



(43) International Publication Date
13 September 2012 (13.09.2012)

(51) International Patent Classification:
G01B 7/34 (2006.01)

(21) International Application Number:
PCT/US2012/028098

(22) International Filing Date:
7 March 2012 (07.03.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/045,173 10 March 2011 (10.03.2011) US

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

(72) Inventor; and

(75) Inventor/Applicant (for US only): **SAMPSELL, Jeffrey, B.** [US/US]; 233 S. Alta Vista Lane, Pueblo West, Colorado 81007 (US).

(74) Agent: **ABUMERI, Mark, M.**; Knobbe Martens Olson & Bear LLP, 2040 Main Street, Fourteenth Floor, Irvine, California 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, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, 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, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, 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, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

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

(54) Title: SYSTEM AND METHOD FOR DETECTING SURFACE PERTURBATIONS

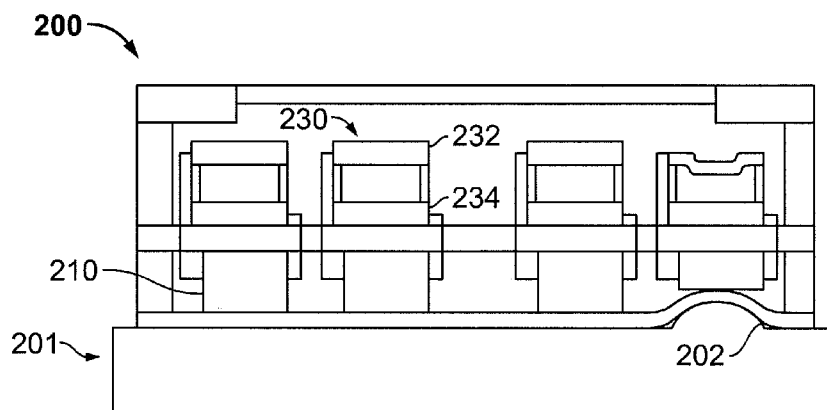


Figure 3A

(57) Abstract: This disclosure provides systems, methods and apparatus for assessing a surface using a piezoelectric element. The method includes applying a device to the surface, wherein the device includes at least one piezoelectric element and at least one electromechanical system (EMS) device, wherein the EMS device includes a conductive first layer separated from a conductive second layer, and wherein the piezoelectric element is electrically coupled to the EMS device such that a force applied to the piezoelectric element results in a voltage applied across the first and second layers. The EMS is an optical interferometric modulator having reflective properties that change in response to an introduction of charge to both the first and the second layers.



WO 2012/122287 A1

SYSTEM AND METHOD FOR DETECTING SURFACE PERTURBATIONS

TECHNICAL FIELD

[0001] This disclosure relates to sensors configured to detect surface perturbations.

DESCRIPTION OF THE 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.

[0003] One type of electromechanical systems device is called an interferometric modulator (IMOD). 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 some implementations, an interferometric modulator may include a pair of conductive plates, one or both of which may be transparent and/or reflective, wholly or in part, and capable of relative motion upon application of an appropriate electrical signal. In an implementation, one plate may include a stationary layer deposited on a substrate and the other plate may include a metallic membrane separated from the stationary layer by an air gap. The position of one plate in relation to another can change the optical interference of light incident on the interferometric modulator. Interferometric modulator devices have a wide range of applications, and are anticipated to be used in improving existing products and creating new products.

[0005] In many manufacturing and quality control processes, it can be desirable to assess the flatness and/or uniformity of a surface. Traditionally, such assessment was performed either by sight or touch of a craftsman or using expensive ultrasonic, optical, or capacitive sensors that use a processor to provide an analysis of the surface under examination. It would be desirable to have a reliable and reproducible method of detecting surface perturbations without the need for expensive equipment

SUMMARY

[0004] The systems, methods and devices of the disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0005] One innovative aspect of the subject matter described in this disclosure can be implemented in a device for assessing a surface. In some implementations, the device includes at least one piezoelectric element and at least one electromechanical system (EMS) device. The EMS device may include a conductive first layer separated from a conductive second layer. The piezoelectric element may be electrically coupled to the EMS device such that a force applied to the piezoelectric element results in an introduction of charge to both the first and second layers.

In some implementations, the at least one piezoelectric element includes a two-dimensional array of piezoelectric elements, the at least one EMS device comprises a two-dimensional array of EMS devices, and each of the piezoelectric elements is electrically coupled to an EMS device at a corresponding location.

In some implementations, the at least one EMS device comprises at least one interferometric modulator. In some implementations, the first layer is at least partially reflective and at least partially transmissive and wherein the second layer is at least partially reflective. In some implementations, the at least one EMS device is stable in a first position and a second position and an introduction of charge to both the first layer and second layer results in a transition from the first position to the second position.

In some implementations, a method of assessing a surface comprises applying a device to the surface, the device comprising at least one piezoelectric element and at least one EMS device including a conductive first layer separated from a conductive

second layer, wherein the piezoelectric element is electrically coupled to the EMS device such that a force applied to the piezoelectric element results in an introduction of charge to both the first and second layers.

In some implementations, the method further includes viewing the at least one EMS device and determining the presence of a perturbation on the surface based on the viewing. The viewing may be performed by an image capturing device and the determining may be performed by a processor.

In some implementations, determining the presence of a perturbation comprises determining that at least one EMS device at a specific location has changed appearance and determining the presence of a perturbation at a corresponding location of the specific location. In some implementations, the method further includes removing the perturbation from the surface. In some implementations, removing the perturbation comprises machining, sanding, or laser-removing the perturbation.

In some implementations, a device for assessing a surface comprises means for generating a voltage in response to an applied force and means for changing reflective properties in response to an applied voltage. The means for generating may be electrically coupled to the means for changing such that a force applied to the means for generating results in a voltage applied across means for changing.

In some implementations, the means for generating comprises at least one piezoelectric element. In some implementations, the means for changing comprises at least one EMS device.

[0006] Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figures 1A and 1B are example block diagrams of a system including a piezoelectric element coupled to an EMS device.

[0008] Figure 2 is an example cross-sectional view of a device for detecting perturbations in a surface.

[0009] Figure 3A is an example cross-sectional view of the device of Figure 2 applied to a surface.

[0010] Figure 3B illustrates the cross-sectional view of Figure 3A with the device in another position.

[0011] Figure 4 is another example cross-sectional view of a device for detecting perturbations in a surface.

[0012] Figure 5 is an example flowchart illustrating a method of assessing a surface.

[0013] Figure 6 is an example flowchart illustrating a method of manufacturing a device for assessing a surface.

[0014] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0015] The following detailed description is directed to certain implementations for the purposes of describing the innovative aspects. However, the teachings herein can be applied in a multitude of different ways. Thus, the teachings are not intended to be limited to the implementations depicted solely in the Figures, but instead have wide applicability as will be readily apparent to one having ordinary skill in the art.

[0016] One implementation described herein includes a sensor with at least one piezoelectric element coupled to at least one EMS device. When pressure is applied to the piezoelectric element, a voltage is generated and applied to opposing surfaces of the EMS device, thereby drawing the opposing surfaces together. Pressure can be applied to the piezoelectric element when the sensor is pressed against a surface. Perturbations or asperities in the surface can result in additional pressure that can result in additional voltage generated by the piezoelectric element. The additional voltage, in turn, can result in additional displacement of the surfaces of the EMS device.

[0017] Particular implementations of the subject matter described in this disclosure can be implemented to realize one or more of the following potential advantages. In some implementations, such a sensor can be incorporated into a device that transforms,

without a battery or external power source, surface perturbations into a false color image that can be viewed by a user to determine locations and magnitudes of such perturbations. Thus, the device can be used to reliably and reproducibly detect surface perturbations without the need for expensive equipment such as a processor or a power source. Of course, in other implementations, the device may include these features, including, for example, a processor or a power source.

[0018] One example of a suitable EMS device, to which the described implementations may apply, is a reflective display device. Reflective display devices can incorporate interferometric modulators (IMODs) to selectively absorb and/or reflect light incident thereon using principles of optical interference. IMODs can include an absorber, a reflector that is movable with respect to the absorber, and an optical resonant cavity defined between the absorber and the reflector. The reflector can be moved to two or more different positions, which can change the size of the optical resonant cavity and thereby affect the reflectance of the interferometric modulator. The reflectance spectrums of IMODs can create fairly broad spectral bands which can be shifted across the visible wavelengths to generate different colors. The position of the spectral band can be adjusted by changing the thickness of the optical resonant cavity, i.e., by changing the position of the reflector.

[0019] Figures 1A and 1B are example block diagrams of a system including a piezoelectric element 110 coupled to an EMS device 130.

[0020] The piezoelectric element 110 generates a voltage across two points of the piezoelectric element 110 when a force F , such as a pressure, is applied to the piezoelectric element 110. The piezoelectric element 110 can be a naturally occurring or man-made material. For example, the piezoelectric element 110 can be quartz, wood, gallium orthophosphate (GaPO_4), langasite ($\text{La}_3\text{Ga}_5\text{SiO}_{14}$), barium titanate (BaTiO_3), lead titanate (PbTiO_3), potassium niobate (KNbO_3), lithium niobate (LiNbO_3), lithium tantalate (LiTaO_3), sodium tungstate (Na_2WO_3), sodium potassium niobate (NaKNb), bismuth ferrite (BiFeO_3), sodium niobate NaNbO_3 , or polyvinylidene fluoride (PVDF). In some implementations, the piezoelectric element 110 is lead zirconate titanate ($\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$, $0 < x < 1$), also known as PZT.

[0021] Depending on how the piezoelectric element 110 is prepared, three main modes of operation can be distinguished: transverse, longitudinal, and shear. In transverse operation, a force applied along a first axis can generate a voltage across a second axis perpendicular to the first axis. The amount of voltage generated can be generally proportional to the applied force and also can depend on the geometric dimensions of the piezoelectric element 110.

[0022] In longitudinal operation, a force applied along a first axis can generate a voltage across the same axis. The amount of voltage generated can be generally proportional to the applied force and may not strongly depend on the geometric dimensions of the piezoelectric element 110. Thus, in some implementations, the piezoelectric element 110 can include many piezoelectric elements 110 mechanically in series and electrically in parallel to increase the resulting voltage.

[0023] In shear operation, as in longitudinal operation, a force applied along a first axis can generate a voltage across the same axis that can be generally proportional to the applied force and may not strongly depend on the geometric dimensions of the piezoelectric element 110.

[0024] As described above, in response to a force applied to the piezoelectric element 110, a voltage can be generated across the piezoelectric element 110. The piezoelectric element 110 can be coupled via one or more conductors 120 to a EMS device 130. Thus, a generated voltage can be applied to the EMS device 130.

[0025] In some implementations, as illustrated in Figure 1A, a first surface 112 of the piezoelectric element 110 can be coupled via a first conductor 122 to a first layer 132 of the EMS device 130 and a second surface 114 can be coupled via a second conductor 124 to a second layer 134 of the EMS device 130. In some other implementations, as illustrated in Figure 1B, a first surface 112 of the piezoelectric element 110 can be coupled via a first conductor 122 to both a first layer 132 and a second layer 134 of the EMS device 130 and a second surface 114 can be coupled via a second conductor 124 to a separate capacitive element 126.

When a force is applied to a piezoelectric element, the element creates a field that moves positive charges in one direction and negative charges in another. In the implementation of Figure 1A, a first conductor 122 connects to a location where positive

charges are transported and a second conductor 124 connects to a location where negative charges are transported. Thus, the first layer 132 and second layer 134 of the EMS device 130 are pulled towards one another as the opposite charges attract. However, in the implementation of Figure 1B, The first conductor 132 couples the first layer 132 and the second layer 134 of the EMS device to the same surface 112 of the piezoelectric element 110. Thus, both the first layer 132 and second layer 134 acquire either negative or positive charges. Thus, the first layer 132 and second layer 134 are pushed apart from one another as the similar charges repel.

[0026] When positive or negative charge is introduced to the first layer 132 and charge of an opposite polarity is introduced to the second layer 134 of the EMS device 130, the first layer 132 and second layer 134 can be attracted to one another. When positive or negative charge is introduced to the first layer 132 and charge of the same polarity is introduced to the second layer 134 of the EMS device 130, the first layer 132 and second layer 134 can be repelled from one another **[0027]** In some implementations, the EMS device 130 can be an interferometric modulator. Thus, the first layer 132 can be conductive, at least partially reflective, and at least partially transmissive and the second layer 134 can be conductive and at least partially reflective. Thus, the cavity between the two surfaces can function as an interferometric cavity. In some implementations, the EMS device 130 can interferometrically modulate at least one visible wavelength of light. In some implementations, the gap distance between the first layer 132 and second layer can be less than 5 μm , less than 4 μm , less than 3 μm , less than 2 μm , or less than 1 μm . The reflective properties of the EMS device 130 can depend, at least in part, on the gap distance between the first layer 132 and the second layer 134. In some implementations, the EMS device 130 can reflect different wavelengths of light depending on the gap distance. Thus, the EMS device 130 can appear as a different color depending on the gap distance, which is a function of the voltage applied which is, in turn, a function of the force applied to the piezoelectric element 110.

[0028] In other implementations, the EMS device can be a cantilevered device in which a first surface can bend towards a second surface when a voltage is applied across the surfaces. In other implementations, the EMS device can be a liquid crystal element

that can change its absorptive properties when a voltage is applied across the surfaces. In some implementations, the EMS device can be a spatial light modulator. In some implementations, the EMS device can be a holographic spatial light modulator. Each of these EMS devices can change its reflective properties in response to an applied voltage.

[0029] The gap distance of the EMS device can be a static distance when no voltage is applied to the device. However, as mentioned above, when a force is applied to the piezoelectric element 110, the gap distance and reflective properties of the EMS device 130 can change. Thus, the gap distance of the EMS device can be a deflected distance whose amount of deflection is based on the force applied to the piezoelectric element 110. When the force is removed, the piezoelectric element 110 may no longer generate a voltage and, therefore, a voltage may not be applied to the EMS device 130. In some implementations, because of hysteresis in the materials of the EMS device 130, the EMS device 130 can automatically return to the static distance.

In some implementations, the EMS device 130 does not automatically return to the static gap distance, but requires application of a reset voltage to return the EMS 130 device to the static gap distance. Thus, the device 100 retains an image of the surface perturbations until the reset voltage is applied.

[0030] Although the piezoelectric element 110 can be modeled as a voltage source when a force is applied, the piezoelectric element 110 may be dissimilar to a battery in that the piezoelectric element may not continuously generate a current. Particularly, in response to an amount of applied force, the piezoelectric element 110 can generate a proportional amount of charge. If this charge is removed by, for example, completing a circuit between the two sides of the piezoelectric element 110 or by coupling both sides of the piezoelectric element 110 to a ground potential, the piezoelectric element 110 may be rendered inert. Once the circuit is broken and the force removed, an opposite charge can be generated. This charge can also be removed by completing a circuit between the two sides or by coupling both sides to a ground potential. However, in the implementation illustrated in Figure 1, no circuit is formed and a maintained force can generate a maintained voltage applied across the first layer 132 and second layer 134 of the EMS device 130.

[0031] The system 100 and principles described above with respect to Figure 1 can be used in a device for detecting perturbations in a surface. Figure 2 is an example cross-sectional view of a device for detecting perturbations in a surface. The device 200 can include an array of piezoelectric elements 210, each electrically coupled to at least one interferometric modulator 230. The coupling of the piezoelectric elements 210 to the interferometric modulators 230 can be one-to-one, many-to-one, or one-to-many. In some implementations, the device can include a two-dimensional array of piezoelectric elements 210 and a two-dimensional array of interferometric modulators 230 and each piezoelectric element 210 can be coupled to an interferometric modulator 230 at a corresponding location.

[0032] In some implementations, such as the implementation illustrated in Figure 2, each piezoelectric element 210 can be coupled to an interferometric modulator 230 by two conductors 222, 224. In particular, a first side of the piezoelectric element 210 can be coupled by a first conductor 222 to a first layer 232 of the interferometric modulator 230 and a second side of the piezoelectric element 210 can be coupled by a second conductor 224 to a second layer 234 of the interferometric modulator 230. The first layer 232 of the interferometric modulator 230 can be conductive, at least partially reflective, and at least partially transmissive. The second layer 234 of the interferometric modulator 230 can be conductive and at least partially reflective. The first layer 232 and second layer 234 can be separated by support posts 233.

[0033] The array of piezoelectric elements 210 can be supported and protected by a flexible membrane 240 that can be applied to the surface 201 to be tested. The flexible membrane 240 can be made of an elastomer or other suitable material. An elastomer can be an elastic polymer, such as rubber. The array of piezoelectric elements 210 can be sandwiched between the flexible membrane 240 and a substrate 250. The piezoelectric elements 210 can be directly attached to the flexible membrane 240 or can be formed on or attached to the substrate 250. Similarly, the interferometric modulators can be formed on the substrate 250. The substrate 250 can be formed of glass, plastic, metal, ceramic, or any suitable material.

[0034] The degree of flexibility of the flexible membrane 240 can be made commensurate with a range of surface irregularity to be measured. An artisan or user

might use multiple such devices 200 as a series of inspection tools of various sensitivity, just as the surface to be measured might have been created through the use of a series of progressively less coarse sand papers.

[0035] In some implementations, the device 200 can also include a housing 260 that protects the interferometric modulators. The housing 260 can be formed of glass, plastic, metal, ceramic, or any suitable material. In some implementations, the housing 260 can include a transparent window 262 through which the interferometric modulators 230 can be viewed by a user of the device 200. In some implementations, the housing 260 can include a portion 245 between the flexible membrane 240 and the substrate 250. In some implementations, the portion 245 can be elastic, allowing for pressure from a uniformly flat surface to be applied to all the piezoelectric elements 210 simultaneously. In other implementations, the portion 245 can be rigid such that only perturbations 202 in the surface 201 result in pressure applied to the piezoelectric elements 210.

[0036] When the device 200 is pressed against the surface 201, pressure from the surface can push against the flexible membrane 240. The piezoelectric elements 230 can be squeezed between the flexible membrane 240 and the substrate 250, thereby deforming the piezoelectric elements 210 and generating a voltage that can be applied to the interferometric modulator 230 via the conductors. The first layer 232 of each interferometric modulator 230 can be displaced with respect to the second layer 234 according to the amount of voltage applied via the conductors. In some implementations, the second layer 234 is rigidly attached to the substrate 250 and, therefore, may not be displaced. When the first layer 232 is displaced relative to the second layer 234, the reflective properties and apparent color of the interferometric modulator 230 can change, revealing to a user the amount of force applied to the corresponding piezoelectric element 210.

[0037] In some implementations, perfect surface flatness can be displayed as magenta, and increasing deviations from flatness can cause the interferometric modulator 230 to display red, orange, yellow, green, cyan and blue. In other implementations, the colors are reversed.

[0038] Figure 3A is an example cross-sectional view of the device of Figure 2 applied to a surface. When the device 200 is pressed against the surface 201, the

perturbation 202 can press against the rightmost piezoelectric element 210. The piezoelectric element 210 can deform and generate a voltage. The voltage can be applied to the interferometric modulator 230 in the corresponding location, resulting in the first layer 232 of the interferometric modulator moving closer the second layer 234. Thus, the reflective properties and the apparent color of the interferometric modulator 230 can change and, in particular, differ from the apparent color of the other interferometric modulators 230. Thus, a user of the device 200 can detect and locate the perturbation 202.

[0039] Figure 3B illustrates the cross-sectional view of Figure 3A with the device in another position. If the device 200 is moved along the surface 201, the relative position of the perturbation 202 with respect to the device 200 can change. Thus, the perturbation 202 can apply a force to a different piezoelectric element 210 resulting in a change of color of a different interferometric modulator 230. Thus, a user of the device 200 can detect and locate the perturbation 202 by moving the device along the surface 201.

[0040] In some implementations, the device 200 also can include an image capture device to image the interferometric modulators 230. In some implementations, such imaging can include measuring the capacitance of each interferometric modulator 230 and saving this information into a memory.

[0041] As described above with respect to Figure 1, if two surfaces of a piezoelectric element 210 are electrically coupled, or if both surfaces are coupled to ground, a current can flow removing charge accumulated by the piezoelectric element. In some implementations, the device 200 can include shunts that can, based on input from a user, selectively discharge the accumulated charge of the piezoelectric elements 210 by either electrically coupling both surfaces together or by electrically coupling both surfaces to a ground potential. Thus, if a user of the device 200 activates the shunts, the device can be zeroed to a particular pressure profile. This can be useful to reset the device before assessing a surface.

[0042] Figure 4 is another example cross-sectional view of a device for detecting perturbations in a surface. The device 400 of Figure 4 can be the same as the device 200 of Figure 2 except for the relative position of the interferometric modulators 230 with respect to the substrate 250. Whereas, in some implementations, such as the device 200

illustrated in Figure 2, the interferometric modulators 230 can be attached to substrate 250 against which the piezoelectric elements 210 can be pressed, in other implementations, such as the device 400 illustrated in Figure 4, the interferometric modulators can be attached to a second substrate 452 that is not between the interferometric modulators and the piezoelectric elements. In some implementations, the second substrate 452 can also perform the function of the window, thereby reducing the number of parts and simplifying construction of the tool.

[0043] Figure 5 is an example flowchart illustrating a method of assessing a surface. The method 500 can begin in block 510 by applying a device to the surface such as the device 200 of Figure 2. In particular, the device can include at least one piezoelectric element and at least one EMS device including a conductive first layer separated from a conductive second layer. In some implementations, the piezoelectric element can be electrically coupled to the EMS device such that a force applied to the piezoelectric element results in a voltage applied across the first and second layers. Thus, a perturbation of a surface can be detected. In some implementations, the device can be applied by a user, such as a craftsman, a manufacturer, or a quality control inspector. In other implementations, the device can be applied automatically by a testing machine. In some implementations, applying the device to the surface can include moving the device along the surface.

[0044] In some implementations, the at least one piezoelectric element can include a two-dimensional array of piezoelectric elements. Likewise, in some implementations, the at least one EMS device can include a two-dimensional array of EMS devices. In some implementations, each of the piezoelectric elements can be electrically coupled to a EMS device at a corresponding location. The at least one EMS device can include, for example, an interferometric modulator or a two-dimensional array of interferometric modulators. In particular, in some implementations, the first layer can be at least partially reflective and at least partially transmissive and the second layer can be at least partially reflective.

[0045] In some implementations, the device can include a flexible membrane and a substrate and the at least one piezoelectric element can be sandwiched between the flexible membrane and the substrate. Thus, applying the device to the surface can

include applying a flexible membrane of the device to the substrate. In some implementations, the device can include a housing. Thus, applying the device to the surface can include holding the device by the housing and moving the device along the surface.

[0046] The method 500 can continue to block 520 by viewing the at least one EMS device. In some implementations, the housing can include a transparent window through which a user can view the at least one EMS device. In some implementations, the viewing can be performed by a user. In other implementations, the viewing can be performed by a testing machine including a camera or other image capturing device.

[0047] The method 500 can continue to block 530 by determining the presence of a perturbation on the surface based on the viewing. Determining the presence can include, for example, determining that at least one MEMS device at a specific location has changed appearance and determining the presence of a perturbation at a corresponding location of the specific location. In some implementations, the determining can be performed by a user. In other implementations, the determining can be performed by a testing machine including a processor which determines the presence of a perturbation based on a captured image of the at least one EMS device. In some implementations, the changed appearance may be a changed color of the at least one MEMS device. In some other implementations, the changed appearance may be a change brightness of the at least one MEMS device.

[0048] The method 500 can continue to block 540 by removing the perturbation from the surface. The perturbation can be removed by machining the perturbation, sanding the perturbation, laser-removing the perturbation, etc. In some implementations, the perturbation can be removed by a user, such as a craftsman or a quality control inspector. In other implementations, the perturbation can be removed automatically by a testing or finishing machine.

[0049] Once a perturbation is removed, the method 500 can end or repeat (in block 540) to further assess the surface and remove other perturbations.

[0050] Figure 6 is an example flowchart illustrating a method of manufacturing a device for assessing a surface. The method 600 can begin in block 610 by electrically coupling at least one piezoelectric element to at least one EMS device including a

conductive first layer separated from a conductive second layer. The piezoelectric element can be electrically coupled to the EMS device such that a force applied to the piezoelectric element results in a voltage applied across the first and second layers. The electrical coupling can be performed, for example, by positioning the piezoelectric element next to the EMS device or by connecting conductors between the piezoelectric element and the EMS device.

[0051] In some implementations, the coupling can include electrically coupling a two-dimensional array of piezoelectric elements to a two-dimensional array of EMS devices such that each of the piezoelectric elements is electrically coupled to a EMS device at a corresponding location. In some implementations, the at least one EMS device can include at least one interferometric modulator or a two-dimensional array of interferometric modulators.

[0052] In some implementations, the method 600 can include sandwiching the at least one EMS device between a flexible membrane and a substrate. In some implementations, the flexible membrane can be made of an elastomer and the substrate can be made of glass, plastic, metal, or ceramic. In some implementations, the method 600 also can include forming the at least one EMS device on the substrate. The at least one EMS element can be formed as an interferometric modulator, a cantilevered device, a liquid crystal element, a spatial light modulator, or a holographic spatial light modulator. In some implementations, the method 600 can include forming the at least one EMS device on a second substrate.

[0053] The various illustrative logics, logical blocks, modules, circuits and algorithm steps described in connection with the implementations disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. The interchangeability of hardware and software has been described generally, in terms of functionality, and illustrated in the various illustrative components, blocks, modules, circuits and steps described above. Whether such functionality is implemented in hardware or software depends upon the particular application and design constraints imposed on the overall system.

[0054] The hardware and data processing apparatus used to implement the various illustrative logics, logical blocks, modules and circuits described in connection with the

aspects disclosed herein may be implemented or performed with a general purpose single- or multi-chip processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, or, any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some implementations, particular steps and methods may be performed by circuitry that is specific to a given function.

[0055] In one or more aspects, the functions described may be implemented in hardware, digital electronic circuitry, computer software, firmware, including the structures disclosed in this specification and their structural equivalents thereof, or in any combination thereof. Implementations of the subject matter described in this specification also can be implemented as one or more computer programs, i.e., one or more modules of computer program instructions, encoded on a computer storage media for execution by, or to control the operation of, data processing apparatus.

[0056] If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. The steps of a method or algorithm disclosed herein may be implemented in a processor-executable software module which may reside on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that can be enabled to transfer a computer program from one place to another. A storage media may be any available media that may be accessed by a computer. By way of example, and not limitation, such computer-readable media may include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Also, any connection can be properly termed a computer-readable medium.

Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and instructions on a machine readable medium and computer-readable medium, which may be incorporated into a computer program product.

[0057] Various modifications to the implementations described in this disclosure may be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the disclosure is not intended to be limited to the implementations shown herein, but is to be accorded the widest scope consistent with the claims, the principles and the novel features disclosed herein. The word “exemplary” is used exclusively herein to mean “serving as an example, instance, or illustration.” Any implementation described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other implementations. Additionally, a person having ordinary skill in the art will readily appreciate, the terms “upper” and “lower” are sometimes used for ease of describing the figures, and indicate relative positions corresponding to the orientation of the figure on a properly oriented page, and may not reflect the proper orientation of the IMOD as implemented.

[0058] Certain features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0059] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

CLAIMS

What is claimed is:

1. A device for assessing a surface, the device comprising:
at least one piezoelectric element; and
at least one electromechanical system (EMS) device including a
conductive first layer separated from a conductive second layer,
wherein the piezoelectric element is electrically coupled to the EMS
device such that a force applied to the piezoelectric element results in an
introduction of charge to both the first and second layers.
2. The device of claim 1, wherein the at least one piezoelectric element
comprises a two-dimensional array of piezoelectric elements, wherein the at least one
EMS device comprises a two-dimensional array of EMS devices, and wherein each of the
piezoelectric elements is electrically coupled to a EMS device at a corresponding
location.
3. The device of claim 1, wherein the at least one piezoelectric element
comprises lead zirconate titanate.
4. The device of claim 1, the at least one EMS device having reflective
properties that change in response to an introduction of charge to both the first and
second layers.
5. The device of claim 1, wherein the at least one EMS device comprises at
least one interferometric modulator.
6. The device of claim 1, wherein the first layer is at least partially reflective
and at least partially transmissive and wherein the second layer is at least partially
reflective.
7. The device of claim 1, wherein the piezoelectric element is electrically
coupled to the EMS device via at least one conductor.
8. The device of claim 1, wherein a first surface of the piezoelectric element
is electrically coupled to the first layer and wherein a second surface of the piezoelectric
element is electrically coupled to the second layer.

9. The device of claim 1, further comprising a separate capacitive element, wherein a first surface of the piezoelectric element is electrically coupled to both the first layer and the second layer and a second surface of the piezoelectric element is electrically coupled to the separate capacitive element.

10. The device of claim 1, further comprising a flexible membrane and a substrate, wherein the at least one piezoelectric element is sandwiched between the flexible membrane and the substrate.

11. The device of claim 10, further comprising a housing, wherein the housing comprises a transparent window through which a user can view the at least one MEM device.

12. The device of claim 11, wherein the housing comprises a rigid portion between the flexible membrane and the substrate.

13. The device of claim 11, wherein the housing comprises a flexible portion between the flexible membrane and the substrate.

14. The device of claim 10, wherein the at least one EMS device is formed on the substrate.

15. The device of claim 10, further comprising a second substrate, wherein the at least one EMS device is formed on the second substrate.

16. The device of claim 1, further comprising one or more shunts configured to discharge accumulated charge from the piezoelectric element.

17. The device of claim 16, further comprising a user input device which, when used by a user, causes the shunts to discharge the accumulated charge.

18. The device of claim 1, wherein the at least one EMS device is stable in a first position and a second position and wherein an introduction of charge to both the first layer and second layer results in a transition from the first position to the second position.

19. The device of claim 18, further comprising a user input device which, when used by a user, causes the at least one EMS device to transition from the second position to the first position.

20. The device of claim 1, further comprising an image capture device configured to image the at least one EMS device.

21. The device of claim 20, wherein the image capture device is configured to measure a capacitance of the at least one EMS device.

22. The device of claim 21, wherein the image capture device further comprises a memory to store the measured capacitances.

23. The device of claim 1, further comprising at least one of a processor or a power source.

24. A method of assessing a surface, the method comprising:

applying a device to the surface, the device comprising at least one piezoelectric element and at least one EMS device including a conductive first layer separated from a conductive second layer, wherein the piezoelectric element is electrically coupled to the EMS device such that a force applied to the piezoelectric element results in an introduction of charge to both the first and second layers.

25. The method of claim 24, further comprising:

viewing the at least one EMS device; and

determining the presence of a perturbation on the surface based on the viewing.

26. The method of claim 25, wherein viewing the at least one EMS device is performed by an image capturing device and wherein determining the presence of a perturbation on the surface is performed by a processor.

27. The method of claim 25, wherein determining the presence of a perturbation comprises:

determining that at least one EMS device at a specific location has changed appearance; and

determining the presence of a perturbation at a corresponding location of the specific location.

28. The method of claim 25, further comprising removing the perturbation from the surface.

29. The method of claim 28, further comprising repeating the method for a plurality of perturbations.

30. The method of claim 28, wherein removing the perturbation comprises machining, sanding, or laser-removing the perturbation.

31. The method of claim 24, wherein the device comprises a flexible membrane and applying the device to the surface comprises applying the flexible membrane to the surface.

32. The method of claim 24, further comprising:

applying a second device to the surface, the second device comprising at least one piezoelectric element and at least one EMS device including a conductive first layer separated from a conductive second layer, wherein the piezoelectric element is electrically coupled to the EMS device such that a force applied to the piezoelectric element results in a voltage applied across the first and second layers,

wherein the second device comprises a second flexible membrane and applying the second device to the surface comprises applying the second flexible membrane to the surface, and

wherein the flexible membrane and the second flexible membrane have different degrees of flexibility.

33. The method of claim 24, further comprising moving the device.

34. A device for assessing a surface, the device comprising:

means for generating a voltage in response to an applied force; and

means for changing reflective properties in response to an applied voltage,

wherein the means for generating is electrically coupled to the means for changing such that a force applied to the means for generating results in a voltage applied across means for changing.

35. The device of claim 34, wherein the means for generating comprises at least one piezoelectric element.

36. The device of claim 34, wherein the means for changing comprises at least one EMS device.

37. The device of claim 34, wherein the means for changing comprises at least one interferometric modulator.

38. The device of claim 34, wherein means for generating is electrically coupled to means for generating via at least one means for conducting electric current.

39. The device of claim 34, further comprising means for flexing and a means for supporting, wherein the means for generating is sandwiched between the means for flexing and the means for supporting.

40. The device of claim 34, further comprising means for housing, wherein the means for housing comprises a transparent means through which a user can view the means for changing.

41. The device of claim 34, further comprising means for discharging accumulated charge of the means for generating.

42. The device of claim 41, further comprising means for receiving user input which, when used by a user, causes the means for discharging to discharge the accumulated charge.

43. The device of claim 34, further comprises at least one of means for processing or means for providing power.

1/6

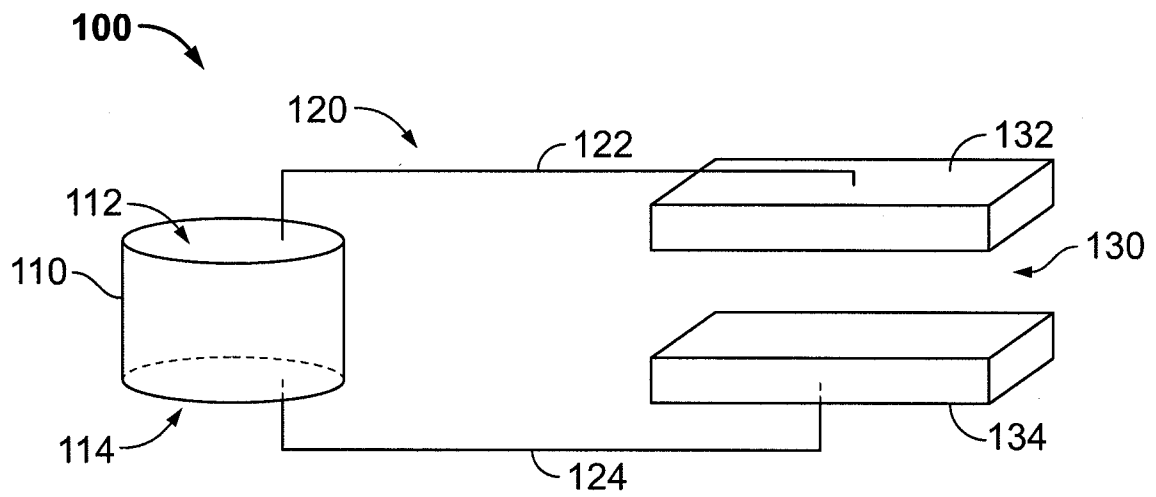


Figure 1A

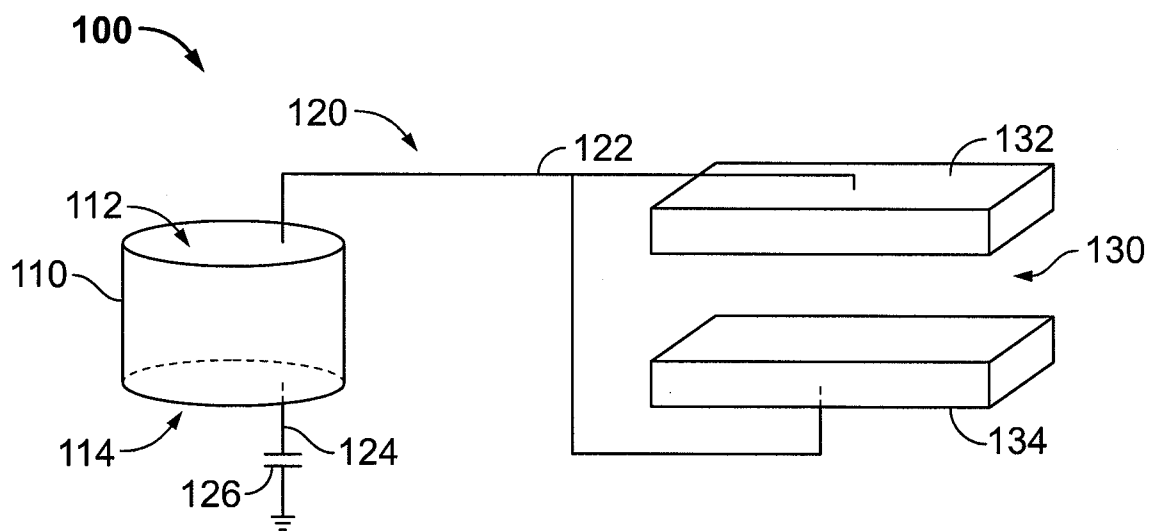


Figure 1B

2/6

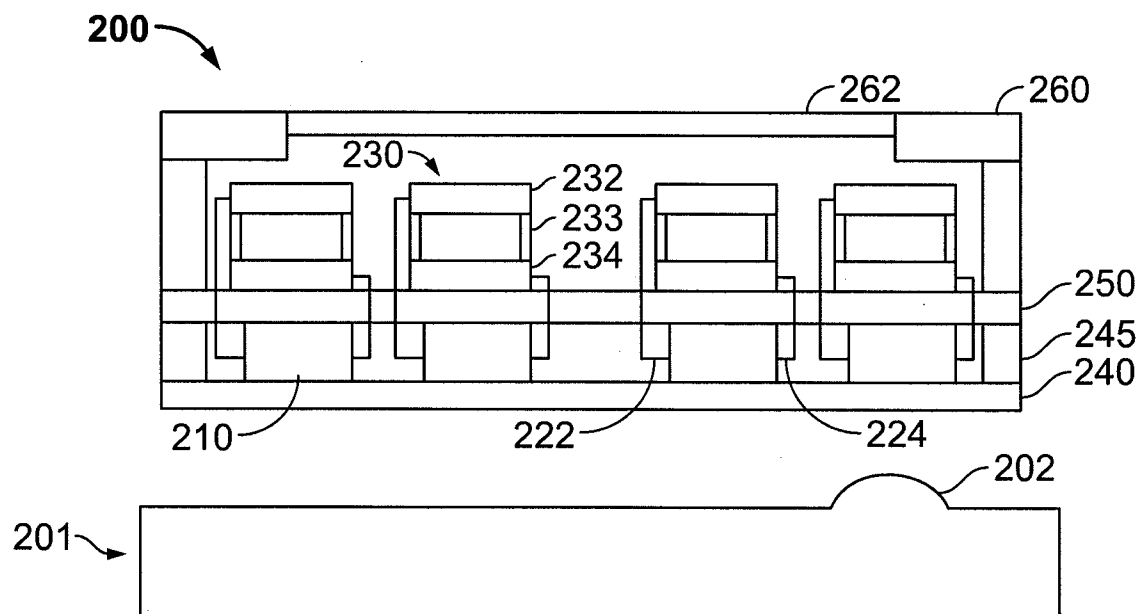


Figure 2

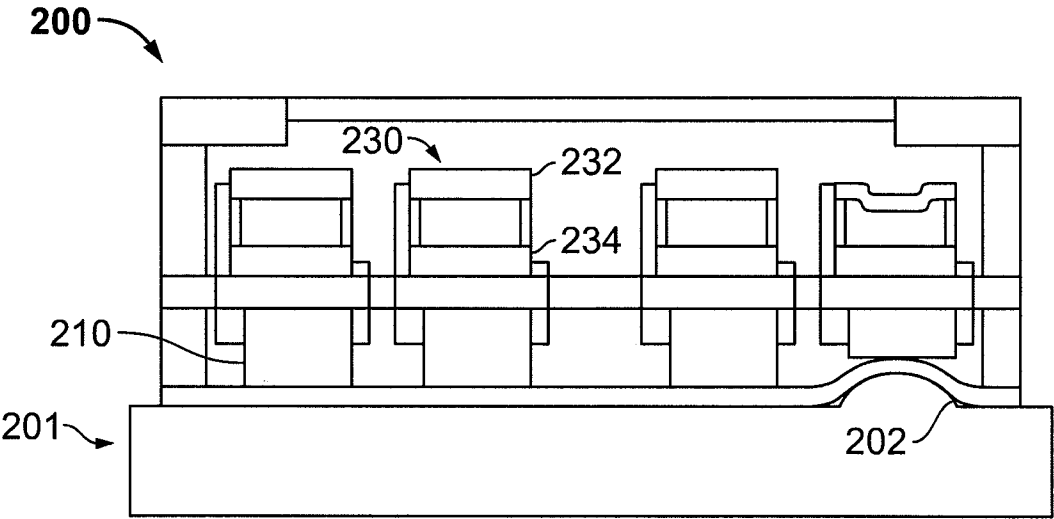


Figure 3A

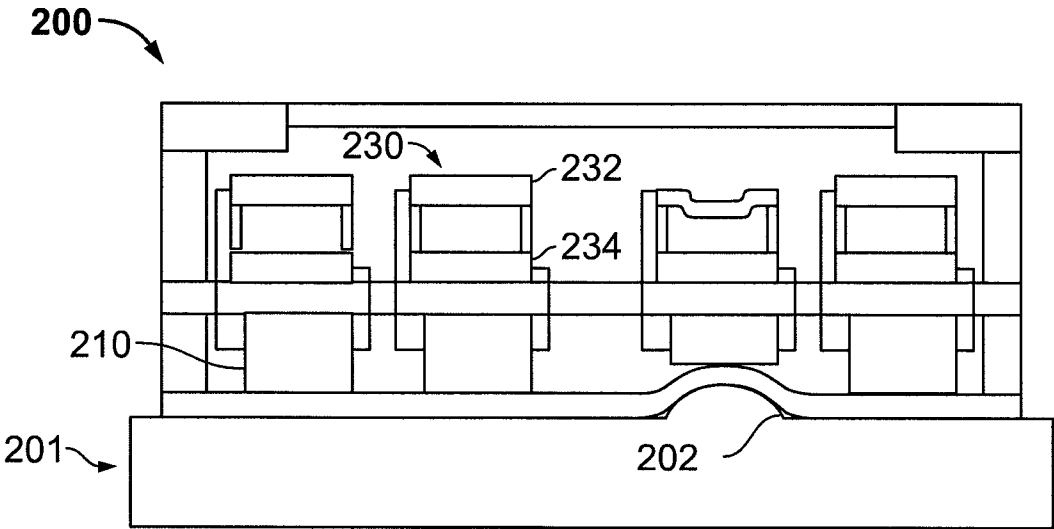


Figure 3B

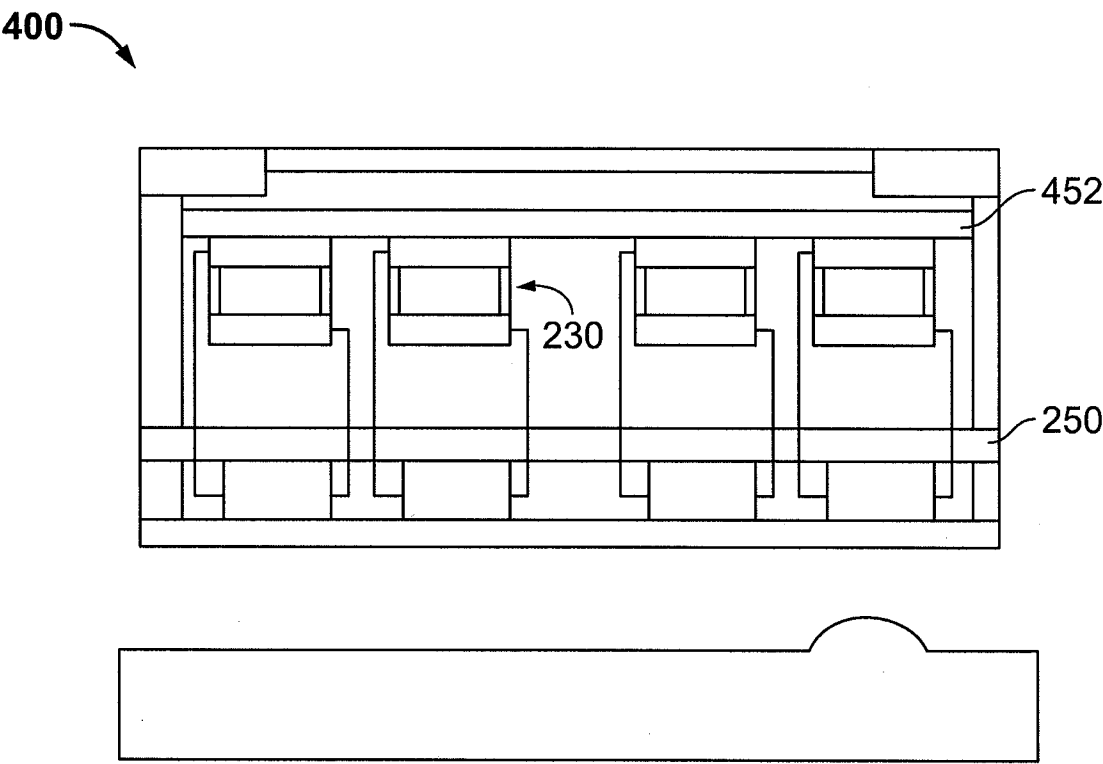


Figure 4

5/6

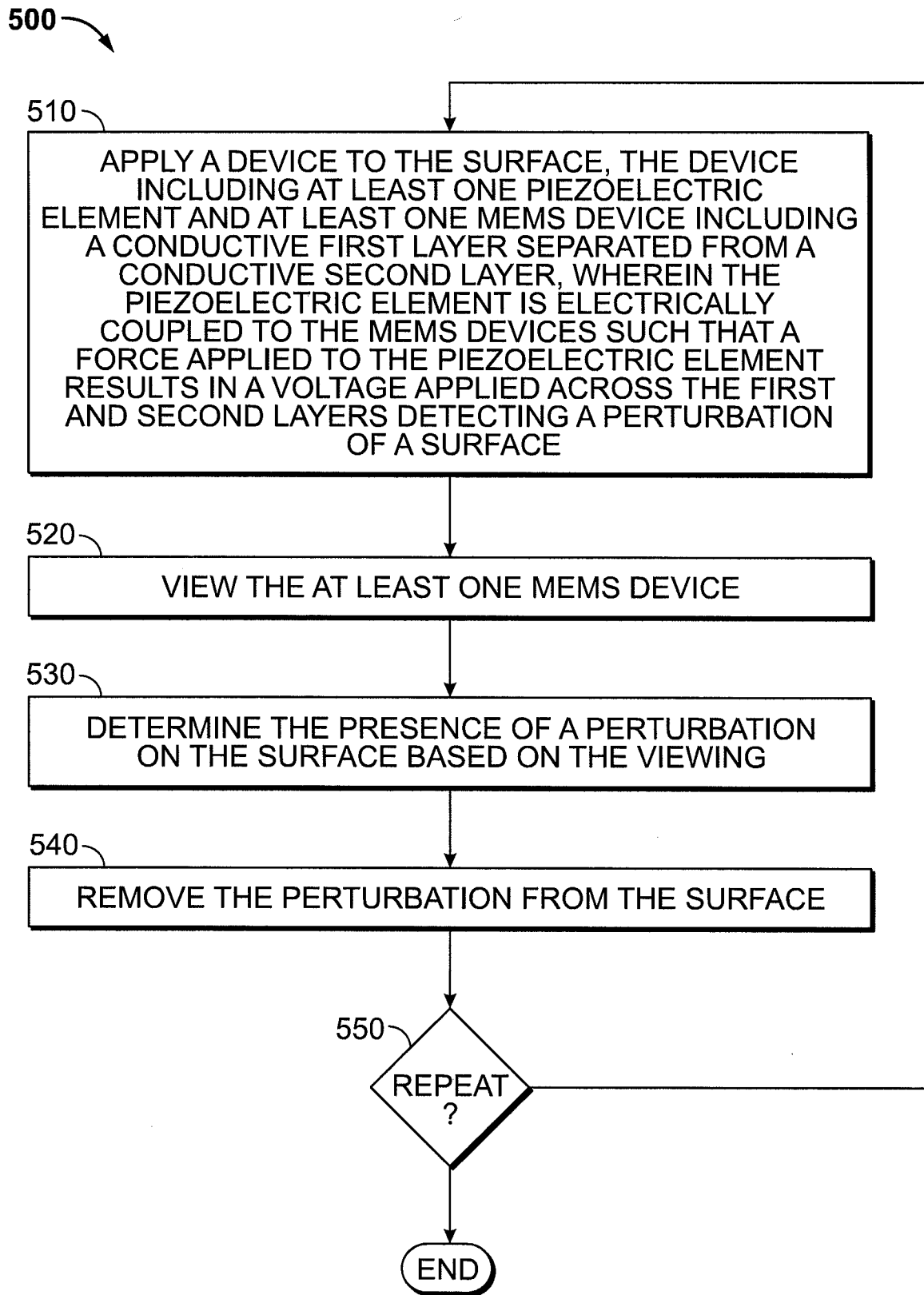


Figure 5

6/6

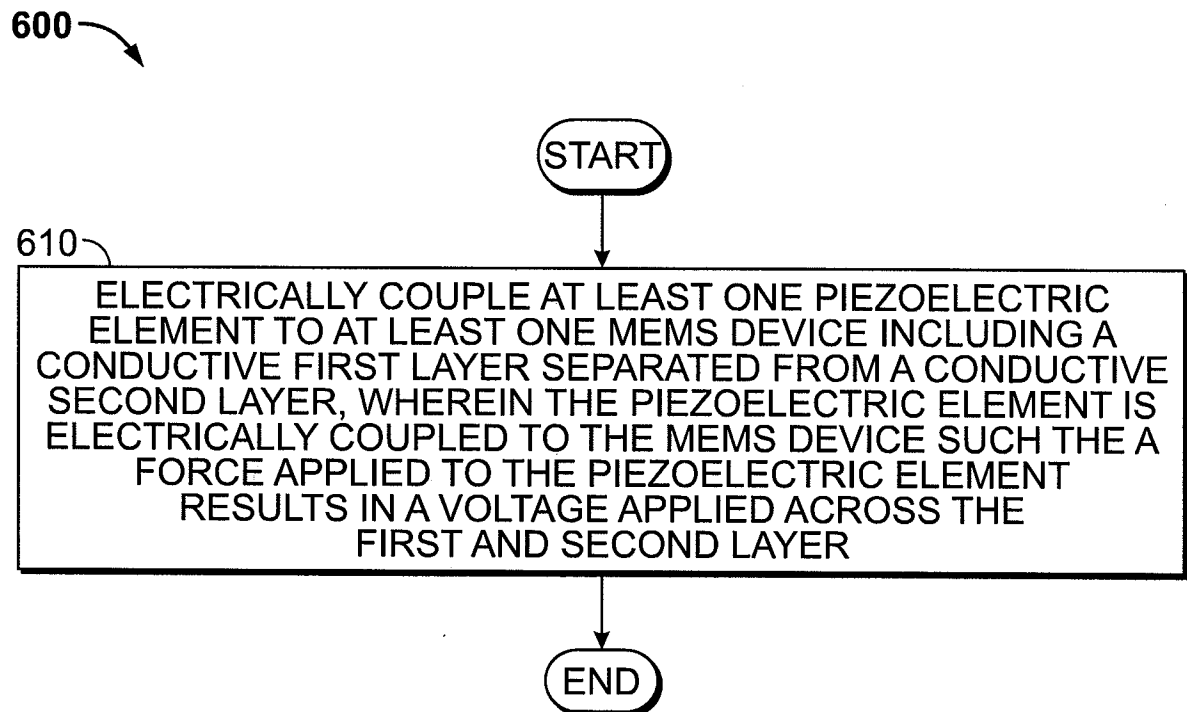


Figure 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/028098

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01B7/34

ADD.

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)

G01B G01Q G06K

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/054148 A2 (CROSS MATCH TECHNOLOGIES INC [US]; ARNOLD JOE F [US]; HALPERT DANIEL []) 16 June 2005 (2005-06-16) paragraphs [0030], [0041] - [0045]; figures 2,7B,8 -----	1-3,7,8, 10,18, 23,24, 31,33
A	EP 0 539 321 A1 (SUISSE ELECTRONIQUE MICROTECH [CH]) 28 April 1993 (1993-04-28) column 2, line 56 - column 4, line 31; figure 2 -----	1-8,24, 34-39
X	US 5 818 605 A (CREWE ALBERT [US] ET AL) 6 October 1998 (1998-10-06) column 8, lines 56-65; figure 3 column 10, line 32 - column 11, line 12; figures 4,5 -----	1,7,8
A	----- -/--	2-6,24, 34-39



Further documents are listed in the continuation of Box C.



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 application or patent 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

15 May 2012

Date of mailing of the international search report

22/05/2012

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Fazio, Valentina

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2012/028098

Box No. IV Text of the abstract (Continuation of item 5 of the first sheet)

This disclosure provides systems, methods and apparatus for assessing a surface using a piezoelectric element. The method includes applying a device to the surface, wherein the device includes at least one piezoelectric element and at least one electromechanical system (EMS) device, wherein the EMS device includes a conductive first layer separated from a conductive second layer, and wherein the piezoelectric element is electrically coupled to the EMS device such that a force applied to the piezoelectric element results in a voltage applied across the first and second layers.

The EMS is an optical interferometric modulator having reflective properties that change in response to an introduction of charge to both the first and the second layers.

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/028098

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2 017 599 A2 (MITUTOYO CORP [JP]) 21 January 2009 (2009-01-21) paragraphs [0050] - [0053]; figure 1 -----	1-9,11, 24,34-39
A	US 2008/209988 A1 (DEGERTEKIN FAHRETTIN L [US] DEGERTEKIN FAHRETTIN LEVENT [US]) 4 September 2008 (2008-09-04) paragraphs [0028] - [0039]; figure 10 -----	1,24,34
A	US 5 565 987 A (JAIN KANTI [US] ET AL) 15 October 1996 (1996-10-15) column 5, line 37 - column 4, line 24; figures 1,2,3 -----	1-8,24, 34-43
A	JP 2005 039995 A (EAMEX CO) 10 February 2005 (2005-02-10) abstract -----	1,24,34
A	EP 0 422 548 A2 (OLYMPUS OPTICAL CO [JP]) 17 April 1991 (1991-04-17) column 4, line 17 - column 6, line 9; figure 1 -----	1-8,24, 34-43
A	US 2006/207317 A1 (WATANABE KAZUTOSHI [JP]) 21 September 2006 (2006-09-21) paragraph [0033]; figure 3 -----	1,24,34
A	US 2003/226955 A1 (KIM JAE WAN [KR] ET AL) 11 December 2003 (2003-12-11) paragraphs [0031], [0032], [0036]; figure 3 -----	1-8,24, 34-43

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/028098

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2005054148 A2	16-06-2005	EP 1692081 A2	23-08-2006
		EP 1694479 A2	30-08-2006
		JP 2007513504 A	24-05-2007
		JP 2007515367 A	14-06-2007
		US 2005156362 A1	21-07-2005
		US 2005203231 A1	15-09-2005
		US 2006121200 A1	08-06-2006
		WO 2005054148 A2	16-06-2005
		WO 2005055118 A2	16-06-2005
		WO 2005055119 A2	16-06-2005
EP 0539321 A1	28-04-1993	CH 685518 A5	31-07-1995
		EP 0539321 A1	28-04-1993
US 5818605 A	06-10-1998	NONE	
EP 2017599 A2	21-01-2009	EP 2017599 A2	21-01-2009
		JP 2009025126 A	05-02-2009
		US 2009021747 A1	22-01-2009
US 2008209988 A1	04-09-2008	US 2008209988 A1	04-09-2008
		US 2010306885 A1	02-12-2010
US 5565987 A	15-10-1996	NONE	
JP 2005039995 A	10-02-2005	NONE	
EP 0422548 A2	17-04-1991	DE 69019913 D1	13-07-1995
		DE 69019913 T2	07-12-1995
		EP 0422548 A2	17-04-1991
		US 5206702 A	27-04-1993
US 2006207317 A1	21-09-2006	JP 2006258429 A	28-09-2006
		US 2006207317 A1	21-09-2006
US 2003226955 A1	11-12-2003	KR 20030095049 A	18-12-2003
		US 2003226955 A1	11-12-2003