DEVICE AND METHOD FOR DISPLAY MEMORY USING MANIPULATION OF MECHANICAL RESPONSE

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, 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 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 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 Preferred Embodiments" one will understand how the features of this invention provide advantages over other display devices.

One embodiment includes a MEMS device including a fixed layer including a first electrode, a movable layer configured to move between a first location distal to the first electrode and a second location proximal to the first electrode, the movable layer and the fixed layer forming a cavity when the movable layer is in the first location, and a second electrode connected to the movable layer. Movement of the movable layer is based on a voltage difference between the first and second electrodes and the movable layer is configured to move from the first location to the second location at a first average rate and to move from the second location to the first location at a second average rate. The first and second average rates are different.

Another embodiment includes a MEMS device including first means for moving a movable layer between a first location distal to the first moving means and a second location proximal to the first moving means, second means for moving the movable layer between the first and second locations, the movable layer and the first moving means forming a cavity when the movable layer is in the first location, and third means for moving the movable layer from the first location to the second location at a first average rate and to move the movable layer from the second location to the first location at a second average rate. The first and second average rates are different.

Another embodiment includes a method of actuating an array of interferometric modulators multiple times to display a single frame of data, the method including receiving a data signal for actuating one or more interferometric modulators during a time period corresponding to a single frame, actuating the one or more interferometric modulators with a potential difference such that the interferometric modulator moves to an actuated state at a first average rate, and releasing the one or more interferometric modulators such that the interferometric modulator moves from the actuated state and towards a released state at a second, different average rate.

Another embodiment includes a method of driving an interferometric modulator element to display a frame of data. The method includes receiving a data signal for display by the interferometric modulator during a period of time corresponding to a single frame display period, and periodically applying a first potential difference to the interferometric modulator display element during the single frame display period. The interferometric modulator moves from an actuated state towards a released state each time the first potential difference is applied and moves to the actuated state before reaching the released state when a second potential difference is applied to the interferometric modulator.

Another embodiment includes a method of writing display data to a row of interferometric modulator display elements in an array of display elements. The method includes writing a first set of display data to the row of the array with a potential difference so as to move at least some of the interferometric modulator elements to an actuated state, releasing the interferometric modulator elements in the row of the array such that the interferometric modulator elements slowly move from the actuated state and towards the released state, and re-writing the first set of display data to the row of the array with a potential difference so as to return the interferometric modulator elements to the actuated state before the interferometric modulator elements reach the released state.

Another embodiment includes a method of actuating an array of interferometric modulators multiple times to display a single frame of data. The method includes receiving a data signal for actuating one or more interferometric modulators during a time period corresponding to a single frame, releasing the interferometric modulator display element with a potential difference such that the interferometric modulator moves to a released state, actuating the interferometric

modulator display element such that the interferometric modulator moves away from the released state and towards an actuated state, and re-releasing the interferometric modulator display element such that before reaching the actuated state, the interferometric modulator moves back to the released state.

Another embodiment includes a method of driving an interferometric modulator element to display a frame of data. The method includes receiving a data signal for display by the interferometric modulator during a period of time corresponding to a single frame display period, and periodically applying a first potential difference to the interferometric modulator display element during the single frame display period. The interferometric modulator moves from a released state towards an actuated state each time the first potential difference is applied and moves to the released state before reaching the actuated state when a second potential difference is applied to the interferometric modulator.

Another embodiment includes a method of writing display data to a row of interferometric modulator display elements in an array of display elements. The method includes writing a first set of display data to the row of the array with a potential difference so as to move at least some of the interferometric modulator elements to a released state, actuating the interferometric modulator elements in the row of the array such that the interferometric modulator elements move away from the released state and towards the actuated state, and re-writing the first set of display data to the row of the array with a potential difference so as to return the interferometric modulator elements to the released state before the interferometric modulators reach the actuated state.

Another embodiment includes a method of manufacturing a MEMS device. The method includes forming a fixed layer including a first electrode, forming a movable layer configured to move between a first location distal to the first electrode and a second location proximal to the first electrode, the movable layer and the fixed layer forming a cavity including a gas when the movable layer is in the first location, and forming a second electrode connected to the movable layer. Movement of the movable layer is based on a voltage difference between the first and second electrodes and the movable layer is fabricated to move from the first location to the second location at a first average rate and to move from the second location to the first location at a second average rate. The first and second average rates are different.

Another embodiment includes an apparatus for driving an array of interferometric modulators multiple times to display a single frame of data. The apparatus comprises means for receiving a data signal for moving one or more interferometric modulators to between first and second states during a time period corresponding to a single frame, first means for moving the interferometric modulator display element with a potential difference from the first state to the second, second means for moving the interferometric modulator display element with a potential difference from the second state toward the first state, and third means for moving the

interferometric modulator display element with a potential difference to the second state prior to the interferometric modulator reaching the first state.

Brief Description of the Drawings

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 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 that operates within a stability window.

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.

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.

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

Figure 7 is a diagram of movable mirror position versus applied voltage for one exemplary embodiment of an interferometric modulator of Figure 1 that operates without taking advantage of the hysteresis property of the modulator.

Figure 8 is an illustration of a set of row and column voltages that may be used to drive an interferometric modulator display that results in the modulator drifting to a released state when the row voltage is released.

Figure 9 illustrates the operational response of a modulator having a long activation time and being driven according to the row and column voltages of Figure 8.

Figure 10 illustrates the operational response of a modulator having a short release time and being driven according to the row and column voltages of Figure 8.

Figures 11A and 11B illustrate a geometric variation in post spacing that affects the actuation and release times of the modulator so as to improve the operational response of the modulator.

Figures 12A and 12B illustrate a geometric variation in tension of the movable layer that affects the actuation and release times of the modulator so as to improve the operational response of the modulator.

Figures 13A and 13B illustrate a geometric variation in thickness of the movable layer that affects the actuation and release times of the modulator so as to improve the operational response of the modulator.

Figures 14A and 14B illustrate a geometric variation in tether size of the movable layer that affects the actuation and release times of the modulator so as to improve the operational response of the modulator.

Figures 15A and 15B illustrate a geometric variation in the movable layer that affects the actuation and release times of the modulator so as to improve the operational response of the modulator.

Figures 16A and 16B illustrate a geometric variation in the surface of the fixed layer that affects the actuation and release times of the modulator so as to improve the operational response of the modulator.

Figure 17 illustrates the timing effects of motion video in an array of modulators driven according to the row and column voltages of Figure 8 so as to drift to a released state when the row select is removed.

Figure 18 is an illustration of a set of row and column voltages that may be used to drive an interferometric modulator display that results in the modulator drifting to an actuated state when the row voltage is released.

Figure 19 illustrates the operational response of a modulator having a long release time and being driven according to the row and column voltages of Figure 18.

Figure 20 illustrates the operational response of a modulator having a short actuation time and being driven according to the row and column voltages of Figure 18.

Figure 21 illustrates the timing effects of motion video in an array of modulators driven according to the row and column voltages of Figure 18 so as to drift to an actuated state when the row select is removed.

Figures 22A and 22B are system block diagrams illustrating an embodiment of a visual display device comprising a plurality of interferometric modulators.

Detailed Description of Preferred Embodiments

An exemplary MEMS interferometric modulator comprises a movable layer and a fixed layer separated by an air gap. A driving scheme employs row/column actuation protocols which maintain voltages to the MEMS interferometric modulator that are above or below the voltage range necessary to place the MEMS interferometric modulator within a "hysteresis window" or "stability window." Stable operation of the MEMS interferometric modulator is achieved by

selecting mechanical design features that improve the actuation and release times of the interferometric modulator. In general, features that make the movable layer more compliant result in an increased release time and a decreased actuation time. It has been found that a more compliant movable layer is advantageous when the driving scheme relies at least in part upon the movable layer slowly drifting to a released state when the row voltage is released. Similarly, features that make the movable layer less compliant result in an increased actuation time and a decreased release time. A less compliant movable layer may be advantageous when the driving scheme relies at least in part upon the movable layer slowly drifting to an actuated state when the row voltage is released. Some of the features affecting the release and actuation times include altering post spacing, altering internal stress or tension of the movable layer, altering the thickness or composition of the movable layer, altering the bulkiness of the tethers, perforating the movable layer and providing vias in the fixed layer.

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 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 posts 18 and an intervening sacrificial material deposited between the posts 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.

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 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 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 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 illustrated in Figure 1 is shown by the lines 1-1 in Figure 2. For MEMS interferometric modulators, the row/column actuation protocol may or may not take advantage of a hysteresis property of these devices illustrated in Figure 3. To take advantage of this hysteresis property 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 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 $-V_{bias}$, 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 $+V_{bias}$, and the appropriate row to the same $+\Delta V$, producing a zero volt potential difference across the pixel. In those rows where the row voltage is held at zero volts, the pixels are stable in whatever state they were originally in, regardless of whether the column is at $+V_{bias}$, or $-V_{bias}$. As is also illustrated in Figure 4, it will be appreciated that voltages of opposite polarity than those described above can be used, e.g., actuating a pixel can involve setting the appropriate column to $+V_{bias}$, and the appropriate row to $-\Delta V$. In this embodiment, releasing the pixel is accomplished by setting the appropriate column to $-V_{bias}$, and the appropriate row to the same $-\Delta V$, producing a zero volt potential difference across the pixel.

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. For example, the polarity of the row strobe for a first frame may be reversed for use in the next frame.

Still referring to Figure 5A, the writing operation sequentially progresses through the each row, from row 1 to row 3 and then returns to write new data on row 1. The time interval between writing data to the modulators of row 1 and the time it takes to return to row 1 to write new data or to rewrite old data to modulators of row 1 is referred to herein as the update time T_u. The time interval over which the displayed information remains constant is referred to as the frame period T_f. For example, motion video may run at frame rate of 30 Hz, which corresponds to a frame period of 33.3 ms. In one embodiment, the update time T_u is selected to be higher than the frame period T_f. In the exemplary embodiment of motion video running at 30 Hz, an update rate is selected as 150 Hz, such that each row of the array is updated 5 times for each unique frame of motion video. This update rate of 150Hz corresponds to an update time T_u of 6.6 ms. It will be understood by one skilled in the art that the systems described herein are equally applicable to other frame periods and update times and that these are exemplary cases for ease of illustration.

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 7 through 21 illustrate additional processes and systems for using the array of interferometric modulators to those processes and systems illustrated in Figures 3 through 5. Figure 7 is one exemplary diagram of movable mirror position versus applied voltage for one interferometric modulator of Figure 1 that operates without taking advantage of the hysteresis property of the modulator. Instead, the processes and systems described with reference to Figures 7 through 21 employ row/column actuation protocols which maintain voltages to the MEMS interferometric modulators that are always above or below, but not within, "hysteresis window" or "stability window". Exemplary embodiments that operate in accordance with Figure 7 are described with reference to Figures 8 through 10 and 17 and with reference to Figures 18 through 21.

Stable operation of the MEMS interferometric modulator is achieved by selecting mechanical design features of the interferometric modulator that optimize the actuation and release times for the particular row/column actuation protocol. Described herein are certain structures and methods of making interferometric modulators having varying release and actuation times. In general, features making the movable layer more compliant result in an increased release time and a decreased actuation time. Similarly, features that make the movable layer less compliant result in an increased actuation time and a decreased release time.

An exemplary row/column actuation protocol described with reference to Figure 8 operates the modulator in the released region of Figure 7 between row strobes. Another exemplary row/column actuation protocol described with reference to Figure 18 operates the modulator in the actuated region of Figure 7 between row strobes. Other combinations of modulator design and driving scheme may be employed to operate the modulator in different regions of Figure 7 without relying upon a hysteresis window.

The protocols described with reference to Figures 7 through 21 advantageously operate the MEMS interferometric modulator at lower voltages than the voltages employed with the processes and systems described with reference to Figures 3 through 5. For example, the row/column actuation protocols described with reference to Figures 3 through 5 apply an exemplary voltage range from 0 volts to ± 10 volts. In contrast, the row/column actuation protocols disclosed with reference to Figures 7 through 21 apply lower voltages. For example, the row/column actuation protocol described with reference to Figures 8 through 10 and 17 employs a range of $-2V_{bias}$ volts to $+2V_{bias}$ volts where $V_{bias} = 1$ volt. The row/column actuation protocol described with reference to Figures 18-21 employs a range of $-4V_{bias}$ volts to $+4V_{bias}$ volts where $V_{bias} = 0.5$ volt. With such low bias voltages, the hysteresis window is very narrow, so drive methods which do not utilize voltages within the hysteresis window are advantageous.

Operating the MEMS interferometric modulator with lower voltage row/column actuation protocols may increase the efficiency of a display device employing the MEMS device. Advantageously for portable display devices, the storage capacity of the battery power source may be reduced while maintaining the display device's operating time as compared to display devices that operate over a wider voltage range of, for example, 20 volts. The voltage range of 4 volts is only exemplary and other voltage ranges may be employed that are lower than the typical 20 volt range while staying within the scope of the invention. For the embodiment described with reference to Figure 8, V_{bias} lies within the released region of Figure 7. For the embodiment described with reference to Figure 18, V_{bias} lies within the actuated region of Figure 7. While exemplary values for V_{bias} such as 1 volt and 0.5 volts have been described, other values of V_{bias} are within the scope of the invention. In these embodiments, the narrowness of the hysteresis window results in the row/column actuation protocol operating the interferometric modulator substantially outside of the hysteresis window at all times.

The embodiment described with reference to Figure 7 through 10 operates the array of MEMS interferometric modulators without relying upon the hysteresis property of the interferometric modulator. In Figure 7, the inverse of the intensity is plotted against the voltage between the column and row electrodes of the modulator. Starting at 0 and moving right in the direction of a positive voltage applied between the column and row electrodes, the intensity of the light displayed is at maximum with the modulator cavity 19 fully open until the applied voltage reaches the voltage represented by point 700. At this point, the potential between the column and row electrodes is sufficient to begin to collapse the cavity 19 of the modulator, which will result in the modulator displaying black or reflecting a minimum intensity of light. At point 702, the modulator is displaying black. As this voltage is reduced from point 702, the modulator will continue to display black until point 704, where the electromechanical forces of the modulator will begin to outweigh the electrical potential being applied. Continuing to reduce the potential between the column and row electrodes will result in the intensity of the light displayed to increase until, at point 706, the cavity 19 of the modulator is fully open and the light displayed is at maximum intensity.

In the case of a negative potential being applied between the column and row electrode, starting at 0 and moving left in the direction of a negative voltage applied between the column and row electrodes, the intensity of the light displayed is at maximum with the modulator cavity 19 fully open until the applied voltage reaches the voltage represented by point 710. At this point, the potential between the column and row electrodes is sufficient to begin to collapse the cavity 19, which will result in the modulator displaying black or reflecting a minimum intensity of light. At point 712, the modulator is displaying black. As this potential is reduced from point 712 (moving back to the right), the modulator will continue to display black until point 714, where the electromechanical forces of the modulator will begin to outweigh the electrical potential being

applied the modulator. Continuing to reduce the potential between the column and row electrodes will result in the intensity of the light displayed to increase until, at point 716, the cavity 19 of the modulator is fully open and the light displayed is again at maximum intensity.

Figure 8 is an illustration of a set of row and column voltages that may be used to drive an interferometric modulator display that results in the modulator drifting to a released state between row strobes. In the exemplary embodiment, the row select signal takes on the values of + V or - V during a row strobe and the row select signal takes on a value of 0 between the row strobes. When a row is strobed with a - V signal, the data takes on the value of $+V_{bias}$ to actuate the modulator collapsing the cavity 19 or $-V_{bias}$ to release the modulator which opens the cavity 19. When a row is selected with a + V signal, the column takes on the value of $-V_{bias}$ to actuate the modulator or $+V_{bias}$ to release the modulator. In the present embodiment, between row strobes, the row voltage is set to 0. During these periods, the column signal taking on the values of $+V_{bias}$ and $-V_{bias}$ will result in the modulator slowly releasing.

Figure 9 illustrates the operational response of a modulator having a long actuation time and being driven according to the row and column voltages of Figure 8. At t=0, the interferometric modulator is actuated by a potential expressed between the column and row electrodes. This voltage will only be applied during the time interval that the row electrode has an enabling voltage applied to it, referred to herein as T_S, as described above. When the row strobe is over, the modulators in that row will gradually migrate to the released position under the mechanical restoring forces of the moving electrode. If the actuation time T_A exceeds T_S as is the case illustrated by the solid line in Figure 9, then the modulator will not fully actuate and may drift back to the released position when the voltage is removed from the row electrode. Preferably, the actuation time T_A is the same as or less than T_S such that the operational response follows line 900.

Figure 10 illustrates the operational response of a modulator having a short release time and being driven according to the row and column voltages of Figure 8. If the release time is too short, the modulator may get fully actuated as illustrated in Figure 10. However, the mechanical forces cause the modulator to open too quickly, which results in the maximum intensity being incorrectly displayed for a significant portion of the update interval. Preferably, the release time T_R is the same as or greater than update time T_u such that the operational response follows line 1000.

Figures 11 through 16 illustrate methods and structures for optimizing the release and actuation times of an interferometric modulator. Figures 11A and 11B illustrate a geometric variation in post 18 spacing that affects the actuation and release times of the modulator so as to improve the operational response of the modulator. By increasing the distance between posts 18, the release time of the modulator is increased and the actuation time is decreased. In Figure 11A, the posts 18 of the modulator are set a distance W apart from one another. In Figure 11B, by

increasing the distance between the posts 18 to W+Δ, the release time is increased and the actuation time is decreased.

Figures 12A and 12B illustrate a geometric variation in tension of the movable layer 14 that affects the actuation and release times of the modulator so as to improve the operational response of the modulator. By reducing the stress or tension in the movable layer 14, the release time is increased and the actuation time is decreased. Stress in the movable layer 14 can be induced in many ways such as the material used, temperature cycling, method of deposition, and so on. For example, the tension in the movable layer 14 may be decreased by increasing the power or the gas pressure during the deposition process forming the movable layer 14. In Figure 12A, the movable layer 14 is under stress and tension. In Figure 12B, the stress is reduced (represented by the wavy nature of the movable layer 14). The reduced tension in the movable layer 14 will result in an increased release time and a decreased actuation time.

Figures 13A and 13B illustrate a geometric variation in thickness of the movable 14 layer that affects the actuation and release times of the modulator so as to improve the operational response of the modulator. Reducing the thickness of the movable layer 14 also increases the release time of the modulator while decreasing the actuation time of the modulator. In Figure 13A, the thickness of the movable layer 14 is t. In Figure 13B, the thickness of the movable layer 14 is reduced to t-Δ, which increases the release time of the modulator and decreases the actuation time of the modulator. Alternatively or in addition, the material composition of the movable layer 14 can be changed to a more pliant material, which will also increase the release time of the modulator and decrease the actuation time of the modulator. For example, materials such as aluminum/aluminum alloys, metal oxides, chrome, and nickel could be used for the movable layer 14 with the later materials being less compliant.

Figures 14A and 14B illustrate a geometric variation in tether 32 size of the movable layer 14 that affects the actuation and release times of the modulator so as to improve the operational response of the modulator. Figures 14A and 14B are top down representation of the movable layer 14. As explained above, the tethers 32 connect the movable layer 14 to the posts 18 of an interferometric modulator. By reducing the bulkiness of the tethers 32, the resiliency of the movable layer 14 is reduced which in turn results in an increase in the release time of the modulator and a decrease in the actuation time of the modulator. In Figure 14B the size of the tethers 32 is reduced so as to increase the release time of the modulator and decrease the actuation time of the modulator.

Figures 15A and 15B illustrate a geometric variation in the movable layer 14 that affects the actuation and release times of the modulator so as to improve the operational response of the modulator. When the modulator is actuated and the cavity 19 is collapsed, air is forced out of the cavity 19. By perforating the movable layer 14, the air is allowed to pass out of the cavity 19 through the movable layer 14, resulting in a decrease of the actuation time. In Figure 15A a solid

movable layer 14 is illustrated. In Figure 15B, the movable layer 14 includes one or more perforations 1500 so as to decrease the actuation time of the modulator. This will also increase the release time, because the air pressure that would have built up beneath the collapsed movable layer 14 has been discharged.

Figures 16A and 16B illustrate a geometric variation in the surface of the fixed layers 16 that affects the actuation and release times of the modulator so as to improve the operational response of the modulator. Figure 16B illustrates vias 1600 in the fixed layer 16, which form cavity channels to release the gas captured by the cavity. The vias 1600 give the air in the cavity 19 a place to go when the cavity 19 is collapsed, thus reducing the actuation time. In addition, the reduction in upward pressure from compressed air in the collapsed cavity 19 increases the release time of the modulator. Cavity gas release channels may also be created in other layers. It will be understood that any combination of the methods above can also be used to achieve the desired end result.

Figure 17 illustrates the timing effects of motion video in an array of modulators driven according to the row and column voltages of Figure 8 so as to drift toward a released state when the row select is removed. In this exemplary embodiment, the motion video is displayed at 30 frames per second (30Hz), thus, the frame time is 33.3ms. In this exemplary embodiment, rows are updated five times per frame at a rate of 150Hz (T_U=6.6ms). In this example, the modulator has been tuned to have a very fast actuation time and a long release time of 30ms by one or a combination of the methods described with reference to Figures 11 through 16. The subframe updates in the form of commands to a particular modulator are provided above the frame numbers. These commands are presented in the form of open and close commands, which correspond to voltages applied to the row and column electrodes of the modulator which respectively release and actuate the modulator. These voltages are provided below the commands in Figure 17. The cavity 19 size is illustrated directly above the subframes to illustrate the cavity 19 thickness at all times during operation.

The sequence begins with the last two update subframes of Frame 0. The modulator is in steady state with the cavity 19 at maximum aperture. At the start of Frame $\bar{1}$, the modulator is instructed to actuate. The cavity 19 is collapsed at point 1700. As the row pulse is removed from the modulator and the remaining lines are scanned, the cavity 19 will drift open a certain amount. After T_U (6.6 ms) later, the actuation voltage again is applied driving the modulator into a state of maximum actuation. This occurs five times during the display of Frame 1 at points labeled 1702, 1704, 1706, 1708 and 1710.

During Frame 2, the modulator is written to the open position with the potential between the row and column electrodes being about 0 during the row strobes. The modulator releases over the next 30 ms to reach its maximum aperture size at point 1712. Frame 3 also displays the modulator in the open state. Thus the modulator at the open state will remain as such for the

entirety of Frame 3. If the modulator were actuated in Frame 4, the process described with respect to Frame 1 would repeat.

Figure 18 is an illustration of a set of row and column voltages that may be used to drive an interferometric modulator display that results in the modulator drifting to an actuated state between row strobes. In contrast to the row/column actuation protocol of Figure 8 which results in the modulator drifting to a released state, by altering the display driving strategy and the actuation and release times of the modulator, the natural state of the modulator is the actuated state such that the modulators will drift toward an actuated condition between row updates. The driving strategy applies row voltages and data combinations such that the when the row is not being strobed the modulator will be driven to an actuated state and when the row is strobed the modulators in that row can be written to a released state. This row/column actuation protocol has characteristics that are the converse of those present in the embodiment described with reference to Figures 8-10 and 17.

Figure 19 illustrates the operational response of a modulator having a long release time and being driven according to the row and column voltages of Figure 18. Figure 19 assumes the same optical response as illustrated in Figure 7. In Figure 19, if the release time is too long then the modulator will not be released during the period of time in which the row is enabled. The modulator in this embodiment will drift toward the actuated state and will assume the actuated state in the interval prior to the rewriting of the modulator state. Preferably, the release time T_R is the same as or shorter than T_S such that the operational response follows line 1900.

Figure 20 illustrates the operational response of a modulator having a short actuation time and being driven according to the row and column voltages of Figure 18. In Figure 20, the actuation time is too short, so following the successful release of the modulator, the modulator drifts too rapidly to the actuated state displaying the incorrect optical response for an unacceptable fraction of the update period. Preferably, the actuation time T_A is the same as or longer than update time T_u such that the operational response follows line 2000.

It is desired to increase the actuation time and decrease the release time for the modulator having the optical response illustrated in Figure 19 and 20 when driven by the row and column voltages illustrated in Figure 18. This is done by the converse of the methods described with respect to Figures 11 through 16. Specifically, the goals of increasing the actuation time and decreasing the release time can be achieved by: decreasing the post spacing as illustrated in Figure 11A; increasing the tension of the movable layer 14 as illustrated in Figure 12A; increasing the thickness of the movable layer 14 as illustrated in Figure 13A; using a less flexible material in the formation of the movable layer 14, increasing the bulkiness of the tethers 32 as illustrated in Figure 14A; using solid materials in the formation of the movable layer 14 as illustrated in Figure 15A; and using a uniformly flat solid layer in the fixed layer 16. It will be understood that any combination of the methods above can also be used to achieve the desired end result.

Figure 21 illustrates the timing effects of motion video in an array of modulators driven according to the row and column voltages of Figure 18 so as to drift to an actuated state when the row select is removed. In this exemplary embodiment, the motion video is displayed at 30 frames per second (30Hz), thus, the frame time is 33.3ms. In this exemplary embodiment, rows are updated five times per frame at a rate of 150Hz (T_U=6.6ms). In this example, the modulator has been tuned to have a very fast release time and a long actuation time of 30ms by one or a combination of the methods described with reference to Figures 11-16. The subframe updates in the form of commands to a particular modulator are provided above the frame numbers. These commands are presented in the form of open and close commands which correspond to voltages applied to the row and column electrodes of the modulator which respectively release and actuate the modulator. These voltages are provided below the commands in Figure 21. The cavity 19 size is illustrated directly above the subframes to illustrate the cavity 19 thickness at all times during the operation.

The sequence begins with the last two subframes of Frame 0. The modulator is in steady state with the cavity 19 at minimum aperture. At the start of Frame 1, the modulator is instructed to release. The cavity 19 is opened at point 2100. As the row select pulse is removed from the modulator, and the remaining lines are scanned, the cavity 19 will drift closed by a small amount. After T_U (6.6 ms) later, the release voltage is reapplied driving the modulator into the release state. This occurs five times during the display of Frame 1 at points labeled 2102, 2104, 2106, 2108 and 2110. These correspond to the row update points for the array.

During Frame 2, the modulator is written to the open position with the potential between the row and column electrodes removed. The modulator releases over the next 30 ms taking almost the entire frame duration to reach its maximum aperture size at point 2112. Frame 3 also displays the modulator in the actuated state. Thus the modulator at the closed state will remain as such for the entirety of Frame 3. If the modulato

Figures 22A and 22B 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 22B. 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 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 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 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 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 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 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 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. r were released in Frame 4, the process as described with respect to Frame 1 would repeat.

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.

WHAT IS CLAIMED IS:

1. A MEMS device comprising:

a fixed layer comprising a first electrode;

a movable layer configured to move between a first location distal to the first electrode and a second location proximal to the first electrode, the movable layer and the fixed layer forming a cavity when the movable layer is in the first location; and

a second electrode connected to the movable layer,

wherein movement of the movable layer is based on a voltage difference between the first and second electrodes and the movable layer is configured to move from the first location to the second location at a first average rate and to move from the second location to the first location at a second average rate, wherein the first and second average rates are different.

2. The device of Claim 1, wherein the first average rate is greater than the second average rate.

3. The device of Claim 1, wherein the second average rate is greater than the first average rate.

4. The device of Claim 1, wherein the movable layer is reflective.

5. The device of Claim 1, wherein the cavity is configured to interferometrically modulate light.

6. The device of Claim 1, wherein the movable layer comprises at least one of aluminum, metal oxide, chrome, and nickel.

7. The device of Claim 1, wherein the movable layer comprises perforations.

8. The device of Claim 1, wherein the cavity comprises gas release channels.

9. The device of Claim 1, further comprising:

a processor that is in electrical communication with at least one of said first and second electrodes, said processor being configured to process image data; and

a memory device in electrical communication with said processor.

10. The device of Claim 9, further comprising a driver circuit configured to send at least one signal to at least one of said first and second electrodes.

11. The device of Claim 10, further comprising a controller configured to send at least a portion of said image data to said driver circuit.

12. The device of Claim 9, further comprising an image source module configured to send said image data to said processor.

13. The device of Claim 12, wherein said image source module comprises at least one of a receiver, transceiver, and transmitter.

14. The device of Claim 9, further comprising an input device configured to receive input data and to communicate said input data to said processor.

15. A MEMS device comprising:

first means for moving a movable layer between a first location distal to the first moving means and a second location proximal to the first moving means;

second means for moving the movable layer between the first and second locations, the movable layer and the first moving means forming a cavity when the movable layer is in the first location; and

third means for moving the movable layer from the first location to the second location at a first average rate and for moving the movable layer from the second location to the first location at a second average rate, wherein the first and second average rates are different.

16. The device of Claim 15, wherein the first moving means comprises a fixed layer comprising a first electrode.

17. The device of Claim 15, wherein the second moving means comprises a second electrode connected to the movable layer.

18. The device of Claim 15, wherein the third moving means comprises said first and second electrodes.

19. The device of Claim 15, further comprising means for interferometrically modulating light.

20. The device of Claim 19, wherein the light modulating means comprises a cavity.

21. The device of Claim 15, wherein the first average rate is greater than the second average rate.

22. The device of Claim 15, wherein the second average rate is greater than the first average rate.

23. The device of Claim 15, wherein the movable layer is reflective.

24. The device of Claim 15, wherein the movable layer comprises at least one of aluminum, metal oxide, chrome, and nickel.

25. The device of Claim 15, wherein the movable layer comprises perforations.

26. The device of Claim 15, wherein the cavity comprises cavity gas release channels.

27. A method of actuating an array of interferometric modulators multiple times to display a single frame of data, the method comprising:

receiving a data signal for actuating one or more interferometric modulators during a time period corresponding to a single frame;

actuating the one or more interferometric modulators with a potential difference such that the interferometric modulator moves to an actuated state at a first average rate; and

releasing the one or more interferometric modulators display element such that the interferometric modulator moves from the actuated state and towards a released state at a second, different average rate.

28. The method of Claim 27, further comprising re-actuating the interferometric modulator display element such that before reaching the released state, the interferometric modulator moves back to the actuated state.

29. The method of Claim 27, further comprising applying a bias voltage to the interferometric modulator while the interferometric modulator moves from the actuated state.

30. The method of Claim 29, wherein the potential difference is substantially equal to twice the bias voltage.

31. The method of Claim 29, wherein an absolute value of the bias voltage is less than an absolute value of a voltage corresponding to a hysteresis window for the interferometric modulator display element.

32. A method of driving an interferometric modulator element to display a frame of data, the method comprising:

receiving a data signal for display by the interferometric modulator during a period of time corresponding to a single frame display period; and

periodically applying a first potential difference to the interferometric modulator display element during the single frame display period, wherein the interferometric modulator moves from an actuated state towards a released state each time the first potential difference is applied and moves to the actuated state before reaching the released state when a second potential difference is applied to the interferometric modulator.

33. The method of Claim 32 further comprising applying a bias voltage to the interferometric modulator while the interferometric modulator moves away from the actuated state.

34. The method of Claim 33, wherein the first potential difference is substantially equal to twice the bias voltage.

35. The method of Claim 33, wherein an absolute value of the bias voltage is less than an absolute value of a voltage corresponding to a hysteresis window for the interferometric modulator display element.

36. A method of writing display data to a row of interferometric modulator display elements in an array of display elements, the method comprising:

writing a first set of display data to the row of the array with a potential difference so as to move at least some of the interferometric modulator elements to an actuated state;

releasing the interferometric modulator elements in the row of the array such that the interferometric modulator elements slowly move from the actuated state and towards the released state; and

re-writing the first set of display data to the row of the array with a potential difference so as to return the interferometric modulator elements to the actuated state before the interferometric modulators reach the released state.

37. The method of Claim 36 further comprising applying a bias voltage to the interferometric elements in the row of the array while the interferometric modulators move away from the actuated state.

38. The method of Claim 37, wherein the potential difference is substantially equal to twice the bias voltage.

39. The method of Claim 37, wherein an absolute value of the bias voltage is less than an absolute value of a voltage corresponding to a hysteresis window for the interferometric modulator elements.

40. A method of actuating an array of interferometric modulators multiple times to display a single frame of data, the method comprising:

receiving a data signal for actuating one or more interferometric modulators during a time period corresponding to a single frame;

releasing the interferometric modulator display element with a potential difference such that the interferometric modulator moves to a released state;

actuating the interferometric modulator display element such that the interferometric modulator moves away from the released state and towards an actuated state; and

re-releasing the interferometric modulator display element such that before reaching the actuated state, the interferometric modulator moves back to the released state.

41. The method of Claim 40 further comprising applying a bias voltage to the interferometric modulator while the interferometric modulator moves from the released state.

42. The method of Claim 41, wherein the potential difference is substantially equal to twice the bias voltage.

43. The method of Claim 41, wherein an absolute value of the bias voltage is greater than an absolute value of a voltage corresponding to a hysteresis window for the interferometric modulator display element.

44. A method of driving an interferometric modulator element to display a frame of data, the method comprising:

receiving a data signal for display by the interferometric modulator during a period of time corresponding to a single frame display period; and

periodically applying a first potential difference to the interferometric modulator display element during the single frame display period, wherein the interferometric modulator moves from a released state towards an actuated state each time the first potential difference is applied and moves to the released state before reaching the actuated state when a second potential difference is applied to the interferometric modulator.

45. The method of Claim 44 further comprising applying a bias voltage to the interferometric modulator while the interferometric modulator moves away from the released state.

46. The method of Claim 45, wherein the potential difference is substantially equal to twice the bias voltage.

47. The method of Claim 45, wherein an absolute value of the bias voltage is greater than an absolute value of a voltage corresponding to a hysteresis window for the interferometric modulator display element.

48. A method of writing display data to a row of interferometric modulator display elements in an array of display elements, the method comprising:

writing a first set of display data to the row of the array with a potential difference so as to move at least some of the interferometric modulator elements to a released state;

actuating the interferometric modulator elements in the row of the array such that the interferometric modulator elements move away from the released state and towards the actuated state; and

re-writing the first set of display data to the row of the array with a potential difference so as to return the interferometric modulator elements to the released state before the interferometric modulator elements reach the actuated state.

49. The method of Claim 48 further comprising applying a bias voltage to the interferometric modulator elements in the row of the array while the interferometric modulator elements move slowly away from the released state.

50. The method of Claim 49, wherein the potential difference is substantially equal to twice the bias voltage.

51. The method of Claim 49, wherein an absolute value of the bias voltage is greater than an absolute value of a voltage corresponding to a hysteresis window for the interferometric modulator elements.

52. A method of manufacturing a MEMS device, the method comprising:

forming a fixed layer comprising a first electrode;

forming a movable layer configured to move between a first location distal to the first electrode and a second location proximal to the first electrode, the movable layer and

the fixed layer forming a cavity comprising a gas when the movable layer is in the first location; and

forming a second electrode connected to the movable layer,

wherein movement of the movable layer is based on a voltage difference between the first and second electrodes and the movable layer is fabricated to move from the first location to the second location at a first average rate and to move from the second location to the first location at a second average rate, wherein the first and second average rates are different.

53. The method of Claim 52, wherein the first average rate is greater than the second average rate.

54. The method of Claim 52, wherein the second average rate is greater than the first average rate.

55. The method of Claim 52, wherein forming the movable layer comprises forming a reflective layer.

56. The method of Claim 52, wherein forming the cavity comprises forming an interferometrically light modulating cavity.

57. The method of Claim 52, wherein forming the movable layer comprises forming the movable layer to comprise at least one of aluminum, metal oxide, chrome, and nickel.

58. The method of Claim 52, wherein forming the movable layer comprises forming perforations in the movable layer.

59. The method of Claim 52, wherein forming the cavity comprises forming gas release channels in the cavity.

60. A MEMS device manufactured by the method of Claim 52.