(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 February 2010 (18.02.2010)

PCT

(10) International Publication Number
WO 2010/019521 A1

(51) International Patent Classification:
G02B 26/00 (2006.01) *B81B 3/00* (2006.01)

(21) International Application Number:
PCT/US2009/053315

(22) International Filing Date:
10 August 2009 (10.08.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/190,407 12 August 2008 (12.08.2008) US

(71) Applicant *(for all designated States except US)*: **QUALCOMM MEMS TECHNOLOGIES, INC.** [US/US]; 5775 Morehouse Drive, San Diego, CA 92121 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **DE GROOT, Wilhelmus, A.** [US/US]; 2581 Junction Ave., San Jose, CA 95134-1923 (US). **GUDLAVALLETI, Sauri** [IN/US]; 2581 Junction Ave., San Jose, CA 95134-1923 (US). **TUNG, Yeh-Jiun** [US/US]; 2581 Junction Ave., San Jose, CA 95134-1923 (US).

(74) Agent: **ABUMERI, Mark, M.**; Knobbe Martens Olson & Bear, LLP, 2040 Main Street, Fourteenth Floor, Irvine, CA 92614 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: METHOD AND APPARATUS TO REDUCE OR ELIMINATE STICTION AND IMAGE RETENTION IN INTERFEROMETRIC MODULATOR DEVICES

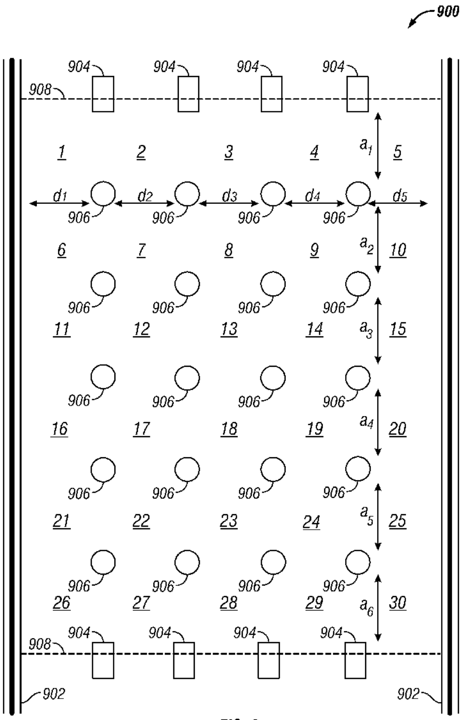

FIG. 9

(57) Abstract: Method and apparatus to reduce or eliminate stiction and image retention in interferometric display devices are disclosed. In some embodiments, a display element comprises a plurality of interferometric modulator devices configured in a matrix, each interferometric modulator device having a movable reflective layer and a plurality of supporting posts, the plurality of posts defining a post spacing distance in at least one direction that is greater for one or more interferometric modulator devices disposed adjacent to an edge of the display element than one or more interferometric modulator devices disposed nonadjacent to an edge of the display element.

WO 2010/019521 A1

Published:

— *with international search report (Art. 21(3))*

METHOD AND APPARATUS TO REDUCE OR ELIMINATE STICTION AND IMAGE RETENTION IN INTERFEROMETRIC MODULATOR DEVICES

Field of the Invention

[0001] The field of the invention relates to electromechanical systems.

Description of Related Technology

[0002] Electromechanical systems include devices having electrical and mechanical elements, actuators, transducers, sensors, optical components (e.g., mirrors), and electronics. Electromechanical systems can be manufactured at a variety of scales including, but not limited to, microscales and nanoscales. For example, microelectromechanical systems (MEMS) devices can include structures having sizes ranging from about a micron to hundreds of microns or more. Nanoelectromechanical systems (NEMS) devices can include structures having sizes smaller than a micron including, for example, sizes smaller than several hundred nanometers. Electromechanical elements may be created using deposition, etching, lithography, 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 electromechanical systems device is called an interferometric modulator. As used herein, the term interferometric modulator or interferometric light modulator refers to a device that selectively absorbs and/or reflects light using the principles of optical interference. In certain embodiments, an interferometric modulator may comprise a pair of conductive plates, one or both of which may be transparent and/or reflective in whole or part and capable of relative motion upon application of an appropriate electrical signal. In a particular embodiment, one plate may comprise a stationary layer deposited on a substrate and the other plate may comprise a metallic membrane separated from the stationary layer by an air gap. As described herein in more detail, the position of one plate in relation to another can change the optical interference of light incident on the interferometric modulator. Such devices have a wide range of applications, and it would be beneficial in the art to utilize and/or modify the characteristics of these types of devices so that their features can be exploited in improving existing products and creating new products that have not yet been developed.

Summary of Certain Embodiments

[0003] 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. In one embodiment, a display element includes a plurality of interferometric modulator devices configured in a matrix forming a plurality of rows and columns, each interferometric modulator device comprising a movable reflective layer comprising two opposite edges that are each supported by a rail and two opposing free edges, and a plurality of posts configured to support the movable reflective layer, the plurality of posts being spaced apart to define post spacing distances between adjacent posts positioned along an axis parallel to one of the rails, wherein the post spacing distance between adjacent posts along the axis and closest to each free edge is smaller than the post spacing distance between a plurality of other adjacent posts along the axis. The post spacing distance between said plurality of other adjacent posts along the axis may be substantially the same. The post spacing distance between the adjacent posts along the axis and closest to each free edge may be substantially the same. In some embodiments, the post spacing distances between adjacent posts along the axis increase as the distance from one of the free edges increases. In some embodiments, the post spacing distance between the adjacent posts along the axis and closest to each free edge can be approximately 32 μm, and the post spacing distance between said plurality of other adjacent posts along the axis can be approximately 38 μm. In some embodiments, the post spacing distance between the adjacent posts along the axis and closest to each free edge maybe approximately 2-10 μm smaller than the post spacing distance between said plurality of other adjacent posts along the axis. In various embodiments, the defined post spacing distances minimize a voltage required to release the interferometric modulator device. The post spacing distances can be defined such that the at least one free edge of the movable layer has a higher stiffness than another portion of the movable layer that is not on the at least one free edge.

[0004] Embodiments of the invention can include a display that includes the plurality of interferometric modulator devices, a processor that is configured to communicate with said display, said processor being configured to process image data, and a memory device that is configured to communicate with said processor. They can further comprise a driver circuit configured to send at least one signal to said display. Embodiments may further include a controller configured to send at least a portion of said image data to said driver circuit, and also an image source module configured to send said image data to said processor. The image source module can include at least one of a receiver, transceiver, and transmitter.

[0005] Another embodiment includes a display element that includes a plurality of interferometric modulator devices configured in a matrix forming a plurality of rows and columns, each interferometric modulator device including a movable reflective layer comprising two opposite edges that are each supported by a rail and two opposing free edges, and a plurality of posts configured to support the movable reflective layer, the plurality of posts being spaced apart to define post spacing distances between adjacent posts positioned along an axis parallel to one of the rails, wherein an outer post spacing distance between two adjacent outer posts along the axis is smaller than an inner post spacing distance between two adjacent inner posts along the axis, where the outer posts are closer to a free edge than the inner posts. The post spacing distances between a plurality of adjacent inner posts along the axis can be substantially the same. The post spacing distance between the outer adjacent posts close to each free edge can be substantially the same. In some embodiments, the post spacing distances between adjacent inner posts along the axis increases as the distance from one of the free edges increases. Some embodiments have a post spacing distance between two adjacent outer posts along the axis and closest to each free edge defined as approximately 32 μm. In some embodiments, the post spacing distance between two adjacent inner posts along the axis is approximately 38 μm. The post spacing distance between two adjacent outer posts along the axis and closest to each free edge can be approximately 2-10 μm smaller than the post spacing distance between two adjacent inner posts along the axis.

[0006] Another embodiment includes a method of manufacturing an interferometric modulator, comprising forming posts configured to support a movable layer, the posts having a plurality of post spacing distances, the distances defining a stiffness of respective portions of the movable layer, wherein the post spacing distances are such that a portion on a free edge of the movable layer has a lower stiffness than another portion that is not on a free edge of the movable layer. In some embodiments, a post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge, and closest to the free edge, of the movable layer is approximately 32 microns. In other embodiments, a post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge, and disposed closest to the free edge, of the movable layer is approximately 2-10 microns smaller than a post spacing distance between a second set of two adjacent posts that are disposed farther away from the free edge than the first set of adjacent posts. In other embodiments, a post spacing distance between a second set of two adjacent posts, disposed farther away from the free edge than the first set of adjacent posts, is approximately 38 microns. In other embodiments, a post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge and disposed closest to the free edge defines a stiffness of a first portion of the movable layer that is higher than a stiffness of the movable layer defined by a second set of two adjacent posts that are disposed farther away from the free edge than the first set of adjacent posts.

[0007] In one embodiment, a display apparatus comprises a plurality of interferometric modulator means configured in a matrix forming a plurality of rows and columns, each interferometric modulator means comprising first supporting means for supporting a movable reflective layer along two opposite edges such that two opposing edges of the movable reflective layer are free edges, and a plurality of second supporting means for supporting the movable reflective layer, the plurality of second supporting means being spaced apart to define second supporting means spacing distances between adjacent second supporting means positioned along an axis parallel to one of the first supporting means, wherein the second supporting means spacing distance between adjacent second supporting means along the axis and closest to each free edge is smaller than the second supporting means spacing distance between a plurality of other adjacent second supporting means along the axis. In some embodiments, the first supporting means includes two rails disposed to support opposite edges of the movable reflective layer. In some embodiments, the plurality of second supporting means includes posts.

[0008] Another embodiment includes a method of changing the state of a display element comprising a plurality of rows of interferometric modulator devices (IMODs), each row comprising a plurality of IMODs, the method comprising releasing IMODs along a first free edge of the display element and along a second free edge of the display element, the first and second free edges being opposite edges of the display element; and releasing IMODs not along the first free edge or the second free edge substantially after initiating release of the IMODS along the first and second free edges. In one aspect of this embodiment releasing the IMODs not along the first or second free edges comprises releasing substantially all IMODS not along the first or second free edges at substantially the same time. In another aspect, a first IMOD is released substantially before a second IMOD located nearer an area equidistant from the first and second free edges than the first IMOD.

Brief Description of the Drawings

[0009] 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 relaxed position and a movable reflective layer of a second interferometric modulator is in an actuated position.

[0010] Figure 2 is a system block diagram illustrating one embodiment of an electronic device incorporating a 3x3 interferometric modulator display.

[0011] Figure 3 is a diagram of movable mirror position versus applied voltage for one exemplary embodiment of an interferometric modulator of Figure 1.

[0012] Figure 4 is an illustration of a set of row and column voltages that may be used to drive an interferometric modulator display.

[0013] 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.

[0014] Figures 6A and 6B are system block diagrams illustrating an embodiment of a visual display device comprising a plurality of interferometric modulators.

[0015] Figure 7A is a cross section of the device of Figure 1.

[0016] Figure 7B is a cross section of an alternative embodiment of an interferometric modulator.

[0017] Figure 7C is a cross section of another alternative embodiment of an interferometric modulator.

[0018] FIG 7D is a cross section of yet another alternative embodiment of an interferometric modulator.

[0019] Figure 7E is a cross section of an additional alternative embodiment of an interferometric modulator.

[0020] Figure 8 is a diagram illustrating the release of an edge of movable layer of an interferometric modulator.

[0021] Figure 9 is a diagram illustrating an interferometric modulator pixel having two free edges and comprising a plurality of interferometric modulator devices having consistent spacing between support posts.

[0022] Figure 10 is a diagram illustrating an interferometric modulator pixel embodiment having consistent post spacing distance in one direction along the free edges of the pixel and more than one post spacing distance in a second direction substantially orthogonal to the first direction.

[0023] Figure 11 is a diagram illustrating an embodiment of an interferometric modulator pixel having varied post spacing.

[0024] Figure 12 is a flowchart illustrating an embodiment of manufacturing an interferometric modulator display element.

[0025] Figure 13 is a flowchart illustrating an embodiment of manufacturing an interferometric modulator display element.

Detailed Description of Certain Embodiments

[0026] The following detailed description is directed to certain specific embodiments. However, the teachings herein can be applied in a multitude of different ways. In this description, reference is made to the drawings wherein like parts are typically designated with like numerals throughout. The embodiments may be implemented in any device that is configured to display an image, whether in motion (e.g., video) or stationary (e.g., still image), and whether textual or pictorial. More particularly, it is contemplated that the embodiments may be implemented in or associated with a variety of electronic devices such as, but not limited to, mobile telephones, wireless devices, personal data assistants (PDAs), hand-held or portable computers, GPS receivers/navigators, cameras, MP3 players, camcorders, game consoles, wrist watches, clocks, calculators, television monitors, flat panel displays, computer monitors, auto displays (e.g., an 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.

[0027] "Stiction" and/or "image retention" are two conditions that can cause manufacturing yield loss and reliability problems in MEMS devices. Stiction describes a condition where a movable reflective layer of the MEMS device becomes stuck in a certain position (e.g., actuated) due to adhesion factors. Image retention occurs when a movable layer of the MEMS device becomes stuck when displaying a stationary image for a longer period of time, which can be due to several factors including stiction. These conditions can limit the use of MEMS devices in low use display applications where the displayed data content is not often changed. Layer stress and relaxation factors contribute to stiction and image retention. The restoring force resulti ng from tension and stiffness of the movable layer is one factor that contributes to releasing an actuated movable layer. Embodiments of the invention allow targeted sections of a display element (or pixel) to have a higher stiffness than other sections, thus affecting the release of the movable layer from an actuated position. In some embodiments, the structural support features (e.g., posts) that support the movable layer are placed in positions to increase stiffness near a free edge of the pixel. Stiffness of the movable layer can be increased by decreasing the spacing between the posts. Because the movable layer releases (usually) starting at the pixel edge, having a higher stiffness at the edge of the pixel facilitates the release process. Similarly, image retention can be caused by "aging" of the device and results in deformation of high stress areas of the movable layer. Selected post spacing in certain areas of the pixel can increase the layer stiffness near edges of the pixel and reduce layer bending in lower stiffness areas near center posts of the display element, thus reducing the aging effect and lowering image retention. Other anti-stiction techniques, for example, surface roughening, relief features and anti-stiction coatings, can be used in conjunction with varied post spacing and any of the embodiments described herein to decrease and/or eliminate stiction and prevent image retention.

[0028] 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 ("relaxed" or "open") state, the display element reflects a large portion of incident visible light to a user. When in the dark ("actuated" 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.

[0029] 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 gap with at least one variable dimension. In one embodiment, one of the reflective layers may be moved between two positions. In the first position, referred to herein as the relaxed position, the movable reflective layer is positioned at a relatively large distance from a fixed partially reflective layer. In the second position, referred to herein as the actuated position, the movable reflective layer is positioned more closely adjacent to the partially reflective layer. Incident light that reflects from the two layers interferes constructively or destructively depending on the position of the movable reflective layer, producing either an overall reflective or non-reflective state for each pixel.

[0030] The depicted portion of the pixel array in Figure 1 includes two adjacent interferometric modulators **12a** and **12b**. In the interferometric modulator **12a** on the left, a movable reflective layer **14a** is illustrated in a relaxed position at a predetermined distance from an optical stack **16a**, which includes a partially reflective layer. In the interferometric modulator

12b on the right, the movable reflective layer 14b is illustrated in an actuated position adjacent to the optical stack **16b**.

[0031] The optical stacks **16a** and **16b** (collectively referred to as optical stack **16**), as referenced herein, typically comprise several fused layers, which can include an electrode layer, such as indium tin oxide (ITO), a partially reflective layer, such as chromium, and a transparent dielectric. The optical stack **16** is thus electrically conductive, partially transparent and partially reflective, and may be fabricated, for example, by depositing one or more of the above layers onto a transparent substrate **20**. The partially reflective layer can be formed from a variety of materials that are partially reflective such as various metals, semiconductors, and dielectrics. The partially reflective layer can be formed of one or more layers of materials, and each of the layers can be formed of a single material or a combination of materials.

[0032] In some embodiments, the layers of the optical stack **16** are patterned into parallel strips, and may form row electrodes in a display device as described further below. The movable reflective layers **14a, 14b** may be formed as a series of parallel strips of a deposited metal layer or layers (orthogonal to the row electrodes of **16a, 16b**) to form columns deposited on top of posts **18** and an intervening sacrificial material deposited between the posts **18**. When the sacrificial material is etched away, the movable reflective layers **14a, 14b** are separated from the optical stacks **16a, 16b** by a defined gap **19**. A highly conductive and reflective material such as aluminum may be used for the reflective layers **14**, and these strips may form column electrodes in a display device. Note that Figure 1 may not be to scale. In some embodiments, the spacing between posts **18** may be on the order of 10-100 um, while the gap **19** may be on the order of <1000 Angstroms.

[0033] With no applied voltage, the gap **19** remains between the movable reflective layer **14a** and optical stack **16a**, with the movable reflective layer **14a** in a mechanically relaxed state, as illustrated by the pixel **12a** in Figure 1. However, when a potential (voltage) difference is applied to a selected row and column, the capacitor formed at the intersection of the row and column electrodes at the corresponding pixel becomes charged, and electrostatic forces pull the electrodes together. If the voltage is high enough, the movable reflective layer **14** is deformed and is forced against the optical stack **16**. A dielectric layer (not illustrated in this Figure) within the optical stack **16** may prevent shorting and control the separation distance between layers **14**

and **16**, as illustrated by actuated pixel **12b** on the right in Figure 1. The behavior is the same regardless of the polarity of the applied potential difference.

[0034] Figures 2 through 5 illustrate one exemplary process and system for using an array of interferometric modulators in a display application.

[0035] Figure 2 is a system block diagram illustrating one embodiment of an electronic device that may incorporate interferometric modulators. The electronic device includes a processor **21** which may be any general purpose single- or multi-chip microprocessor such as an ARM®, Pentium®, 8051, MIPS®, Power PC®, or 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.

[0036] In one embodiment, the processor **21** is also configured to communicate with an array driver **22**. In one embodiment, the array driver **22** includes a row driver circuit 24 and a column driver circuit **26** that provide signals to a display array or panel **30**. The cross section of the array illustrated in Figure 1 is shown by the lines 1-1 in Figure 2. Note that although Figure 2 illustrates a 3x3 array of interferometric modulators for the sake of clarity, the display array **30** may contain a very large number of interferometric modulators, and may have a different number of interferometric modulators in rows than in columns (e.g., 300 pixels per row by 190 pixels per column).

[0037] Figure 3 is a diagram of movable mirror position versus applied voltage for one exemplary embodiment of an interferometric modulator of Figure 1. For MEMS interferometric modulators, the row/column actuation protocol may take advantage of a hysteresis property of these devices as illustrated in Figure 3. An interferometric modulator may require, for example, a 10 volt potential difference to cause a movable layer to deform from the relaxed state to the actuated state. However, when the voltage is reduced from that value, the movable layer maintains its state as the voltage drops back below 10 volts. In the exemplary embodiment of Figure 3, the movable layer does not relax completely until the voltage drops below 2 volts. There is thus a range of voltage, about 3 to 7 V in the example illustrated in

Figure 3, where there exists a window of applied voltage within which the device is stable in either the relaxed or actuated state. This is referred to herein as the "hysteresis window" or "stability window." For a display array having the hysteresis characteristics of Figure 3, the row/column actuation protocol can be designed such that during row strobing, pixels in the strobed row that are to be actuated are exposed to a voltage difference of about 10 volts, and pixels that are to be relaxed are exposed to a voltage difference of close to zero volts. After the strobe, the pixels are exposed to a steady state or bias voltage difference of about 5 volts such that they remain in whatever state the row strobe put them in. After being written, each pixel sees a potential difference within the "stability window" of 3-7 volts in this example. This feature makes the pixel design illustrated in Figure 1 stable under the same applied voltage conditions in either an actuated or relaxed pre-existing state. Since each pixel of the interferometric modulator, whether in the actuated or relaxed state, is essentially a capacitor formed by the fixed and moving reflective layers, this stable state can be held at a voltage within the hysteresis window with almost no power dissipation. Essentially no current flows into the pixel if the applied potential is fixed.

[0038] As described further below, in typical applications, a frame of an image may be created by sending a set of data signals (each having a certain voltage level) across 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 a first row electrode, actuating the pixels corresponding to the set of data signals. The set of data signals is then changed to correspond to the desired set of actuated pixels in a second row. A pulse is then applied to the second row electrode, actuating the appropriate pixels in the second row in accordance with the data signals. The first row of pixels are unaffected by the second row pulse, and remain in the state they were set to during the first row 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 image 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 image frames may be used.

[0039] 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 Relaxing the pixel is accomplished by setting the appropriate column to $+V_{bias}$, and the appropriate row to the same $+\Delta V$, producing a zero volt potential difference across the pixel. In those rows where the row voltage is held at zero volts, the pixels are stable in whatever state they were originally in, regardless of whether the column is at $+V_{bias}$, or $-V_{bias}$. As is also illustrated in Figure 4, 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.

[0040] 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 initially at 0 volts, and all the columns are at +5 volts. With these applied voltages, all pixels are stable in their existing actuated or relaxed states.

[0041] In the Figure 5A frame, pixels (1,1), (1,2), (2,2), (3,2) and (3,3) are actuated. To accomplish this, during a "line time" for row 1, columns 1 and 2 are set to -5 volts, and column 3 is set to +5 volts. This does not change the state of any pixels, because all the pixels remain in the 3-7 volt stability window. Row 1 is then strobed with a pulse that goes from 0, up to 5 volts, and back to zero. This actuates the (1,1) and (1,2) pixels and relaxes the (1,3) pixel. No other pixels in the array are affected. To set row 2 as desired, column 2 is set to -5 volts, and columns 1 and 3 are set to +5 volts. The same strobe applied to row 2 will then actuate pixel (2,2) and relax pixels (2,1) and (2,3). Again, no other pixels of the array are affected. Row 3 is similarly set by setting columns 2 and 3 to -5 volts, and column 1 to +5 volts. The row 3 strobe sets the row 3 pixels as shown in Figure 5A. After writing the frame, the row potentials are zero, and the column potentials can remain at either +5 or -5 volts, and the display is then stable in the arrangement of Figure 5A. The same procedure can be employed for arrays of dozens or hundreds of rows and columns. The timing, sequence, and levels of voltages used to perform row and column actuation can be varied widely within the general principles outlined above, and the above example is exemplary only, and any actuation voltage method can be used with the systems and methods described herein.

[0042] Figures 6A and 6B are system block diagrams illustrating an embodiment of a display device **40**. The display device **40** can be, for example, a cellular or mobile telephone. However, the same components of display device **40** or slight variations thereof are also illustrative of various types of display devices such as televisions and portable media players.

[0043] The display device **40** includes a housing **41**, a display **30**, an antenna **43**, a speaker **45**, an input device **48**, and a microphone **46**. The housing **41** is generally formed from any of a variety of manufacturing processes, including injection molding, and vacuum forming. In addition, the housing **41** may be made from any of a variety of materials, including but not limited to plastic, metal, glass, rubber, and ceramic, or a combination thereof. In one embodiment the housing **41** includes removable portions (not shown) that may be interchanged with other removable portions of different color, or containing different logos, pictures, or symbols.

[0044] The display **30** of exemplary display device 40 may be any of a variety of displays, including a bi-stable display, as described herein. In other embodiments, the display **30** includes a flat-panel display, such as plasma, EL, OLED, STN LCD, or TFT LCD as described above, or a non-flat-panel display, such as a CRT or other tube device,. However, for purposes of describing the present embodiment, the display **30** includes an interferometric modulator display, as described herein.

[0045] The components of one embodiment of exemplary display device **40** are schematically illustrated in Figure 6B. The illustrated exemplary display device **40** includes a housing **41** and can include additional components at least partially enclosed therein. For example, in one embodiment, the exemplary display device **40** includes a network interface **27** that includes an antenna **43** which is coupled to a transceiver **47**. The transceiver 47 is connected to a processor **21**, which is connected to conditioning hardware **52**. The conditioning hardware **52** may be configured to condition a signal (e.g. filter a signal). The conditioning hardware **52** is connected to a speaker **45** and a microphone **46**. The processor **21** is also connected to an input device **48** and a driver controller **29**. The driver controller **29** is coupled to a frame buffer **28**, and to an array driver **22**, which in turn is coupled to a display array **30**. A power supply **50**

provides power to all components as required by the particular exemplary display device **40** design.

[0046] The network interface **27** includes the antenna **43** and the transceiver **47** so that the exemplary display device **40** can communicate with one ore more devices over a network. In one embodiment the network interface **27** may also have some processing capabilities to relieve requirements of the processor **21**. The antenna **43** is any antenna 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, W-CDMA, or other known signals that are used to communicate within a wireless cell phone network. The transceiver **47** pre-processes the signals received from the antenna **43** so that they may be received by and further manipulated by the processor **21**. The transceiver **47** also processes signals received from the processor **21** so that they may be transmitted from the exemplary display device **40** via the antenna **43**.

[0047] In an alternative embodiment, the transceiver **47** can be replaced by a receiver. In yet another alternative embodiment, network interface **27** can be replaced by an image source, which can store or generate image data to be sent to the processor **21**. For example, the image source can be a digital video disc (DVD) or a hard-disc drive that contains image data, or a software module that generates image data.

[0048] Processor **21** generally controls the overall operation of the exemplary display device 40. The processor **21** receives data, such as compressed image data from the network interface **27** or an image source, and processes the data into raw image data or into a format that is readily processed into raw image data. The processor **21** then sends the processed data to the driver controller **29** or to frame buffer **28** for storage. Raw data typically refers to the information that identifies the image characteristics at each location within an image. For example, such image characteristics can include color, saturation, and gray-scale level.

[0049] In one embodiment, the processor **21** includes a microcontroller, CPU, or logic unit to control operation of the exemplary display device **40**. Conditioning hardware **52** generally includes amplifiers and filters for transmitting signals to the speaker **45**, and for receiving signals from the microphone **46**. Conditioning hardware **52** may be discrete components within the exemplary display device **40**, or may be incorporated within the processor **21** or other components.

[0050] The driver controller **29** takes the raw image data generated by the processor **21** either directly from the processor **21** or from the frame buffer **28** and reformats the raw image data appropriately for high speed transmission to the array driver **22**. Specifically, the driver controller **29** reformats the raw image data into a data flow having a raster-like format, such that it has a time order suitable for scanning across the display array **30**. Then the driver controller **29** sends the formatted information to the array driver **22**. Although a driver controller **29**, such as a LCD controller, is often associated with the system processor **21** as a stand-alone Integrated Circuit (IC), such controllers may be implemented in many ways. They may be embedded in the processor **21** as hardware, embedded in the processor **21** as software, or fully integrated in hardware with the array driver **22**.

[0051] Typically, the array driver **22** receives the formatted information from the driver controller **29** and reformats the video data into a parallel set of waveforms that are applied many times per second to the hundreds and sometimes thousands of leads coming from the display's x-y matrix of pixels.

[0052] In one embodiment, the driver controller **29**, array driver **22**, and display array **30** are appropriate for any of the types of displays described herein. For example, in one embodiment, driver controller **29** is a conventional display controller or a bi-stable display controller (e.g., an interferometric modulator controller). In another embodiment, array driver **22** is a conventional driver or a bi-stable display driver (e.g., an interferometric modulator display). In one embodiment, a driver controller **29** is integrated with the array driver **22**. Such an embodiment is common in highly integrated systems such as cellular phones, watches, and other small area displays. In yet another embodiment, display array **30** is a typical display array or a bi-stable display array (e.g., a display including an array of interferometric modulators).

[0053] The input device b allows a user to control the operation of the exemplary display device **40**. In one embodiment, input device 48 includes a keypad, such as a QWERTY keyboard or a telephone keypad, a button, a switch, a touch-sensitive screen, a pressure- or heat-sensitive membrane. In one embodiment, the microphone **46** is an input device for the exemplary display device **40**. When the microphone **46** is used to input data to the device, voice commands may be provided by a user for controlling operations of the exemplary display device 40.

[0054] Power supply **50** can include a variety of energy storage devices as are well known in the art. For example, in one embodiment, power supply **50** is a rechargeable battery, such as a nickel-cadmium battery or a lithium ion battery. In another embodiment, power supply 50 is a renewable energy source, a capacitor, or a solar cell, including a plastic solar cell, and solar-cell paint. In another embodiment, power supply **50** is configured to receive power from a wall outlet.

[0055] 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 **22**. The above-described optimization may be implemented in any number of hardware and/or software components and in various configurations.

[0056] The details of the structure of interferometric modulators that operate in accordance with the principles set forth above may vary widely. For example, Figures 7A-7E illustrate five different embodiments of the movable reflective layer **14** and its supporting structures. Figure 7A is a cross section of the embodiment of Figure 1, where a strip of metal material **14** is deposited on orthogonally extending supports **18**. In Figure 7B, the movable reflective layer **14** of each interferometric modulator is square or rectangular in shape and attached to supports at the corners only, on tethers **32**. In Figure 7C, the movable reflective layer **14** is square or rectangular in shape and suspended from a deformable layer 34, which may comprise a flexible metal. The deformable layer **34** connects, directly or indirectly, to the substrate **20** around the perimeter of the deformable layer **34**. These connections are herein referred to as support posts. The embodiment illustrated in Figure 7D has support post plugs **42** upon which the deformable layer **34** rests. The movable reflective layer **14** remains suspended over the gap, as in Figures 7A-7C, but the deformable layer **34** does not form the support posts by filling holes between the deformable layer **34** and the optical stack **16**. Rather, the support posts are formed of a planarization material, which is used to form support post plugs **42**. The embodiment illustrated in Figure 7E is based on the embodiment shown in Figure 7D, but may also be adapted to work with any of the embodiments illustrated in Figures 7A-7C as well as additional embodiments not shown. In the embodiment shown in Figure 7E, an extra layer of metal or other conductive material has been used to form a bus structure **44**. This allows signal routing along the back of the interferometric modulators, eliminating a number of electrodes that may otherwise have had to be formed on the substrate **20**.

[0057] In embodiments such as those shown in Figure 7, the interferometric modulators function as direct-view devices, in which images are viewed from the front side of the transparent substrate **20**, the side opposite to that upon which the modulator is arranged. In these embodiments, the reflective layer **14** optically shields the portions of the interferometric modulator on the side of the reflective layer opposite the substrate 20, including the deformable layer **34**. This allows the shielded areas to be configured and operated upon without negatively affecting the image quality. For example, such shielding allows the bus structure **44** in Figure 7E, which provides the ability to separate the optical properties of the modulator from the electromechanical properties of the modulator, such as addressing and the movements that result from that addressing. This separable modulator architecture allows the structural design and materials used for the electromechanical aspects and the optical aspects of the modulator to be selected and to function independently of each other. Moreover, the embodiments shown in Figures 7C-7E have additional benefits deriving from the decoupling of the optical properties of the movable reflective layer **14** from its mechanical properties, which are carried out by the deformable layer **34**. This allows the structural design and materials used for the movable reflective layer **14** to be optimized with respect to the optical properties, and the structural design and materials used for the deformable layer **34** to be optimized with respect to desired mechanical properties.

[0058] Referring back to Figure 1, when a potential difference is applied to a movable reflective layer **14a** and the partially reflective layer (optical stack **16a**), a capacitor is formed between these two layers which creates electrostatic forces that moves the movable reflective layer **14a** towards the optical stack **16a** and changes the shape of interferometric cavity **19**. If the voltage is high enough, the reflective layer **14b** is forced against the partially reflective layer **16b** collapsing the cavity **19**. When no potential difference is applied, however, the mechanical restoration forces of the movable reflective layer and its surrounding structure return the movable reflective layer to its original position, as illustrated by layer **14a**, thereby restoring the cavity **19**. Even in the undriven state, both of the layers **14a** and **16b** are positioned relatively close to each other, for example, about 0.2 μm.

[0059] An undesired condition known as stiction occurs when adhesion forces holding the movable layer against the optical stack are greater than the restoring force acting on the movable layer. When this occurs, the movable layer is immobilized in an actuated or an unactuated state, more commonly the actuated state. In other words, the movable layer "sticks" in a particular position which adversely affects the performance of the MEMS device. For example, with reference to Figure 1, stiction can cause the actuated movable reflective layer **14b** to remain in contact with the optical stack **16b** even in the presence of a restoring force that would be expected to return the movable reflective layer **14b** to a relaxed position. The restoring force includes the combined mechanical tensile stresses in the actuated movable reflective layer 14b and the structures supporting the movable layer.

[0060] Stiction is a concern for MEMS devices, including interferometric modulators, because surface adhesion forces become more significant with decreasing device dimensions and restoring forces shrink with decreasing device dimensions. Interferometric modulator devices can suffer from both manufacturing yield loss and reliability fallout as the result of stiction and/or image retention due to long term stationary image display. This phenomenon limits the usage of interferometric modulator devices to certain low use applications and causes reliability problems.

[0061] Adhesion forces that affect stiction may arise from several mechanisms including, for example, capillary forces, van der Waals force, chemical bonds and trapped charges. Adhesion forces, in varying degrees, depend on the contact area and surface separation between movable and stationary layers, for example, when a MEMS device is in the actuated state. Adhesion forces may also depend on environmental conditions including moisture present within and around the MEMS device. During the lifetime of a MEMS device, water vapor (or water) may permeate into the interior of the device and be present on the optical stack and the movable reflective layer. When these two layers are in close proximity, water vapor may cause the optical stack and the movable layer to have an additional attractive capillary force between them due to capillary water condensation. Furthermore, van der Waals force which is a short range force causing adjacent materials to become attracted at the molecular level, also can be an attractive force between the optical stack and the movable reflective layers causing the layers to stick together.

[0062] Various configurations which implement surface "roughness" structure may minimize or eliminate stiction. Examples of surface roughness configurations include bumps, dimples, grooves, and actuation rails. Some of these configurations are described, for example, in U.S. Patent No. 6,674,562, titled INTERFEROMETRIC MODULATION OF RADIATION.. Other ways to minimize or eliminate stiction include using an anti-stiction coating on one or more of the surfaces (or sublayer surfaces) of an interferometric light modulating device so that the additional attractive forces due to events such as capillary water condensation or van der Waals forces may be minimized or eliminated. Certain examples of such anti-stiction coatings are described in Patent Application No. 11/119,433 filed April 29, 2005, titled SYSTEM AND METHOD OF PROVIDING MEMS DEVICE WITH ANTI-STICTION COATING..

[0063] MEMS devices may be tested to estimate the restoring forces provided by the combined mechanical stresses of the movable layer and support structures. Some exemplary embodiments of methods of testing MEMS devices to estimate adhesion forces are described in U.S. Application No. 11/614,795, titled METHOD AND APPARATUS FOR MEASURING THE FORCE OF STICTION OF A MEMBRANE IN A MEMS DEVICE, filed on December 21, 2006. By testing various configurations of anti-stiction configurations (for example, bumps, dimples, grooves, support structure dimensions, and anti-stiction coatings), an optimal (or at least sufficient) configuration to avoid stiction may be identified for a particular MEMS implementation. By testing various environmental condition, and/or materials introduced to affect the environment in which the movable layer operates (for example, desiccants), the most favorable conditions and/or materials may be identified.

[0064] Stiction in a MEMS device may be minimized or eliminated by using structural support configurations that affect the amount of stiffness in the movable reflective layer. For example, increased stiffness in a movable reflective layer increases the restoring force necessary to release the movable reflective layer from a surface against which it resides. However, merely increasing the stiffness across the entire movable reflective layer may not be desired because increased stiffness implies a higher voltage which results in a closer and consistent "fit" of a larger portion of the movable reflective layer against the optical stack thereby producing more adhesion forces. Instead, certain structural support configuration embodiments can be used to increase stiffness in certain portions of the movable layer to help the movable reflective layer initiate the release process, setting off a release sequence among the plurality of modulator devices and thereby decreasing the likelihood of stiction.

[0065] The restoring force necessary to overcome the adhesion forces in the absence of electrostatic force is inversely proportional to post spacing. "Post spacing" as used herein is a broad term and refers to the distance between two adjacent "post" structures which support the movable reflective layer. The post spacing determines how much of the movable reflective layer is unsupported and thus affects the stiffness of the movable layer. Accordingly, post spacing can be considered a center-to-center distance for posts which provide a relatively small support point (for example, at a point or small circular area). However, if the post structure covers a larger support area the relevant post spacing distance is the edge post-to-post spacing between supporting structure between two adjacent posts because the nearest support point of such structures define an unsupported length of the movable reflective layer and thus affects the stiffness of the movable layer. For example, if the post structure is configured in the shape of a "Y," a "T," or an "X," and each portion of the post provides support, the relevant post spacing is considered the edge-to-edge post spacing because the edges of the posts define an unsupported portion or length of the movable reflective layer.

[0066] By reducing post spacing in interferometric modulator devices adjacent to one of the free edges of the display element, the stiffness in these devices increases, leading to a higher restoring force and more margin against adhesion forces and stiction. Upon initial release of these edge adjacent devices, subsequent release of devices that are not along the free edge of the display elements is facilitated by the restoring force from the edge adjacent devices across device boundaries. Figure 8 is a diagram illustrating the release of an edge **802** of a membrane **804** from a surface **806**. The membrane **804** may be, for example, a movable reflective layer **14b** (Figure 1) and the surface **806** may be optical stack **16b** (Figure 1). For an infinite length membrane, restoring force (F) pulling on the edge of the membrane in the actuated state is shown in equation 1:

$$F = \sin\alpha \sum_i (\sigma_i t_i) \qquad [1]$$

where σ_i is layer tensile stress, t_i is layer thickness, i is any constituent of the membrane. The dominant adhesion force is a capillary attraction which has a "zipper" effect of the edge of the membrane. In other words, once the edge **802** is released from the optical stack **806**, the rest of the movable reflective layer **804** requires progressively less restoring force to release from the optical stack **806** as it can be essentially peeled away from the optical stack **806** from the free edge **802** inward. A higher restoring force on the edge **802** of the membrane **804** provides more margin against stiction. Increasing stiffness in the free edge portions of a movable membrane can facilitate the release process and decrease the likelihood of stiction. Embodiments which increase stiffness in the free edge portions of a movable membrane may have many applications, including in interferometric modulators that are used in displays or other devices outside of a display.

[0067] Figure 9 is a schematic illustrating a plan view of the placement of structure that supports a movable reflective layer in some examples of an interferometric modulator display pixel (or element) **900**. Figure 9 is not drawn to scale, nor are any of the other figures. The pixel **900** includes a movable layer and an optical stack which are not illustrated in Figure 9 in order to see the first supporting means, for example, rails, and the second supporting means, for example, posts. In this embodiment, pixel **900** is configured as a rectangular-shaped pixel having one pair of opposite edges along rails **902** and another pair of opposite edges along edge posts **904**. Pixel **900** may be included in a display (not shown) comprising a plurality of pixels such that one or more of the other pixels may be located adjacent to pixel **900** along one or more of the rails **902** or one or more of the edge posts **904.** In such embodiments, the display may comprise a plurality of rails **902** disposed in parallel with a plurality of pixels disposed therebetween. Each pixel of the display can comprise an optical stack and a movable layer defining an interferometric cavity, where the movable layer is supported by support structure of rails **902**, edge posts **904** and mid-support posts **906**, wherein the perimeter outlined by the two rails **902** and edge posts **904** defines an IMOD pixel.

[0068] In this embodiment, pixel **900** comprises a 5 x 6 matrix of interferometric modulator devices, which are labeled **1-30** in Figure 9 and also in subsequent Figures 10-11. Each of the modulator devices **1-30** in Figure 9 comprise a portion of pixel **900** including a portion of a reflective movable layer and a portion of a partially reflective optical stack associated with pixel **900**. Other pixel matrix configurations are contemplated in other embodiments and implementations. For example, in some embodiments a pixel may include a 4 x 5 matrix of interferometric modulators. In other embodiments, a pixel may be configured to comprise, for example, a matrix of 3 x 5, 3 x 6, 4 x 4, 4 x 6, 5 x 3, 6 x 3, 5 x 4, 6x5, or 6 x 4 interferometric modulators. The matrix of interferometric modulators may have larger or smaller dimensions such that more or fewer interferometric modulators are included in the pixel.

[0069] Figure 9 illustrates the relative placement of certain structure including rails and posts that support a movable layer of pixel **900**. The movable layer nor the substrate are shown in Figure 9 in order to better illustrate the support structure (for example, edge posts **904**, middle support posts **906**, and rails **902**) that support and separate the movable layer from the optical stack. Pixel **900** comprises interferometric modulating structure including a partially reflective optical stack, a movable reflective layer, and support structure (for example, rails and posts) which can operate as described above in reference to Figures 1-7e. In this embodiment, the movable reflective layers of the modulator devices **1-30** are configured to be driven and operate together. The movable reflective layers of modulator devices **1-30** may be electrically connected. Also, the partially reflective optical stacks of modulator devices **1-30** may be electrically connected. In this embodiment, when pixel **900** is driven to an actuated or released state, all of the modulator devices **1-30** of pixel **900** are driven to that actuated or released state such that they all achieve the same state (either actuated or released) after each write cycle. In some embodiments movable reflective layers and/or the optical stacks of the modulator devices **1-30** may not all be electrically connected but can be driven to operate together.

[0070] The movable layer and the optical stack **910** are both disposed between two edge rails **902** and a plurality of edge posts **904** as illustrated in Figure 9. The rails **902** are connected to two opposite edges of the movable reflective layer of the pixel **900**, and the edge posts **904** are disposed on the other two non-rail edges of pixel **900**. The rails **902** support the movable layer along the edges of pixel **900** separate it from a partially reflective optical stack **910**. The edge posts **904** are connected to a portion of the movable reflective layer of pixel **900** at its edges to support the movable layer and separate in from the optical stack **910**. Two of the edges of the movable layer of pixel **900** are connected (or at least substantially connected) to the rails **902**. Portions of two of the other edges of the movable layer of pixel **900** are connected to edge posts **904** such that at least a portion of these edges of the movable layer are unsupported or "free." Accordingly, each of the two edges of the movable layer that are supported by edge posts may be referred to herein as a "free edge" **908**. The pixel **900** also comprises a plurality of mid-support posts **906**. The embodiment in Figure 9 illustrates twenty (20) mid-support posts **906** that support the movable reflective layer of pixel **900**. The number of mid-support posts **906** may vary for other embodiments and can be affected by the number of interferometric devices in the pixel.

[0071] In an embodiment shown in Figure 9, the distance in a first direction between a first mid-support post and an adjacent mid-support post is illustrated as post spacing distances d_2, d_3, and d_4. The distances between mid-support posts **906** and adjacent rails **902** in the first direction are illustrated as distances d_1 and d_5, and the first direction is indicated by the associated horizontal double-ended arrows. The post spacing distances between two adjacent mid-support posts **906** along a second direction are illustrated by a_2, a_3, a_4, and a_5. The distances between mid-support posts and adjacent edge posts **904** in the second direction are illustrated as distances a_1 and a_6, and the second direction is indicated by the associated vertical double-ended arrows. In this embodiment, the second direction is at least substantially orthogonal to the first direction.

[0072] Still referring to Figure 9, some embodiments of pixel **900** have consistent post spacing distances (a_2, a_3, a_4, and a_5) between the adjacent mid-support posts **906** in the second direction which is the same as the post spacing distances (a_1 and a_6) between mid-support posts and edge posts. In other words, $a_1 = a_2 = a_3 = a_3 = a_4 = a_5 = a_6$. The post spacing distances in the first direction may also be consistent (for example, $d_1 = d_2 = d_3 = d_3 = d_4 = d_5$).

[0073] To increase stiction margin, in some embodiments the posts that support a movable reflective layer can be positioned such that the stiffness of the movable reflective layer at or near the free edge is greater than the stiffness of other portions of the movable reflective layer. Such embodiments allow the movable layer to be moved away from the optical stack starting with the free edge in the manner illustrated in Figure 8. In other words, when driven to release, the free edge of the movable layer releases from the optical stack first, which facilitates the release of the remaining portion of the movable reflective layer. Referring again to Figure 9, the stiffness of the movable reflective layer can also be affected by the distance between support posts in the first direction, for example, the distance between two mid-support posts **906** or a mid-support post **906** and a rail **902**. In certain embodiments this too can reduce stiction. However, the rails **902** are connected to a large portion (if not all) of the adjacent edges of the movable reflective layer such that the mechanical behavior during a release state of the movable layer along the connected edge will be different than along the free edge of the movable layer.

[0074] Embodiments described herein illustrate examples of varying post distance spacing to affect the stiffness of the movable layer. In one embodiment, the pixel **900** is configured such that the stiffness of the movable layer along the edge posts **904** is no less than a first stiffness value and the stiffness of any other portion of the movable layer is no greater than a second stiffness value, the first stiffness value being higher than the second stiffness value. For example, in some embodiments, the pixel **900** can be configured so the one or more of the distances between the edge posts **904** and the adjacent mid-support posts **906** (for example, a_1 and a_6) is less than the distance between mid-support posts **906** that are non-adjacent to the free edge (for example, mid-support posts separated by post spacing distance a_4). In other words, the post spacing distance a_1 and/or $a_6 < a_4$. Other embodiments of increasing the stiffness in the portion of the free edge of a movable layer so as to prevent stiction are described below.

[0075] Figure 10 is a schematic illustrating a plan view of an embodiment of a display pixel **1000** where post spacing distances are varied to increase stiffness in a movable layer along a free edge of pixel **1000** relative to the stiffness in other portions of the movable layer. Similarly to Figure 9, pixel **1000** includes modulator devices **1**-**30** and a movable reflective layer and an optical stack disposed between and connected to the rails **902** and the edge posts **904**. The movable layer and the optical stack are not shown in Figure 10 for clarity of illustrating support structure spacing. The movable layer has free edges along the two sets of edge posts **904**, where the other two edges are connected to the rails **902**. The post spacing distances d_1, d_2, d_3, and d_4 in the first direction along the free edges of the pixel **1000** are the same. Here, a_1 and a_6 illustrate the post spacing distance between edge posts **904** and adjacent mid-support posts **906**. The mid-support posts **906** are separated by post spacing distances a_2, a_3, a_4 and a_5 which are substantially equal. In this embodiment, one or both of post spacing distances a_1 and a_6 in the second direction can be less than the post spacing distances a_2, a_3, a_4 and

a_5 of the mid-support posts **906**. In some embodiments, the post spacing distance of a_1 and/or a_6 is between about 1μm and about 10μm less than the post spacing between the mid-support posts **906** (for example, a_4). In some embodiments, the post spacing distance of a_1 and/or a_6 is between about 3μm and about 7μm less than a_2, a_3, a_4 and a_5, and in other embodiments the post spacing distance of a_1 and/or a_6 is about 5μm less than a_2, a_3, a_4 and a_5. For example, in some embodiments the distance between one or more edge post **904** and one or more mid-support posts **906** adjacent to the one or more edge posts (for example, a_1 and/or a_6) is about 32 μm, and the distance between mid-support posts (for example, a_4) is about 38 μm.

[0076] Figure 11 is a diagram illustrating a support structure embodiment of interferometric modulator pixel **1100** which comprises rails **902**, edge posts **904**, and mid-support posts **906**. Similarly to Figures 9 and 10, pixel **1100** includes a reflective movable layer and the optical stack disposed between the rails **902** and the edge posts **904** but they are not shown here in order to more clearly show the structural support elements. In this embodiment, the pixel **1100** has post spacing in the second direction (again indicated by $a_1 - a_6$) that is closer near the free edge of the movable layer (along the edge posts **904**) than in other portions of the movable reflective layer. In this embodiment, the post spacing in the second direction decreases from the center of pixel **1100** to the edge of pixel **1100**. For example, post spacing a_1 is less than a_2 which is less than a_3 (e.g., $a_1<a_2<a_3$). Both sides of the pixel **1100** may exhibit this type of post spacing such that a_6 is less than a_5 which is less than a_4 (e.g., $a_6<a_5<a_4$). Such an embodiment increases the stiffness on the movable reflective layer at its free edges along edge posts **904**. For example, in some embodiments the post spacing distance a_1 and a_6 can be about 32μm, a_2 and a_5 can be about 35μm, and a_3 and a_4 can be about 38μm. When a restoring force is applied to this embodiment, the movable reflective layer releases from the free edges first which helps to release the remaining portions of the movable reflective layer.

[0077] Figure 12 is a flowchart illustrating another embodiment of a method of manufacturing a interferometric modulator display element which can be, for example, the pixel illustrated in Figures 9-11. Referring to Figure 12 step **1202**, the display element is made by selecting post spacing distances for forming a plurality of posts and support rails to support a movable layer of an interferometric modulator display element, the movable layer being connected on two sides to the support rails and having at least one partially supported free edge, said post spacing distances being selected such that the at least one free edge of the movable layer has a higher layer stiffness than another portion of the movable layer not on the at least one free edge. Determining proper post spacing can involve testing various post spacing embodiments that affect the stiffness of the movable layer, estimating adhesion forces and also considering other anti-stiction embodiments (for example, bumps, dimples, groves, and anti-stiction coatings).

[0078] Still referring to Figure 12, at step **1204** a movable layer is formed comprising support rails and a plurality of posts, wherein the movable layer is connected on two opposite sides to the support rails and to the plurality of posts, and wherein the post spacing distances for the plurality of posts is substantially equivalent to the selected spacing distances. The movable layer and support structure may be formed similarly to the movable layers **14a**, **14b** and posts **18** described in reference to Figure 1.

[0079] Interferometric modulators can be manufactured in accordance with the above-described embodiments. For example, Figure 13 is a flowchart that illustrates a process **1300** of manufacturing an interferometric modulator. At process step **1302**, the process **1300** includes forming posts configured to support a movable layer, the posts having a plurality of post spacing distances, the distances defining a stiffness of respective portions of the movable layer, wherein the post spacing distances are such that a portion on a free edge of the movable layer has a lower stiffness than another portion that is not on a free edge of the movable layer. The process 1300 may define the post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge, and disposed closest to the free edge, of the movable layer to be approximately 2-10 microns smaller than a post spacing distance between a second set of two adjacent posts that are disposed farther away from the free edge than the first set of adjacent posts. In certain examples, the process **1300** defines a post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge, and closest to the free edge, of the movable layer can be defined to be approximately 32 microns. In other examples, the process 1300 defines a post spacing distance between a second set of two adjacent posts, disposed farther away from the free edge than the first set of adjacent posts, to be approximately 38 microns. In some examples, a post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge and disposed closest to the free edge defines a stiffness of a first portion of the movable layer that is higher than a stiffness of the movable layer defined by a second set of two adjacent posts that are disposed farther away from the free edge than the first set of adjacent posts.

[0080] A wide variety of variation is possible for the above-described exemplary embodiments. Films, layers, components, and/or elements may be added, removed, or rearranged. Additionally, processing steps may be added, removed, or reordered. Also, although the terms film and layer have been used herein, such terms as used herein include film stacks and multilayers. Such film stacks and multilayers may be adhered to other structures using adhesive or may be formed on other structures using deposition or in other manners.

[0081] The example embodiments described above are merely exemplary and those skilled in the art may now make numerous uses of, and departures from, the above-described examples without departing from the inventive concepts disclosed herein. The word "exemplary" is used exclusively herein to mean "serving as an example, instance, or illustration." Any example described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other examples. Various modifications to these examples may be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other examples without departing from the spirit or scope of the novel aspects described herein. Thus, the scope of the disclosure is not intended to be limited to the examples shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[0082] 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.

WHAT IS CLAIMED IS:

1. A display element comprising:

a plurality of interferometric modulator devices configured in a matrix forming a plurality of rows and columns, each interferometric modulator device comprising:

a movable reflective layer comprising two opposite edges that are each supported by a rail and two opposing free edges; and

a plurality of posts configured to support the movable reflective layer, the plurality of posts being spaced apart to define post spacing distances between adjacent posts positioned along an axis parallel to one of the rails, wherein the post spacing distance between adjacent posts along the axis and closest to each free edge is smaller than the post spacing distance between a plurality of other adjacent posts along the axis.

2. The display element of Claim 1, wherein the post spacing distance between said plurality of other adjacent posts along the axis are substantially the same.

3. The display element of Claim 1, wherein the post spacing distance between the adjacent posts along the axis and closest to each free edge are substantially the same.

4. The display element of Claim 1, wherein the post spacing distances between adjacent posts along the axis increase as the distance from one of the free edges increases.

5. The display element of Claim 1, wherein the post spacing distance between the adjacent posts along the axis and closest to each free edge is approximately 32 μm.

6. The display element of Claim 4, wherein the post spacing distance between said plurality of other adjacent posts along the axis is approximately 38 μm.

7. The display element of Claim 1, wherein the post spacing distance between the adjacent posts along the axis and closest to each free edge is approximately 2-10 μm smaller than the post spacing distance between said plurality of other adjacent posts along the axis.

8. The display element of Claim 1, wherein the defined post spacing distances minimize a voltage required to release the interferometric modulator device.

9. The display element of Claim 1, wherein the post spacing distances are defined such that the at least one free edge of the movable layer has a higher stiffness than another portion of the movable layer that is not on the at least one free edge.

10. The display element of Claim 1, further comprising:

a display comprising said plurality of interferometric modulator devices;

a processor that is configured to communicate with said display, said processor being configured to process image data; and

a memory device that is configured to communicate with said processor.

11. The display element as recited in Claim 10, further comprising a driver circuit configured to send at least one signal to said display.

12. The display element as recited in Claim 11, further comprising a controller configured to send at least a portion of said image data to said driver circuit.

13. The display element as recited in Claim 10, further comprising an image source module configured to send said image data to said processor.

14. The display element as recited in Claim 13, wherein said image source module comprises at least one of a receiver, transceiver, and transmitter.

15. A display element comprising:

a plurality of interferometric modulator devices configured in a matrix forming a plurality of rows and columns, each interferometric modulator device comprising:

a movable reflective layer comprising two opposite edges that are each supported by a rail and two opposing free edges, and

a plurality of posts configured to support the movable reflective layer, the plurality of posts being spaced apart to define post spacing distances between adjacent posts positioned along an axis parallel to one of the rails, wherein an outer post spacing distance between two adjacent outer posts along the axis is smaller than an inner post spacing distance between two adjacent inner posts along the axis, where the outer posts are closer to a free edge than the inner posts.

16. The display element of Claim 15, wherein the post spacing distances between a plurality of adjacent inner posts along the axis are substantially the same.

17. The display element of Claim 15, wherein the post spacing distance between the outer adjacent posts close to each free edge are substantially the same.

18. The display element of Claim 15, wherein the post spacing distances between adjacent inner posts along the axis increases as the distance from one of the free edges increases.

19. The display element of Claim 15, wherein the post spacing distance between two adjacent outer posts along the axis and closest to each free edge is approximately 32 µm.

20. The display element of Claim 20, wherein the post spacing distance between two adjacent inner posts along the axis is approximately 38 µm.

21. The display element of Claim 15, wherein the post spacing distance between two adjacent outer posts along the axis and closest to each free edge is approximately 2-10 µm smaller than the post spacing distance between two adjacent inner posts along the axis.

22. A method of manufacturing an interferometric modulator, comprising forming posts configured to support a movable layer, the posts having a plurality of post spacing distances, the distances defining a stiffness of respective portions of the movable layer, wherein the post spacing distances are such that a portion on a free edge of the movable layer has a lower stiffness than another portion that is not on a free edge of the movable layer.

23. The method of Claim 22, wherein a post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge, and closest to the free edge, of the movable layer is approximately 32 microns.

24. The method of Claim 22, wherein a post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge, and disposed closest to the free edge, of the movable layer is approximately 2-10 microns smaller than a post spacing distance between a second set of two adjacent posts that are disposed farther away from the free edge than the first set of adjacent posts.

25. The method of Claim 23, wherein a post spacing distance between a second set of two adjacent posts, disposed farther away from the free edge than the first set of adjacent posts, is approximately 38 microns.

26. The method of Claim 22, wherein a post spacing distance between a first set of two adjacent posts aligned in a direction about normal to the free edge and disposed closest to the free edge defines a stiffness of a first portion of the movable layer that is higher than a stiffness of the movable layer defined by a second set of two adjacent posts that are disposed farther away from the free edge than the first set of adjacent posts.

27. A display apparatus comprising:

a plurality of interferometric modulator means configured in a matrix forming a plurality of rows and columns, each interferometric modulator means comprising:

first supporting means for supporting a movable reflective layer along two opposite edges such that two other opposing edges of the movable reflective layer are free edges unsupported along at least a portion of the edge; and

a plurality of second supporting means for supporting the movable reflective layer, the plurality of second supporting means being spaced apart to define second supporting means spacing distances between adjacent second supporting means positioned along an axis parallel to one of the first supporting means, wherein the second supporting means spacing distance between adjacent second supporting means along the axis and closest to each free edge is smaller than the second supporting means spacing distance between a plurality of other adjacent second supporting means along the axis.

28. The apparatus of Claim 27, wherein the first supporting means comprises two rails disposed to support opposite edges of the movable reflective layer.

29. The apparatus of Claim 27, wherein the plurality of second supporting means comprises posts.

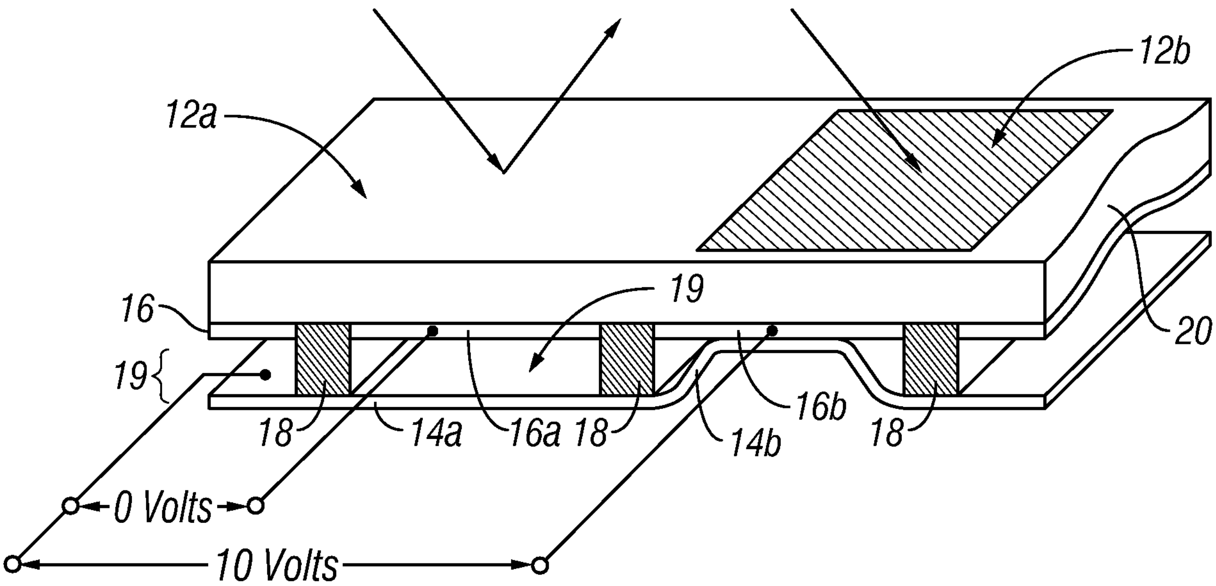

FIG. 1

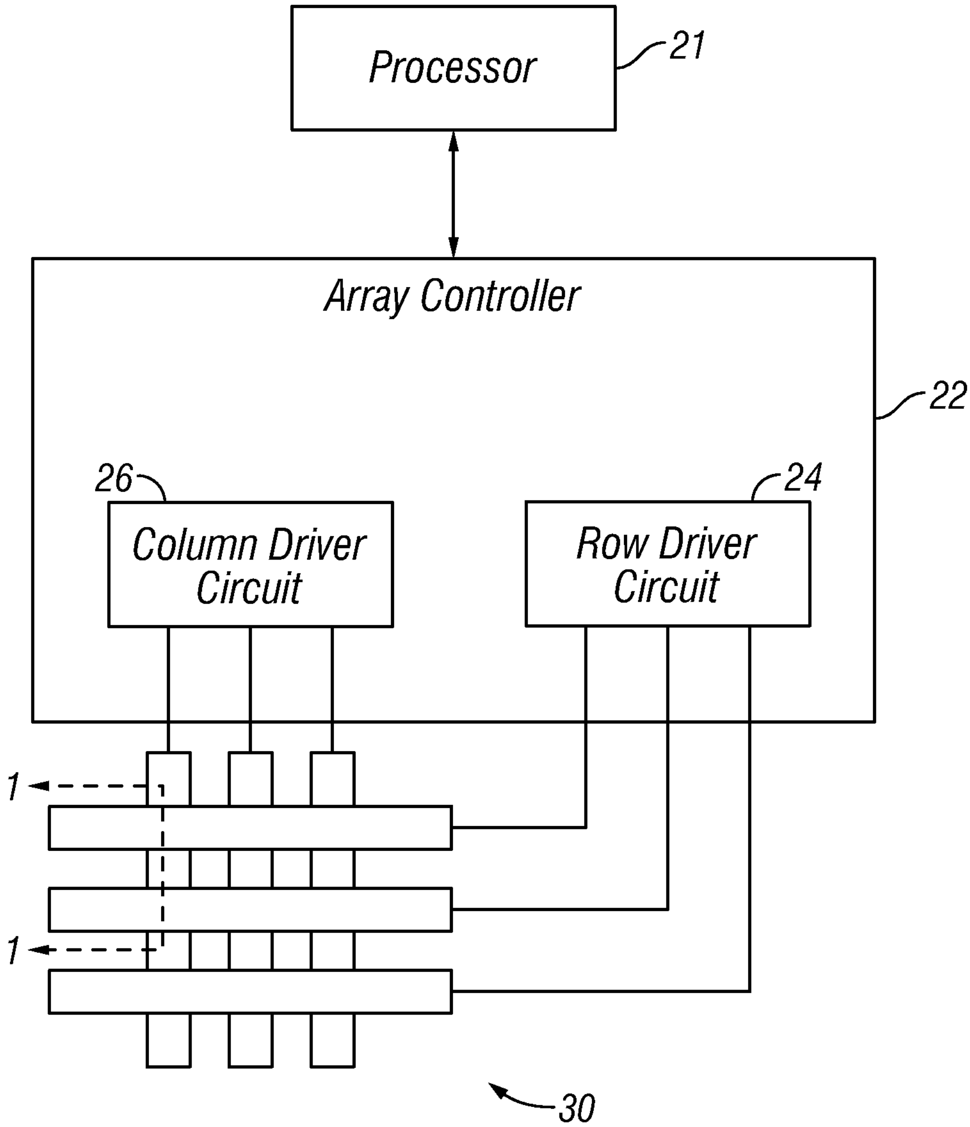
Processor
21
Array Controller
22
26
Column Driver Circuit
24
Row Driver Circuit
1
1
30

FIG. 2

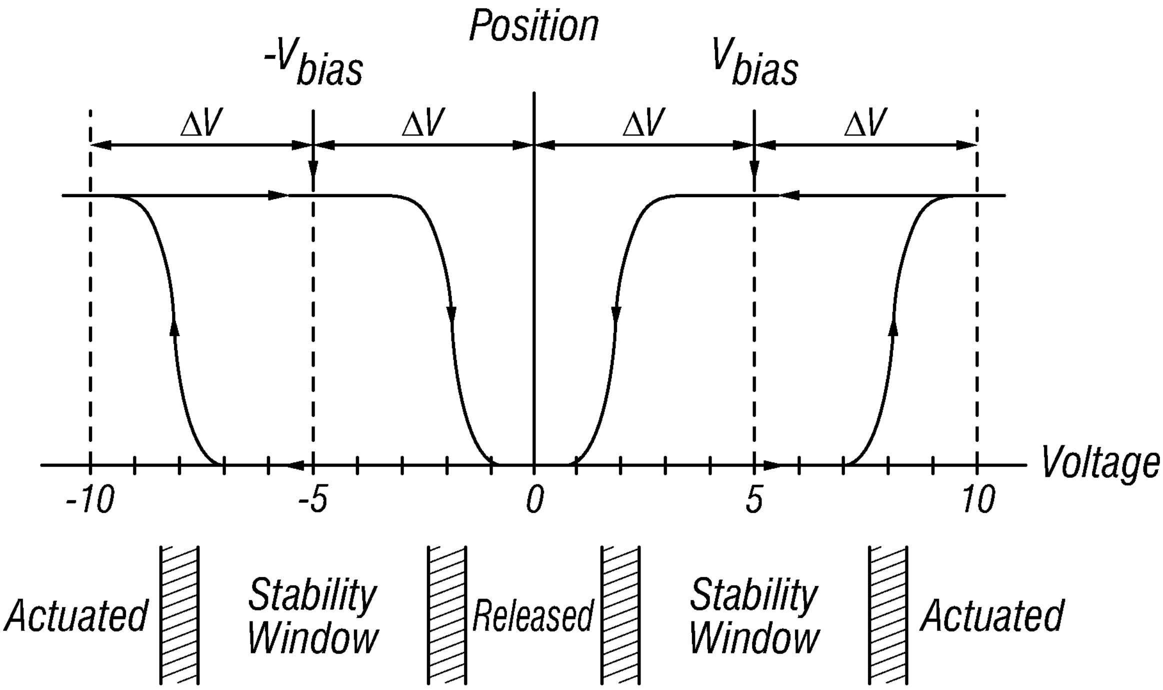

FIG. 3

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

FIG. 4

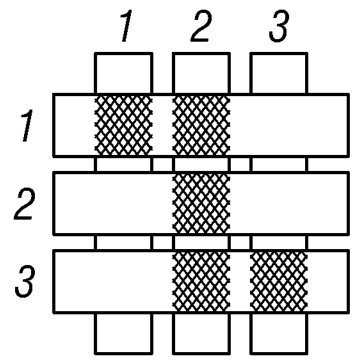
1
2
3
1
2
3

FIG. 5A

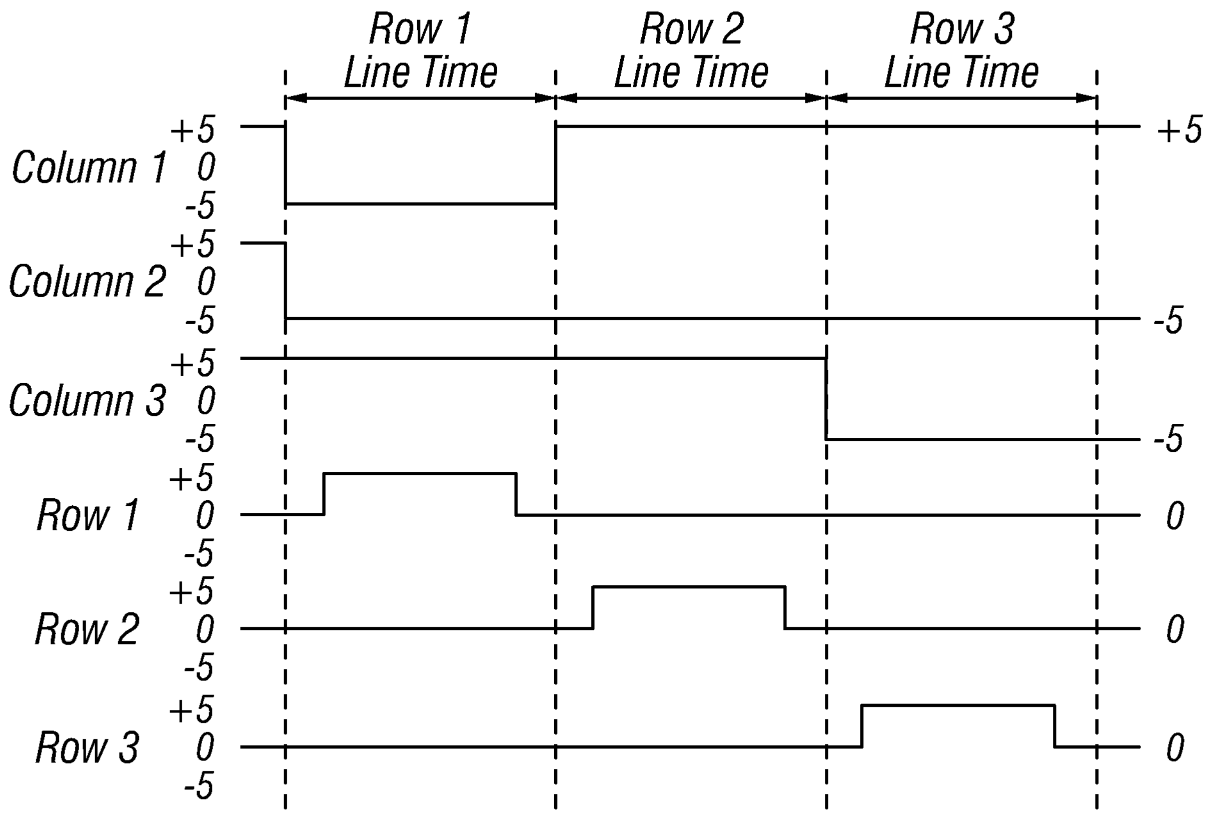
Row 1
Line Time
Row 2
Line Time
Row 3
Line Time
Column 1
Column 2
Column 3
Row 1
Row 2
Row 3
+5
0
-5

FIG. 5B

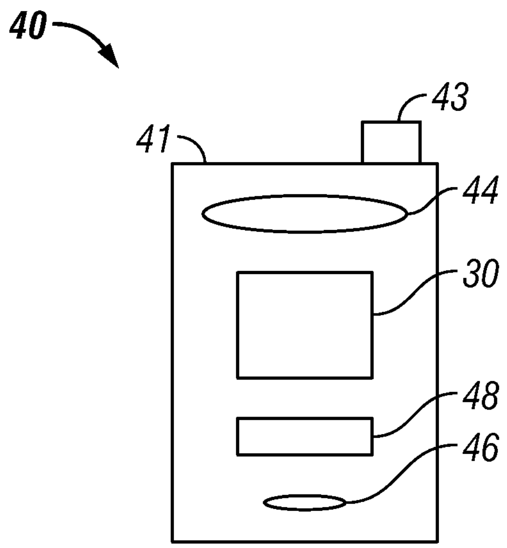
40
43
41
44
30
48
46

FIG. 6A

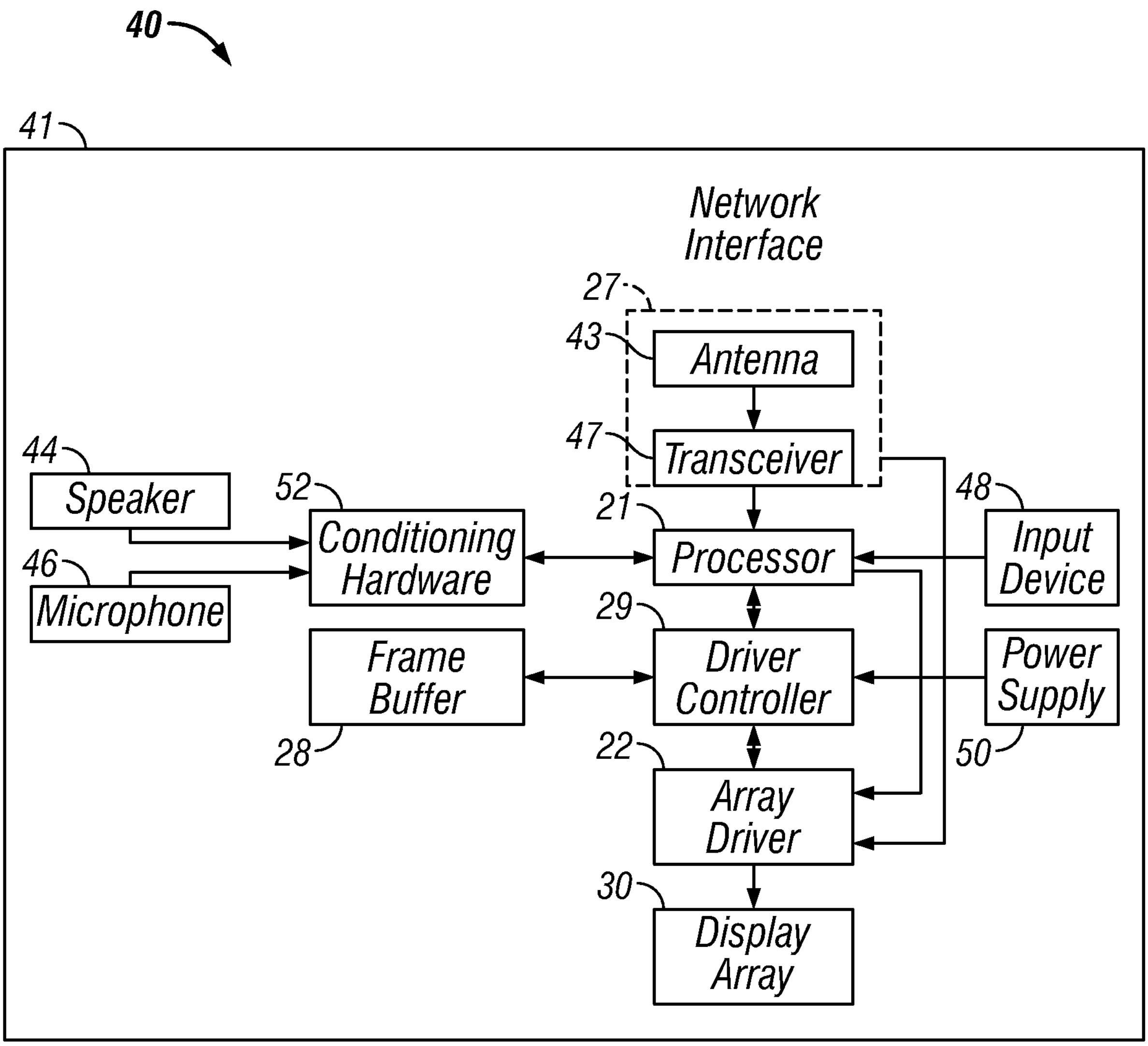
40
41
Network
Interface
27
43
Antenna
47
Transceiver
44
Speaker
52
Conditioning
Hardware
21
Processor
48
Input
Device
46
Microphone
29
Frame
Buffer
Driver
Controller
Power
Supply
28
22
50
Array
Driver
30
Display
Array

FIG. 6B

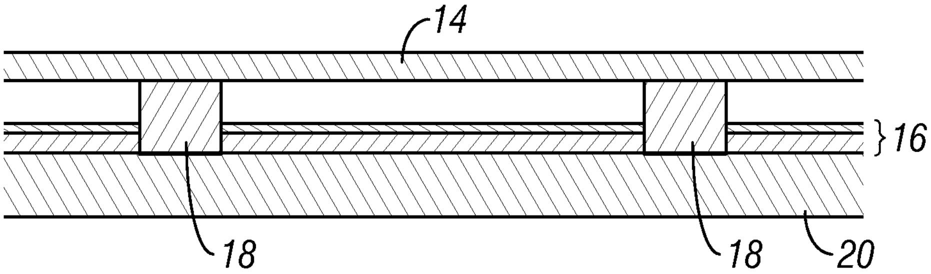

FIG. 7A

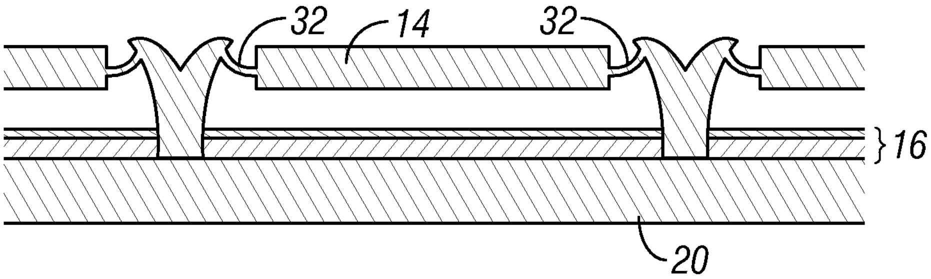

FIG. 7B

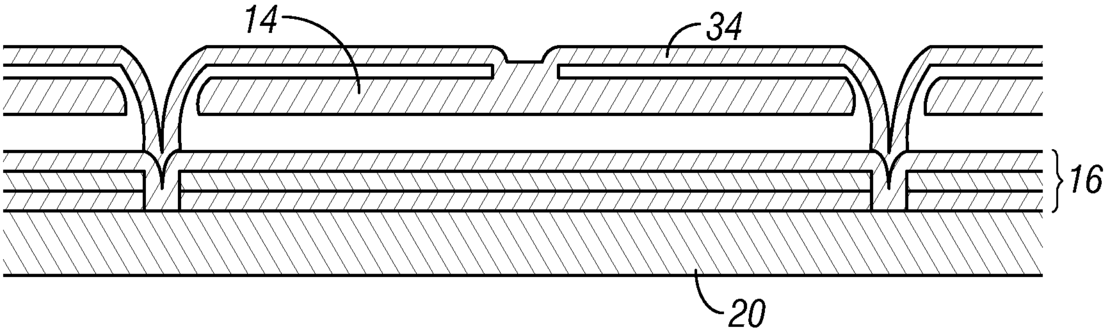

FIG. 7C

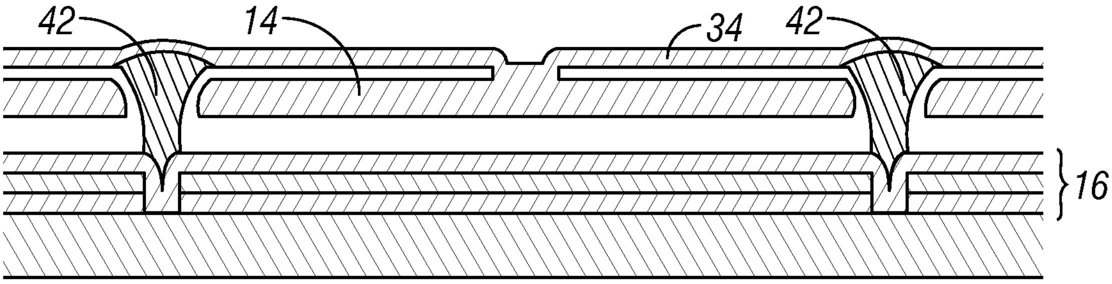

FIG. 7D

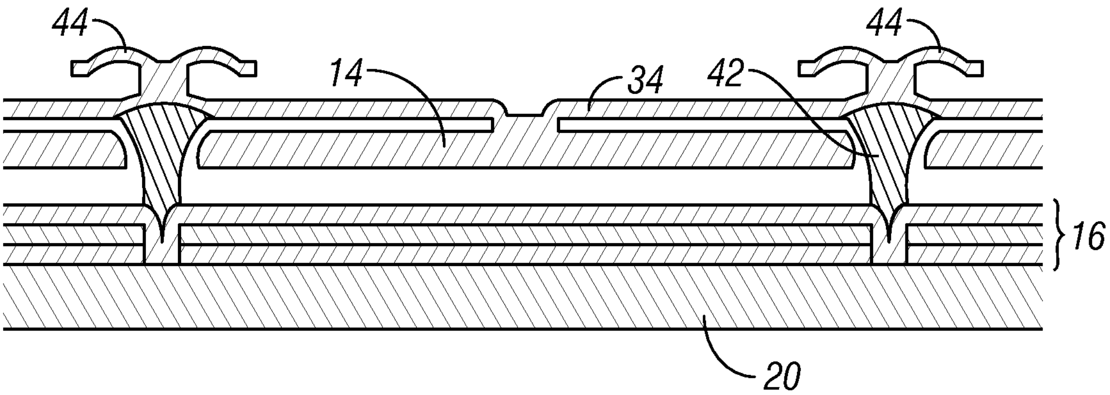

FIG. 7E

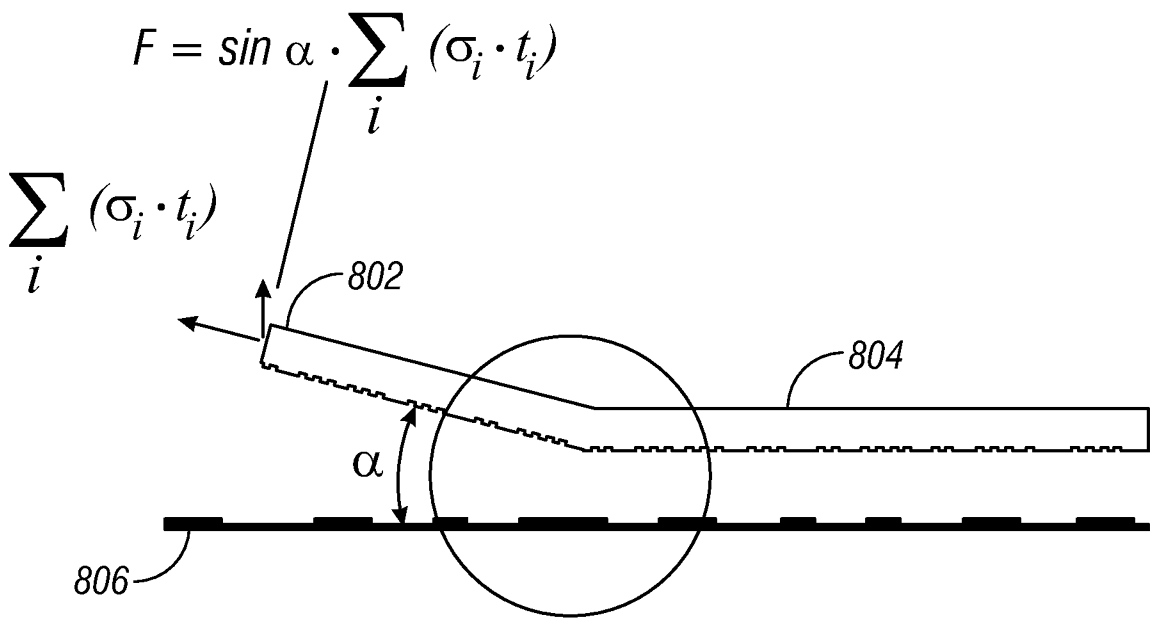
$F = sin\,\alpha \cdot \sum_i (\sigma_i \cdot t_i)$
$\sum_i (\sigma_i \cdot t_i)$
802
804
α
806

FIG. 8

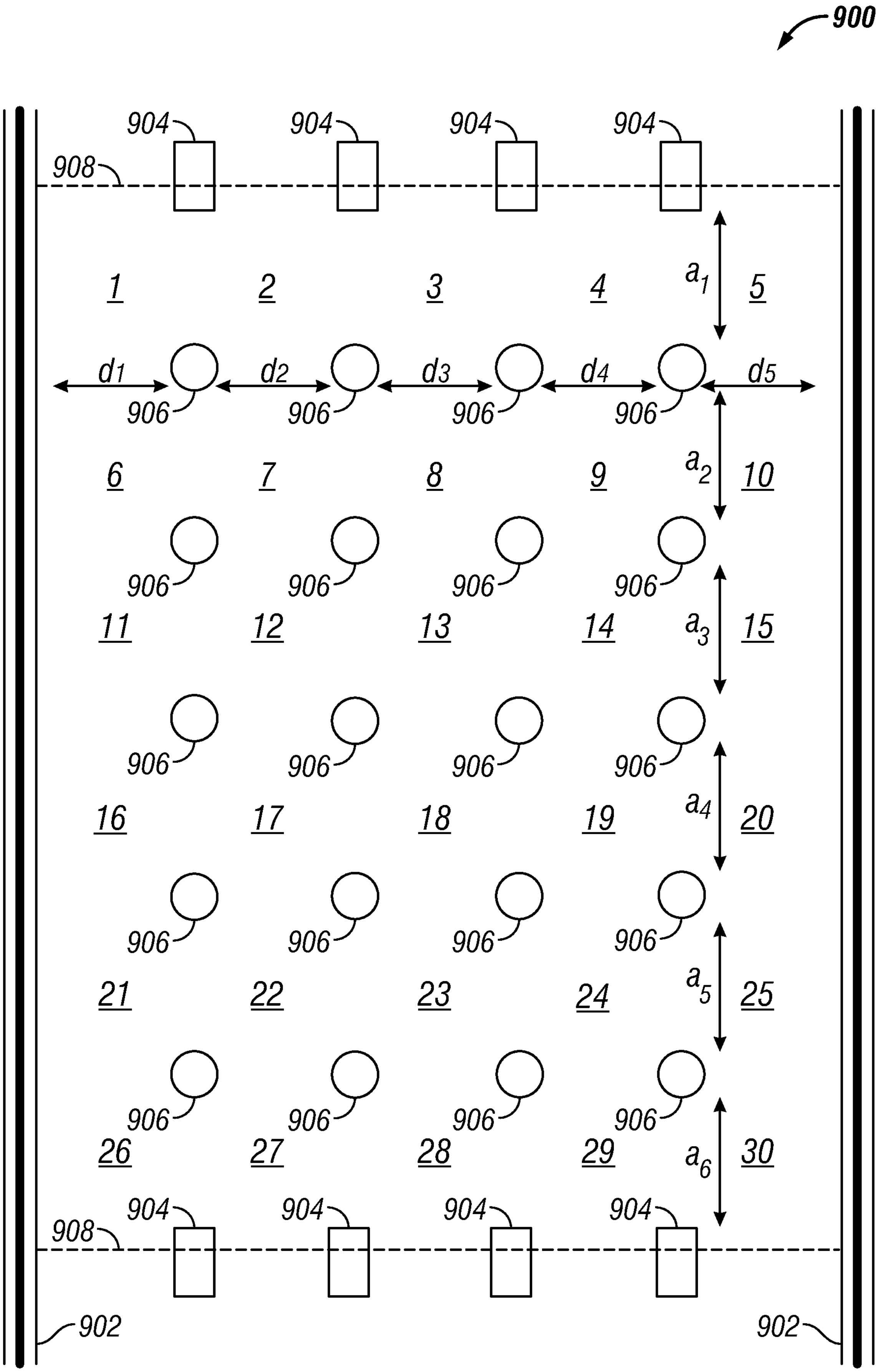
900
904
904
904
904
908
1
2
3
4
5
a_1
d_1
d_2
d_3
d_4
d_5
906
6
7
8
9
10
a_2
11
12
13
14
15
a_3
16
17
18
19
20
a_4
21
22
23
24
25
a_5
26
27
28
29
30
a_6
902
902

FIG. 9

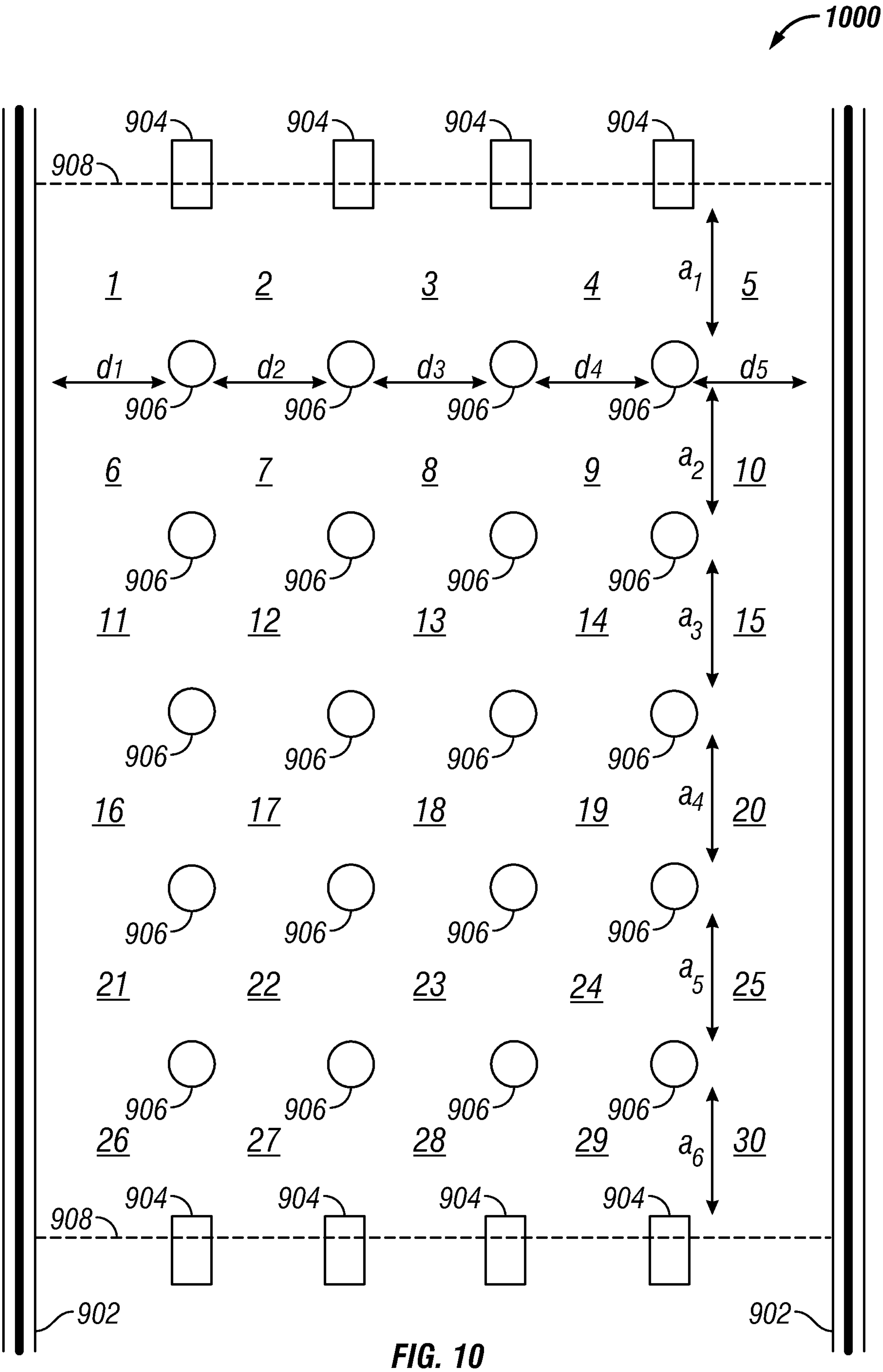
1000
904
904
904
904
908
1
2
3
4
a_1
5
d_1
d_2
d_3
d_4
d_5
906
906
906
906
6
7
8
9
a_2
10
906
906
906
906
11
12
13
14
a_3
15
906
906
906
906
16
17
18
19
a_4
20
906
906
906
906
21
22
23
24
a_5
25
906
906
906
906
26
27
28
29
a_6
30
904
904
904
904
908
902
902

FIG. 10

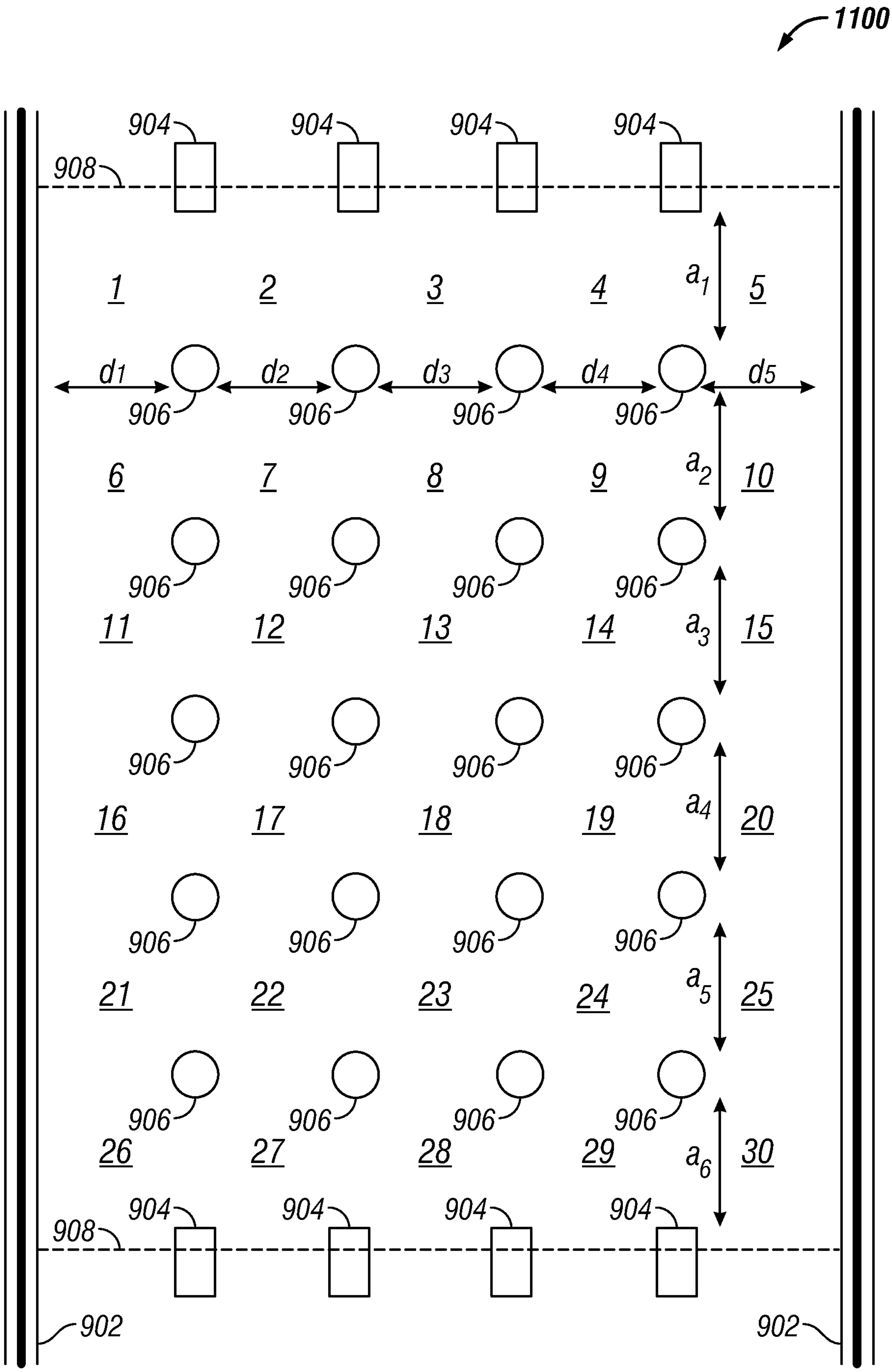
1100
904
904
904
904
908
1
2
3
4
5
a1
d1
d2
d3
d4
d5
906
906
906
906
6
7
8
9
10
a2
906
906
906
906
11
12
13
14
15
a3
906
906
906
906
16
17
18
19
20
a4
906
906
906
906
21
22
23
24
25
a5
906
906
906
906
26
27
28
29
30
a6
904
904
904
904
908
902
902

FIG. 11

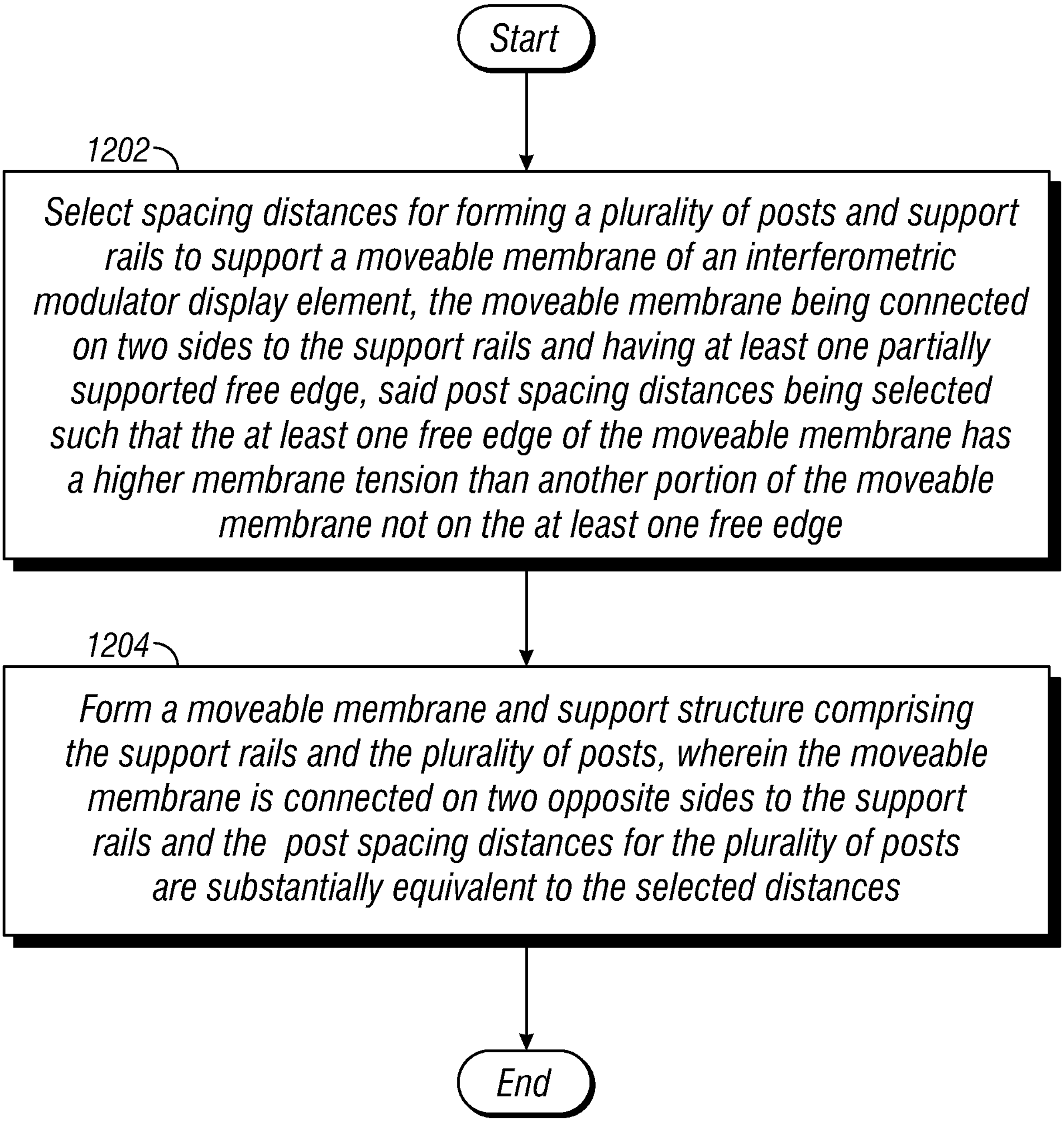
Start
1202
Select spacing distances for forming a plurality of posts and support rails to support a moveable membrane of an interferometric modulator display element, the moveable membrane being connected on two sides to the support rails and having at least one partially supported free edge, said post spacing distances being selected such that the at least one free edge of the moveable membrane has a higher membrane tension than another portion of the moveable membrane not on the at least one free edge
1204
Form a moveable membrane and support structure comprising the support rails and the plurality of posts, wherein the moveable membrane is connected on two opposite sides to the support rails and the post spacing distances for the plurality of posts are substantially equivalent to the selected distances
End

FIG. 12

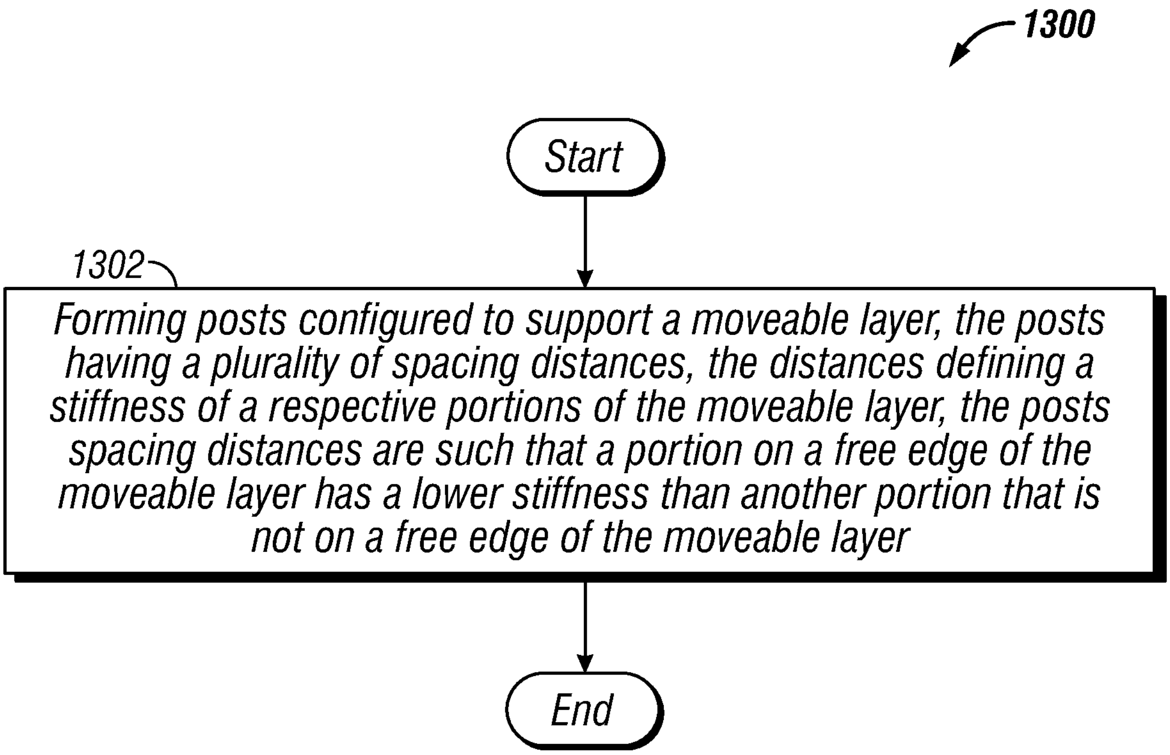
1300
Start
1302
Forming posts configured to support a moveable layer, the posts having a plurality of spacing distances, the distances defining a stiffness of a respective portions of the moveable layer, the posts spacing distances are such that a portion on a free edge of the moveable layer has a lower stiffness than another portion that is not on a free edge of the moveable layer
End

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/053315

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B26/00 B81B3/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B B81B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2006/066864 A1 (CUMMINGS WILLIAM [US] ET AL) 30 March 2006 (2006-03-30) paragraph [0125]; figure 12	1-29 1-29
Y	US 2005/036095 A1 (YEH JIA-JIUN [TW] ET AL) 17 February 2005 (2005-02-17) paragraph [0017] - paragraph [0018] paragraph [0029] - paragraph [0034]; figure 3	1-29
Y	EP 1 640 329 A (IDC LLC [US]) 29 March 2006 (2006-03-29) paragraph [0054]; figure 15 paragraph [0057] - paragraph [0063]; figures 16-23	1-29

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 October 2009	20/10/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	P Theopistou-Bertram

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/053315

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2007/022476 A (QUALCOMM MEMS TECHNOLOGIES INC [US]; KOGUT LIOR [US]; ZHONG FAN [US]) 22 February 2007 (2007-02-22) paragraph [0060]; figure 8	1-29

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2009/053315

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006066864 A1	30-03-2006	JP 2007301719 A	22-11-2007
		JP 2008026877 A	07-02-2008
		JP 2008044093 A	28-02-2008
		JP 2008046603 A	28-02-2008
		JP 2008516267 T	15-05-2008
		KR 20070062586 A	15-06-2007
		KR 20070067707 A	28-06-2007
		KR 20070072574 A	04-07-2007
		KR 20070067708 A	28-06-2007
		KR 20070067709 A	28-06-2007
		US 2006176487 A1	10-08-2006
		US 2006066871 A1	30-03-2006
		US 2006066872 A1	30-03-2006
		US 2006077381 A1	13-04-2006
		WO 2006036601 A2	06-04-2006
US 2005036095 A1	17-02-2005	JP 2005062814 A	10-03-2005
		KR 20050015981 A	21-02-2005
EP 1640329 A	29-03-2006	AU 2005203430 A1	13-04-2006
		BR PI0503937 A	09-05-2006
		CA 2516638 A1	27-03-2006
		JP 2006099069 A	13-04-2006
		KR 20060092877 A	23-08-2006
		MX PA05009409 A	29-03-2006
		SG 121062 A1	26-04-2006
		US 2006076648 A1	13-04-2006
WO 2007022476 A	22-02-2007	CN 101282903 A	08-10-2008
		CN 101258101 A	03-09-2008
		EP 1915319 A1	30-04-2008
		JP 2009505162 T	05-02-2009
		JP 2009505163 T	05-02-2009
		KR 20080055849 A	19-06-2008
		KR 20080055851 A	19-06-2008
		US 2008218840 A1	11-09-2008
		WO 2007022479 A1	22-02-2007
		WO 2007022528 A1	22-02-2007