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(54) **METHOD AND SYSTEM FOR PACKAGING MEMS DEVICES WITH INCORPORATED GETTER**

(76) Inventors: **Lauren Palmateer**, San Francisco, CA (US); **William J. Cummings**, San Francisco, CA (US); **Brian Gally**, San Rafael, CA (US); **Clarence Chui**, San Mateo, CA (US); **Manish Kothari**, Cupertino, CA (US)

Correspondence Address:
KNOBBE MARTENS OLSON & BEAR LLP
2040 MAIN STREET
FOURTEENTH FLOOR
IRVINE, CA 92614 (US)

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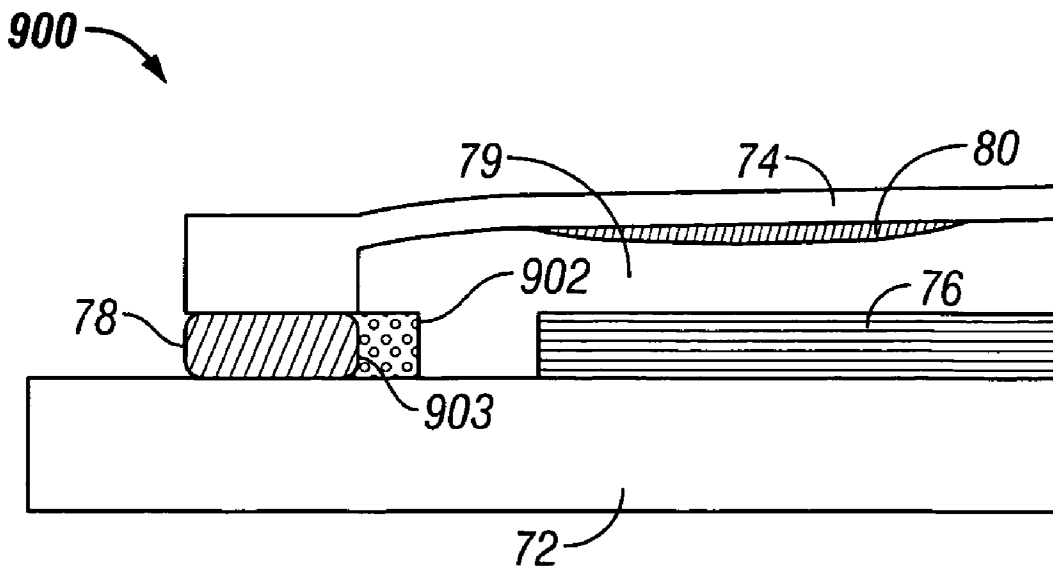
(57) **ABSTRACT**

Methods and systems for packaging MEMS devices such as interferometric modulator arrays are disclosed. One embodiment of a MEMS device package structure includes a seal with a chemically reactant getter. Another embodiment of a MEMS device package comprises a primary seal with a getter, and a secondary seal proximate an outer periphery of the primary seal. Yet another embodiment of a MEMS device package comprises a getter positioned inside the MEMS device package and proximate an inner periphery of the package seal.



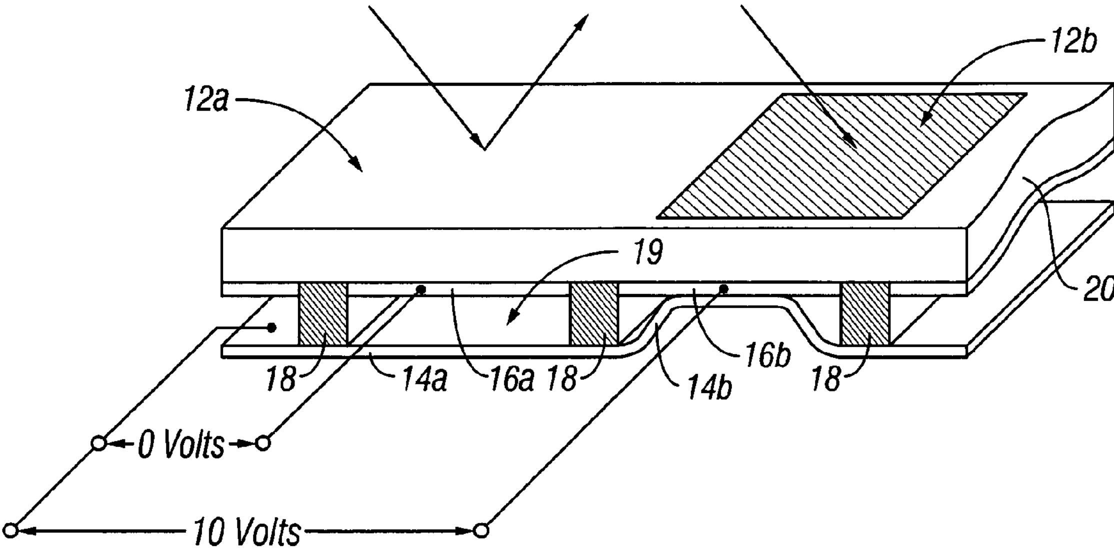


FIG. 1

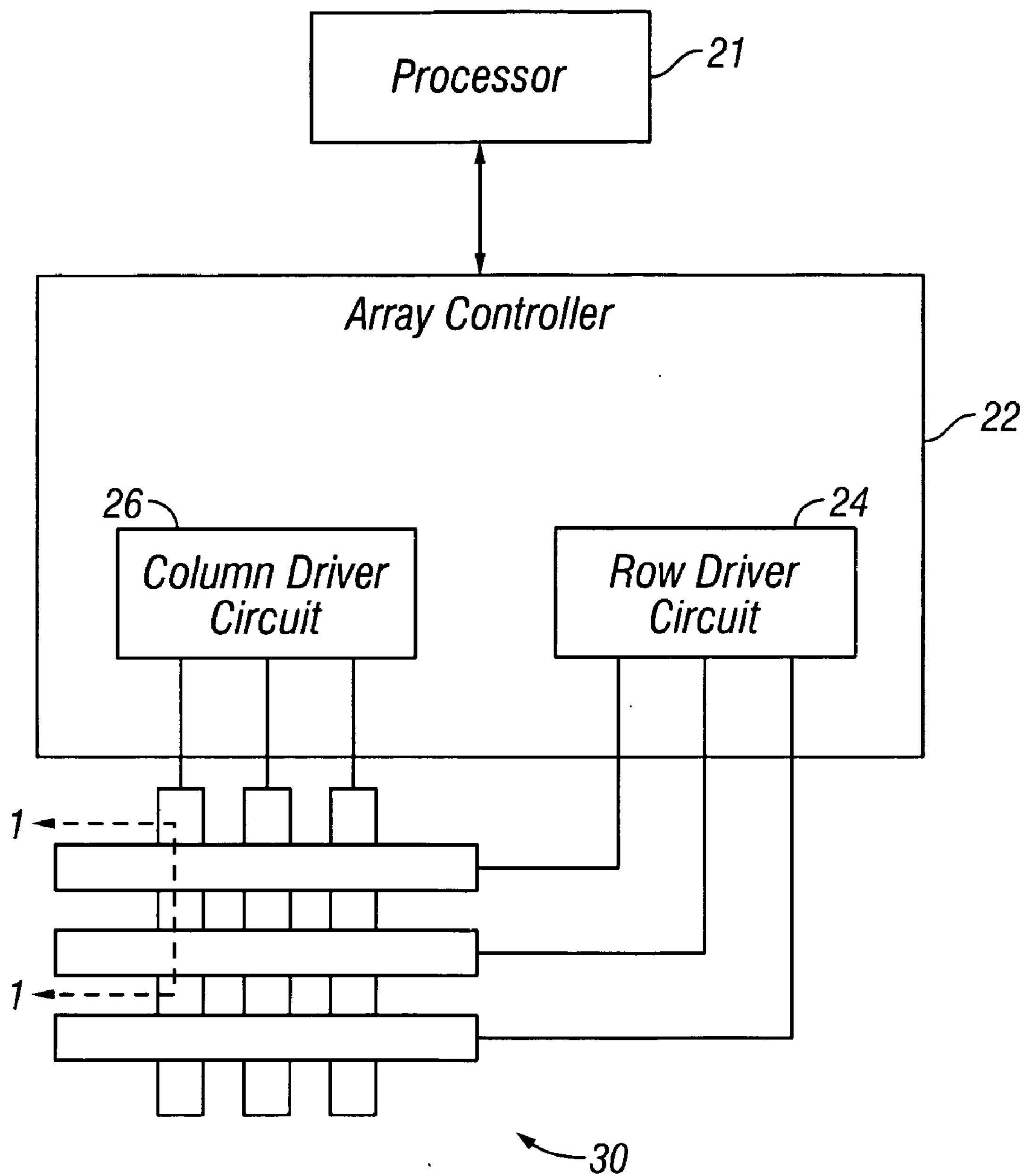


FIG. 2

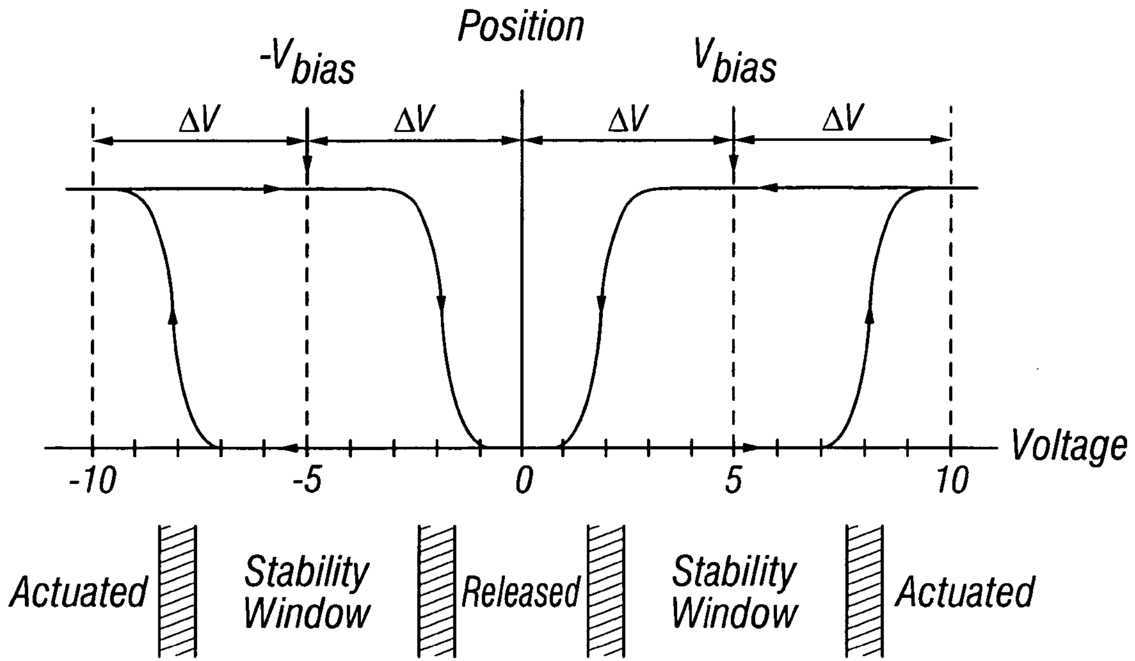


FIG. 3

		Column Output Signals	
		$+V_{bias}$	$-V_{bias}$
Row Output Signals	0	Stable	Stable
	$+\Delta V$	Release	Actuate
	$-\Delta V$	Actuate	Release

FIG. 4

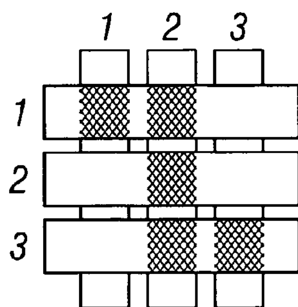


FIG. 5A

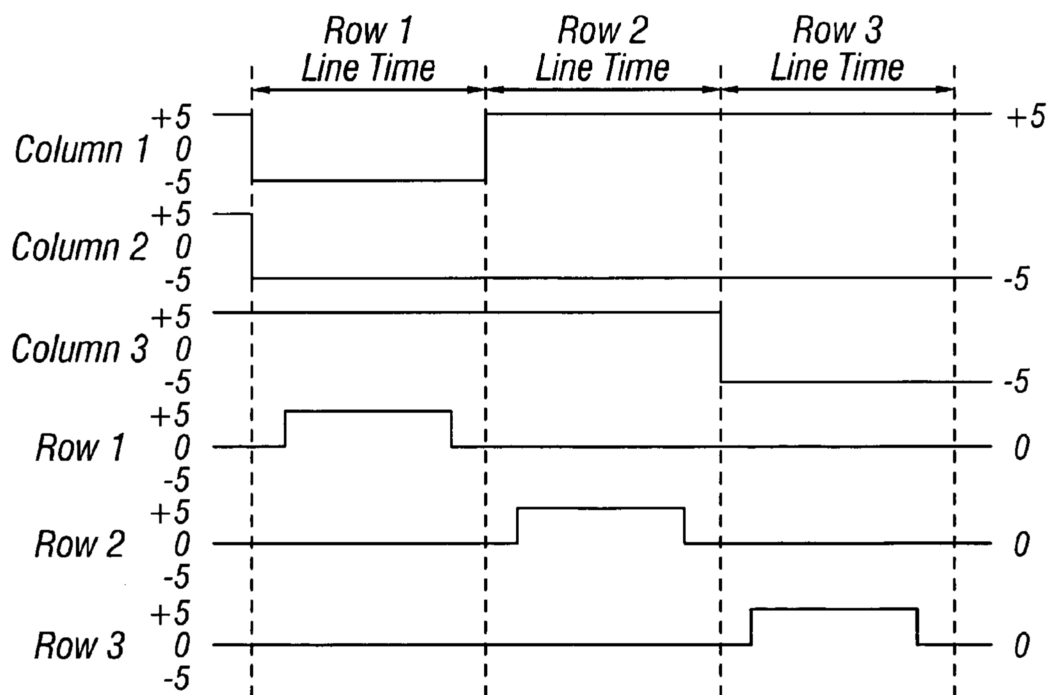


FIG. 5B

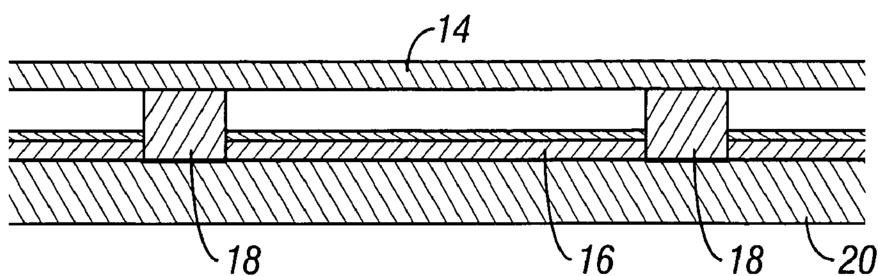


FIG. 6A

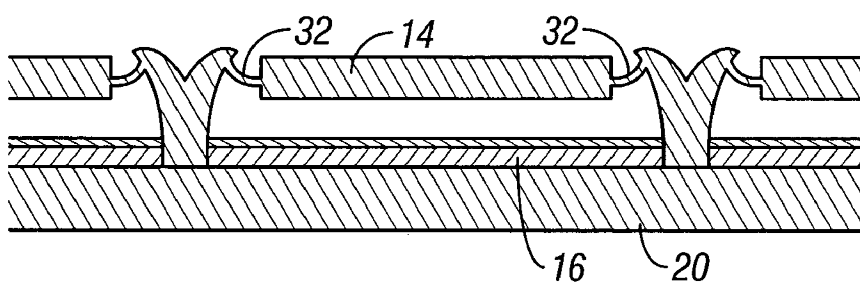


FIG. 6B

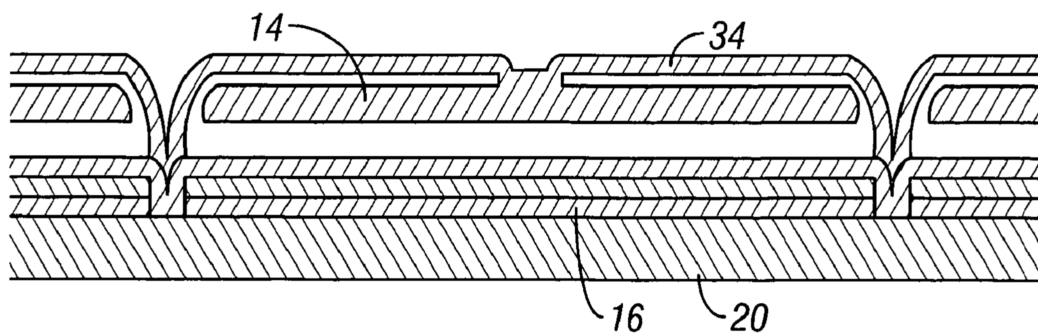


FIG. 6C

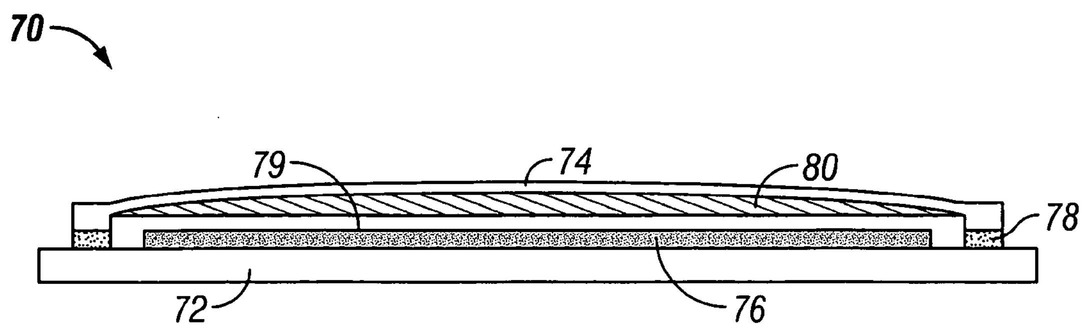


FIG. 7

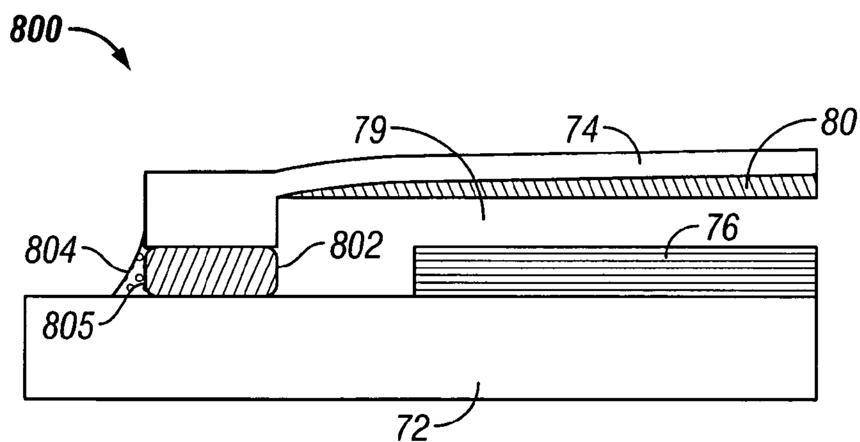


FIG. 8

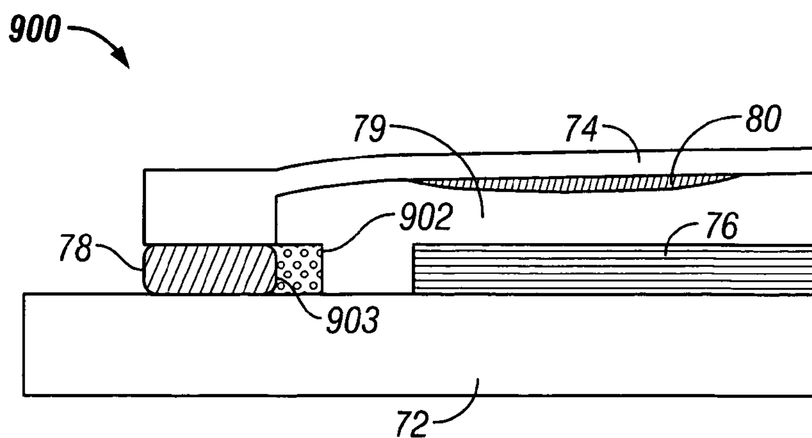


FIG. 9

METHOD AND SYSTEM FOR PACKAGING MEMS DEVICES WITH INCORPORATED GETTER

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Patent Application 60/613,476 entitled "METHOD AND DEVICE FOR PACKAGING INTERFEROMETRIC MODULATORS WITH HERMETIC BARRIER" and filed on Sep. 27, 2004. The disclosure of the above-described application is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] 1. Field of the Invention

[0003] The field of the invention relates to microelectromechanical systems (MEMS), and more particularly, to methods and systems for packaging MEMS devices.

[0004] 2. Description of the Related Technology

[0005] 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

[0006] 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.

[0007] One embodiment of a microelectromechanical system (MEMS) device package comprises a substrate, a MEMS device formed on the substrate, a backplane, and a seal positioned proximate a perimeter of the MEMS device and in contact with the substrate and the backplane, wherein the seal comprises a chemically reactant getter.

[0008] In certain embodiments, the seal comprises an amount of getter sufficient to getter substantially all substances outgassed from the seal during at least one of manufacture and assembly. The seal may comprise an adhesive, and the chemically reactant getter may comprise at least one of calcium oxide, strontium, strontium oxide, and an aluminum complex.

[0009] Another embodiment of a MEMS device package comprises a substrate, a MEMS device formed on the substrate, a backplane, a primary seal positioned proximate a perimeter of the MEMS device and in contact with the substrate and the backplane, wherein the primary seal includes a getter, and a secondary seal positioned proximate the primary seal at an outer periphery. The secondary seal may comprise a hydrophobic material, and the getter may comprise a desiccant. The primary seal may comprise an adhesive.

[0010] Yet another embodiment of a MEMS device package comprises a substrate, a MEMS device formed on the substrate, a backplane, a seal positioned around a periphery of the MEMS device and in contact with the substrate and the backplane, and a getter positioned proximate the seal at an inner periphery. The seal may comprise at least one of a metal and an adhesive, and the getter may comprise a desiccant. In certain embodiments, the getter is positioned in contact with the seal.

[0011] One embodiment of a method of sealing a MEMS device package comprises forming a seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the seal is formed proximate a perimeter of the MEMS device, and wherein the seal comprises a chemically reactant getter, and attaching the substrate, the seal, and the backplane, thereby encapsulating the MEMS device.

[0012] One embodiment of a MEMS device package is produced by the method comprising forming a seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the seal is formed proximate a perimeter of the MEMS device, and wherein the seal comprises a chemically reactant getter, and attaching the substrate, the seal, and the backplane, thereby encapsulating the MEMS device.

[0013] One embodiment of a system for sealing a MEMS device package comprises means for forming a seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the seal is formed proximate a perimeter of the MEMS device, and wherein the seal comprises a chemically reactant desiccant, and means for attaching the substrate, the seal, and the backplane to thereby encapsulate the MEMS device.

[0014] One embodiment of a method of sealing a microelectromechanical system (MEMS) device package comprises forming a primary seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the primary seal is formed proximate a perimeter of the MEMS device, attaching the substrate, the primary seal, and the backplane, thereby encapsulating the MEMS device, and forming a secondary seal proximate the primary seal at an outer periphery.

[0015] One embodiment of a MEMS device package is produced by the method comprising forming a primary seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the primary seal is formed proximate a perimeter of the MEMS device, attaching the substrate, the primary seal, and the

backplane, thereby encapsulating the MEMS device, and forming a secondary seal proximate the primary seal at an outer periphery.

[0016] One embodiment of a system for sealing a MEMS device package comprises means for forming a primary seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the primary seal is formed proximate a perimeter of the MEMS device, means for attaching the substrate, the primary seal, and the backplane, thereby encapsulating the MEMS device, and means for forming a secondary seal proximate the primary seal at an outer periphery.

[0017] One embodiment of a method of sealing a MEMS device package comprises forming a seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the seal is formed proximate a perimeter of the MEMS device, forming a getter positioned proximate the seal at an inner periphery, and attaching the substrate, the seal, and the backplane, thereby encapsulating the MEMS device.

[0018] One embodiment of a MEMS device package is produced by the method comprising forming a seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the seal is formed proximate a perimeter of the MEMS device, forming a getter positioned proximate the seal at an inner periphery, and attaching the substrate, the seal, and the backplane, thereby encapsulating the MEMS device.

[0019] One embodiment of a system for sealing a microelectromechanical system (MEMS) device package comprises means for forming a seal on at least one of a substrate and a backplane, wherein the substrate comprises a MEMS device formed thereon and the seal is formed proximate a perimeter of the MEMS device, means for forming a getter positioned proximate the seal at an inner periphery, and means for attaching the substrate, the seal, and the backplane, thereby encapsulating the MEMS device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] **FIG. 1** is an isometric view depicting a portion of one embodiment of an interferometric modulator display in which a movable reflective layer of a first interferometric modulator is in a released position and a movable reflective layer of a second interferometric modulator is in an actuated position.

[0021] **FIG. 2** is a system block diagram illustrating one embodiment of an electronic device incorporating a 3×3 interferometric modulator display.

[0022] **FIG. 3** is a diagram of movable mirror position versus applied voltage for one exemplary embodiment of an interferometric modulator of **FIG. 1**.

[0023] **FIG. 4** is an illustration of a set of row and column voltages that may be used to drive an interferometric modulator display.

[0024] **FIGS. 5A and 5B** illustrate one exemplary timing diagram for row and column signals that may be used to write a frame of display data to the 3×3 interferometric modulator display of **FIG. 2**.

[0025] **FIG. 6A** is a cross-sectional view of the device of **FIG. 1**.

[0026] **FIG. 6B** is a cross-sectional view of an alternative embodiment of an interferometric modulator.

[0027] **FIG. 6C** is a cross-sectional view of another alternative embodiment of an interferometric modulator.

[0028] **FIG. 7** is a cross-sectional view of a basic package structure for an interferometric modulator device.

[0029] **FIG. 8** is a cross-sectional view of a portion of one embodiment of an interferometric modulator package structure with a primary seal and a secondary seal.

[0030] **FIG. 9** is a cross-sectional view of a portion of one embodiment of an interferometric modulator package structure with a getter material positioned inside the package structure proximate the seal.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0031] A plurality of embodiments of MEMS device package structures including improved sealant structures are described below. In one embodiment, the MEMS device is packaged between a backplate and a substrate which are held together by a primary seal. In one embodiment, the primary seal includes a chemically reactant getter. As is known in the art, a getter is a substance that captures or binds another substance by absorption, adsorption, or chemical reaction for example. A chemically reactant getter is a getter configured to chemically react with a gettered substance as opposed to absorbing or adsorbing a gettered substance. In other embodiments, the package structure includes a secondary seal disposed along an outer periphery of the primary seal. In one embodiment, the secondary seal includes a hydrophobic material, for example. In yet another embodiment, the package structure comprises a getter positioned proximate an inner periphery of the seal and is configured to getter water vapor or contaminants attempting to enter the interior of the package structure. In the described embodiments, no further getter or desiccant may be necessary to meet the desired lifetime attributes of the packaged device, thereby allowing for reduced package dimensions and cost.

[0032] 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.

[0033] One interferometric modulator display embodiment comprising an interferometric MEMS display element is illustrated in **FIG. 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.

[0034] **FIG. 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.

[0035] The depicted portion of the pixel array in **FIG. 1** includes two adjacent interferometric modulators **12***a* and **12***b*. In the interferometric modulator **12***a* on the left, a movable and highly reflective layer **14***a* is illustrated in a released position at a predetermined distance from a fixed partially reflective layer **16***a*. In the interferometric modulator **12***b* on the right, the movable highly reflective layer **14***b* is illustrated in an actuated position adjacent to the fixed partially reflective layer **16***b*.

[0036] The fixed layers **16***a*, **16***b* 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 **14***a*, **14***b* may be formed as a series of parallel strips of a deposited metal layer or layers (orthogonal to the row electrodes **16***a*, **16***b*) 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.

[0037] With no applied voltage, the cavity **19** remains between the layers **14***a*, **16***a* and the deformable layer is in a mechanically relaxed state as illustrated by the pixel **12***a* in **FIG. 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 **12***b* on the right in **FIG. 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.

[0038] **FIGS. 2 through 5** illustrate one exemplary process and system for using an array of interferometric modulators in a display application. **FIG. 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.

[0039] 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 **FIG. 1** is shown by the lines **1-1** in **FIG. 2**. For MEMS interferometric modulators, the row/column actuation protocol may take advantage of a hysteresis property of these devices illustrated in **FIG. 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 **FIG. 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 **FIG. 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 **FIG. 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 **FIG. 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.

[**0040**] 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.

[**0041**] **FIGS. 4 and 5** illustrate one possible actuation protocol for creating a display frame on the 3×3 array of **FIG. 2**. **FIG. 4** illustrates a possible set of column and row voltage levels that may be used for pixels exhibiting the hysteresis curves of **FIG. 3**. In the **FIG. 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 **FIG. 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.

[**0042**] **FIG. 5B** is a timing diagram showing a series of row and column signals applied to the 3×3array of **FIG. 2** which will result in the display arrangement illustrated in **FIG. 5A**, where actuated pixels are non-reflective. Prior to writing the frame illustrated in **FIG. 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.

[**0043**] In the **FIG. 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 **FIG. 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 **FIG. 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.

[**0044**] The details of the structure of interferometric modulators that operate in accordance with the principles set forth above may vary widely. For example, **FIGS. 6A-6C** illustrate three different embodiments of the moving mirror structure. **FIG. 6A** is a cross section of the embodiment of **FIG. 1**, where a strip of metal material **14** is deposited on orthogonally extending supports **18**. In **FIG. 6B**, the moveable reflective material **14** is attached to supports at the corners only, on tethers **32**. In **FIG. 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.

[**0045**] The moving parts of a MEMS device, such as an interferometric modulator array, preferably have a protected space in which to move. Packaging techniques for a MEMS device will be described in more detail below. A schematic of a basic package structure for a MEMS device, such as an interferometric modulator array, is illustrated in **FIG. 7**. As shown in **FIG. 7**, a basic package structure **70** includes a substrate **72** and a backplane cover or "cap"**74**, wherein an interferometric modulator array **76** is formed on the substrate **72**. This cap **74** is also called a "backplane".

[**0046**] The substrate **72** and the backplane **74** are joined by a seal **78** to form the package structure **70**, such that the interferometric modulator array **76** is encapsulated by the substrate **72**, backplane **74**, and the seal **78**. This forms a cavity **79** between the backplane **74** and the substrate **72**. The seal **78** may be a non-hermetic seal, such as a conventional epoxy-based adhesive. In other embodiments, the seal **78** 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 seal **78** may be a hermetic seal and may comprise, for example, metals, welds, and glass frits. Methods of hermetic sealing comprise, for example, metal or solder thin film or preforms, laser or resistive welding techniques, and anodic bonding techniques, wherein the resulting package structure may or may not require a desiccant to achieve the desired internal package requirements.

[**0047**] The seal **78** may be implemented as a closed seal or an open seal, and may be applied or formed on the substrate **72**, backplane **74**, or both the substrate and backplane **74** in a method of packaging the interferometric modulator array **76**. The seal **78** may be applied through simple in-line manufacturing processes and may have advantages for lower temperature processes, whereas the techniques of welding and soldering may require very high temperature processes that can damage the package structure **20**, are relatively expensive. In some cases, localized heating methods can be used to reduce the process temperatures and yield a viable process solution.

[**0048**] In some embodiments, the package structure **70** includes a getter such as a desiccant **80** configured to reduce moisture within the cavity **79**. 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 **80** is positioned between the interferometric modulator array **76** and the backplane **74**. 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 **80**. Suitable getter and desiccant materials include, but are not limited to, zeolites, molecular sieves, surface adsorbents, bulk adsorbents, and chemical reactants.

[**0049**] The desiccant **80** may be in different forms, shapes, and sizes. In addition to being in solid form, the desiccant **80** 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 **80** may be formed into different shapes, such as cylinders, rings, or sheets, before being applied inside the package.

[**0050**] The skilled artisan will understand that the desiccant **80** can be applied in different ways. In one embodiment, the desiccant **80** is deposited as part of the interferometric modulator array **76**. In another embodiment, the desiccant **80** is applied inside the package **70** as a spray or a dip coat.

[**0051**] The substrate **72** 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 interferometric modulator array **76** may comprise membrane modulators or modulators of the separable type. The skilled artisan will appreciate that the backplane **74** may be formed of any suitable material, such as glass, metal, foil, polymer, plastic, ceramic, or semiconductor materials (e.g., silicon).

[**0052**] The packaging process may be accomplished in a vacuum, pressure between a vacuum up to and including ambient pressure, normal atmospheric pressure conditions, 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 interferometric modulator array **76** 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.

[**0053**] Generally, it is desirable to minimize the permeation of water vapor into the package structure **70**, and thus control the environment in the cavity **79** of the package structure **70** and hermetically seal it to ensure that the environment remains constant. When the humidity or water vapor level within the package exceeds a level beyond which surface tension from the water vapor becomes higher than the restoration force of a movable element (not shown) in the interferometric modulator array **76**, the movable element may become permanently adhered to the surface. There is thus a need to reduce the moisture level within the package.

[**0054**] In embodiments of the package structure **70** where the seal **78** includes an adhesive, the adhesive component alone may not act as a suitable environmental barrier because it eventually allows water vapor and/or contaminates to permeate into the cavity **79** of the package structure **70**. Accordingly, certain embodiments of a package structure **70** include a getter inside the package structure **70** or incorporated into the seal **78**. The getter may be configured to getter contaminant gases that are outgassed from the interferometric modulator array **76** or packaging components after the package structure **70** is assembled, such as substances outgassed or evaporated from an adhesive in the seal **78** into the cavity **79** while the adhesive is curing. The getter may be a chemically reactant getter configured to chemically react with specific substances, or the getter may be configured to physical transform in the presence of a specific substance, such as water. For example, the getter may comprise a desiccant such as zeolites, configured to physically transform in contact with water or water vapor. In other embodiments the getter is positioned inside the package structure **70** proximate an inner perimeter of the seal **78** so as to getter water vapor or contaminants inside the package structure **70** as they are released from components inside the cavity **79**, or substances that have permeated through the seal **78**. In yet another embodiment, the package structure **70** includes a secondary seal applied to the outside of the seal **78**, wherein the secondary seal comprises a hydrophobic material configured to keep water vapor out of the package structure **70**, or reduce the rate of permeation of water vapor into the package structure **70**.

[**0055**] In one embodiment of a package structure **70**, the seal **78** comprises a chemically reactant getter configured to

getter substances attempting to permeate the seal **78** and enter the package structure **70**, and/or substances within the package structure **78** that were present at the time of manufacture or assembly, or released during or subsequent to manufacture or assembly. The chemically reactant getter may include, for example, calcium oxide, strontium (Sr), strontium oxide, and aluminum complexes. In certain embodiments, the seal **78** comprises a mixture of the chemically reactant getter and an adhesive. In some embodiments, the seal **78** includes a sufficient amount of getter to getter or capture substantially all of the substances outgassed or released from the sealant components during manufacture or assembly, such as substances outgassed from an adhesive material while curing. The amount of getter included in the seal may be limited to such amount so as not to adversely effect the permeability of the seal, yet still capture the substances released from the sealant components during manufacture or assembly of the package structure **70**.

[0056] Another embodiment of a package structure **800**, as illustrated in cross-section in **FIG. 8**, includes a primary seal **802** positioned in contact with the substrate **72** and the backplane **74**, and a secondary seal **804** positioned proximate an outer periphery **805** of the primary seal **802**. The secondary seal **804** may be in contact with the primary seal **802** as illustrated in **FIG. 8**, or there may be a gap between the secondary seal **804** and the primary seal **802**. In some embodiments, the secondary seal **804** is in contact with the primary seal **802**, the substrate **76**, and the backplane **74**. The cross-sectional geometry of the secondary seal **804** may be dependent upon the material of the seal **804**, and may further be dependent on the method of formation or application of the seal **804** and is not limited to that illustrated in **FIG. 8**.

[0057] In certain embodiments, the secondary seal **804** comprises a low permeation rate adhesive or a hydrophobic material, such as PTFE or related compounds. In some embodiments, the secondary seal **804** comprises polyisobutylene (sometimes called butyl rubber, and other times PIB), o-rings, polyurethane, thin film metal weld, liquid spin-on glass, solder, polymers, or plastics, or combinations thereof.

[0058] In other embodiments, the secondary seal **804** comprises a low-cost sealant material regardless of permeation attributes and is configured to act in concert with the primary seal **802** to reduce the permeation rate of water vapor or other contaminants into the cavity **79** of the package structure **800**. Embodiments of a method of applying or forming the secondary seal **804** may comprise, for example, dispensing or printing a bead of sealant material, spray-on, placement of preform, printing, or other methods known to those skilled in the art.

[0059] In embodiments where the primary seal **802** comprises a getter such as a desiccant, the permeation rate of water vapor through the primary seal **802** may increase rapidly as the desiccant approaches or reaches its maximum capacity to absorb or react with water molecules. The secondary seal **804** advantageously reduces this water vapor permeation rate, thereby extending the life of the interferometric modulator array **76** within the package structure **800**. Although the package structure **800** is illustrated in **FIG. 8** as including the desiccant **80** on the backplane **74**, embodiments of the package structure **800** may be manufactured or assembled without the desiccant **80**, or wherein the desiccant is place in another position within the package structure.

[0060] **FIG. 9** is a cross-sectional view of one embodiment of a package structure **900** including a getter **902** positioned proximate an inner periphery **903** of the seal **78**. The getter may comprise zeolites, molecular sieves, surface adsorbents, bulk adsorbents, and chemically reactant substances, or a combination thereof, for example. In one embodiment, the getter **902** comprises a mixture of a getter material and an adhesive. The getter **902** is preferably configured to getter substances such as water vapor and contaminants that have permeated the seal **78** from the environment, substances outgassed or released from the seal **78** during manufacture or assembly, and substances within the cavity **79** of the package structure **900**. The getter **902** may be in contact with the seal **78** or there may be a gap between the getter **902** and the seal **78**. For example, in embodiments wherein the getter **902** increases in size when saturated with an absorbed substance, there is preferably a gap between the getter **902** and the seal **78**.

[0061] The getter **902** as illustrated in **FIG. 9** has a substantially rectangular cross-section and is in contact with the substrate **72** and the seal **78**. However, as will be appreciated by those skilled in the art, the cross-sectional geometry of the getter **902** may be different than that illustrated in **FIG. 9** and may, in certain embodiments, depend upon the method of formation or application of the getter **902**. In one embodiment, the getter **902** is formed using thin film technology. In addition, the getter **902** may be in contact with the backplane **74** in addition to the substrate **72** or instead of the substrate **72**.

[0062] In embodiments of the package structure **900** wherein the seal **78** comprises a metal seal, for example, contaminant substances may be outgassed or released due to a chemical reaction during formation of the seal. For example, where the seal **78** comprises a solder, an oxide may be released during application or formation of the seal, or assembly of the package structure **900**. Accordingly, the getter **902** is preferably configured to getter the substances outgassed or released from the seal during application or formation of the seal, or assembly of the package structure **900**.

[0063] In certain embodiments, as illustrated in **FIG. 9**, the package structure **900** does not include the desiccant **80** which is included in other package structures, such as the package structure **70** of **FIG. 7**. However, the package structure **900** may include the desiccant **80** and is not limited to the configuration or components illustrated in **FIG. 9**.

[0064] In one embodiment, the getter may include calcium oxide, or aluminosilicate-structured minerals such as sodium aluminosilicate. In another embodiment, the getter may include microporous silicate-structured minerals. It will be appreciated that active components other than zeolites that can act as absorbing filters on the molecular level can also be implemented as the getter. The adhesives discussed above may include an adhesive with low outgassing numbers, or an adhesive with various outgassing numbers.

[0065] The skilled artisan will understand that the amount of material for the seal **78** or the amount of getter or hydrophobic material may depend on the estimated amount of moisture or contaminant gases that will need to be removed from the package structure during its desired operational lifetime. The amount of material for the seal **78**, or amount of getter or hydrophobic material, either incor-

porated into the seal **78** or inside or outside the cavity **79** of the package structure **70** also depends not only on the amount of moisture or contaminant gases inside the package structure **20** when the package is formed, but also the permeation rate of the seal **78** and the outgassing potential of the package components.

[**0066**] In certain embodiments, the seal **78** is preferably formed to a thickness in a range of about 100-300 Å (using thin films, for example), about 10-30 μ, or about 50 μm. The skilled artisan will appreciate that the thickness of the seal **78** and the amount of getter incorporated into the seal **78** or the cavity **79** of the package structure **70**, or the secondary seal proximate the outer periphery of the seal **78**, will depend on various factors, such as the desired lifetime of the packaged device, the material components of the seal **78**, the amount of contaminants and moisture that are estimated to permeate into the package structure **70** during the lifetime, the anticipated humidity level of the ambient environment for the package structure **70**, and whether an additional getter or desiccant **80** is included within the package structure **70**.

[**0067**] As discussed above, the package structures may or may not include the desiccant **80** described in connection with **FIG. 7**. For example, where the seal **78** includes a getter, where a secondary seal is formed at the outer periphery of the seal **78**, or where a getter is positioned proximate an inner periphery of the seal **78**, no additional desiccant within the package structure may be necessary to meet the desired lifetime attributes of the packaged device. In embodiments where the package structure does not have to accommodate the desiccant **80**, the package dimensions and cost can be reduced accordingly.

[**0068**] In some embodiments, the getter comprises zeolites. Zeolites may absorb water molecules at relatively high temperatures. Zeolites can trap moisture and contaminant gases in their pores. The skilled artisan will understand that zeolites having deferent pore sizes can be selected for the seal **78** material to absorb different contaminants. In some embodiments, the getter includes zeolites that are selected to absorb contaminant molecules, such as aromatic branched-chain hydrocarbons that have critical diameters of up to ten angstroms. In another embodiment, zeolites having pore sizes between two and three angstroms may be selected to abort contaminant molecules having diameters of less than two angstroms, such as hydrogen and moisture molecules. In still another embodiment, zeolites having pore sizes of fifty angstroms can be used to absorb nitrogen and carbon dioxide molecules. The skilled artisan will appreciate that the seal **78** and getters or hydrophobic materials used inside and outside the package structure may comprise a mixture of zeolites or other tailored or functionalized getter materials having various pore sizes.

[**0069**] The foregoing description details certain embodiments of the invention. It will be appreciated, however, that no matter how detailed the foregoing appears in text, the invention can be practiced in many ways. As is also stated above, it should be noted that the use of particular terminology when describing certain features or aspects of the invention should not be taken to imply that the terminology is being re-defined herein to be restricted to including any specific characteristics of the features or aspects of the invention with which that terminology is associated. The scope of the invention should therefore be construed in accordance with the appended claims and any equivalents thereof.

What is claimed is:

1. A microelectromechanical system (MEMS) device package, comprising:

a substrate;

a MEMS device formed on said substrate;

a backplane; and

a seal positioned proximate a perimeter of the MEMS device and in contact with said substrate and said backplane, wherein said seal comprises a chemically reactant getter.

2. The MEMS system of claim 1, wherein said seal comprises an amount of getter sufficient to getter substantially all substances outgassed from said seal during at least one of manufacture and assembly.

3. The MEMS system of claim 1, wherein said seal comprises an adhesive.

4. The MEMS system of claim 1, wherein said chemically reactant getter comprises at least one of calcium oxide, strontium, strontium oxide, and an aluminum complex.

5. A microelectromechanical system (MEMS) device package, comprising:

a substrate;

a MEMS device formed on said substrate;

a backplane;

a primary seal positioned proximate a perimeter of the MEMS device and in contact with said substrate and said backplane, wherein said primary seal includes a getter; and

a secondary seal positioned proximate said primary seal at an outer periphery.

6. The MEMS device package of claim 5, wherein said secondary seal comprises a hydrophobic material.

7. The MEMS device package of claim 5, wherein said getter comprises a desiccant.

8. The MEMS device package of claim 5, wherein said primary seal comprises an adhesive.

9. A microelectromechanical system (MEMS) device package, comprising:

a substrate;

a MEMS device formed on said substrate;

a backplane;

a seal positioned around a periphery of said MEMS device and in contact with said substrate and said backplane; and

a getter positioned proximate said seal at an inner periphery.

10. The MEMS device package of claim 9, wherein said seal comprises at least one of a metal and an adhesive.

11. The MEMS device package of claim 9, wherein said getter comprises a desiccant.

12. The MEMS device package of claim 9, wherein said getter is positioned in contact with said seal.

13. A method of sealing a microelectromechanical system (MEMS) device package, comprising:

forming a seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said seal is formed proximate a perimeter of said MEMS device, and wherein said seal comprises a chemically reactant getter; and

attaching said substrate, said seal, and said backplane, thereby encapsulating said MEMS device.

14. The method of claim 13, wherein said seal comprises an amount of getter sufficient to getter substantially all substances outgassed from said seal during at least one of manufacture and assembly.

15. The method of claim 13, wherein said seal comprises an adhesive.

16. The method of claim 13, wherein said chemically reactant getter comprises at least one of calcium oxide, strontium, strontium oxide, and an aluminum complex.

17. A microelectromechanical system (MEMS) device package produced by the method comprising:

forming a seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said seal is formed proximate a perimeter of said MEMS device, and wherein said seal comprises a chemically reactant getter; and

attaching said substrate, said seal, and said backplane, thereby encapsulating said MEMS device.

18. The MEMS device package of claim 17, wherein said seal comprises an amount of getter sufficient to getter substantially all substances outgassed from said seal during at least one of manufacture and assembly.

19. The MEMS device package of claim 17, wherein said seal comprises an adhesive.

20. The MEMS device package of claim 17, wherein said chemically reactant getter comprises at least one of calcium oxide, strontium, strontium oxide, and an aluminum complex.

21. A system for sealing a microelectromechanical system (MEMS) device package, comprising:

means for forming a seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said seal is formed proximate a perimeter of said MEMS device, and wherein said seal comprises a chemically reactant desiccant; and

means for attaching said substrate, said seal, and said backplane to thereby encapsulate said MEMS device.

22. The system of claim 21, wherein said seal comprises an amount of getter sufficient to getter substantially all substances outgassed from said seal during at least one of manufacture and assembly.

23. The system of claim 21, wherein said chemically reactant getter comprises at least one of calcium oxide, strontium, strontium oxide, and an aluminum complex.

24. A method of sealing a microelectromechanical system (MEMS) device package, comprising:

forming a primary seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said primary seal is formed proximate a perimeter of said MEMS device;

attaching said substrate, said primary seal, and said backplane, thereby encapsulating said MEMS device; and

forming a secondary seal proximate said primary seal at an outer periphery.

25. The method of claim 24, wherein said secondary seal comprises a hydrophobic material.

26. The method of claim 24, wherein said getter comprises a desiccant.

27. The method of claim 24, wherein said primary seal comprises an adhesive.

28. A microelectromechanical system (MEMS) device package produced by the method comprising:

forming a primary seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said primary seal is formed proximate a perimeter of said MEMS device;

attaching said substrate, said primary seal, and said backplane, thereby encapsulating said MEMS device; and

forming a secondary seal proximate said primary seal at an outer periphery.

29. The MEMS device package of claim 28, wherein said secondary seal comprises a hydrophobic material.

30. The MEMS device package of claim 28, wherein said getter comprises a desiccant.

31. The MEMS device package of claim 28, wherein said primary seal comprises an adhesive.

32. A system for sealing a microelectromechanical system (MEMS) device package, comprising:

means for forming a primary seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said primary seal is formed proximate a perimeter of said MEMS device;

means for attaching said substrate, said primary seal, and said backplane, thereby encapsulating said MEMS device; and

means for forming a secondary seal proximate said primary seal at an outer periphery.

33. The system of claim 32, wherein said secondary seal comprises a hydrophobic material.

34. The system of claim 32, wherein said getter comprises a desiccant.

35. A method of sealing a microelectromechanical system (MEMS) device package, comprising:

forming a seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said seal is formed proximate a perimeter of said MEMS device;

forming a getter positioned proximate said seal at an inner periphery; and

attaching said substrate, said seal, and said backplane, thereby encapsulating said MEMS device.

36. The method of claim 35, wherein said seal comprises at least one of a metal and an adhesive.

37. The method of claim 35, wherein said getter comprises a desiccant.

38. The method of claim 35, wherein said getter is positioned in contact with said seal.

39. A microelectromechanical system (MEMS) device package produced by the method comprising:

forming a seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said seal is formed proximate a perimeter of said MEMS device;

forming a getter positioned proximate said seal at an inner periphery; and

attaching said substrate, said seal, and said backplane, thereby encapsulating said MEMS device.

40. The MEMS device package of claim 39, wherein said seal comprises at least one of a metal and an adhesive.

41. The MEMS device package of claim 39, wherein said getter comprises a desiccant.

42. The MEMS device package of claim 39, wherein said getter is positioned in contact with said seal.

43. A system for sealing a microelectromechanical system (MEMS) device package, comprising:

means for forming a seal on at least one of a substrate and a backplane, wherein said substrate comprises a MEMS device formed thereon and said seal is formed proximate a perimeter of said MEMS device;

means for forming a getter positioned proximate said seal at an inner periphery; and

means for attaching said substrate, said seal, and said backplane, thereby encapsulating said MEMS device.

44. The system of claim 43, wherein said seal comprises at least one of a metal and an adhesive.

45. The system of claim 43, wherein said getter comprises a desiccant.

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