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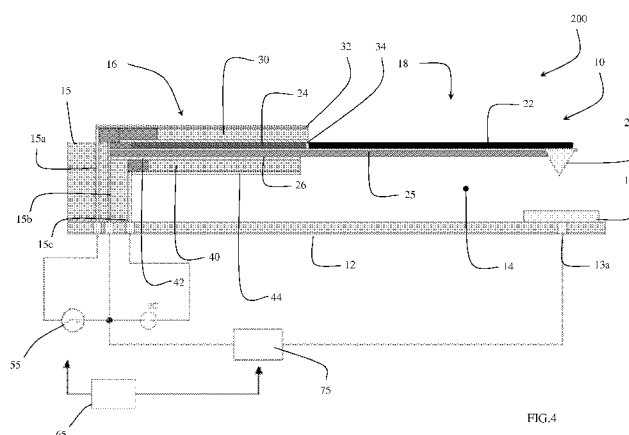
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(54) Title: MICRO-BOLOMETER HAVING AN ADJUSTABLE DYNAMIC RANGE



(57) Abstract: In some aspects, the present invention embodies both the method and apparatus for converting a pattern of irradiation to a visible image. An embodiment of the present invention provides an array of micro-electro-mechanical sensors with each sensor includes a deflectable micro-cantilever, responsive to absorbed incident radiation and to an applied repulsive electrostatic field. Associated circuitry senses a change in an output signal of the sensor as it responds to incident radiation incident upon the cantilever and provides a biasing force to deflect the cantilever and maintain the detector output signal at a desirable level. The biasing element may be a piezoelectric element, a heater or a pair of electrodes and the corresponding biasing stimulus may be stress (expansion), heat, or electrostatic change. The stimulus compensates for the effect of the infrared radiation and maintains the chosen detector output level at the same level.

MICRO-BOLOMETER HAVING AN ADJUSTABLE DYNAMIC RANGE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Non-Provisional Application of U.S. Provisional Patent Application 62/022,509 and U.S. Provisional Patent Application 62/022,492, filed July 9, 2014; which are incorporated herein by reference.

TECHNICAL FIELD

[0002] This invention relates to radiant energy imaging sensors, and, in particular to such methods, systems, apparatus and devices for sensors as employ a micro-cantilever as a responsive element.

BACKGROUND ART

[0003] Various optical detectors such as infrared radiation detectors are available in today's electronics industry. Many techniques for converting infrared radiation to visible images are also known. One such example of an infrared imager available in today's art includes a deflectable microelectromechanical (MEM) cantilever device formed of a bi-material on a semiconductor substrate. The bi-material portion of the micro-cantilever device is formed of two different materials sharing a contiguous surface, and having mismatched thermal coefficients of expansion (TCE). Examples of such bi-material MEM micro-cantilever devices and methods for forming the same, are as disclosed in U.S. Pat. No. 5,844,238 issued to Sauer et al. and U.S. Pat. Nos. 6,140,646 and 6,420,706, issued to Lurie et al.

[0004] The bi-material MEM micro-cantilever devices presently available in the art, bend, or deflect, when infrared radiation is absorbed upon an absorber element of the micro-cantilever heating the bi-material section of the micro-cantilever, thereby urging one of the bi-materials to expand at a greater rate than the other bi-material, thereby causing the micro-cantilever to deflect, or bend. The terms bend and deflect may be used interchangeably hereinafter.

[0005] When infrared radiation is incident upon such a micro-cantilever being used as an optical detector, it is desired to produce a visible image having an intensity which varies directly with the intensity of the incident infrared radiation. As a micro-

cantilever device bends in response to such incident infrared radiation, it approaches a physical limitation to its degree of bending. For example, if a micro-cantilever device is fabricated so as to bend downward in response to incident infrared radiation, the physical limitation is reached when the micro-cantilever touches the substrate over which it is formed. For a micro-cantilever device chosen to bend upward in response to incident infrared radiation, this, too, will reach a physical limitation point past which it can no longer bend. As such, when this point of the physical limitation of bending is approached, the micro-cantilever device is more resistant to bending and therefore, less responsive to additional infrared radiation. An increased amount of incident infrared radiation will not cause the same extent of bending as when the micro-cantilever is in the rest position. While a significantly higher dose of infrared radiation may force the micro-cantilever to bend slightly more towards its physical limitation, the degree of this bending will not be proportional, so the device will not be linear in this region. Thus, the linear range of the device is limited.

[0006] Moreover, after the physical limitation point is reached, additional incident infrared radiation will simply not cause any further bending. This limits the dynamic range of the device. Since the intensity of an optical image ultimately produced from such a device, is based on the degree of bending, it can be seen that such a device having a poor dynamic range and limited linearity, produces an image having the same shortcomings.

[0007] Various methods for sensing the degree of bending are available in the art. Examples of such methods include optically measuring the distance between the micro-cantilever and the substrate, and electrically measuring the capacitance of a capacitor which includes an electrode formed in the substrate and another electrode formed in the micro-cantilever above the substrate. Various methods for producing a visible image having an intensity based upon the extent of bending are also known.

SUMMARY OF THE INVENTION

[0008] In one embodiment the inventive detector includes a deflectable bi-material micro-cantilever. The micro-cantilever is deflectable in response to either of an incident of infrared radiation and/or a further mechanical stimulus. The cantilever has a neutral

reference position relative to the substrate when not exposed to either infrared radiation or the mechanical stimulus.

[0009] A biasing mechanism applies the mechanical stimulus to the micro-cantilever. The biasing mechanism includes a first and second conductive element with a piezoelectric element disposed there between. A contact tip disposed adjacent one end of the micro-cantilever is in electrical communication with a power source. A contact plate is positioned on the substrate beneath the contact tip with a predetermined space there between with the micro-cantilever is in the reference position. The space between the contact plate and the contact tip is defined by a spacer between the micro-cantilever and the substrate when the cantilever is in the neutral position.

[0010] The piezoelectric element of the biasing mechanism expands when a current is applied to at least one of the first and second conductive elements. The expansion causes deflection of the micro-cantilever such that the contact tip comes into contact with the contact plate thereby closing a circuit.

[0011] In another embodiment the inventive detector also includes a deflectable bi-material micro-cantilever. The micro-cantilever is deflectable in response to either of an incident of infrared radiation and/or a further mechanical stimulus. The cantilever has a neutral reference position relative to the substrate when not exposed to either infrared radiation or the mechanical stimulus.

[0012] A first biasing mechanism applies a first mechanical stimulus to the micro-cantilever. The biasing mechanism includes a first and second conductive element with a piezoelectric element disposed there between. A contact tip disposed adjacent one end of the micro-cantilever is in electrical communication with a power source. A contact plate is positioned on the substrate beneath the contact tip with a predetermined space there between with the micro-cantilever is in the reference position. The space between the contact plate and the contact tip is defined by a spacer between the micro-cantilever and the substrate when the cantilever is in the neutral position.

[0013] The piezoelectric element of the biasing mechanism expands when a current is applied to at least one of the first and second conductive elements of the first biasing mechanism. The expansion causes deflection of the micro-cantilever such that the contact tip comes into contact with the contact plate thereby closing a circuit.

[0014] A second biasing mechanism applies a second mechanical stimulus to the micro-cantilever. The second biasing mechanism includes a first and second conductive element with a piezoelectric element disposed there between.

[0015] The piezoelectric element of the second biasing mechanism expands when a current is applied to at least one of the first and second conductive elements of the second biasing mechanism. The expansion causes upward deflection of the micro-cantilever such that the contact tip loses contact with the contact plate thereby opening the circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] For a fuller understanding of the invention, reference should be made to the following detailed description, taken in connection with the accompanying drawings, in which:

FIG. 1 is a cross sectional view showing an illustrative embodiment of inventive detector;

FIG. 2 is cross sectional view showing an illustrative embodiment of inventive detector and associated electronics;

FIG. 3 is a cross sectional view showing an illustrative embodiment of inventive detector having at least two biasing mechanisms; and

FIG. 4 is cross sectional view showing an illustrative embodiment of inventive detector having at least two biasing mechanisms and associated electronics.

BEST MODE FOR CARRYING OUT THE INVENTION

[0017] In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings, which form a part hereof, and within which are shown by way of illustration specific embodiments by which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the invention.

[0018] The following is a list of the reference numbers used in the drawings and the detailed specification to identify components:

Detector	100	Arm conductor	25
Biomorph arm	10	2 nd biomorph material	26
Substrate	12	Biasing plate	30
Contact plate	13	Upper conductive element	32
Contact plate lead	13a	Lower conductive element	34
Gap	14	2 nd biasing plate	40
Spacer	15	Upper conductive element	42
1 st spacer conductor	15a	Lower conductive element	44
2 nd spacer conductor	15b	Power source	50
3 rd spacer conductor	15c	Voltage generator	55
Bi-material Region	16	Digital clock counter	60
Absorption Region	18	Digital Register	65
Contact Tip	20	Time Register Circuit	70
Absorber	22	Voltage Register Circuit	75
1st biomorph material	24		

[0019] In some aspects, the present invention embodies both the method and apparatus for converting a pattern of irradiation to a visible image. A preferred embodiment of the

present invention provides an array of micro-electro-mechanical sensors formed on a substrate. Each sensor includes a deflectable micro-cantilever formed of an irradiance absorber plate supported by a bi-material element. The deflectable micro-cantilever is suspended above the substrate and bends toward the surface plate in response to absorbed incident radiation which increases its temperature. The deflectable micro-cantilever, according to another embodiment, also bends away from the surface plate in response to an applied upward bias from biasing plate underlying the micro-cantilever.

[0020] FIG. 1 is a cross sectional view showing an illustrative embodiment of inventive detector **100**. As shown, detector **100** includes biomorph arm **10** suspended over substrate **12**. Gap **14** forms the opening between substrate **12** and biomorph arm **10** and is defined by the height of spacer **15**. Substrate **12** includes contact plate **13** and contact plate lead **13a**.

[0021] Biomorph arm **10** includes bi-material region **16** and absorbing region **18**. Within absorbing region **18**, absorber material **22** absorbs radiation which is incident on biomorph arm **10**. In bi-material region **16**, first bi-material film **24** and second bi-material **26** are present. First bi-material film **24** and absorber material **22** are contiguous and disposed in overlying relation to second bi-material film **26**.

[0022] Contact tip **20** is adjacent the end of biomorph arm **10**. Tip **20** and is preferably contiguous with second biomorph material **26** and in underlying relation to first biomorph material **24**. Arm conductor **25** provides electrical communication between tip **20** and the conductive elements of spacer **15** (discussed below). Arm conductor **25** is preferably disposed in overlying relation to second biomorph material **26** and underlying relation to first biomorph material **24** and absorber material **22**. Contact plate **13** and contact plate lead **13a** electrically couple the device to other circuitry and devices (discussed below) when an electrical circuit is closed by the contact of tip **20** with plate **13**.

[0023] First bi-material material **24** and second bi-material material **26** have different coefficients of thermal expansion. When radiation is incident upon the MEM structure, biomorph arm **10** is heated and bends because the two bi-material expand **24** and **26** expand at different rates. FIG. 1 shows biomorph arm **10** in a neutral

position when the device is not exposed to radiation. The bi-materials are made of materials chosen to have a maximal differential coefficient of thermal expansion (CTE). The principles of operation of bi-material micro-cantilever devices are well known to those skilled in the sensor art. In the past, silicon carbide or silicon nitride has been used for the low-CTE layer, and gold or aluminum for the high-CTE layer. In a preferred embodiment silicon dioxide is used for its low CTE, approaching zero, and zinc is used for its high CTE. Though selenium and plutonium each have higher CTEs, their use in industrial processes is problematic. Polymers may be used for their very high CTEs, but have limited mechanical strength, particularly in the very thin films required for high bi-material element sensitivity.

[0024] In addition to differential thermal expansion, another parameter determining the responsivity (microns of plate deflection per degree C.) of the bi-material is its thickness, or the separation between the center, or neutral, fiber of each of the bi-material layers. Responsivity increases with decreasing bi-material thickness. However, the mechanical resonant frequency of the absorber plate mass on the flexing bi-material support also decreases with bi-material thickness and stiffness.

[0025] In another embodiment of the invention, device **100** further includes biasing plate **30**. In the embodiment shown in FIG. 1, biasing plate **30** is shown in superior relation to first biomorph material **24**, although other arrangements are contemplated.

[0026] One embodiment incorporates a construction having an upper conductive element **32**, a biasing plate **30** and a lower conductive element **34** and a support layer **26** between the second electrode **31** and the substrate **15**. Biasing plate **30**, in this embodiment, is supported by first bimorph material **24** with lower conductive element **34** there between. The biasing plate **30** is between upper conductive element **32** and lower conductive element **34**, which apply an electric field to the material of biasing plate **30**.

[0027] Biasing plate can be constructed from piezoelectric material, such as crystalline or ceramic material, that expands or contracts when subjected to an electric field. Examples of the piezoelectric material include, but are not limited to, lead zirconate titanate (PZT), lead lanthanum zirconate titanate (PLZT), lead magnesium niobate-

lead zirconate titanate (PMN-PZT), lead zirconate niobate-lead zirconate titanate (PZN-PZT), aluminum nitride (AlN), and zinc oxide (ZnO).

[0028] A poling process can be used to polarize the piezoelectric material. During the poling process, the piezoelectric material is heated and a large uniform unidirectional electric field is applied to align the domain dipoles in the material. The large uniform unidirectional electric field is removed after the piezoelectric material is cooled. In an alternative embodiment, the piezoelectric material is cooled after the large uniform unidirectional electric field is removed. In one embodiment, biasing plate **30** is poled by voltage applied to at least one of upper and lower biasing plate conductors **32** and **34**.

[0029] When a voltage is applied to upper biasing plate conductor **32**, and lower biasing plate **34** is grounded, an electric field is established in biasing plate **30**. Voltage is applied to upper biasing plate conductor **32** through first spacer conductor **15a**. Voltage is applied to lower biasing plate conductor **34** through second spacer conductor **15b**. Both conductors extend through substrate **12** to provide electrical communication with a power source. Second spacer conductor **15b** is also in electrical communication with arm conductor **25**.

[0030] When biasing plate **30** is poled in the same direction as the electric field, biasing plate **30** expands under tensile stress. The expansion of biasing plate causes biomorph arm **10** to bend towards substrate **12** into gap **14**. Contact of tip **20** with contact plate **13** is detected by the closing of the circuit resulting in the electrical connection of contact plate lead **13a** and second spacer conductor **15b**.

[0031] Referring now to FIG. 2, voltage applied to upper biasing plate conductor **32** is supplied by power source **50**, such as a linear ramp voltage generator, through first spacer conductor **15a**. Power source **50** is communicatively coupled to digital clock counter **60**. Counter **60** is initiated when power source **50** begins voltage generation. Counter **60** stops responsive to a signal from time register circuit **70**. Time register circuit **70** is communicatively coupled to contact plate lead **13a**. When tip **20** engages contact plate **13**, thereby closing the circuit, the contact is detected by time register circuit **70** and the termination signal is sent to counter **60**. The time count accumulated in counter **60** is loaded into a register with time register circuit **70**.

[0032] In this configuration, the biasing plate **30** can optionally deflect bimorph arm **10** in the absence of infrared radiation to achieve a desired level of deflection. As incident radiation increases, the amount of deflection as a result of the expansion of biasing plate **30** is decreased to maintain the device of the desired level of deflection.

[0033] When used in conjunction with first embodiment, discussed above; the absorption of radiant energy by absorber material **22** causes a temperature increase in first and second biomorph materials (**24**, **26**). The differential properties of the materials causes arm **10** to deflect at a rate faster than if arm **10** was deflected by biasing plate **30** alone. This results in a lower accumulated time count.

[0034] The accumulated time count can constitute a part or all of an output signal of the device. This signal may be used to provide a visible image which has an intensity based upon, at least partially, the duration of the accumulated time count. Conventional methods may be used.

[0035] As discussed, other embodiments employing a biasing plate are contemplated. Rather than being constructed from a piezoelectric material, for example, biasing plate **30** may be a heat generating element that heats up in response to a supplied current. Conventional methods may be used to form and pattern the heat generating element and to couple the heat generating element to the power source by means of conductors **15a** and **15b**. When an input current is supplied to the heat generating element the heat generating element heats up. Biasing plate **30** is in thermal contact with first biomorph material **24** within bi-material region **16**. As such, biomorph arm **10** deflects downward responsive to the heat supplied by biasing plate **30** through first biomorph material **24**.

[0036] In this configuration, the biasing plate **30** heats first biomorph material **24** in the absence of infrared radiation to achieve a desired level of deflection. As incident radiation increases, the amount of heat provided by biasing plate **30** is decreased to maintain the device of the desired level of deflection.

[0037] As discussed above, another embodiment of the invention includes a means of returning biomorph arm **10** to a neutral position. The deflectable micro-cantilever, according to this embodiment, bends away from the substrate in response to an applied upward bias from biasing plate underlying the micro-cantilever.

[0038] As shown in FIG. 3, this embodiment is similar to the embodiments depicted in FIGS.

1 and 3. FIG. 3 is a cross sectional view showing an alternate embodiment of inventive detector **200**. As shown, detector **200** includes biomorph arm **10** suspended over substrate **12**. Gap **14** forms the opening between substrate **12** and biomorph arm **10** and is defined by the height of spacer **15**. Substrate **12** includes contact plate **13** and contact plate lead **13a**.

[0039] Biomorph arm **10** includes bi-material region **16** and absorbing region **18**. Within absorbing region **18**, absorber material **22** absorbs radiation which is incident on biomorph arm **10**. In bi-material region **16**, first bi-material film **24** and second bi-material **26** are present. First bi-material film **24** and absorber material **22** are contiguous and disposed in overlying relation to second bi-material film **26**.

[0040] Contact tip **20** is adjacent the end of biomorph arm **10**. Tip **20** and is preferably contiguous with second biomorph material **26** and in underlying relation to first biomorph material **24**. Arm conductor **25** provides electrical communication between tip **20** and the conductive elements of spacer **15** (discussed below). Arm conductor **25** is preferably disposed in overlying relation to second biomorph material **26** and underlying relation to first biomorph material **24** and absorber material **22**. Contact plate **13** and contact plate lead **13a** electrically couple the device to other circuitry and devices (discussed below) when an electrical circuit is closed by the contact of tip **20** with plate **13**.

[0041] First bi-material film **24** and second bi-material film **26** have different coefficients of thermal expansion. When radiation is incident upon the MEM structure, biomorph arm **10** is heated and bends because the two bi-material films **24** and **26** expand at different rates. FIG. 3 shows biomorph arm **10** in an original position when the device is not exposed to radiation.

[0042] As with previous embodiments, device **200** further includes first biasing plate **30**. In the embodiment shown in FIG. 3, first biasing plate **30** is shown in superior relation to first biomorph material **24** and second biasing plate **40** is shown in inferior relation to second biomorph material **26**, although other arrangements are contemplated.

[0043] As before, this embodiment incorporates a construction having an upper conductive element **32**, a first biasing plate **30** and a lower conductive element **34**. Biasing plate

30, in this embodiment, is supported by first bimorph material **24** with lower conductive element **34** there between. First biasing plate **30** is between upper conductive element **32** and lower conductive element **34**, which apply an electric field to the material of first biasing plate **30**.

[0044] The voltage applied to the conductors is generated by voltage generator **55** that is controlled by digital register **65** in electrical communication there with. As voltage generator **55** is stepped upward in voltage by digital register **65** bimorph arm **10** is caused through piezo action to bend downward such that tip **20** contacts contact plate **13**. When tip **20** contacts plate **13**, the contact is detected by current voltage register circuit **75** and the current voltage level is loaded into a register within the current voltage register circuit **75**. In this configuration, the biasing plate **30** can optionally deflect bimorph arm **10** in the absence of infrared radiation to achieve a desired level of deflection. As incident radiation increases, the amount of deflection as a result of the expansion of biasing plate **30** is decreased to maintain the device of the desired level of deflection.

[0045] When radiant energy is also absorbed absorber **22**, the temperature of first and second bimorph materials (**24**, **26**) increases. The bimorph action causes tip **20** to move downward toward contact plate **13**. This increase in bending causes tip **13** to contact plate **13** at a lower applied piezo voltage.

[0046] Device **200** further includes second biasing plate an upper conductive element **42**, second biasing plate **40** and a lower conductive element **44**. Biasing plate **40**, in this embodiment, is positioned in superior relation to second bimorph material **26** with upper conductive element **42** there between. Second biasing plate **40** is between upper conductive element **42** and lower conductive element **44**, which apply an electric field to the material of second biasing plate **40**. Second biasing plate **40** is poled by voltage applied to at least one of upper and lower biasing plate conductors **42** and **44**.

[0047] When a fixed voltage is applied to upper biasing plate conductor **42**, and lower biasing plate **44** is grounded, an electric field is established in second biasing plate **40**. Voltage is applied to upper biasing plate conductor **42** through second spacer conductor **15b**. Voltage is applied to lower biasing plate conductor **44** through third spacer conductor **15c**. Both conductors extend through substrate **12** to provide

electrical communication with power source **50**. Second spacer conductor **15b** is in electrical communication with arm conductor **25** as in the previous embodiments.

[0048] When second biasing plate **40** is poled in the same direction as the electric field, second biasing plate **40** expands under tensile stress. The expansion of biasing plate causes biomorph arm **10** to bend upward and away from substrate **12**. The upward movement of biomorph arm **10** causes tip **20** to lose contact with contact plate **13** and thereby open the circuit. The result is that the arm bends upward thus increasing the amount of piezo voltage on first biasing plate **30** or the amount of energy absorbed by absorber **22** that is required to achieve contact between tip **20** and contact plate **13**. In this way the dynamic range of the device can be modified.

[0049] Rather than being constructed from a piezoelectric material, second biasing plate **40** may also be a heat generating element that heats up in response to a supplied current. Conventional methods may be used to form and pattern the heat generating element and to couple the heat generating element to the power source by means of conductors **15b** and **15c**. When an input current is supplied to the heat generating element the heat generating element heats up. Second biasing plate **40** is in thermal contact with second bimorph material **26** within bi-material region **16**. As such, bimorph arm **10** deflects upward responsive to the heat supplied by second biasing plate **40** through second bimorph material **26**.

[0050] It will be seen that the advantages set forth above, and those made apparent from the foregoing description, are efficiently attained and since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matters contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense. Any materials, which may be cited above, are fully incorporated herein by reference.

[0051] It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall there between. Relative terminology, such as “substantially” or “about,” describe the specified materials, steps, parameters or ranges as well as those that do not materially affect the basic and novel characteristics of the claimed inventions as whole (as would

be appreciated by one of ordinary skill in the art). Now that the invention has been described,

[0052] What is claimed is:

1. An apparatus, comprising:
 - (a) a deflectable bi-material micro-cantilever, said micro-cantilever being deflectable in response to each of incident infrared radiation and a further stimulus, and having a reference position relative to the substrate when not exposed to said infrared radiation and said further stimulus;
 - (b) a biasing mechanism to apply said further stimulus operatively coupled to the micro-cantilever, said biasing mechanism comprising a first and second conductive element with a piezoelectric element disposed there between;
 - (c) a contact tip disposed adjacent one end of the micro-cantilever and in electrical communication with a power source;
 - (d) a contact plate positioned on the substrate beneath the contact tip with a predetermined space there between with the micro-cantilever is in the reference position; and
 - (e) a spacer between the micro-cantilever and the substrate.
 - (f) wherein the piezoelectric element expands when a current is applied to at least one of the first and second conductive elements, said expansion causing deflection of the micro-cantilever such that the contact tip comes into contact with the contact plate thereby closing a circuit.
2. The apparatus of claim 1, wherein the micro-cantilever is attached to the spacer at an end opposite the contact tip.
3. The apparatus of claim 2, wherein the micro-cantilever further comprises:
 - (a) a lower layer formed from a first bimorph material;
 - (b) an upper layer adjacent the spacer and formed from a second bimorph material;
 - (c) an absorption layer adjacent the upper layer and extending to the end of the micro-cantilever; and

- (d) a conductive element, in electrical contact with the contact tip at one end, disposed between the lower layer and the upper and absorption layers.
4. The apparatus of claim 1, wherein the first conductive element of the biasing mechanism is communicatively coupled with a power source through a first conductive element in the spacer and the second conductive element of the biasing mechanism is communicatively coupled with a power source through a second conductive element in the spacer.
 5. The apparatus of claim 4 wherein the micro-cantilever further comprises:
 - (a) a lower layer formed from a first bimorph material;
 - (b) an upper layer adjacent the spacer and formed from a second bimorph material;
 - (c) an absorption layer adjacent the upper layer and extending to the end of the micro-cantilever; and
 - (d) a conductive element, in electrical contact with the contact tip at one end, disposed between the lower layer and the upper and absorption layers;
 - (e) wherein the longitudinal conductive element is in electrical communication with the second conductive element in the spacer.
 6. The apparatus of claim 4 wherein the biasing mechanism is in superior relation to the second bimorph material.
 7. The apparatus of claim 4 wherein a voltage applied from the power source applies a voltage potential to the first conductive element of the biasing element through the first conductive element of the spacer.
 8. The apparatus of claim 4 wherein the power source is communicatively coupled to a timing element and a time register circuit, wherein the timing element is started when a current is generated by the power source.
 9. The apparatus of claim 8 wherein contact of the contact tip with the contact plate establishes a closed circuit with the second conductive element of the spacer and wherein the closing of the circuit is detected by the time register circuit and stops the timing element.

10. An apparatus, comprising:

- (a) a deflectable bi-material micro-cantilever, said micro-cantilever being deflectable in response to each of an incident infrared radiation and a further stimulus, and having a reference position relative to the substrate when not exposed to said infrared radiation and said further stimulus;
- (b) a spacer between the micro-cantilever and the substrate;
- (c) a contact tip disposed adjacent one end of the micro-cantilever and in electrical communication with a power source;
- (d) contact plate positioned on the substrate beneath the contact tip with a predetermined space there between with the micro-cantilever is in the reference position;
- (e) a first biasing mechanism to apply said further stimulus operatively coupled to the micro-cantilever, said biasing mechanism comprising a first and second conductive element with a piezoelectric element disposed there between; and
- (f) second biasing mechanism to apply a second further stimulus operatively coupled to the micro-cantilever, said biasing mechanism comprising a first and second conductive element with a piezoelectric element disposed there between;
- (g) wherein the piezoelectric element expands when a current is applied to at least one of the first and second conductive elements of the first biasing mechanism, said expansion causing deflection of the micro-cantilever such that the contact tip comes into contact with the contact plate thereby closing a circuit.

11. The apparatus of claim 10, wherein the micro-cantilever is attached to the spacer at an end opposite the contact tip and wherein the micro-cantilever further comprises:

- (a) a lower layer formed from a first bimorph material;
- (b) an upper layer adjacent the spacer and formed from a second bimorph material;

- (c) an absorption layer adjacent the upper layer and extending to the end of the micro-cantilever; and
- (d) a longitudinal conductive element, in electrical contact with the contact tip at one end, disposed between the lower layer and the upper and absorption layers.

12. The apparatus of claim 11,

- (a) wherein the first conductive element of the first biasing mechanism is communicatively coupled with a power source through a first conductive element in the spacer and the second conductive element of the first biasing mechanism is communicatively coupled with a power source through a second conductive element in the spacer; and
- (b) wherein the first conductive element of the second biasing mechanism is communicatively coupled with a power source through the second conductive element in the spacer and the second conductive element of the second biasing mechanism is communicatively coupled with a power source through a third conductive element in the spacer.

13. The apparatus of claim 12 wherein the micro-cantilever further comprises:

- (a) a lower layer formed from a first bimorph material;
- (b) an upper layer adjacent the spacer and formed from a second bimorph material;
- (c) an absorption layer adjacent the upper layer and extending to the end of the micro-cantilever; and
- (d) a conductive element, in electrical contact with the contact tip at one end, disposed between the lower layer and the upper and absorption layers;
- (e) wherein the longitudinal conductive element is in electrical communication with the second conductive element in the spacer.

14. The apparatus of claim 13 wherein the first biasing mechanism is in superior relation to the second bimorph material and the second biasing mechanism is in inferior relation to the first bimorph material.

15. The apparatus of claim 13 wherein a voltage applied from the power source applies a voltage potential to the first conductive element of the biasing element through the first conductive element of the spacer.
16. The apparatus of claim 13 wherein a voltage applied from the power source applies a voltage potential to the second conductive element of the second biasing mechanism through the third conductive element of the spacer.
17. The apparatus of claim 13 wherein the power source is communicatively coupled to a digital voltage register and a voltage register circuit.
18. The apparatus of claim 17 wherein contact of the contact tip with the contact plate establishes a closed circuit with the second conductive element of the spacer.

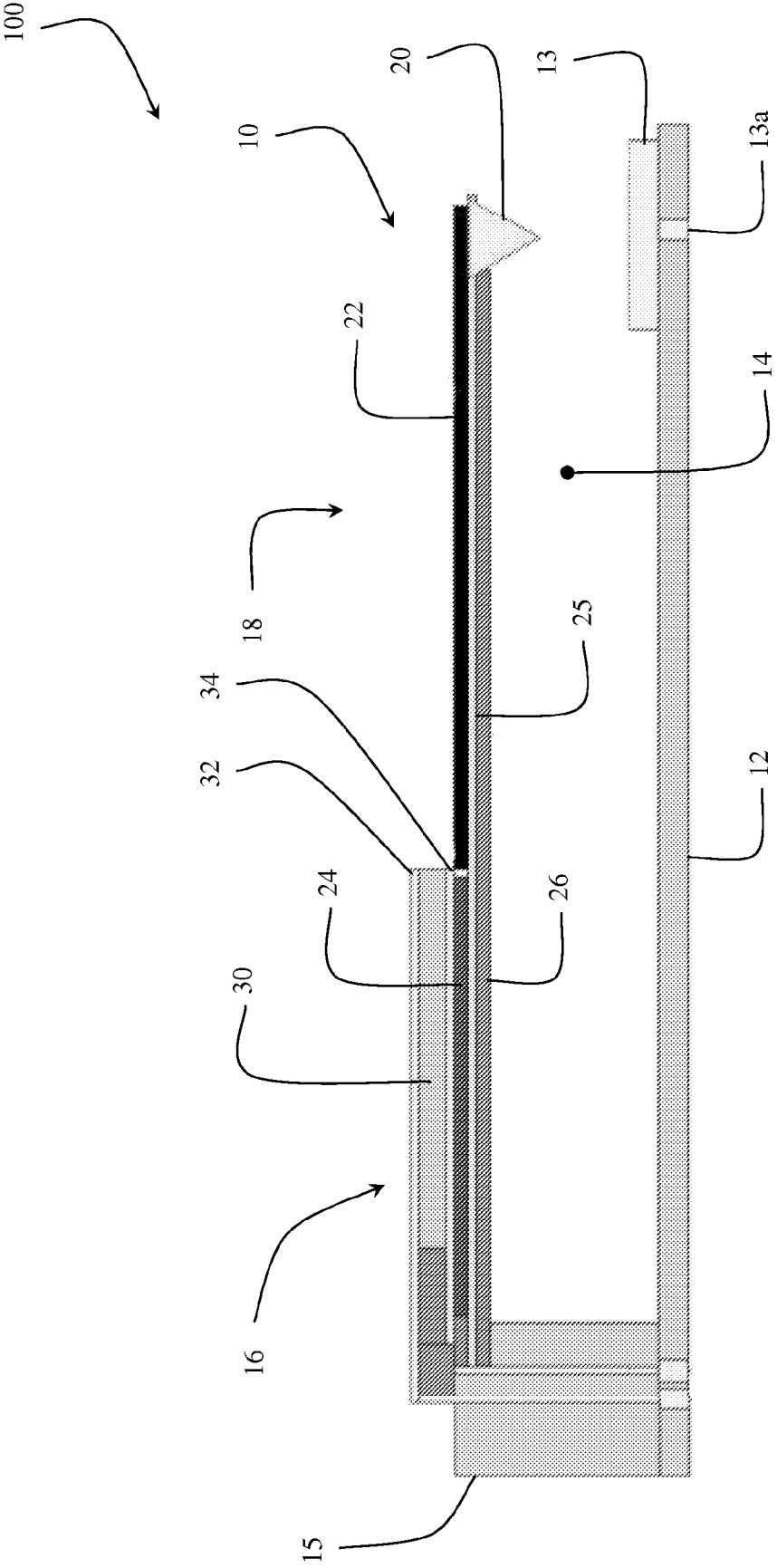
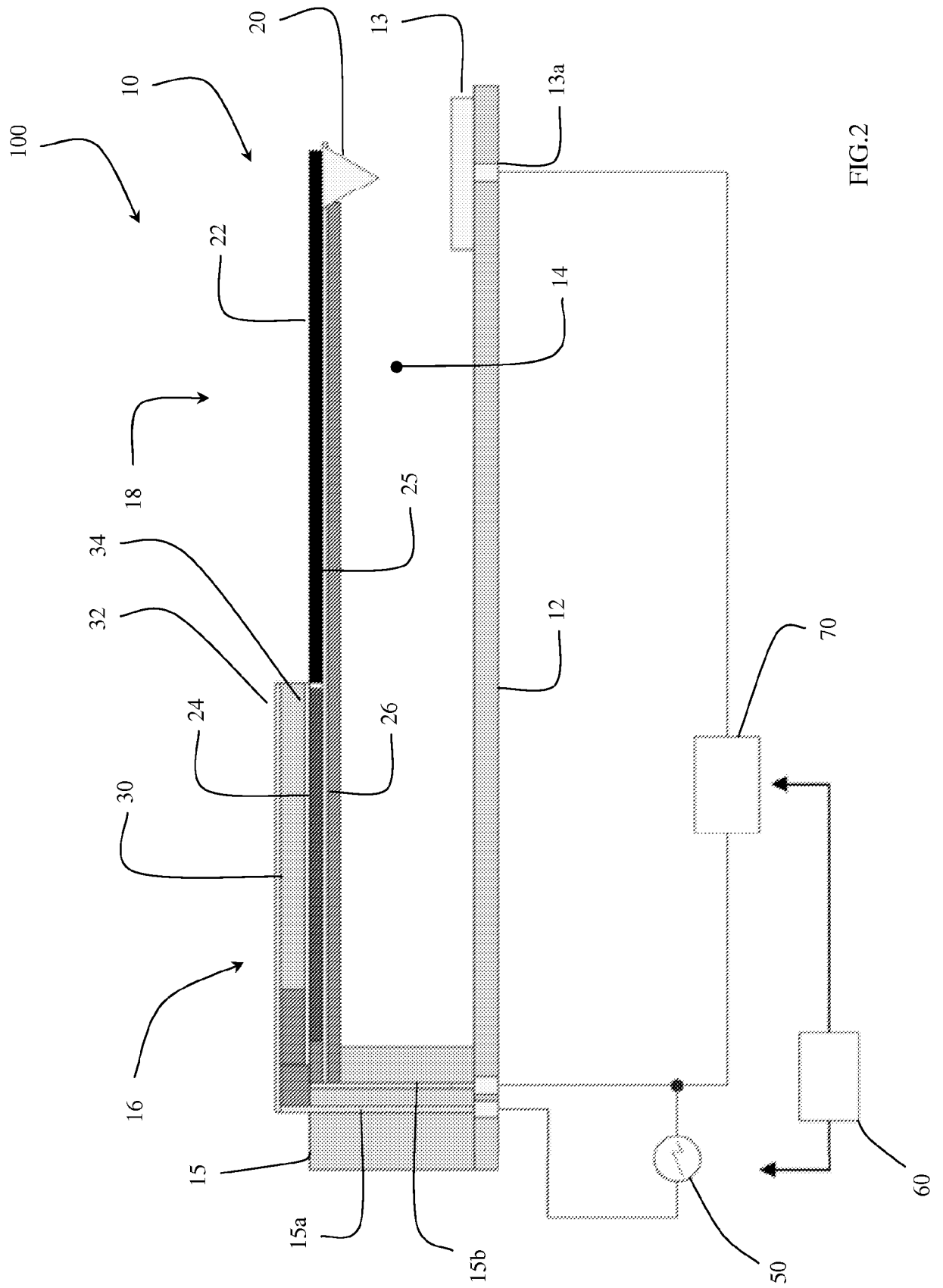


FIG.1



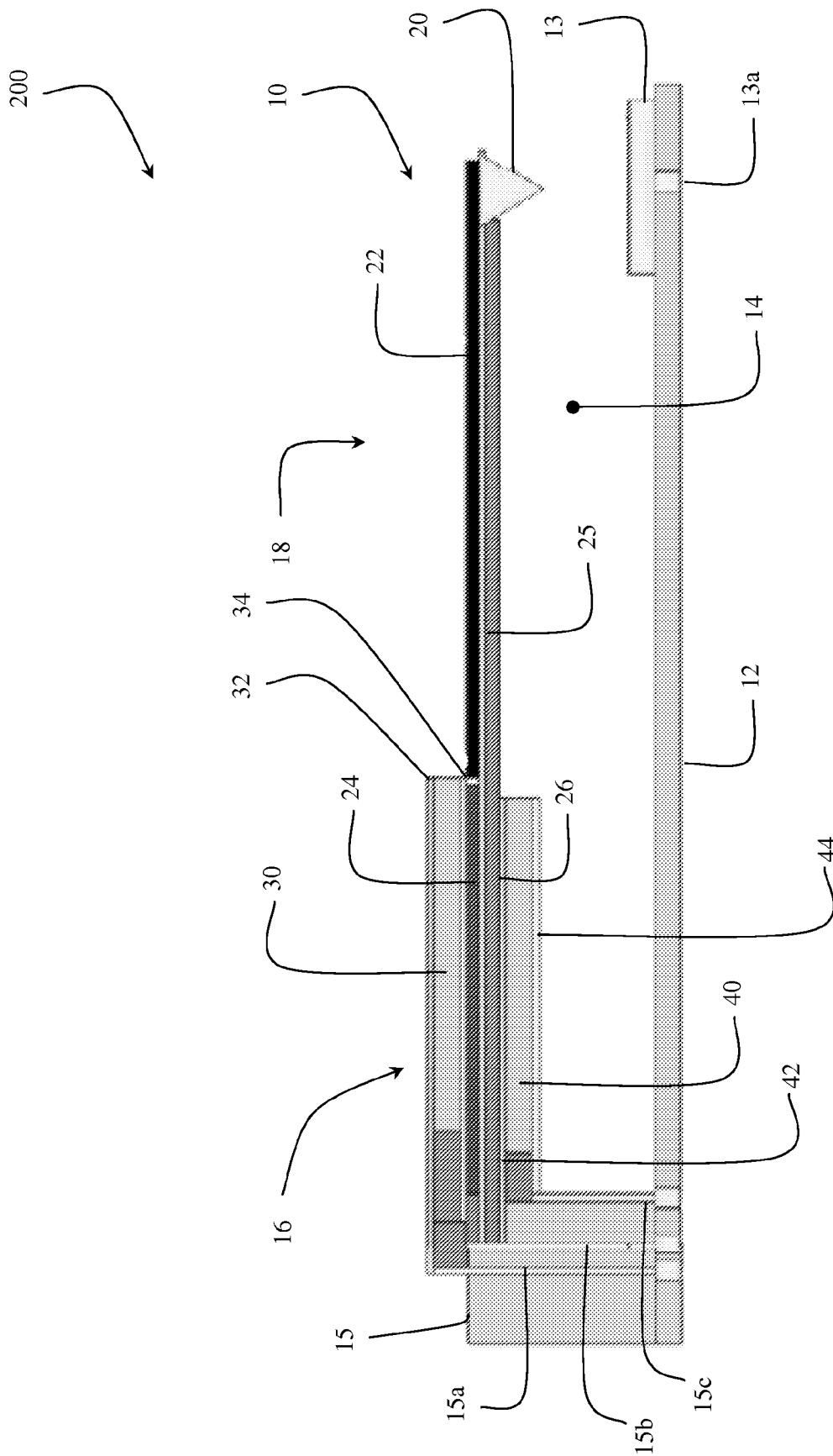


FIG. 3

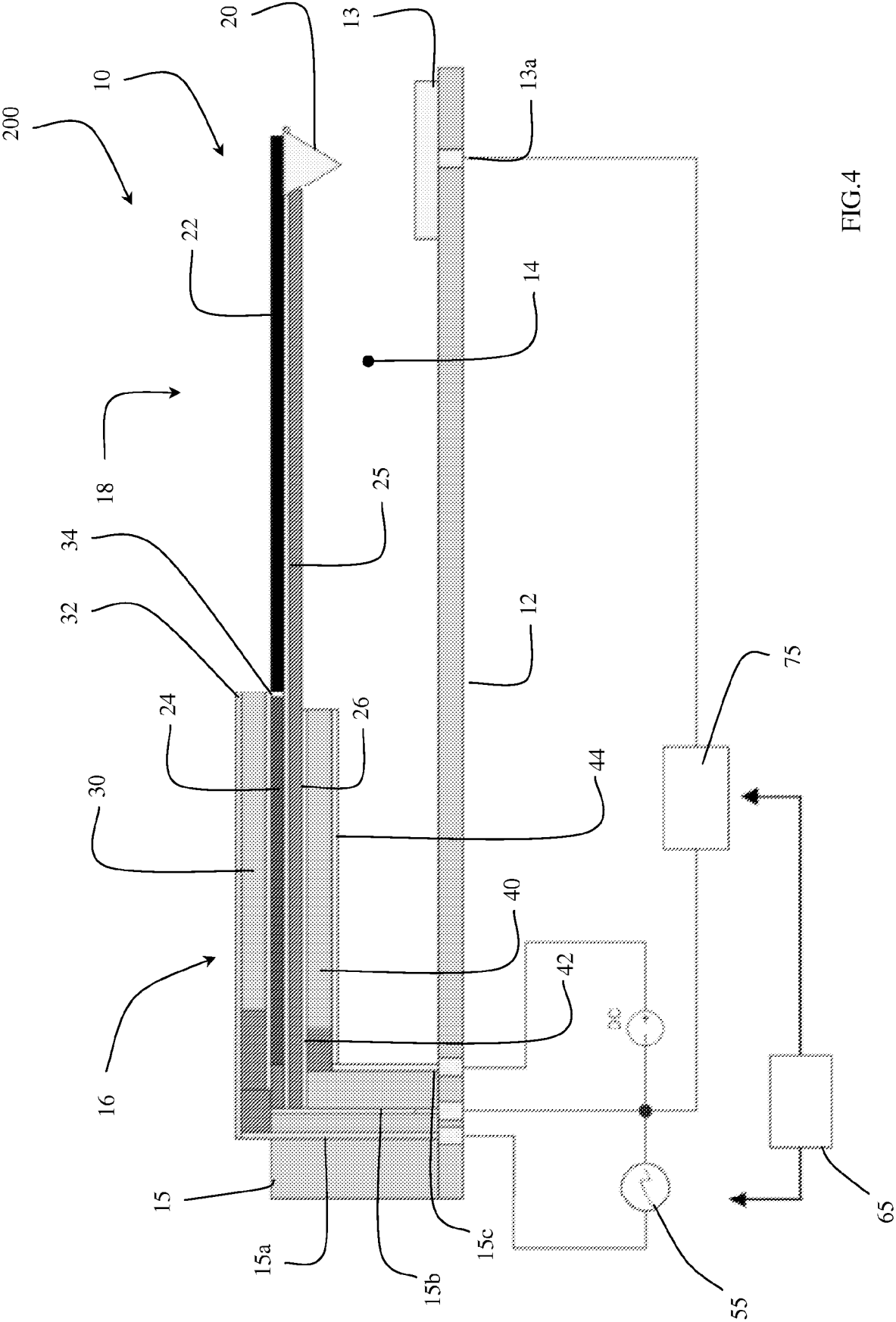


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 15/39815

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01Q 60/00 (2015.01)

CPC - B82Y 35/00; G01N 29/2406; G01N 29/2437; G01Q 60/38; G01Q 10/045; Y10S 977/86

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)

IPC(8): G01Q 60/00 (2015.01)

CPC: B82Y 35/00; G01N 29/2406; G01N 29/2437; G01Q 60/38; G01Q 10/045; Y10S 977/86

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

IPC(8): G01Q 60/00 (2015.01); CPC: B82Y 35/00; G01N 29/2406; G01N 29/2437; G01Q 60/38; G01Q 10/045; Y10S 977/86; G01J5/40; H04N5/33; USPC: 356/501, 498; 250/338.1

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

Patbase, Google Web/Scholar Search terms used: Cantilever microcantilever beam pole infrared ir deflect bend deform piezoelectric pzt between above below surround sandwich electrode plate conductor sense detect convert probe point tip circuit switch power source volt voltage current bimorph sheet layer film contact touch time timer timing second

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,420,706 B1 (LURIE et al.) 16 July 2002 (16.07.2002) col 3, ln 12-37; col 5, ln 64-col 6, ln 28; col 6, ln 60-col 7, ln 8	1-18
Y	US 2005/0236935 A1 (OHMORI et al.) 27 October 2005 (27.10.2005) para [0010], [0025], [0070]-[0072], [0088], [0097], [0118], [0120]	1-9, 11-18
Y	US 2013/0037395 A1 (HORI et al.) 14 February 2013 (14.02.2013) para [0006]-[0007], [0023]-[0025], [0027]-[0028]	10-18
Y	US 2009/0026892 A1 (NAKAMURA et al.) 29 January 2009 (29.01.2009) para [0014], [0032]	4, 5, 7-9, 12-18
Y	US 2011/0089324 A1 (EDWARDS) 21 April 2011 (21.04.2011) para [0144]-[0145]	8, 9
Y	US 2012/0037805 A1 (DUPONT et al.) 16 February 2012 (16.02.2012), para [0152], [0153]	17, 18
A	US 2011/0317325 A1 (ESPINOSA et al.) 29 December 2011 (29.12.2011)	1-18
A	US 2013/0283922 A1 (QUALTIERI et al.) 31 October 2013 (31.10.2013)	1-18

☐ Further documents are listed in the continuation of Box C.

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"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

14 September 2015 (14.09.2015)

Date of mailing of the international search report

06 OCT 2015

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