SYSTEM AND METHOD FOR PROTECTING MICROELECTROMECHANICAL SYSTEMS ARRAY USING BACK-PLATE WITH NON-FLAT PORTION

Background

Field of Technology

The disclosure relates to microelectromechanical systems (MEMS), and more particularly to protection of MEMS devices from damage.

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. In designing commercial products utilizing this MEMS technology, packaging is developed in consideration of the requirements of cost, reliability and manufacturability. The packaging associated with the MEMS devices can incorporate various features to protect MEMS elements from being damaged by external forces.

Summary

The system, method, and devices of the invention each have several aspects, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of this invention, its more prominent features will now be discussed briefly. After considering this discussion, and particularly after reading the section entitled "Detailed Description of Certain Embodiments" one will understand how the features of this invention provide advantages over other display devices.

One aspect of the invention provides an electronic device. The electronic device comprises a substrate having a surface, an array of microelectromechanical devices and a back-plate. The array of the microelectronic devices is formed on the surface of the substrate and has a back-surface facing away from the substrate. The back-plate is placed over the array and has an interior surface and an exterior surface. The interior surface of the back-plate faces the back-surface of the array with a gap therebetween. The exterior surface faces away from the substrate. The electronic device further comprises one or more reinforcing structures which are integrated with the back-plate. The reinforcing structures add stiffness to the back-plate. In the electronic device, a distance between the interior surface of the back-plate and the surface of the substrate may change over the surface of the substrate.

Another aspect of the invention provides an electronic device. The electronic device comprises a substrate having a surface; a microelectromechanical array and a back-plate. The array is formed on the substrate surface and has a back-surface facing away from the substrate. The back-plate is placed over the array and has an interior surface. The interior surface faces the back-surface of the array with a gap therebetween. The back-plate has a thickness varying along an edge thereof.

Still another aspect of the invention provides an electronic device. The electronic device comprises: a substrate; an array of interferometric modulators and a back-plate. The array is formed on the substrate and has a back-surface facing away from the substrate. The back-plate is placed over the array and has an interior surface facing the back-surface of the array with a gap between the interior surface of the back-plate and the back-surface of the array. The electronic device further comprises means for preventing the interior surface of the back-plate from directly contacting the back-surface of the array.

A further aspect of the invention provides a method of making an electronic device. The method comprises providing an intermediate device, providing a back-plate, placing the back-plate over the intermediate device and binding the back-plate and the substrate. The intermediate device comprises a substrate and an array of microelectromechanical devices formed on the substrate. The back-plate has an interior surface and an exterior surface. The back-plate is integrated with one or more reinforcing structures formed on at least one of the interior surface and the exterior surface. The back-plate is placed over the array of the intermediate device such that the interior surface of the back-plate faces the back-surface of the array with a gap therebetween. A further aspect of the invention provides an electronic device produced by the foregoing method of making such an electronic device.

Still another aspect of the invention provides an electronic device. The device comprises a substrate, an array of microelectromechanical devices formed on the substrate and a back-plate placed over the array. The back-plate has an interior surface and an exterior surface. The interior

surface of the back-plate faces the array with a gap therebetween. The exterior surface faces away from the substrate. A distance between the interior surface of the back-plate and the substrate varies across the substrate.

A further aspect of the invention provides an electronic device. The electronic device comprises a transmitting means for transmitting light therethrough; modulating means for modulating light transmitted through the transmitting means; covering means for covering the modulating means, wherein the covering means comprises an interior surface and an exterior surface, the interior surface facing the transmitting means with a gap therebetween, the exterior surface facing away from the transmitting means; and wherein a distance between the interior surface of the covering means and the transmitting means varies across the transmitting means.

A still further aspect of the invention provides a method of making an electronic device. The method comprises providing an intermediate device which comprises a substrate and an array of microelectromechanical devices formed on the substrate. The method further comprises forming a back-plate over the array of the intermediate device with a gap between the back-plate and the array. The back-plate has an interior surface facing the array, and a distance between the interior surface and the substrate varies across the substrate. A further aspect of the invention provides an electronic device produced by the foregoing method of making such an electronic device.

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.

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

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

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 top plan view illustrating a MEMS array.

Figures 8 and 9 are side views illustrating a cross-section of packaged MEMS display devices.

Figure 10 is a side view illustrating bending of a back-plate of a packaged MEMS display device.

Figure 11 is a top plane view of the back-plate of Figure 10.

Figures 12, 14, 16, 18, 20, 22, 24-26 are side views illustrating a cross-section of packaged MEMS display device with various constructions of the back-plate.

Figures 13A and 15 are perspective views illustrating the shape of the back-plates used in Figures 12 and 14, respectively.

Figures 13B and 13C are side views of a back-plate illustrating production of the back-plate illustrated in Figures 12 and 13A.

Figures 17A-17C, 19, 21 and 23 are bottom plan views illustrating reinforcing structures of the back-plates used in Figures 16, 18, 20 and 22, respectively.

Figure 27 is a flowchart describing an exemplary process to produce the embodiments illustrated in Figure 26.

Figures 28A and 28B are system block diagrams illustrating an embodiment of a visual display device comprising a plurality of interferometric modulators.

Detailed Description of Embodiments

Various reinforcing structures are formed on a back-plate of MEMS devices. The reinforcing structures increase the stiffness of the back-plate and therefore prevent the back-plate from contacting and damaging the MEMS elements or array of the device. The reinforcing structures are integrated with the back-plate on either or both of the surfaces thereof. The back-plate can be formed in various configurations which improve the stiffness thereof or reduce the likelihood of it contacting the MEMS array when the back-plate is subject to an external force. The configurations include a curved back-plate, curved surfaces of the back-plate, a back-plate having one or more recesses, varying thickness of the back-plate, etc. The reinforcing structures and the various configurations can be combined to further prevent damage to the MEMS array when an external force is applied to the back-plate of a MEMS device.

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 5 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 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 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 and 5 illustrate one possible actuation protocol for creating a display frame on the 3x3 array of Figure 2. Figure 4 illustrates a possible set of column and row voltage levels that may be used for pixels exhibiting the hysteresis curves of Figure 3. In the Figure 4 embodiment, actuating a pixel involves setting the appropriate column to $-V_{bias}$, and the appropriate row to $+\Delta V$, which may correspond to -5 volts and +5 volts respectively. 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 $-V_{bias}$.

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.

Figure 7 illustrates an embodiment of a MEMS array 111 formed on a substrate 101. The MEMS array 111 is comprised of a number of MEMS elements arranged on the substrate 101. Each MEMS element 103, 105, 107 corresponds to the interferometric modulator 12a or 12b. In the illustrated embodiment, the MEMS elements are substantially regularly arranged. The dotted lines are to represent the arrangement of the MEMS elements. In one embodiment, all of the MEMS elements in the array 111 have substantially the same size. In another embodiment, MEMS elements of the MEMS array 111 may have different sizes. As depicted in the enlarged portion of the MEMS array 111, for example, the elements 103 and 105 are defined by the four (4) neighboring posts 18 while the element 107 is defined by six (6) neighboring posts 18. Although, in the illustrated embodiment, the posts 18 are regularly arranged with substantially the same pitch, there may be variations in the locations of the posts 18 and the pitches between the neighboring posts 18.

The MEMS array 111 and its elements 103, 105, 107 form a robust construction. For example, although depicted as narrow columns in Figures 1, 6A, 6B and 6C, the posts 18, 18' and 18'' may be constructed to be much wider than as shown in comparison to the depth (vertical distance) and width (horizontal distance) of the cavity 19. Thus, a force or pressure on the members 14 (Figures 6A and 6B) and 34 (Figure 6C) of the MEMS elements from the top would not easily break the members 14 and 36 unless such a force or pressure is focused on a single MEMS element or a portion thereof. Nevertheless, this robustly constructed MEMS array 111 and individual MEMS elements are still susceptible to some strong forces that can be applied thereto. Thus, in the packaging of MEMS devices comprised of an array of MEMS elements, features to protect the structure and integrity of the MEMS elements and their array are implemented.

Figure 8 illustrates a typical packaging configuration of a MEMS device 100. As illustrated in Figure 7, a MEMS array 111 is formed over the substrate 101. An image or information can be displayed on the bottom surface 109 of the substrate 101 by the operation of the MEMS array 111. A back-plate 121 is placed over but not in direct contact with the top

surface of the MEMS array 111 and is supported by a sealing or bonding material 123 extending about the periphery thereof. The sealing or bonding material 123 bonds the back-plate 121 and the substrate 101 together.

The sealing 123 may be a non-hermetic seal made of a material, such as a conventional epoxy-based adhesive. In other embodiments, the sealing material may be a polyisobutylene (sometimes called butyl rubber, and other times PIB), o-rings, polyurethane, thin film metal weld, liquid spin-on glass, solder, polymers, or plastics, among other types of seals that may have a range of permeability of water vapor of about $0.2-4.7$ g mm/m^{2}kPa day. In still other embodiments, the sealing 123 may be a hermetic seal.

In some embodiments, the packaged MEMS device 100 includes a desiccant (not shown) configured to reduce moisture within the cavity 124. The skilled artisan will appreciate that a desiccant may not be necessary for a hermetically sealed package, but may be desirable to control moisture resident within the package. In one embodiment, the desiccant is positioned between the MEMS array 111 and the back-plate 121. Desiccants may be used for packages that have either hermetic or non-hermetic seals. In packages having a hermetic seal, desiccants are typically used to control moisture resident within the interior of the package. In packages having a non-hermetic seal, a desiccant may be used to control moisture moving into the package from the environment. Generally, any substance that can trap moisture while not interfering with the optical properties of the interferometric modulator array may be used as the desiccant. Suitable desiccant materials include, but are not limited to, zeolites, molecular sieves, surface adsorbents, bulk adsorbents, and chemical reactants.

The desiccant may be in different forms, shapes, and sizes. In addition to being in solid form, the desiccant may alternatively be in powder form. These powders may be inserted directly into the package or they may be mixed with an adhesive for application. In an alternative embodiment, the desiccant may be formed into different shapes, such as cylinders or sheets, before being applied inside the package.

The skilled artisan will understand that the desiccant can be applied in different ways. In one embodiment, the desiccant is deposited as part of the MEMS array 111. In another embodiment, the desiccant is applied inside the package 100 as a spray or a dip coat.

The substrate 101 may be a semi-transparent or transparent substance capable of having thin film, MEMS devices built upon it. Such transparent substances include, but are not limited to, glass, plastic, and transparent polymers. The MEMS array 111 may comprise membrane modulators or modulators of the separable type. The skilled artisan will appreciate that the back-plate 121 may be formed of any suitable material, such as glass, metal, foil, polymer, plastic, ceramic, or semiconductor materials (*e.g.*, silicon).

The packaging process may be accomplished in a vacuum, pressure between a vacuum up to and including ambient pressure, or pressure higher than ambient pressure. The packaging process may also be accomplished in an environment of varied and controlled high or low pressure during the sealing process. There may be advantages to packaging the MEMS array 111 in a completely dry environment, but it is not necessary. Similarly, the packaging environment may be of an inert gas at ambient conditions. Packaging at ambient conditions allows for a lower cost process and more potential for versatility in equipment choice because the device may be transported through ambient conditions without affecting the operation of the device.

Generally, it is desirable to minimize the permeation of water vapor into the package structure and thus control the environment inside the MEMS device 100 and hermetically seal it to ensure that the environment remains constant. When the humidity within the package exceeds a level beyond which surface tension from the moisture becomes higher than the restoration force of a movable element (not shown) in the interferometric modulator 10, the movable element may become permanently stuck to the surface. If the humidity level is too low, the moisture charges up to the same polarity as the movable element when the element comes into contact with the coated surface.

As noted above, a desiccant may be used to control moisture resident within the MEMS device 100. However, the need for a desiccant can be reduced or eliminated with the implementation of a hermetic seal to prevent moisture from traveling from the atmosphere into the interior of the MEMS device 100.

The continued reduction in display device dimensions restricts available methods to manage the environment within the MEMS device 100 because there is less area to place a desiccant within the MEMS device 100. The elimination of the need for a desiccant also allows the MEMS device 100 to be thinner, which is desirable in some embodiments. Typically, in packages containing desiccants, the lifetime expectation of the packaged device may depend on the lifetime of the desiccant. When the desiccant is fully consumed, the interferometric modulator device may fail as sufficient moisture enters the package structure and damages the interferometric modulator array.

Figure 9 illustrates another embodiment of packaging used in a MEMS device 100, in which the back-plate 121 has a protrusion 125 such as a lip along its edges. The protrusion 125 is connected to the substrate 101 by the bonding material 123. Use of this protrusion of the back-plate 121 creates the desired space or gap 124 between the back-plate 121 and the MEMS array 111 while reducing the necessary thickness of the sealing or bonding material 123. The illustrated back-plate 121 with the lip protrusion 125 can be produced by molding or forming. Alternatively, a structure forming the lip protrusion 125 can be attached to a substantially flat panel (not shown) along its edges, thereby creating the configuration of the back-plate 121

illustrated in Figure 9. Still alternatively, the back-plate 121 with the lip protrusion 125 can also be formed by making a recess on a surface of a flat panel, wherein a central area of the surface is carved out, thereby forming the protrusion 125 along its edges. One can also make more than one recess in the flat back-plate 121. This has the effect of making ribs or reinforcing structures in the back-plate (Figures 16-24) as will be discussed later in detail. Here, the ribs or reinforcing structures can be formed by leaving the original material of the back-plate 121 in place in some regions, and forming recesses elsewhere.

It is preferable that the back-plate 121 is assembled to the MEMS device 100 with the gap 124 between the MEMS array 111 and the back-plate 121. However, no-gap constructions (not illustrated) are also possible. The gap 124 can provide some protection against damaging of the MEMS array 111 by an external force applied on the back-plate 121. As illustrated in Figure 10, the back-plate 121 will absorb such a force exerted on it by bowing within the gap 124 without touching the MEMS array 111 or with only slight touching. Thus, the external force may not be transferred to the MEMS array 111 or only a fraction of the force may be transferred to the MEMS array 111. The larger the gap 124, the better protection for the MEMS array 111. The size of the gap 124 can be controlled by adjusting thickness or height of the sealing or bonding material 123. Also, the size of the gap 124 can be controlled by adjusting the thickness of the lip protrusion 125 and/or the depth of the above-described recess.

Although the gap 124 protects the MEMS device 100 as discussed, it is not always desirable to have a large gap because of the resulting increase in the overall thickness of the MEMS device 100. Further, in MEMS display devices having a large display area, forming a gap 124 between the MEMS array 111 and the back-plate 121 may not effectively protect the MEMS array 111 from being damaged. Referring to Figure 11, the central area 126 of the back-plate 201, particularly in a display having a large display area, is remote from the sealing/bonding material 123 that maintains the distance between the substrate 101 and the back-plate 201, and therefore maintains the size of the gap 124. In the package constructions shown in Figures 8-10, there is no structural support to maintain the size of the gap 124 in the central area 126 of the back-plate 121 (Figure 11). Thus, external forces exerted onto the central area 126 would be more likely to be transferred to the MEMS array 111 than other areas that are close to the sealing/bonding material 123.

Figure 12 illustrates another embodiment of the MEMS device 100 having a curved back-plate 121a. In the illustrated embodiment, the curved back-plate 121a covers the MEMS array 111 and bows out away therefrom. Thus, the curved back-plate 121a provides one means for covering the MEMS array 111. As will be discussed in more detail below, the curved configuration will provide a larger gap 124 between the MEMS array 111 and the back-plate 121a, particularly in the central area 126 (Figure 11) of the back-plate 121a. Further, the curved

configuration will increase the stiffness of the back-plate 121a. This increased stiffness results in a reduced deflection for a given load relative to a flat plate of similar thickness.

In the embodiment illustrated in Figure 12, the depth of the gap 124 may be greater than that of the MEMS device illustrated in Figure 8 throughout the gap 124. The term, the depth of the gap 124, refers to the distance between the top surface of the MEMS array 111 and the interior surface of the back-plate 121a. Further, the bowed-out construction of the back-plate 121a may be deflected less when the back-plate 121a is subjected to an external force. With the larger gap depth and the increased stiffness of the back-plate 121a, the MEMS array 111 in this embodiment is less susceptible to being contacted and damaged by external forces exerted on the back-plate 121a than in the case of the flat back-plate embodiment of Figure 8. Thus, the curved configuration provides one means for preventing the back-plate from directly contacting the MEMS array 111 and also provides a means for reducing or minimizing the likelihood of such contact.

Moreover, in the curved construction of the back-plate 121a, the depth of the gap 124 is greater in the central area than in the other areas of the back plate. Accordingly, even in a large display, an external force applied onto the central area 126 would not necessarily be more easily transferred to the MEMS array 111 than forces applied onto the other areas 130. Thus, the area of the MEMS array 111 corresponding to the central area 126 of the back-plate 121a would be better protected from being damaged by external forces or pressure than in the case of the flat back-plate 121 embodiment of Figure 8.

A perspective view of the curved back-plate 121a is showing in Figure 13A. Although, in the illustrated embodiment, the back-plate 121a is bowed only along the edge 133, it may be also bowed along the edge 135. In the embodiment where the back-plate 121a is bowed along both of the edges 133 and 135, the radii of the curvature along the edges 133 and 135 may be the same. Then, the back-plate 121a would essentially comprise a fragment of a spherical shell. In another embodiment, the radii of the curvature along the edges 133 and 135 may be different from each other.

In embodiments of the invention, the back-plate 121a is curved such that the radius of the curvature (R) may be constant or vary over the curvature of the back-plate 121a. In another embodiment, the curved back-plate 121a may include a flat section. The radius of the curvature (R) is, for example, from about 50 mm to about 5000 mm, whether it varies or is a constant. Preferably, the radius of the curvature is selected from about 100 mm to about 700 mm. The thickness of the back-plate 121a is from about 0.1 mm to about 5.0 mm although not limited thereto. Preferably, the thickness is from about 0.4 mm to about 1.5 mm. One of ordinary skill in the art will be able to adjust appropriate thicknesses within the described ranges of thickness in consideration of the characteristics of the materials for use in the back-plate 121a.

The curved back-plate 121a can be made of a variety of materials. For example, the materials for the back-plate 121a can be steel alloys, including stainless steel alloys, metals, metal alloys, glass, polymers, oxides of metallic or semiconductor materials, ceramics, etc. Preferably, the materials are chosen from those having a thermal expansion coefficient which matches that of the substrate 101 upon which the MEMS array 111 is fabricated. Examples of such a material include KOVAR® alloy, which is an iron alloy containing Ni and Co as principal alloying elements.

The curved back-plate 121a can be produced by a variety of methods. In one embodiment, for example, a substantially flat sheet is subject to warping or stress so as to produce the curved back-plate 121a. The substantially flat sheet may be subject to sheet forming or drawing. In another embodiment illustrated in Figures 13B and 13C, a substantially flat panel 136 having, for example, two layers 137 and 139 of two different materials is subjected to heat. The two materials of the two layers 137 and 139 have different thermal responses, for example, different heat expansion or shrinkage rates. Applying heat to the flat panel 136 produces a curved configuration due to the different thermal responses of the materials in the layers 137 and 139. In another embodiment, the flat panel 136 may include more than two layers.

In some embodiments, forming the back-plate 121a may be produced in the assembly process of the MEMS device 100. In one embodiment, a substrate 101, a flat panel 136 and a thermally curable material for the perimeter sealing 123 are configured as illustrated in Figures 8 or 9. This is an intermediate configuration of the device 100 in the assembly process. When heat is applied to this intermediate product to cure the thermally curable material, the flat panel 136 produces a curved configuration due to the different thermal responses of the layers 137 and 139 (Figures 13B and 13C). In this process, the curvature is created at the same time the seal 123 is being cured, and the curvature remains even after the structure is cooled to room temperature since the back-plate 123 and substrate 101 are firmly integrated with the cured seal 123.

In other embodiments, the back-plate 121a may be formed into a bowed configuration by use of a substantially flat panel that has a single thermal expansion coefficient as opposed to the flat panel 136 having two or more layers with different thermal expansion coefficients. The single thermal expansion coefficient of the back-plate material may be different from that of the substrate 101. Preferably, the thermal expansion coefficient of the back-plate material is smaller than that of the substrate 101. As with the embodiment described previously, the intermediate configuration in the assembly process is as illustrated in Figure 8 or 9 except that the sealing 123 of a thermally curable material has not been cured yet. This device is heated to a temperature slightly below the curing temperature of the thermally curable material, which will allow the materials for the back-plate 121a and the substrate 101 to expand without firmly bonding to the sealing material. Then, the ambient temperature is elevated to the curing temperature, thereby

curing the sealing material and firmly integrating the substrate 101, sealing material 123 and the flat panel for the back-plate 121a. The integrated device is cooled to room temperature. Due to the difference in the thermal expansion coefficient, the material of the back-plate (flat panel) shrinks less than the substrate 101. Since the substrate 101 and the flat panel is firmly integrated, the greater shrinkage in the substrate 101 will create stress in the flat panel, which will cause the flat panel to deform to the bowed configuration as shown in Figure 12.

In still another embodiment, an intermediate device in the assembly process is configured as illustrated in Figure 8 or 9, in which the sealing 123 is a UV-light curable material which substantially seals the perimeter of the device but has not been fully cured yet. The device is placed in a chamber, which is subject to a pressure lower than that of the inside of the intermediate device. Since the UV-light curable material substantially seals the perimeter of the device, the pressure outside the device will not substantially affect the pressure inside the device. This lower pressure outside the device relative to the inside will cause the flat panel (Figure 8 or 9) to bow or curve outward. Then, the UV-light curable material is fully cured with the application of UV light thereto, thereby fixing the curvature of the back-plate. One of ordinary skill in the art will appreciate appropriate methods available for producing the back-plate 121a.

Figures 14 and 15 illustrate another embodiment of the back-plate 121b in accordance with the invention. In this embodiment, the back-plate 121b has varying thickness along the edge 133. The back-plate 121b with varying thickness provides one means for covering the MEMS array 111. The thickness is greater in the middle area than both sides of the middle area along the edge 133. In the illustrated embodiment, the interior surface 129 that faces the MEMS array 111 is formed in a substantially flat configuration while the opposing exterior surface 130 of the back-plate 121b is bulged. The thickness of the back-plate 121b gradually increases from one end of the edge 133 and then gradually decreases toward the other end of the edge 133. Preferably, the thickness of the back-plate 121b ranges from about 0.1 mm to about 5 mm, and more preferably from about 0.4 mm to about 1.5 mm. The two ends of the back-plate 121b along the edge (the thinnest portions) have a thickness preferably from about 0.1 mm to about 3.0, and more preferably from about 0.2 mm to about 1.5 mm. The center of the back-plate 121b (the thickest portion) has a thickness preferably from about 0.4 mm to about 5 mm, and more preferably from about 0.4 mm to about 3 mm. The thickness of the back-plate 121b and its areas may not be limited to the above-described ranges. One of ordinary skill in the art will be able to design appropriate thicknesses of the back-plate 121b and its areas in consideration of the characters of the materials for the back-plate 121b.

The back-plate 121b of Figures 14 and 15 is made of various materials. The materials for making the back-plate 121a of Figure 12 can be used for the back-plate 121b. The back-plate 121b can be produced by various methods. In one embodiment, for example, a substantially flat

panel such as the one shown in Figure 8 is machined to provide the construction shown in Figures 14 and 15. In another embodiment, the back-plate 121b of Figures 14 and 15 is produced by molding. One of ordinary skill in the art will appreciate that appropriate methods are available for producing the back-plate 121b upon selection of the material(s) for use in the back-plate 121b.

In the embodiment of Figures 14 and 15, the depth of the gap 124 is about the same as that of the embodiment of Figure 8 if all the other conditions are the same. Also, the depth of the gap 124 in the central area of the back-plate 121b is about the same as in the other areas of that back-plate 121b. However, the construction of a thicker middle area increases the stiffness of the back-plate 121b particularly in the middle area. With the increased stiffness in the middle area along the edge 133, the back-plate 121b is less susceptible to external forces or pressure exerted thereon, particularly in the central area 126 than is the embodiment illustrated in Figure 8. Thus, the varying thickness configuration provides one means for preventing the back-plate from directly contacting the MEMS array 111 and also provides a means for reducing or minimizing the likelihood of such contact.

In some embodiments (not illustrated,) the thickness of the back-plate 121b may change linearly or stepwise. In other embodiments (not illustrated,) the back-plate thickness may vary along the other edge 135, where the thickness may change gradually or stepwise. In still other embodiments (not illustrated,) the interior surface 129 is bulged toward the MEMS array 111 while the exterior surface 130 remains substantially flat. Still in another embodiment (not illustrated,) both of the interior surface 129 and exterior surface 130 are curved away from each other. In one of such embodiment, the maximum distance between the interior and exterior surfaces is in the center of the back-plate. In a further embodiment, both the interior surface 129 and exterior surface 130 are curved like the embodiment of Figure 12 while the thickness of the back-plate varies along the edge 133 or both of the edges 133 and 135.

In some embodiments, the back-plate 121b of Figure 15 may have one or more recesses formed on its interior surface 129 (not illustrated). The back-plate with one or more recesses provides one means for covering the MEMS array 111. Also, the one or more recesses provides means for preventing the back-plate 111 from directly contacting the MEMS array or means for reducing or minimizing the likelihood of such contact. For example, the one or more recesses may be formed on the central area of the back-plate 121b. In such constructions, the depth of the gap 124 in the central area 126 may be greater than that of the other areas. In one embodiment, the one or more recesses may be configured to facilitate retaining a desiccant therein. In another embodiment, multiple recesses are formed such that partitioning walls of the multiple recesses function as reinforcing structures or ribs, which increase the stiffness of the back-plate, as will be discussed further with reference to Figures 16-26. The one or more recesses may be formed by removing some material of the back-plate 121b that does not have a recess.

Figures 16-26 illustrate additional exemplary embodiments of the back-plate, identified as 121c, 121d, 121e, 121f, 121g, 121h and 121i, in packaging the MEMS array 111. The back-plates 121c, 121d, 121e and 121f (Figures 16-23) are reinforced forms of the back-plate 121a of Figure 12. All of the variations of the back-plate 121a can be further reinforced in the ways as described further with reference to Figures 16-23. Also, the back-plate 121b (Figures 14 and 15) and its variations may also be reinforced in similar ways. Moreover, all of these features and the variations thereof can be combined with the feature of the lip protrusion described above with reference to the embodiment of Figure 9. These back-plates with reinforcing structures provide one means for covering the MEMS array 111. Also, as will be described in detail, the reinforcing structures provide one means for preventing the back-plate from contacting the MEMS array 111 or means for reducing or minimizing the likelihood of such contact.

Referring to Figures 16-23, the back-plates 121c, 121d, 121e and 121f have reinforcing structures or ribs 127a, 127b and/or 127c formed on the interior surface thereof. In the embodiment of Figures 16 and 17, the reinforcing structures or ribs 127a and 127b extend substantially parallel to the edges 133 and 135 of the back-plate 127c, respectively. Referring to Figures 17A and 17B, the reinforcing structures 127a and 127b cross each other at about the center of the back-plate 121c. As illustrated in Figure 17A, the reinforcing structures 127a and 127b extend within only a portion of the back-plate 121c. Alternatively, as showing in Figure 17B, the reinforcing structures 127a and 127b may extend from an edge to the opposing edge of the back-plate 121c. In an embodiment where the lip protrusion 125 (see Figure 9) is provided, the reinforcing structures 127a and 127b may connect the portions of the protrusion 125 that are located along two opposing edges of the back-plate 121c. Referring to Figure 17C, multiple reinforcing structures 127a and 127b cross each other and form a grid structure. Some of the reinforcing structures may extend from an edge to the opposing edge of the back-plate 121c, while other reinforcing structures may not. The number and density of the reinforcing structures 127a and 127b can vary and be adjustable depending upon other design factors.

In the embodiment of Figures 18 and 19, the reinforcing structures or ribs 127a and 127b also cross each other at about the center of the back-plate 121d. However, the reinforcing structures 127a and 127b extend in substantially diagonal directions of the back-plate 121d on its plan view (Figure 19). Although not illustrated the diagonally directed reinforcing structures of the back-plate 121d may have variations such as the extension to the edges thereof and the grid structure as shown in Figures 17B and 17C. Similar variations may be applicable to other embodiments of the reinforcing structures that have been described and will be described below.

In the back-plates 121c and 121d (Figures 16-19), the surfaces of the reinforcing structure 127a (or both 127a and 127b) facing the MEMS array 111 are substantially flat. Accordingly, the thickness of the reinforcing structure 127a (or both 127a and 127b) varies as the

interior surface 129 of the back-plate 121c and 121d is curved. More specifically, the thickness of the reinforcing structures 127a and 127b are greater in the central area of the back-plate 121c and 121d than in the peripheral areas thereof. In other embodiments, the thickness of the reinforcing structures 127a and/or 127b may vary irrespective of the curvature of the interior surface of the back-plate. In other embodiments, the thickness may be substantially constant throughout the reinforcing structures 127a and/or 127b.

In the back-plate 121e illustrated in Figures 20 and 21, additional reinforcing structures 127c are added to the construction of the back-plate 121d (Figure 19). The added reinforcing structures 127c are generally concentric circles connecting to the other reinforcing structures 127a and 127b. The reinforcing structures 127c are formed generally in the central area of the back-plate 121e. The reinforcing structures 127c connecting the other structures 127a and 127b may be in any forms other than concentric circles, including networking meshes (not illustrated). The connecting reinforcing structures 127c may be added to the construction of back-plate 121c and 121d (Figures 17 and 18).

In the back-plate 121f illustrated in Figures 22 and 23, protrusions or spacers 131 are formed on the reinforcing structures 127a and 127b of the construction of back-plate 121c (Figure 17) or 121d (Figure 18). The protrusions or spacers 131 can distribute forces that may otherwise be exerted onto a small focused area of the MEMS array 111 to multiple locations and therefore reduce the impact of such forces to the MEMS array 111. In the illustrated embodiment, the protrusions or spacers 131 are provided generally regularly throughout the surface of the reinforcing structures 127a and 127b. The protrusions or spacers 131 may be distributed with different densities over defined areas. The protrusions or spacers 131 may have the same or different heights. Similar protrusions or spacers 131 may be formed on all or parts of the reinforcing structures 127a, 127b and/or 127c in the back-plates 121c-121e. Also, protrusions or spacers 131 may be formed on the interior surfaces 129 of the back-plates 121a-121b.

In another embodiment, the protrusions or spacers 131 are formed or located such that they contact only predetermined portions of the MEMS array 111 when external force is applied to the back-plate. In this embodiment, the external force is transferred substantially only to the predetermined portions of the MEMS array. Preferably, the predetermined portions are the portions of the MEMS array that are not likely affecting the operation of the MEMS device even if damaged. Additionally or alternatively, the predetermined portions are portions of the MEMS array that are less susceptible to damage by external forces. In still another embodiment, the protrusions or spacers 131 may be formed on only certain areas, for example, the central area of the back-plate 121f. As discussed, the protrusions or spacers 131 provide one means for preventing the back-plate from directly contacting the MEMS array 111. Also, the protrusions or

spacers 131 provide one means for distributing forces applied to the back-plate and/or one means for minimizing or preventing damage to the MEMS array.

Referring to Figure 24, the shape of the back-plate 121g is slightly different from those of the back-plates 121 and 121a-121f. The back-plate 121g is thinner in the central area than the peripheral areas 130 thereof. This shape is combined with the reinforcing structures 127a, 127b and 127c. Although the back-plate 121g itself may be more compliant in the central area than the peripheral areas, the reinforcing structures 127a and 127b add stiffness to the back-plate 121g, and can prevent the back-plate 121g from easily bending toward the MEMS array 111. Any other forms of the reinforcing structures may be used in this construction of the back-plate 121g. Also, the protrusions or spacers 131 illustrated in Figures 22 and 23 may be added to this construction.

Figure 25 illustrates a MEMS device with a substantially planar back-plate 121h with reinforcing structures 127a and 127b integrated thereto. The back-plate 121h without the reinforcing structures 127a and 127b has a thickness that is substantially the same throughout. In this embodiment, the depth of the gap 124 in the central area of the back-plate 121h may be smaller than the peripheral areas due to the thickness of the reinforcing structures 127a and 127b. However, the reinforcing structures 127a and 127b add stiffness to the back-plate 121g, and can prevent the back-plate 121g from contacting the MEMS array 111. The back-plate 121h can also have a lip protrusion 125 as shown in Figure 9. Any other forms of the reinforcing structures may be used in this construction of the back-plate 121h. Also, the protrusions or spacers 131 illustrated in Figures 22 and 23 may be added to this construction.

The reinforcing structures and/or spacers of the back-plate 121c, 121d, 121e, 121f, 121g or 121h may be formed on an intermediate structure for the back-plate. In one embodiment, for example, the intermediate structure comprises a back-plate which does not have any reinforcing structures formed thereon. Attaching reinforcing structures on a surface of the intermediate back-plate 121a produces the back-plate 121c, 121d, 121e, 121f or 121g. In the curved back-plate constructions, the reinforcing structures may be attached onto a substantially flat panel or sheet prior to bending it or after bending. Alternatively, the reinforcing structures and/or spacers can be produced as part of the manufacturing process of the back-plate 121c, 121d, 121e, 121f, 121g or 121h. In an embodiment, for example, a blank is machined to remove some material in some regions while leaving the material elsewhere, thereby producing the back-plates with the reinforcing structures and/or spacers. In still another embodiment, for example, the back-plate with the reinforcing structures and/or spacers is produced by molding or forming. One of ordinary skill in the art will appreciate appropriate methods available for producing the back-plate, reinforcing structures and/or spacers. The methods of producing reinforcing structures and spacers can be used in the methods of producing the lip protrusion 125, and vice versa.

The materials for use in the foregoing reinforcing structures are, for example, polymers, glass, ceramics, metals, oxides of metallic or semiconductor materials, spin-on-glasses, frits, photo-patternable polymers, polymers containing desiccants, etc. The reinforcing structures may be made of the same material for the back-plate 121, 121a or 121b, on which the reinforcing structures are formed. The materials for the protrusions are, for example, polymers, glass, ceramics, metals, oxides of metallic or semiconductor materials, spin-on-glasses, frits, photo-patternable polymers, polymers containing desiccants, etc. Preferably, the reinforcing structures are made of the same material for the reinforcing structures 127a, 127b and/or 121c on which the protrusions are formed.

The reinforcing structures and the protrusions may be formed of one or more desiccants solely or in combination with one or more structural materials such as polymers. Forming the reinforcing structures with desiccant will eliminate or at least reduce the need for an extra space and/or a container for a desiccant within the package of the display, which requires humidity control to insure the proper operation of the MEMS mechanisms. Any of the desiccants described above can be used. Preferably, applicable desiccants are, for example, molecular sieves including aluminum complexes, calcium oxides, zeolites and carbon nano-tubes. One of ordinary skill in the art will appreciate the kinds and amounts of structural materials in case desiccants are selected for use in the reinforcing structures and/or protrusions.

Figure 26 illustrates a MEMS device with a thin film back-plate 121i with reinforcing structures 127d and 127e integrated thereto. In one embodiment, the thin film back-plate 121i has a thickness from about 10 μm to about 100 μm. The illustrated embodiment is configured similar to the embodiment illustrated in Figure 25 except that the peripheral portions 141 of thin film back-plate 121i are directly deposited (without a seal 123) on the surface of the substrate 101 where the MEMS array 111 is not formed. Although not illustrated, one or more intervening layers may be sandwiched between the peripheral portions 141 of the thin film back-plate 121i and the substrate 101. In the illustrated embodiment, the peripheral portions 141 are preferably integrally deposited with the central portion of the back-plate 121i. The reinforcing structures 127d and 127e may be in various shapes. Although not illustrated, the protrusions 131 illustrated in Figures 22 and 23 may be added to this construction.

The embodiment of Figure 26 is further described with reference to an exemplary process flowchart of Figure 27. Depending on embodiments, additional steps may be added and/or some of the existing steps may be removed while the remaining steps are unchanged. In step S2701, the MEMS array 111 is fabricated on the substrate 101. Next at step S2703, a sacrificial layer (not shown) is formed over the MEMS array 111. The sacrificial layer may be formed of a material, such as, for example, molybdenum (Mo), silicon (Si), tungsten (W), or titanium (Ti), which is capable of being released later. In an embodiment, the sacrificial layer is formed of a

material, such as a polymer, spin-on glass, or oxide. The skilled artisan will appreciate that the sacrificial layer can be deposited to the desired thickness. The thickness of the sacrificial layer should be sufficient to separate the thin film back-plate 121i and the MEMS array 111. In one embodiment, the sacrificial layer is deposited to a thickness in the range of about 1000 Å to 10 μm, and more preferably in a range of about 1000 Å to 1 μm.

Proceeding to step S2705, the sacrificial layer is patterned and selectively etched away to form recesses (not shown) using photolithographic techniques. The recesses formed in the sacrificial layer are used as a negative to make the reinforcing structures 127d and 127e therein. The recesses are formed in the depth and shape sufficient to create the reinforcing structures 127d and 127e. Then, in step S2707, the recesses are filled with a material to form the reinforcing structures 127d and 127e. The reinforcing structures 127d and 127e may be any type of materials including, not limited to, semiconductors, metals, alloys, polymers or plastics and composite materials. Continuing to the step S2709, then a thin film back-plate 121i is deposited over the entire structure including the substrate 101, the sacrificial layer and the recesses filled with the material for the reinforcing structures 127d and 127e. In some embodiments, the thin film back-plate 121i may be any type of material that is impermeable or hydrophobic, including, but not limited to, nickel, aluminum, and other types of metals and foils. The thin film may also be formed of an insulator, including, but not limited to, silicon dioxide, aluminum oxide, or nitrides. Alternatively, the thin film may be formed of a permeable material. Suitable permeable materials include polymers, such as, for example, PMMA, epoxies, and organic or inorganic spin-on glass (SOG) type materials. In some embodiments, the thin film back-plate 121i and the reinforcing structures 127d and 127e may be formed of the same material.

Next at step S2711, the thin film back-plate 121i is patterned and etched to form at least one opening through the back-plate 121i. The thin film back-plate 121i may be further patterned and processed to allow electrical connections and contacts to the MEMS array 111 and other parts of the device. Continuing to step S2713, the sacrificial layer located between the MEMS array 111 and the back-plate 121i and/or the reinforcing structures 127d and 127e is selectively removed. The gap 124 is formed where the sacrificial layer is removed. An etchant is supplied via the opening formed in the thin film back-plate 121i. As the etchant contacts and reacts with the exposed area of the sacrificial layer, the sacrificial layer material is selectively etched away. For example, to remove a sacrificial layer of molybdenum (Mo), silicon (Si), tungsten (W), or titanium (Ti), xenon diflouride (XeF_2) may be introduced into the interior of the MEMS device through the at least one opening. After the sacrificial layer is removed and the gap 124 is created, the opening in the thin film back-plate 121i is sealed. One of ordinary skill in the art in the field of semiconductor processing or photolithography will appreciate the process described herein and

determine appropriate parameters to produce the back-plate 121i with the reinforcing structures 127d and 127e.

In the foregoing embodiments, particularly those of Figures 16-26, the reinforcing structures and the interior surface of the back-plate form pockets or recesses. The pocket or recess areas are defined by the walls or surfaces of the reinforcing structures formed on the back-plate. In some embodiments, part or all of the pockets or recesses are filled with one or more desiccants that can absorb water molecules contained within the display device. The desiccants contained in the pocket or recess areas further reinforce the structural strength and stiffness of the back-plate. The embodiments of Figures 12-15 may also accommodate a desiccant by forming a layer of the desiccant on the interior surface 129 of the back-plate 121a, 121b (not illustrated). Alternatively, a container for containing a desiccant may be formed on the interior surface of the back-plate.

Figures 28A and 28B 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 28B. 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.

It is to be understood that persons of skill in the appropriate arts may modify the invention here described while still achieving the favorable results of this invention. Accordingly, the foregoing description is to be understood as being a broad, teaching disclosure directed to persons of skill in the appropriate arts, and not as limiting upon the invention.

WHAT IS CLAIMED IS:

1. An electronic device, comprising:

a substrate;

an array of microelectromechanical devices formed on the substrate; and

a back-plate placed over the array and having an interior surface and an exterior surface, the interior surface of the back-plate facing the array with a gap therebetween, the exterior surface facing away from the substrate,

wherein a distance between the interior surface of the back-plate and the substrate varies across the substrate.

2. The electronic device of Claim 1, wherein the microelectromechanical devices comprise interferometric modulators.

3. The electronic device of Claim 1, wherein the interior surface comprises a central area and a peripheral area, and wherein the distance is greater in the central area than in the peripheral area.

4. The electronic device of Claim 1, wherein the back-plate is generally bowed away from the array.

5. The electronic device of Claim 1, wherein the distance is measured from a point on the interior surface to a closest point of the substrate.

6. The electronic device of Claim 1, wherein the interior surface is substantially smoothly curved.

7. The electronic device of Claim 1, wherein the distance changes substantially abruptly at least one location on the interior surface.

8. The electronic device of Claim 1, wherein the distance is substantially the same in at least a portion of the interior surface.

9. The electronic device of Claim 1, wherein the back-plate has a substantially same thickness throughout.

10. The electronic device of Claim 1, wherein the interior surface comprises a central area and a peripheral area, and wherein the back-plate has a thickness that is generally greater in the central area than in the peripheral area.

11. The electronic device of Claim 1, wherein the exterior surface of the back-plate is substantially flat, and wherein a distance between the exterior surface and the substrate is substantially the same across the substrate.

12. The electronic device of Claim 1, wherein a distance between the exterior surface and the substrate substantially varies across the substrate.

13. The electronic device of Claim 1, further comprising one or more reinforcing structures formed on at least one of the interior surface and the exterior surface of the back-plate.

14. The electronic device of Claim 13, wherein at a location on the interior surface where a reinforcing structure is formed, the distance is measured from a distal end of the reinforcing structure to the substrate.

15. The electronic device of Claim 13, wherein the distance varies over an area of the interior surface where no reinforcing structure is formed.

16. The electronic device of Claim 1, wherein the back-plate comprises a protrusion extending toward the substrate along an edge of the back-plate.

17. The electronic device of Claim 1, further comprises a seal located between the substrate and the interior surface along edges of the interior surface.

18. The electronic device of Claim 1, further comprising:

a processor that is in electrical communication with said array of microelectromechanical devices, said processor being configured to process image data; and

a memory device in electrical communication with said processor.

19. The electronic device of Claim 1, further comprising a driver circuit configured to send at least one signal to said array of microelectromechanical devices.

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

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

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

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

24. A method of making an electronic device, comprising:

providing an intermediate device comprising a substrate and an array of microelectromechanical devices formed on the substrate; and

forming a back-plate over the array of the intermediate device with a gap between the back-plate and the array, the back-plate having an interior surface facing the array, wherein a distance between the interior surface and the substrate varies across the substrate.

25. The method of Claim 24, wherein forming the back-plate further comprises:

providing the back-plate having the interior surface;

placing the back-plate over the array such that the interior surface faces the array; and

binding the back-plate with the substrate along a periphery of the back-plate.

26. The method of Claim 25, wherein the interior surface is substantially curved.

27. The method of Claim 25, wherein the interior surface is recessed in a generally central area thereof.

28. The method of Claim 25, wherein the back-plate has a substantially same thickness throughout.

29. The method of Claim 25, wherein the back-plate has a varying thickness.

30. The method of Claim 25, wherein the interior surface comprises a central area and a peripheral area, and wherein the back-plate has a thickness that is generally greater in the central area than in the peripheral area.

31. The method of Claim 25, wherein the back-plate comprises a curved portion.

32. The method of Claim 31, wherein providing the back-plate comprises subjecting a substantially flat panel to warping.

33. The method of Claim 31, wherein providing the back-plate comprises:

providing a substantially flat panel comprising two layers, which have different heat expansion rates; and

applying heat to the substantially flat panel, thereby creating a curvature in the panel.

34. The method of Claim 31, wherein providing the back-plate comprises providing a substantially flat panel comprising two layers, each layer having a heat expansion rate that is different from that of the other, wherein placing the back-plate comprises forming a layer of a thermally curable material sandwiched between the substrate and the substantially flat panel along a periphery thereof, and wherein binding the back-plate comprises applying heat sufficient to cure the thermally curable material.

35. An electronic device produced by the method of Claim 24.

36. An electronic device, comprising:

transmitting means for transmitting light therethrough;

modulating means for modulating light transmitted through the transmitting means; and

covering means for covering the modulating means, wherein the covering means comprises an interior surface and an exterior surface, the interior surface facing the transmitting means with a gap therebetween, the exterior surface facing away from the transmitting means, and

wherein a distance between the interior surface of the covering means and the transmitting means varies across the transmitting means.

37. The electronic device of Claim 36, wherein the transmitting means comprises a transparent substrate.

38. The electronic device of Claim 36 or 37, wherein the modulating means comprises an interferometric modulator array.

39. The electronic device of Claim 36, 37 or 38, wherein the covering means comprises a curved back-plate.

40. The electronic device of Claim 36, wherein the covering means comprises one or more reinforcing structures integrated thereto.

41. The electronic device of Claim 36, wherein the covering means has a recess formed on the interior surface thereof.

42. The electronic device of Claim 36, wherein the covering means has varying thickness.