bi-stable device, electrode, film stack, support, electrode, mask or other referred to feature is located on a substrate, and can but does not necessarily require direct contact with the substrate, unless so indicated. The mechanical membrane 210 is supported in position by supports 212. In use, the mechanical membrane 210 is driven to contact the oxide layer 206 to produce a desired optical response when viewed from the direction indicated by arrow 110.

The supports 212, the areas of the interferometric modulator 200 on which the supports 212 are formed, and other areas that are not part of the active component of the interferometric

modulator (for example, areas indicated by encircled areas 230) can be masked with a conductive mask to prevent or reduce the reflection of light from these areas which can otherwise interfere with the desired optical response of the active interferometric modulator components. The mask can be fabricated as a stack of films, including at least one electrically conducting film, selected
5 so that the stack has the optical property of being light-absorbing and conductive, according to one embodiment. The mask can be formed on the substrate 202 prior to forming the active optical components of the interferometric modulators, according to one embodiment. The supports 212 of the interferometric modulator 200 can perform several functions. First, the supports 212 function as mechanical supports for the movable mechanical membrane 210. Second, the
10 supports 212 can provide an electrical connection for the conductive mask, if the supports 212 comprise an electrically conductive material. For example, when a support 212 is connected to a conductive layer 222 the support 212 and the conductive layer 222 can provide one or more electrical paths to apply voltages to the movable mechanical membrane 210, as will be illustrated in following Figures 17 - 18, and 20 - 22.

15 As shown in Figure 10 the interferometric modulator 200 includes a conductive mask that comprises a stack of thin films. In one embodiment, the mask comprises a first reflective chrome layer 218, an oxide middle layer 220 and a second reflective chrome layer 222. Other conductive materials can also be used to form the mask. For example, in another embodiment, the mask includes a stack of thin films comprising a chrome layer 218, an oxide middle layer 220 (for
20 example, SiO_2), and an aluminum layer 222. The interferometric modulator 200 includes another oxide layer 226 between the oxide middle layer 220 and the electrode reflective layer 204. One or more electrically conductive layers of the mask can be connected other components of the interferometric modulator 200 to provide an electrical bus. For example, the mask can be connected to one or more column or row electrodes. In one embodiment, chrome layer 222 is
25 connected to the electrode reflective layer 204 by vias 224 that comprise an electrically conductive material. The connections required in the configuration of the conductive mask so that it functions as an electrical bus can depend on the particular application. In some embodiments, the electrode reflective layer 204 includes electrical separators 228 (for example, gaps or non-conductive material) located in various positions to electrically separate conductive portions of
30 the interferometric modulator, for example, the electrode reflective layer 204 or the supports 212, and suitably configure the mask to exhibit the desired bus functionality.

One embodiment of fabricating a conductive mask is disclosed below in reference to Figures 11-17. Figure 11 is a cross-sectional view illustrating various layers that can be included in a MEMS device, for example the MEMS device shown in Figure 1, having a conductive mask
35 402. Only a portion of the MEMS device that includes the conductive mask 402 is shown in Figure 11, the remaining portion of the MEMS device being indicated by the dashed rectangle 203. The conductive mask 402, indicated by the dashed circles, is illustrated as being fabricated

on a substrate 202. The mask 402 comprises three layers of film, including a first reflective layer 218, an oxide layer 220 and a second reflective layer 222. The first reflective layer 218 and the second reflective layer 222 can comprise materials that are both reflective and conductive, for example, chrome, aluminum, or silver. For some embodiments, the conductive mask 402 can be structured as a static interferometric modulator that is configured so that it minimizes reflected light, e.g., appears black. In other embodiments, the conductive mask 402 can be structured as a static interferometric modulator that reflects light of a selected color. The films which make up the conductive mask 402 can be the same films which are used in the fabrication of the interferometric modulator components, thus making it possible to use the same deposition parameters to fabricate the mask and the interferometric modulator components. The conductive mask 402 can be used to provide greater flexibility in the routing of electrical signals around the display device and help minimize resistance of electrical circuits providing signals to the interferometric electrodes by providing electrically parallel connections for the signals.

The various stages in the manufacture of a conductive mask 402 and the MEMS device will now be described with reference to Figures 12-17.

Figure 12 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask illustrating a first reflective mask layer 218 deposited on a substrate 202. After an initial preparatory step wherein the substrate 202 is prepared, for example, cleaned, a first reflective mask layer 218 is deposited by sputter coating it onto substrate 202, according to one embodiment. In one exemplary embodiment, the thickness of first reflective mask layer 218 can be about 60 angstroms.

Figure 13 is a cross-sectional view of a stage in the manufacture of the MEMS device having a conductive mask illustrating the first reflective mask layer 218 of Figure 12 with certain portions removed. For this fabrication, after the first reflective mask layer 218 is deposited, as shown in Figure 12, the first reflective mask layer 218 is patterned and developed using conventional techniques to leave two or more portions or outcrops of chrome, which can serve as a base layer for a thin film stack which serves as a mask.

Figure 14 is a cross-sectional view of a stage in the manufacture of the MEMS device having a conductive mask illustrating additional layers that are fabricated on the embodiment shown in Figure 13. As shown in Figure 14, an oxide layer 220 is deposited on the substrate 202 covering the first reflective mask layer 218. In one embodiment the oxide layer 220 is about 300 to 800 angstroms in depth. This layer can be applied by sputter coating the SiO_2 onto the embodiment shown in Figure 14. The thickness of the oxide layer 220 can depend on the quality of the color (e.g., black) state that is required for the mask, and it can also depend on the desired color of the mask.

A second reflective layer 222 is deposited on the oxide layer 220, and the second reflective layer 222 is patterned and developed to form portions that correspond to the first

reflective layer 218, forming a conductive mask comprising a thin film stack. Then an oxide layer 226 is deposited on the second reflective layer 222. Vias 224 can be formed in the oxide layer 226 so the second reflective layer 222 can be connected to a support 212, for example, as shown in Figure 16. Electrical separators 228 can be formed in the electrode reflective layer 204, which
5 is deposited on the oxide layer 226. The electrode reflective layer 204 is typically about 60 angstroms thick, its exact thickness being dependent on the required brightness of the ultimate display, a thinner layer yielding a brighter display. Based on the desired configuration and the utilization of the conductive mask, portions of the electrodes, for example, the electrode reflective layer 204, can be electrically separated by forming one or more separations 228 in the electrode reflective layer 204.

10 Thereafter, an oxide layer 206 and a sacrificial layer 209 are respectively sputter coated on to electrode reflective layer 204. The oxide layer 206 can comprise silicon oxide and can be about 300 to 800 angstroms thick, according to one embodiment. The sacrificial layer 209 can comprise molybdenum and can typically be about 0.2 to 1.2 microns thick, according
15 to one embodiment.

Figure 15 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask illustrating a patterning and etch step performed to form the recesses for supports. The patterning and an etching step is performed to form recesses which extend through the oxide layer 226 to the vias 224 and the second reflective layer 222, according to this
20 embodiment. The vias 224 can be formed in the oxide layer 226 so the second reflective layer 222 can be connected to a support 212 (shown in Figure 16). To form an electrical connection between the second reflective layer 222 of the conductive mask and another part of the MEMS device (e.g., the mechanical membrane 210 shown in Figure 17) the support 212 can extend through the vias 224 to the second reflective layer 222, according to one embodiment. In another
25 embodiment, the vias 224 are formed in the oxide layer 226 and are filled with an electrically conductive material which is connected to the support.

Figure 16 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask illustrating forming supports 212 in the recesses shown in Figure 15. The supports 212 provide a structure that supports the movable mechanical membrane 210
30 (Figure 17), and can be formed in the recesses by spinning a negative photoresist material over the thin film stack, exposing it through a suitable mask and developing it to form the supports 212. In this embodiment, electrical separators 228 isolate the supports 212 from the electrode reflective layer 204. Such separators 228 can be used to isolate the support 212 from the electrode reflective layer 204 when the support 212 comprises a conductive material.

35 Figure 17 is a cross-sectional view of a stage in the manufacture of a MEMS device having a conductive mask, illustrating a mechanical membrane 210 deposited onto the embodiment shown in Figure 16. The mechanical membrane 210 is deposited by sputter coating

it onto the sacrificial layer 209. Thereafter, the sacrificial layer 209 is removed leaving an air gap 208. In one embodiment, the mechanical membrane 210 comprises an aluminum alloy. With the removal of the sacrificial layer 209, an air gap 208 is formed through which the mechanical membrane 210 moves when the interferometric modulator is actuated.

5 Figure 17 also shows an embodiment of an electrical connection between the second reflective layer 222, the supports 212, and the mechanical membrane 210. Here, the conductive mask includes a dielectric stack that comprises a first reflective layer 218, an oxide layer 220, and a second reflective layer 222, that masks off non-active areas (for example, the supports 212) spaced apart from the active areas. In some embodiments, the conductive mask can comprise
10 chrome, silver, aluminum or a dielectric stack so that one or more of the materials used to form the mask is capable of conducting electricity.

 In this embodiment, the mask is a non-movable (e.g., static) interferometric element configured such that it causes the interference of light so that it reflects minimal light and appears black. The optical layer can be formed from ITO/Cr, ITO/Mo, ITO/Ti, Cr, Mo, Ti or other
15 materials with similar properties. The dielectric layer is typically formed from SiO₂ or other dielectric materials, and the reflector is typically formed from aluminum, chromium or other metallic materials.

 By fabricating the mask so that it comprises an electrically conductive material and using appropriately placed connections to a desired row and/or column electrode the mask can be used
20 to reduce the resistance of the row and/or column electrode. For example, if a conductive mask, configured to always display black, is used in an array comprising a plurality of interferometric modulators, the conductive mask can be also be used as a conduction layer to decrease resistance of row, and/or column electrodes that are used in the array to carry signals to the display elements aligned in rows and/or columns. In this embodiment, vias were created in the dielectric 226 to provide a recess for the support 212 and so it can connect to the second reflective layer 222, which is part of the conductive mask. It will be appreciated that there are many other possible embodiments to utilize a conductive mask. In some embodiments where the mask comprises a first conductive layer 218 and a second conductive layer 222, both conductive layers can be used as an electrical bus. In some embodiments, both conductive layers can be used as part of the same electrical bus. In other embodiments, the conductive layers are each used as part of separate electrical bus.

 Figure 18-22 show various exemplary embodiments of a conductive mask in an interferometric modulator to provide an electrically parallel connection to an electrode. The embodiments can be fabricated using similar techniques as described hereinabove for the
35 embodiment shown in Figure 17. The conductive masks illustrated in Figures 18-22 are configured as non-movable interferometric elements, that provide one or more electrically paralleled connections for application of voltages to the modulating element. Figure 18 is a cross

sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between both layers of the mask and a movable mechanical membrane. In Figure 18, the mask comprises the first reflective layer 218 and the second reflective layer 222. The mask forms an electrically parallel connection to the mechanical
5 membrane 210, a portion of one of the electrodes in the interferometric modulator, as indicated by the diagonally-lined areas. The first reflective layer 218 is electrically connected to the second reflective layer 222 by connectors 229. The supports 212 are made of a conductive material, for example, one of the conductive materials described herein, and are connected to the second reflective layer 222. Electrical separators 228 electrically isolate the supports 212 from the
10 electrode reflective layer 204. The supports 212 are connected to the movable mechanical membrane 210 so that the first reflective layer 218 and the second reflective layer 222 form an electrically parallel connection with the mechanical membrane 210.

Figure 19 is a cross-sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between two conductive
15 layers of a mask and the non-movable electrode layer 204. The first reflective layer 218 and the second reflective layer 222 form an electrically parallel connection to the electrode reflective layer 204, as indicated by the diagonally-lined areas. The first reflective layer 218 is electrically connected to the second reflective layer 222 by connectors 231, which also connect the first reflective layer 218 and the second reflective layer 222 to the electrode reflective layer 204.
20 Electrical separators 228 electrically isolate the supports 212 from the electrode reflective layer 204.

Figure 20 is a cross-sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between a first reflective layer 118 of the mask and the movable mechanical membrane 210. The first reflective layer 218
25 of the mask is electrically connected to the mechanical membrane 210 by the conductive connector 234 which runs through the support 212. The connector 234 is isolated from the support 212 and the second reflective layer 222 of the mask by electrical isolators 232, which are formed from a non-conductive material. Electrical isolators 228 isolate the support 212 from the electrode reflective layer 204. In embodiments where the support 212 is not formed from a
30 conductive material, electrical isolators 232 and electrical isolators 228 may not be necessary to electrically isolate the support 212 from surrounding conductive material. In this embodiment, only the first reflective layer 218 forms an electrically parallel connection to the mechanical membrane 210.

Figure 21 is a cross-sectional view of a MEMS device illustrating an embodiment of a
35 conductive mask where an electrically parallel connection is formed between a first reflective layer 218, a second reflective layer 222 of the mask and a movable mechanical membrane 210. This embodiment is similar to the embodiment shown in Figure 20, except that the first reflective

layer 218 is connected to the second reflective layer 222 by the electrical connector 238. The first reflective layer 218 and the second reflective layer 222 are electrically connected to the mechanical membrane 210 by electrical connector 236, forming an electrical parallel connection between both layers of the conductive mask and the mechanical membrane 210. In this embodiment, the support 212 is not formed from a conductive material, thus isolators 232, although shown for clarity, would not be necessary to electrically isolate the support 212 from surrounding conductive material.

Figure 22 is a cross-sectional view of a MEMS device illustrating an embodiment of a conductive mask where an electrically parallel connection is formed between a first reflective layer 218 of the mask and the electrode layer 204, as indicated by the diagonally lined areas. Another electrically parallel connection is formed between a second reflective layer of the mask 222 and a movable mechanical membrane 210, as indicated by the cross-hatched areas. In Figure 22, the first electrically parallel connection is formed by electrically connecting the first reflective layer 218 of the mask to the electrode layer 204 by electrical connectors 240. Electrical isolators 228 isolate the electrode layer 204 from the conductive support 212. Electrical isolators 233 isolate the electrical connector 240 from the second reflective layer 222 of the mask. The second electrically parallel connection is formed by connecting the second reflective layer 222 of the mask to the support 212, which is connected to the mechanical membrane 210.

Figures 23A and 23B are system block diagrams illustrating an embodiment of a display device 2040. The display device 2040 can be, for example, a cellular or mobile telephone. However, the same components of display device 2040 or slight variations thereof are also illustrative of various types of display devices such as televisions and portable media players.

The display device 2040 includes a housing 2041, a display 2030, an antenna 2043, a speaker 2045, an input device 2048, and a microphone 2046. The housing 2041 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 2041 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 2041 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 2030 of exemplary display device 2040 may be any of a variety of displays, including a bi-stable display, as described herein. In other embodiments, the display 2030 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 2030 includes an interferometric modulator display, as described herein.

The components of one embodiment of exemplary display device 2040 are schematically illustrated in Figure 23B. The illustrated exemplary display device 2040 includes a housing 2041 and can include additional components at least partially enclosed therein. For example, in one embodiment, the exemplary display device 2040 includes a network interface 2027 that includes
5 an antenna 2043 which is coupled to a transceiver 2047. The transceiver 2047 is connected to the processor 2021, which is connected to conditioning hardware 2052. The conditioning hardware 2052 may be configured to condition a signal (e.g. filter a signal). The conditioning hardware 2052 is connected to a speaker 2045 and a microphone 2046. The processor 2021 is also connected to an input device 2048 and a driver controller 2029. The driver controller 2029 is
10 coupled to a frame buffer 2028 and to the array driver 2022, which in turn is coupled to a display array 2030. A power supply 2050 provides power to all components as required by the particular exemplary display device 2040 design.

The network interface 2027 includes the antenna 2043 and the transceiver 2047 so that the exemplary display device 2040 can communicate with one or more devices over a network. In
15 one embodiment the network interface 2027 may also have some processing capabilities to relieve requirements of the processor 2021. The antenna 2043 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
20 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 2047 pre-processes the signals received from the antenna 2043 so that they may be received by and further manipulated by the processor 2021. The transceiver 2047 also processes signals received from the processor 2021 so that they may be transmitted
25 from the exemplary display device 2040 via the antenna 2043.

In an alternative embodiment, the transceiver 2047 can be replaced by a receiver. In yet another alternative embodiment, network interface 2027 can be replaced by an image source, which can store or generate image data to be sent to the processor 2021. For example, the image source can be a digital video disc (DVD) or a hard-disc drive that contains image data, or a
30 software module that generates image data.

Processor 2021 generally controls the overall operation of the exemplary display device 2040. The processor 2021 receives data, such as compressed image data from the network interface 2027 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 2021 then sends the processed data to the
35 driver controller 2029 or to frame buffer 2028 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 2021 includes a microcontroller, CPU, or logic unit to control operation of the exemplary display device 2040. Conditioning hardware 2052 generally includes amplifiers and filters for transmitting signals to the speaker 2045, and for receiving signals from the microphone 2046. Conditioning hardware 2052 may be discrete components within the exemplary display device 2040, or may be incorporated within the processor 2021 or other components.

The driver controller 2029 takes the raw image data generated by the processor 2021 either directly from the processor 2021 or from the frame buffer 2028 and reformats the raw image data appropriately for high speed transmission to the array driver 2022. Specifically, the driver controller 2029 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 2030. Then the driver controller 2029 sends the formatted information to the array driver 2022. Although a driver controller 2029, such as a LCD controller, is often associated with the system processor 2021 as a stand-alone Integrated Circuit (IC), such controllers may be implemented in many ways. They may be embedded in the processor 2021 as hardware, embedded in the processor 2021 as software, or fully integrated in hardware with the array driver 2022.

Typically, the array driver 2022 receives the formatted information from the driver controller 2029 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 2029, array driver 2022, and display array 2030 are appropriate for any of the types of displays described herein. For example, in one embodiment, driver controller 2029 is a conventional display controller or a bi-stable display controller (e.g., an interferometric modulator controller). In another embodiment, array driver 2022 is a conventional driver or a bi-stable display driver (e.g., an interferometric modulator display). In one embodiment, a driver controller 2029 is integrated with the array driver 2022. 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 2030 is a typical display array or a bi-stable display array (e.g., a display including an array of interferometric modulators).

The input device 2048 allows a user to control the operation of the exemplary display device 2040. In one embodiment, input device 2048 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 2046 is an input device for the exemplary display device 2040. When the microphone 2046 is used to input data to the device, voice commands may be provided by a user for controlling operations of the exemplary display device 2040.

Power supply 2050 can include a variety of energy storage devices as are well known in the art. For example, in one embodiment, power supply 2050 is a rechargeable battery, such as a nickel-cadmium battery or a lithium ion battery. In another embodiment, power supply 2050 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 2050 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 the array driver 2022. 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.

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. The scope of the invention is indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

WHAT IS CLAIMED IS:

1. An optical device comprising:
A substrate;
a light modulating element disposed on the substrate, the modulating element having an optical characteristic which changes in response to a voltage applied to the modulating element,
wherein the modulating element comprises an interferometric modulator; and
an electrically-conductive mask disposed on the substrate and spaced from the modulating element, the mask electrically coupled to the modulating element to provide one or more electrical paths for application of voltages to the modulating element.
2. The device of claim 1 wherein the mask is configured to appear black.
3. The device of claim 1, further comprising a column electrode electrically coupled to the mask to form an electrically parallel connection.
4. The device of claim 1, further comprising a row electrode electrically coupled to the mask to form an electrically parallel connection.
5. The device of claim 1, wherein the mask comprises a film stack.
6. The device of claim 1, wherein the mask is electrically coupled to the modulating element by one or more conductive vias.
7. An optical device comprising:
a substrate;
a light modulating element disposed on the substrate, the modulating element having an optical characteristic which changes in response to a voltage applied to the modulating element; and

an electrically-conductive mask disposed on the substrate and spaced from the modulating element, the mask electrically coupled to the modulating element to provide one or more electrical paths for application of voltages to the modulating element, wherein the mask is configured to appear a color other than black.

8. The device of claim 7, wherein the modulating element comprises an interferometric modulator.
9. The device of claim 7, wherein the mask comprises a film stack.
10. The device of claim 7, wherein the mask is electrically coupled to the modulating element by one or more conductive vias.
11. An optical device comprising:
 - a substrate;
 - a light modulating element disposed on the substrate, the modulating element having an optical characteristic which changes in response to a voltage applied to the modulating element; and
 - an electrically-conductive mask disposed on the substrate and spaced from the modulating element, the mask electrically coupled to the modulating element to provide one or more electrical paths for application of voltages to the modulating element, wherein the mask comprises a film stack comprising a first reflective layer and a second reflective layer.
12. The device of claim 11, wherein the first reflective layer is electrically connected to a first electrode and the second reflective layer is electrically connected to a second electrode.
13. The device of claim 11, wherein the first reflective layer and the second reflective layer are electrically connected to the same electrode.

14. The device of claim 11, wherein the first reflective layer is positioned a further distance from the substrate than the second reflective layer.
15. The device of claim 14, wherein the modulating element is electrically coupled to the first reflective layer of the film stack.
16. The device of claim 15, wherein the modulating element comprises a row electrode and wherein the row electrode is electrically coupled to the first reflective layer of the film stack.
17. The device of claim 11, wherein the modulating element comprises an interferometric modulator.
18. An optical device comprising:
a substrate;
a light modulating element disposed on the substrate, the modulating element having an optical characteristic which changes in response to a voltage applied to the modulating element; and
an electrically-conductive mask disposed on the substrate and spaced from the modulating element, the mask electrically coupled to the modulating element to provide one or more electrical paths for application of voltages to the modulating element, wherein the mask comprises one or more interferometric elements.
19. An optical device comprising:
a substrate;
a light modulating element disposed on the substrate, the modulating element having an optical characteristic which changes in response to a voltage applied to the modulating element; and
an electrically-conductive mask disposed on the substrate and spaced from the modulating element, the mask electrically coupled to the modulating element to provide one or more electrical paths for application of voltages to the modulating element,

wherein the mask comprises one or more interferometric elements, and is light-absorbing.

20. An optical device comprising:

a substrate;

one or more light modulating elements disposed on the substrate, the one or more modulating elements having an optical characteristic which changes in response to a voltage applied to the one or more modulating elements; and

an electrically-conductive mask disposed on the substrate and spaced from the one or more modulating elements, the mask electrically coupled to the one or more modulating elements to provide one or more electrical paths for application of voltages to the one or more modulating elements,

wherein the mask comprises a film stack comprising a conductive reflective layer to which a voltage is applied to activate the one or more modulating elements.

21. The device of claim 20, wherein the one or more modulating elements comprise one or more interferometric modulators.

22. An optical device comprising:

a substrate;

a light modulating element disposed on the substrate, the modulating element having an optical characteristic which changes in response to a voltage applied to the modulating element; and

an electrically-conductive mask disposed on the substrate and spaced from the modulating element, the mask electrically coupled to the modulating element to provide one or more electrical paths for application of voltages to the modulating element,

wherein the mask comprises a film stack comprising a non-light-absorbing dielectric material sandwiched between two light-reflecting materials.

23. The device of claim 22, wherein at least one of the two light-reflecting materials comprises silver, aluminum, or chromium.

24. An optical device comprising:
a substrate;
a light modulating element disposed on the substrate, the modulating element having an optical characteristic which changes in response to a voltage applied to the modulating element; and
an electrically-conductive mask disposed on the substrate and spaced from the modulating element, the mask electrically coupled to the modulating element to provide one or more electrical paths for application of voltages to the modulating element,
wherein the mask comprises a film stack, and wherein the film stack comprises a first light-reflecting layer disposed on the substrate;
a non-light-absorbing dielectric layer disposed on the first light-reflecting layer;
and
a second light-reflecting layer disposed on the non-light absorbing dielectric layer,
wherein at least one of the first and second light-reflecting layers is electrically conductive.
25. The device of claim 24, wherein the first and second light-reflecting layers comprise metallic materials.
26. The device of claim 24, wherein the non-light absorbing dielectric layer comprises an oxide layer.