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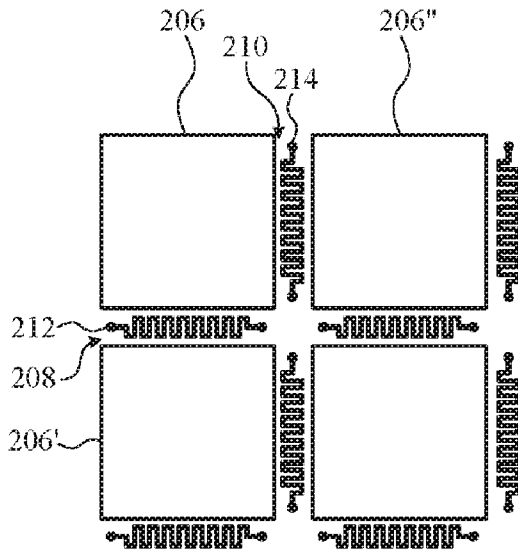


FIG. 2B

(57) Abstract: An input sensor for detecting an input force on an electronic device is disclosed. The input sensor includes a substrate and a structure coupled to the substrate. The input force is measured using strain-sensitive elements. The structure can include one or more stiffeners. The strain-sensitive elements are coupled to the substrate and/or to the stiffeners to measure the input force.



APPARATUS FOR DETECTING AN INPUT FORCE ON AN ELECTRONIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent
5 Application No. 62/279,623, filed on January 15, 2016, and entitled “Strain-Concentrating Input
Sensor,” which is incorporated by reference as if fully disclosed herein.

FIELD

[0002] Embodiments described herein generally relate to input sensors for electronic devices
and, more particularly, to systems and methods for focusing strain that results from a
10 compressive force applied to an input surface of an electronic device.

BACKGROUND

[0003] An electronic device can include an input surface to receive an input force from a user.
A sensor coupled to the input surface can be configured to generate a signal corresponding to a
deformation of the input surface that results from the input force. The signal can be used by the
15 electronic device to determine an operation to perform in response to the input force. In some
cases, the sensor may be incorporated into, or adjacent to, a display of the electronic device.

[0004] The performance of the force sensor may be affected by the precision with which the
deformation of the input surface may be detected. In many cases, the deformation may be a local
displacement of the input surface on the order of micrometers. Conventional means of detecting
20 such displacement typically require power resources unavailable to battery-powered electronic
devices. More specifically, the power required to obtain a signal-to-noise ratio sufficient to
detect the displacement of the input surface may undesirably deplete the battery of such an
electronic device.

SUMMARY

[0005] Embodiments described reference an electronic device having an input surface configured to receive a force input and a strain-concentrating structure. The input surface is configured to receive an input force from a user, either directly from a finger or stylus or
5 indirectly through one or more additional components or elements (e.g., display stack, cover glass, housing, and so on) of an electronic device incorporating the input sensor. The input surface flexes, locally or globally, in response to the input force and experiences mechanical strain in the flexed region. The strain-concentrating structure uses a number of stiffener segments, each separately coupled to the input surface to define a number of strain concentration
10 regions. A strain-sensitive element is couple to at least one strain concentration region to detect the strain.

[0006] The strain-concentrating structure may include a number of independent stiffener segments. In many examples, the stiffener segments are separated from one another and are separately coupled to the input surface. In many embodiments, each stiffener segment has a
15 modulus of elasticity greater than that of the input surface, although this is not required. The stiffener segments locally strengthen and/or stiffen the input surface so that when the input force is received, strain within the input surface is generally concentrated between the stiffener segments, thereby defining one or more strain concentration regions.

[0007] The input sensor also includes a strain-sensitive element coupled to the input surface
20 and positioned within at least one strain concentration region. In operation, the input sensor (and/or a processor in communication with the input sensor) measures an electrical property of the strain-sensitive element and estimates a magnitude of strain experienced by the strain-sensitive element based on one or more characteristics of that electrical property. Thereafter, a magnitude of the input force that caused the input surface to flex in a manner that resulted in the
25 measured strain is estimated. The magnitude of the input force may be estimated based on, without limitation: the estimated magnitude of strain of one or more strain-sensitive elements; a mechanical model of the input sensor and/or the strain-concentrating structure; and/or a location at which the input force was applied to the input sensor.

[0008] In many cases, the strain-sensitive element is a resistive sensor formed from a strain-sensitive material such as a peizoresistive material. The strain-sensitive element may be disposed in a serpentine pattern.

[0009] In some cases, more than one strain-sensitive element is coupled to the input surface. For example, a reference strain-sensitive element may be coupled to a portion of the input surface that is strengthened by a stiffener segment. An electrical property of the reference strain-sensitive element may be measured in tandem with an electrical property of a strain-sensitive element coupled to, adjacent to, and/or otherwise associated with that stiffener segment.

[0010] In some embodiments, an electronic device can include an input surface and a display positioned below the input surface. A substrate may be positioned below the display and a reference strain-sensitive element can be coupled to the substrate. A stiffener may be coupled to the substrate over the reference strain-sensitive element. A measurement strain-sensitive element can be coupled to, adjacent to, and/or otherwise associated with the stiffener.

[0011] In some implementations, an input sensor may include an input surface and a first stiffener coupled to the input surface. A second stiffener can be coupled to the input surface and separated from the first stiffener to define a first strain concentration region between the first and the second stiffeners. A third stiffener may be coupled to the input surface and separated from the first and the second stiffeners to define a second strain concentration region between the first and the third stiffeners. A first strain sensor can be coupled to the input surface within the first strain concentration region, and a second strain sensor may be coupled to the input surface within the second strain concentration region.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Reference will now be made to representative embodiments illustrated in the accompanying figures. It should be understood that the following descriptions are not intended to limit this disclosure to one preferred embodiment. To the contrary, it is intended to cover
5 alternatives, modifications, and equivalents as may be included within the spirit and scope of the described embodiments as defined by the appended claims.

[0013] FIG. 1 depicts an electronic device with an input surface configured to receive force input from a user.

[0014] FIG. 2A depicts a strain-concentrating input sensor incorporating a segmented
10 stiffener that defines a lattice of strain concentration regions.

[0015] FIG. 2B depicts a detailed view of the input sensor of FIG. 2A, specifically showing a number of strain-sensitive element.

[0016] FIG. 2C depicts a side view of the input sensor of FIG. 2B, specifically showing an exaggerated deformation that may occur as a result of a force input.

15 [0017] FIG. 2D depicts a detailed view of the input sensor of FIG. 2A, specifically showing a number of strain-sensitive elements that can be arranged in a balancing network configuration.

[0018] FIG. 3A depicts a cross-section of a strain-concentrating input sensor, specifically showing one example of a segmented stiffener.

[0019] FIG. 3B depicts the strain-concentrating input sensor of FIG. 3A, specifically
20 illustrating an exaggerated deformation that may occur as a result of a force input.

[0020] FIG. 4 depicts a cross-section of a strain-concentrating input sensor, showing another example of a segmented stiffener.

[0021] FIG. 5 depicts example operations of a method of operating a strain-concentrating input sensor.

[0022] FIG. 6 depicts example operations of a method of operating a strain-concentrating input sensor.

[0023] The use of the same or similar reference numerals in different figures indicates similar, related, or identical items.

5 [0024] The use of cross-hatching or shading in the accompanying figures is generally provided to clarify the boundaries between adjacent elements and also to facilitate legibility of the figures. Accordingly, neither the presence nor the absence of cross-hatching or shading conveys or indicates any preference or requirement for particular materials, material properties, element proportions, element dimensions, commonalities of similarly illustrated elements, or any
10 other characteristic, attribute, or property for any element illustrated in the accompanying figures.

[0025] Additionally, it should be understood that the proportions and dimensions (either relative or absolute) of the various features and elements (and collections and groupings thereof) and the boundaries, separations, and positional relationships presented there between, are
15 provided in the accompanying figures merely to facilitate an understanding of the various embodiments described herein and, accordingly, may not necessarily be presented or illustrated to scale, and are not intended to indicate any preference or requirement for an illustrated embodiment to the exclusion of embodiments described with reference thereto.

DETAILED DESCRIPTION

[0026] Embodiments described herein reference electronic devices that incorporate an input sensor with a strain-sensitive element used to gather pressure or force input from a user of the electronic device.

5 [0027] In operation, the input sensor measures a strain-responsive electrical property of the strain-sensitive element, and estimates a magnitude of strain experienced by the strain-sensitive element based on one or more characteristics of that electrical property. In response, the electronic device may perform an operation based on the estimated magnitude of strain experienced by the strain-sensitive element. In many cases, the estimated magnitude of strain
10 may be correlated to an estimated magnitude of force applied by the user to the electronic device.

[0028] The performance of the input sensor is defined and bounded by the precision, accuracy, and resolution with which the strain experienced by the strain-sensitive element may be estimated. Accordingly, for many embodiments, the input sensor may be configured to measure a strain-responsive electrical property of the strain-sensitive element in a manner that
15 results in a high signal-to-noise ratio. Such a strain-sensitive element used by the input sensor to measure a strain-responsive electrical property is generally referred to as “measurement strain-sensitive element” or just “strain-sensitive element” if the context distinguishes it from other strain-sensing elements.

[0029] For example, the strain-sensitive element may have a strain-responsive electrical
20 resistance. The input sensor can measure this resistance by detecting attenuation of an electrical signal passed through the strain-sensitive element. The signal-to-noise ratio in this example may be improved by increasing the amplitude of the electrical signal prior to passing that electrical signal through the strain-sensitive element. However, such an implementation may undesirably increase the power requirements of operating the input sensor.

25 [0030] In another example, the strain-sensitive element may be formed from an exotic or specialized material that has a highly strain-responsive electrical property, such as a piezoresistive material having a high gauge factor (e.g., greater than 2.0). However, such an

implementation may undesirably increase the material costs and/or manufacturing complexity of the input sensor.

[0031] Accordingly, embodiments described herein reference an input sensor that incorporates a strain-sensitive element that can be formed from a low-cost conventional strain-responsive material and that may be measured, at low power, with a high signal-to-noise ratio.

[0032] In these embodiments, the strain-sensitive element of the input sensor is coupled to a substrate that is configured to flex. A strain-concentrating structure is also coupled to the substrate. The strain-concentrating structure includes a number of independent stiffener segments. The stiffener segments are separated from one another and are separately coupled to the substrate. In this manner, the stiffener segments locally strengthen the substrate such that when the substrate flexes in response to an application of pressure by a user, strain in the substrate is generally focused to regions of the substrate that are not strengthened by the stiffener segments. These regions are generally referred to herein as “strain concentration regions” of the substrate.

[0033] The strain-sensitive element of the input sensor is coupled to the substrate within a strain concentration region. In this manner, this strain-sensitive element experiences a greater amount of strain given the same magnitude of pressure applied to the substrate by the user. As a result, in many embodiments, the input sensor can be operated at lower power, compared with conventional strain-responsive input sensors, without negatively affecting the performance, precision, accuracy, and/or resolution thereof.

[0034] These and other embodiments are discussed below with reference to FIGs. 1 - 6. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these figures is for explanation only and should not be construed as limiting.

[0035] FIG. 1 shows an electronic device 100 that can include an input sensor with a strain-sensitive element such as described herein. The electronic device 100 includes a housing 102 to retain, support, and/or enclose various components of the electronic device 100, such as a display 104. The display 104 may be any suitable display element. In many cases, the display 104 may

include a stack of multiple layers including, for example, and in no particular order: an organic light emitting diode layer, a cover glass layer, a touch input layer, and so on.

[0036] The various layers of the display 104 may be adhered together with an optically transparent adhesive. In some embodiments, each of the layers of the display 104 may be attached or deposited onto separate substrates that may be laminated or bonded to each other. The display 104 may also include other layers for improving the structural or optical performance of the display 104, including, for example, a cover glass sheet, polarizer sheets, color masks, and the like. Additionally, the display 104 may include a touch sensor for determining the location of one or more touches on the display 104 of the electronic device 100.

[0037] In many cases, the electronic device 100 can also include a processor, memory, power supply and/or battery, network connections, sensors, input/output ports, acoustic elements, haptic elements, digital and/or analog circuits for performing and/or coordinating tasks of the electronic device 100, and so on. For simplicity of illustration, the electronic device 100 is depicted in FIG. 1 without many of these elements, each of which may be included, partially and/or entirely, within the housing 102.

[0038] The processor can be configured to perform, monitor, or coordinate one or more tasks of the electronic device. For example, the processor may be configured to operate, and/or communicate with, an input sensor having a strain-sensitive element such as described herein.

[0039] Furthermore, although illustrated as a cellular phone, the electronic device 100 can be another electronic device that is either stationary or portable, taking a larger or smaller form factor than illustrated. For example, in certain embodiments, the electronic device 100 can be a laptop computer, a tablet computer, a cellular phone, a wearable device, a health monitoring device, a home or building automation device, a home or building appliance, a craft or vehicle entertainment, control, and/or information system, a navigation device, and so on.

[0040] As noted above, the electronic device 100 can also include an input sensor coupled to the display 104. For simplicity of illustration, as with the example elements of electronic device 100 listed above, FIG. 1 is depicted without the input sensor which may be included, partially and/or entirely, within the housing 102.

[0041] Generally and broadly, FIGs. 2A – 2D reference an input sensor 200 with a strain-sensitive element used by an electronic device, such as the electronic device 100 in FIG. 1, to gather pressure or force inputs from a user of the electronic device.

[0042] With specific reference to FIG. 2A, there is shown a strain-concentrating input sensor incorporating a segmented stiffener that defines a lattice of strain concentration regions. The input sensor 200 may be incorporated within the electronic device 100 of FIG. 1. In some examples, the input sensor 200 can be disposed below the display 104.

[0043] The input sensor 200 includes a substrate 202 that is configured to flex. In many cases, the substrate 202 is supported along its perimeter by a chassis or frame. The chassis or frame may be coupled to an enclosure, such as the housing 102 of the electronic device 100 as shown in FIG. 1. In many cases, the substrate 202 is at least partially suspended by the chassis or frame so that the substrate 202 may flex.

[0044] The substrate 202 may be formed from a single layer or multiple layers of material. In some cases, the substrate 202 may be formed from a material such as, but not limited to: plastic, metal, ceramic, glass, or any combination thereof. The substrate 202 may have any suitable thickness, but in many embodiments, the substrate 202 is less than 1 mm thick. The substrate 202 may be optically clear or optically opaque. The substrate 202 may be electrically conductive or insulating. The substrate 202 may be a multi-purpose element; the substrate 202 may also function as a reflector and/or as an electromagnetic or capacitive shield. The substrate 202 may be electrically isolated, biased to a specific voltage, floating, or grounded.

[0045] The input sensor 200 includes a strain-concentrating structure 204 coupled to the substrate 202. The strain-concentrating structure 204 is shown as a number of independent stiffener segments, one of which is labeled as the stiffener 206. The stiffener 206 takes a generally square shape, however, in other embodiments other shapes may be used. For example, the stiffener 206 may take a triangular, rectangular, circular, or other arbitrary shape.

[0046] As illustrated, each of the independent stiffener segments of the strain-concentrating structure 204 are of uniform size, although this may not be required of all embodiments. In some embodiments, certain stiffeners may have a different size than other stiffener; stiffeners adjacent

to a perimeter of the substrate 202 may have a different size than those adjacent to the geometric center of the substrate 202.

[0047] In many embodiments, each of the independent stiffener segments of the strain-concentrating structure 204 may be formed from the same material. This material may be selected in particular implementations for having a specific modulus of elasticity. In some examples, the modulus of elasticity of each of the independent stiffener segments is greater than then modulus of elasticity of the substrate 202, although this is not required.

[0048] In other embodiments, different stiffener segments of the strain-concentrating structure 204 may be formed from different materials. For example, stiffener segments nearby the perimeter of the substrate 202 maybe formed from a first material whereas stiffener segments nearby the geometric center of the substrate 202 may be formed from a second material.

[0049] The independent stiffener segments of the strain-concentrating structure 204 may be formed from any number of suitable materials such as, but not limited to: metal, glass, sapphire, ceramic, plastic, acrylic, and so on. The independent stiffener segments may be formed from the same material as the substrate 202 or they may be formed from a different material. In some examples, the independent stiffener segments may be formed integrally with the substrate 202. For example, the independent stiffener segments may be defined by etching or ablating the substrate 202.

[0050] The independent stiffener segments of the strain-concentrating structure 204 may be electrically conductive or electrically insulating. The independent stiffener segments may be coupled to electrical circuits (e.g., capacitive sensor circuits), or the independent stiffener segments may be electrically isolated, electrically floating, or electrically grounded.

[0051] The independent stiffener segments can be formed from a single material, or a stack or laminate of multiple materials. In some embodiments, different stiffener segments can include a different number of layers of stacked material than other stiffener segments.

[0052] As illustrated, the independent stiffener segments of the strain-concentrating structure 204 are separated from one another in a regular pattern taking the general shape of a grid. In other embodiments, other patterns may be used including, but not limited to: concentric rings,

triangular patterns, rectilinear patterns, arbitrary patterns and so on. In some examples, the pattern may be a repeating pattern although this may not be required of all embodiments. The pattern may extend across the entirety of the substrate 202, although this is not required; in some examples, the independent stiffener segments of the strain-concentrating structure 204 may be
5 disposed over only a portion of the substrate 202.

[0053] As noted with respect to other embodiments described herein, the individual stiffener segments of the strain-concentrating structure 204 locally strengthen the substrate 202 so that when the substrate 202 flexes (e.g., in response to an input force), strain within the substrate is generally concentrated between the stiffener segments. In this manner, the regions between
10 adjacent independent stiffener segments may be referred to strain concentration regions.

[0054] In the illustrated embodiment, the independent stiffener segments of the strain-concentrating structure 204 are distributed in a grid pattern, defining a square lattice of strain concentration regions defined by eight rows intersecting eight columns. One row of the square lattice is labeled as the strain concentration row 208 and one column of the square lattice is
15 labeled as the strain concentration column 210.

[0055] FIG. 2B depicts a detailed view of portion of the input sensor 200 of FIG. 2A, specifically showing a number of strain-sensitive elements arranged within strain concentration regions defined by the strain-concentrating structure 204.

[0056] A first strain-sensitive element 212 is disposed along the strain concentration row 208 and a second strain-sensitive element 214 is disposed along the strain concentration column 210.
20 As illustrated, the first strain-sensitive element 212 and the second strain-sensitive element 214 are oriented perpendicular to one another, each being coupled to, adjacent to, and/or otherwise associated with the stiffener 206. In other cases, the relative orientation of the first strain-sensitive element 212 and the second strain-sensitive element 214 may be different than
25 illustrated. For example, in some embodiments, more than one strain-sensitive element, in the same or different orientations, may be disposed within either or both the strain concentration row 208 and/or the strain concentration column 210.

[0057] In many cases, the first strain-sensitive element 212 is positioned centrally between the stiffener 206 and a second stiffener 206'. Similarly, the second strain-sensitive element 214 is positioned centrally between the stiffener 206 and a third stiffener 206". In this configuration, the first strain-sensitive element 212 and the second strain-sensitive element 214 are positioned in the most-strained portion of the respective strain concentration regions. More specifically, when a force is applied to the substrate 202 nearby the stiffener 206, the substrate may flex along the force concentration regions, such as shown, exaggerated, in FIG. 2C.

[0058] Returning to FIG. 2B, the first strain-sensitive element 212 and the second strain-sensitive element 214 are formed in a serpentine pattern, although this may not be required and other implementation-specific patterns are possible.

[0059] The first strain-sensitive element 212 and the second strain-sensitive element 214 can be formed from any material that exhibits a strain-responsive electrical property. In many embodiments, the first strain-sensitive element 212 and the second strain-sensitive element 214 are formed from at least one of, without limitation: nickel, constantan, karma, silicon, polysilicon, gallium zinc oxide, metal oxides, doped metal oxides, semiconductor materials and alloys, and so on.

[0060] The first strain-sensitive element 212 and the second strain-sensitive element 214 can be formed from the same material or different materials. The elements can be formed in the same pattern, or different patterns. The elements may be configured to be measured in tandem or separately.

[0061] The first strain-sensitive element 212 and the second strain-sensitive element 214 may be coupled to an electrical circuit (not shown). The electrical circuit may be a portion of the input sensor 200 or the electrical circuit may be a separate electrical circuit.

[0062] In operation, the input sensor 200 measures one or more strain-responsive electrical properties (e.g., resistance, conductance, accumulated charge, impedance, and so on) of either or both the first strain-sensitive element 212 and the second strain-sensitive element 214, and estimates a magnitude of strain experienced by the strain-sensitive elements based on one or more characteristics (e.g., attenuation, phase shift, frequency shift, and so on), of the measured

electrical property. In some cases, the input sensor monitors one or more characteristics of the measured electrical property over time. One may appreciate that measurement and analysis techniques may vary from embodiment and that any number of suitable implementations are possible.

5 **[0063]** In one example, the first strain-sensitive element 212 and the second strain-sensitive element 214 are resistive elements. In this example, the input sensor 200 is configured to measure the resistance(s) of the strain-sensitive elements. The input sensor 200 can measure the resistance of each strain-sensitive element separately or the input sensor 200 can measure the resistance of each strain-sensitive element in tandem. In some cases, more than one measurement
10 is obtained by the input sensor 200. For example, the input sensor 200 can measure a common property of the strain-sensitive elements (e.g., series resistance) in first step and can measure a differential property of the strain-sensitive elements (e.g., parallel resistance) in a second step. As noted above, the input sensor 200 may be configured to measure the resistance of either or both of the strain-sensitive elements.

15 **[0064]** In further embodiments, such as depicted in FIG. 2D, additional strain-sensitive elements may be disposed on the substrate 202. The additional strain-sensitive elements can be used by the input sensor 200 to improve the signal-to-noise ratio obtained when measuring the one or more strain-responsive electrical properties of the first strain-sensitive element 212 and the second strain-sensitive element 214. For example, in many embodiments, a third strain-
20 sensitive element 216 can be aligned generally parallel to the first strain-sensitive element 212. Similarly, a fourth strain-sensitive element 218 can be aligned generally parallel to the second strain-sensitive element 214. In these embodiments, the third strain-sensitive element 216 and the fourth strain-sensitive element 218 are disposed on the substrate 202 over and/or aligned with the stiffener 206. As a result, the third strain-sensitive element 216 and the fourth strain-sensitive
25 element 218 may not be substantially strained when an input force is applied to the substrate 202. More particularly, the stiffener 206 may support the third strain-sensitive element 216 and the fourth strain-sensitive element 218 such that the third strain-sensitive element 216 and the fourth strain-sensitive element 218 do not experience strain upon flexure of the substrate 202.

[0065] In some cases, the third strain-sensitive element 216 and the fourth strain-sensitive element 218 are aligned in the same direction.

[0066] In these embodiments, the input sensor 200 can measure the resistances of the third strain-sensitive element 216 and the fourth strain-sensitive element 218 in order to establish a
5 baseline. The baseline may be used to adjust the measurements obtained from the first strain-sensitive element 212 and the second strain-sensitive element 214.

[0067] In many cases, the first strain-sensitive element 212, the second strain-sensitive element 214, the third strain-sensitive element 216, and the fourth strain-sensitive element 218 are all formed from the same material. In this manner, each of the strain-sensitive elements may
10 respond to strain in substantially the same manner when exposed to the same strain in the same environment (e.g., temperature, humidity, and so on). In many examples, the first strain-sensitive element may be disposed nearby one another (such as shown) so that each of the elements is exposed to substantially the same environmental conditions.

[0068] In one embodiment, the first strain-sensitive element 212, the second strain-sensitive element 214, the third strain-sensitive element 216, and the fourth strain-sensitive element 218 are arranged in a balancing network configuration. In one example, the balancing network is a
15 Wheatstone bridge. In these embodiments, the third strain-sensitive element 216 and the fourth strain-sensitive element 218 serve as a reference resistance voltage divider whereas the first strain-sensitive element 212 and the second strain-sensitive element 214 serve as a variable
20 resistance voltage divider. The input sensor 200 can measure a voltage across the midpoints of the reference resistance voltage divider and the variable resistance voltage divider. Changes in this voltage correspond to changes in the sum of strain experienced by the first strain-sensitive element 212 and the second strain-sensitive element 214.

[0069] The foregoing description of the embodiments depicted in FIGs. 2A – 3D, and various
25 alternatives thereof and variations thereto are presented, generally, for purposes of explanation, and to facilitate a thorough understanding of a strain-concentrating input sensor as contemplated herein. However, it will be apparent to one skilled in the art that some of the specific details presented herein may not be required in order to practice a particular described embodiment, or an equivalent thereof.

[0070] Thus, the foregoing and following descriptions and specific embodiments are understood to be presented for the limited purposes of illustration and description. These descriptions are not target to be exhaustive or to limit the disclosure to the precise forms recited herein. To the contrary, it will be apparent to one of ordinary skill in the art that many
5 modifications and variations are possible in view of the above teachings. Particularly, it may be understood that the embodiments depicted in FIGs. 2A – 3D can be implemented in a number of suitable and implementation-specific ways.

[0071] For example, with reference to FIG. 3A there is shown a cross-section of a strain-concentrating input sensor, specifically showing one example of a segmented stiffener disposed
10 below a display stack 300 of an electronic device. Generally and broadly, the embodiment depicted in FIG. 3A shows a strain-concentrating input sensor disposed on a bottom surface of the display stack 300. The strain-concentrating input sensor includes a substrate, several measurement strain-sensitive elements, and a strain-concentrating structure. In this depicted
15 embodiment, the strain-concentrating structure is orientated outwardly from the display stack 300.

[0072] As noted above, a display stack, such as the display stack 300, typically includes one or more layers of material bonded together with optically clear adhesives. For example, the display stack 300 can include a cover glass layer 302 and an organic light emitting diode layer 304 positioned below the cover glass layer 302.

[0073] The strain-concentrating input sensor is coupled to the underside of the organic light emitting diode layer 304. The strain-concentrating input sensor includes a substrate 306. One or more stiffeners 308, 310 are coupled to the substrate 306. As with other embodiments described herein, the stiffener 308 is separated from the stiffener 310 so as to define an exposed region of the substrate 306, identified in the illustrated embodiment as a strain concentration region 312. In
20 other words, tension T within the substrate 306 may be greater in the strain concentration region 312 than elsewhere when a force F is applied to the display stack 300, such as shown in FIG. 3B.

[0074] Returning to FIG. 3A, a strain sensor 314 is disposed on the substrate 306 within the strain concentration region 312. Particularly, in many embodiments, the strain sensor is disposed at a midpoint between the stiffener 308 and the stiffener 310.

[0075] The strain-concentrating input sensor also includes two reference strain-sensitive elements 316, 318 disposed between the substrate 306 and the stiffener 308. As noted with respect to other embodiments described herein, either or both of the reference strain-sensitive elements 316, 318 may be measured in tandem with the strain sensor 314. Additionally, the strain-concentrating input sensor can include two additional reference strain-sensitive elements 320, 322 disposed between the substrate 306 and the stiffener 310. In some embodiments, either or both of the reference strain-sensitive elements 320, 322 may be measured in tandem with the strain sensor 314. In some embodiments, the strain sensor 314 can be measured in tandem with all four of the reference strain-sensitive elements 316, 318, 320, and 322 although for many 5
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embodiments, this may not be required. In some cases, the strain-concentrating input sensor may select whether to measure the strain sensor 314 in tandem with the reference strain-sensitive elements 316, 318 or in tandem with the reference strain-sensitive elements 320, 322.

[0076] In another embodiment, the strain-concentrating input sensor can be attached to a display stack in another manner. For example, with reference to FIG. 4, there is shown a cross-section of a strain-concentrating input sensor, specifically showing one example of a segmented stiffener disposed below a display stack 400 of an electronic device.

[0077] Generally and broadly, the embodiment depicted in FIG. 4 shows a strain-concentrating input sensor disposed on a bottom surface of the display stack 400. The strain-concentrating input sensor includes a substrate, several strain-sensitive elements, and a strain-concentrating structure. In this depicted embodiment, the strain-concentrating structure is orientated toward the display stack 400, enclosing a volume between the substrate and the display stack 400. 20

[0078] As with other embodiments described herein, a display stack, such as the display stack 400, typically includes one or more layers of material bonded together with optically clear adhesives. For example, the display stack 400 can include a cover glass layer 402 and an organic light emitting diode layer 404 positioned below the cover glass layer 402. 25

[0079] The strain-concentrating input sensor is coupled to the underside of the organic light emitting diode layer 404. One or more stiffeners 406, 408 are coupled to the underside of the organic light emitting diode layer 404. A substrate 410 is coupled to, and extends across, the

stiffeners 406, 408, enclosing a cavity 412. In some embodiments, the cavity 412 can be partially or entirely filled with a flexible material, such as but not limited to a silicone or a polymer material. In other embodiments, the cavity 412 may be left unfilled.

[0080] As with other embodiments described herein, the stiffener 406 is separated from the stiffener 408 so as to define a strain concentration region 414 between them. A strain sensor 416 is disposed on the substrate 410 within the strain concentration region 414. Particularly, in many embodiments, the strain sensor is disposed at a midpoint between the stiffener 406 and the stiffener 408.

[0081] The strain-concentrating input sensor can also include two reference strain-sensitive elements 418, 420 disposed between the substrate 410 and the stiffener 406. As noted with respect to other embodiments described herein, either or both of the reference strain-sensitive elements 418, 420 may be measured in tandem with the strain sensor 416. Additionally, the strain-concentrating input sensor can include two additional reference strain-sensitive elements 422, 424 disposed between the substrate 410 and the stiffener 408. In some embodiments, either or both of the reference strain-sensitive elements 422, 424 may be measured in tandem with the strain sensor 414. In some embodiments, the strain sensor 416 can be measured in tandem with all four of the reference strain-sensitive elements 418, 420, 422, and 424 although for many embodiments, this may not be required. In some cases, the strain-concentrating input sensor may select whether to measure the strain sensor 416 in tandem with the reference strain-sensitive elements 418, 420 or in tandem with the reference strain-sensitive elements 422, 424.

[0082] The foregoing description of the embodiments depicted in FIGs. 3A – 4, and various alternatives thereof and variations thereto are presented, generally, for purposes of explanation, and to facilitate a thorough understanding of various possible configurations of a strain-concentrating input sensor as contemplated herein. However, it will be apparent to one skilled in the art that some of the specific details presented herein may not be required in order to practice a particular described embodiment, or an equivalent thereof.

[0083] Thus, the foregoing and following descriptions and specific embodiments are understood to be presented for the limited purposes of illustration and description. These descriptions are not target to be exhaustive or to limit the disclosure to the precise forms recited

herein. To the contrary, it will be apparent to one of ordinary skill in the art that many modifications and variations are possible in view of the above teachings. Particularly, it may be understood that the embodiments depicted in FIGs. 3A – 4 can be implemented in a number of suitable and implementation-specific ways.

5 [0084] For example, a strain-concentrating input sensor can be incorporated within a display stack that implements technology other than that of organic light emitting diodes, including, but not limited to: liquid-crystal display technology, electroluminescent technology, electronic ink, and the like or any combinations thereof. The display stack may also include other layers for improving its structural or optical performance, including, for example, glass sheets, polymer
10 sheets, polarizer sheets, color masks, rigid or resilient frames, and the like.

[0085] Similarly, the cover glass layers may be formed from materials other than glass. In one example, the cover glass is formed from ion-implanted glass, sapphire glass, laminate glass, and the like or any combination thereof.

15 [0086] In other embodiments, a strain-concentrating input sensor can include a stiffener on both sides of a substrate. These stiffeners may be aligned vertically in pairs, although this may not be required. Each stiffener in a vertically-aligned stiffener pair may be matched, taking the same shape, having the same thickness, made from the same material, and so on. In other embodiments, each stiffener in a vertically-aligned stiffener pair may be mismatched; different stiffeners of a single pair may be formed from different material, may be formed to have
20 different thicknesses, may be formed to have different moduli of elasticity, and so on.

[0087] In still further embodiments, the strain-concentrating input sensor may not be directly coupled to a portion of a display. In these embodiments, the strain-concentrating input sensor may be separated from the display by a separator. The separator may be formed from any suitable element including, but not limited to: metal, plastic, glass, adhesive, ceramic, and so on.
25 In these embodiments, the separator may rigidly couple the strain-concentrating input sensor to the display stack.

[0088] FIG. 5 depicts example operations of a method of operating a strain-concentrating input sensor. In one example, the method 500 can be performed by an electronic device such as

the electronic device 100 depicted and described with respect to FIG. 1. The method 500 begins at operation 502 in which a location of a touch on an input surface coupled to the strain-concentrating input sensor is determined. Next, at operation 504, one or more strain-sensitive structures adjacent to the touch location are measured.

5 [0089] FIG. 6 depicts example operations of a method of operating a strain-concentrating input sensor. In one example, the method 600 can be performed by an electronic device such as the electronic device 100 depicted and described with respect to FIG. 1. The method 600 begins at operation 602 in which a magnitude of strain of a particular strain-sensitive structure of a strain-concentrating input sensor is estimated. Next, at operation 604, the strain magnitude is
10 used to estimate an input force that caused the strain. In many embodiments, the input force estimate is based on the strain magnitude and based on the output of a mechanical model of the strain-concentrating input sensor.

[0090] Although many embodiments are described with reference to an input sensor within a portable electronic device, it should be appreciated that other embodiments can take other forms
15 and may be included within different form factors.

[0091] For example, embodiments described herein are not necessarily limited to measuring resistive sensors or strain sensors, and other sensors and other sensor types can be accurately measured using the systems and method described herein. Accordingly, it should be appreciated that the various embodiments described herein, as well as the functionality, operation,
20 components, and capabilities thereof may be combined with other elements as necessary, and so any physical, functional, or operational discussion of an element or feature is not intended to be limited solely to that particular embodiment to the exclusion of others.

[0092] Furthermore, one may appreciate that although many embodiments are disclosed above, that the operations and steps presented with respect to methods and techniques described
25 herein are meant as exemplary and accordingly are not exhaustive. One may further appreciate that alternate step order or, fewer or additional operations may be required or desired for particular embodiments.

[0093] Although the disclosure above is described in terms of various exemplary embodiments and implementations, it should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described, but instead can be applied, alone or in various combinations, to one or more of the some embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments but is instead defined by the claims herein presented.

CLAIMS

What is claimed is:

1. An input sensor comprising:
an input surface configured to receive a force input;
5 a strain-concentrating structure comprising a number of stiffener segments, each stiffener segment separately coupled to the input surface to define a number of strain concentration regions; and
a strain-sensitive element coupled to at least one strain concentration region of the number of strain concentration regions.
- 10 2. The input sensor of claim 1, wherein the number of strain concentration regions takes a shape of a lattice.
3. The input sensor of claim 1, further comprising a display positioned below the input surface.
4. The input sensor of claim 3, wherein the display is an organic light emitting diode
15 display.
5. The input sensor of claim 1, wherein the at least one stiffener segment of the number of stiffener segments has a first modulus of elasticity that is greater than a second modulus of elasticity of the input surface.
6. The input sensor of claim 1, wherein the input surface is formed from sapphire or glass.
- 20 7. The input sensor of claim 1, wherein the strain-sensitive element is a resistive sensor.
8. The input sensor of claim 7, wherein:
the resistive sensor is a first strain sensor; and
the input sensor further comprises a second strain sensor, the second strain sensor
disposed adjacent to the first strain sensor and between the input surface and the at least one
25 strain concentration region.
9. The input sensor of claim 8, wherein:

the at least one strain concentration region of the input surface is a first region; and
the input sensor further comprises:

a third strain sensor coupled to a second region of the input surface, the second
region adjacent to the at least one strain concentration region; and

5 a fourth strain sensor disposed adjacent the second strain sensor and between the
input surface and the strain-concentrating structure adjacent to the first strain sensor.

10. The input sensor of claim 9, wherein:

the first strain sensor and the third strain sensor are oriented in a first direction; and
the second strain sensor and the fourth strain sensor are oriented in a second direction.

10 11. The input sensor of claim 9, wherein the first strain sensor, the second strain sensor, the
third strain sensor, and the fourth strain sensor are coupled together into a Wheatstone bridge
configuration.

12. An electronic device comprising:

an input surface;

15 a display positioned below the input surface;

a substrate positioned below the display;

a stiffener coupled to the substrate;

a reference strain-sensitive element coupled to the stiffener; and

a measurement strain-sensitive element associated with the stiffener;

20 wherein:

the reference strain-sensitive element experiences a first strain in response to a
flexing of the substrate; and

the measurement strain-sensitive element experiences a second strain in response
to the flexing of the substrate that is greater than the first strain.

25 13. The electronic device of claim 12, further comprising a separator, the separator
positioned between the substrate and the stiffener.

14. The electronic device of claim 13, wherein the separator rigidly couples the stiffener to
the substrate.

15. The electronic device of claim 12, wherein the display is an organic light emitting display.

16. The electronic device of claim 12, wherein the reference strain-sensitive element is made from the same material as the measurement strain-sensitive element.

5 17. The electronic device of claim 12, wherein the stiffener is formed from a material with a first modulus of elasticity that is greater than a second modulus of elasticity of the substrate.

18. The electronic device of claim 12, wherein the measurement strain-sensitive element is adjacent to the stiffener.

19. An input sensor comprising:

10 an input surface;

a first stiffener coupled to the input surface;

a second stiffener coupled to the input surface and separated from the first stiffener thereby defining a first strain concentration region between the first stiffener and the second stiffener;

15 a third stiffener coupled to the input surface separated from the first stiffener and the second stiffener thereby defining a second strain concentration region between the first stiffener and the third stiffener;

a first strain sensor coupled to the input surface within the first strain concentration region; and

20 a second strain sensor coupled to the input surface within the second strain concentration region.

20. The input sensor of claim 19, further comprising:

a third strain sensor coupled to the input surface and positioned below the first stiffener; and

25 a fourth strain sensor coupled to the input surface and positioned below the first stiffener.

21. The input sensor of claim 20, wherein:

the third strain sensor is substantially parallel to the first strain sensor; and

the fourth strain sensor is substantially parallel to the third strain sensor.

22. The input sensor of claim 19, wherein the input surface comprises glass or sapphire.

23. The input sensor of claim 19, wherein the first strain sensor and the second strain sensor are formed from constantan.

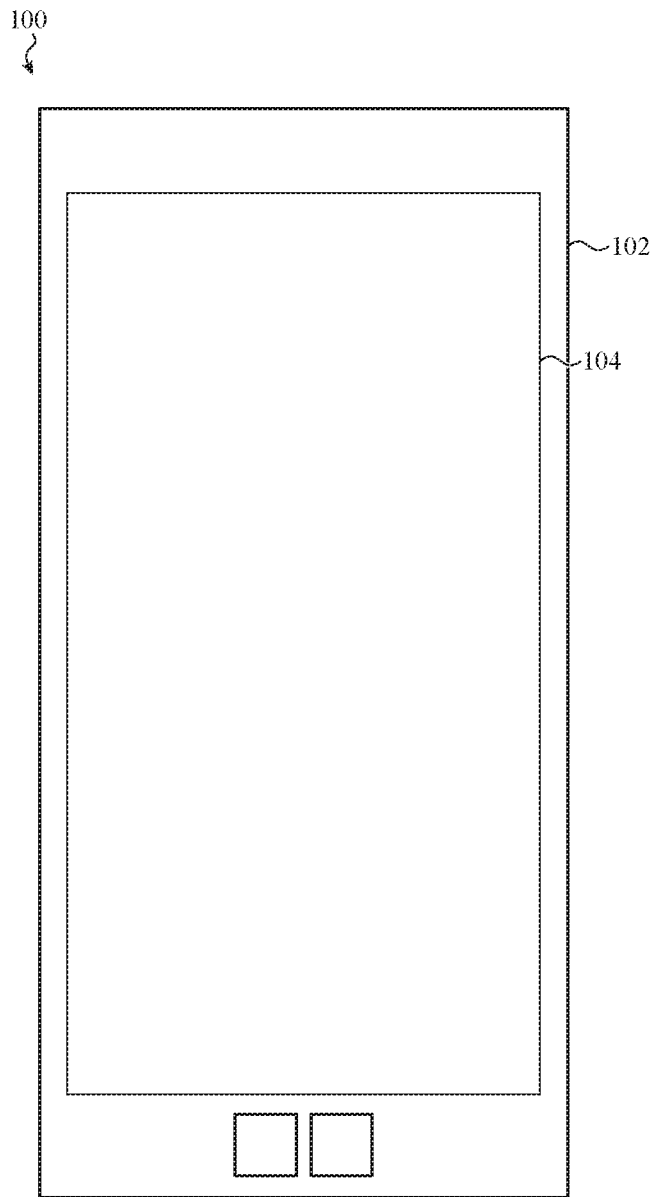


FIG. 1

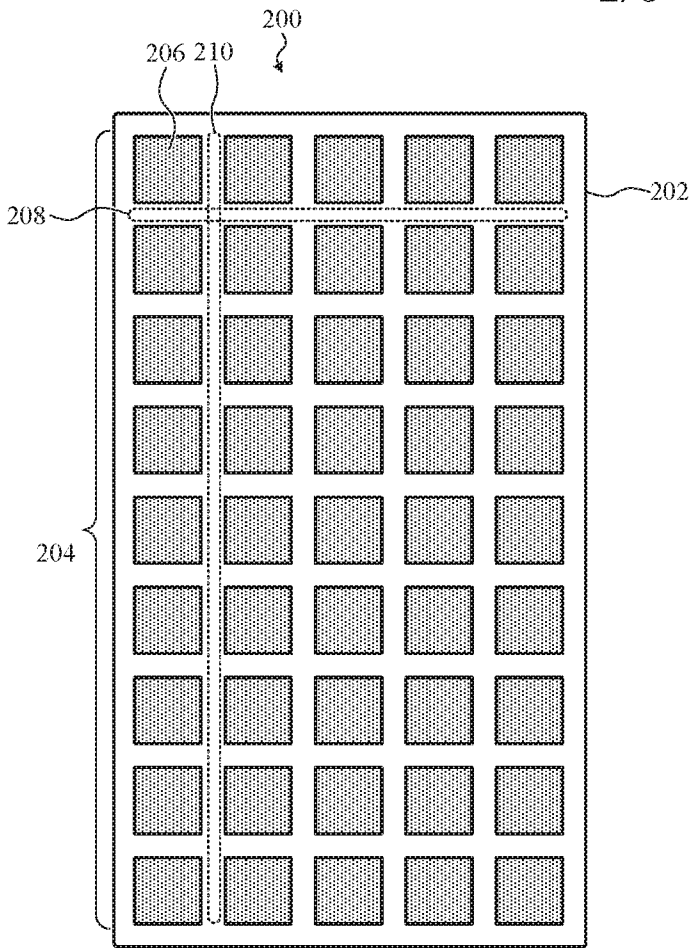


FIG. 2A

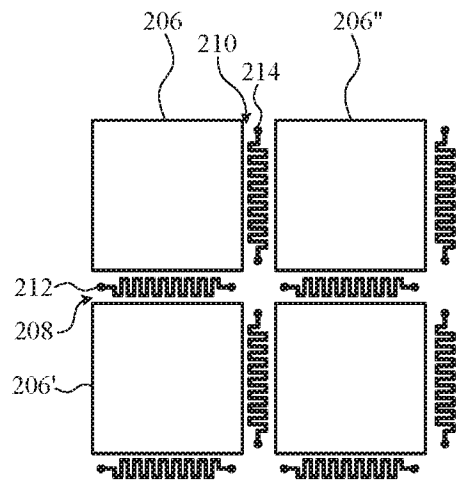


FIG. 2B

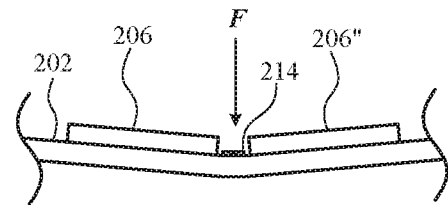


FIG. 2C

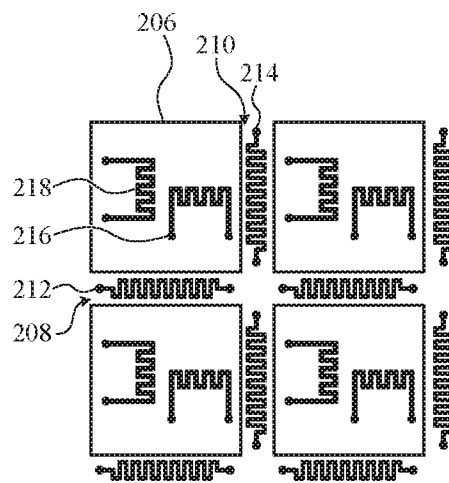


FIG. 2D

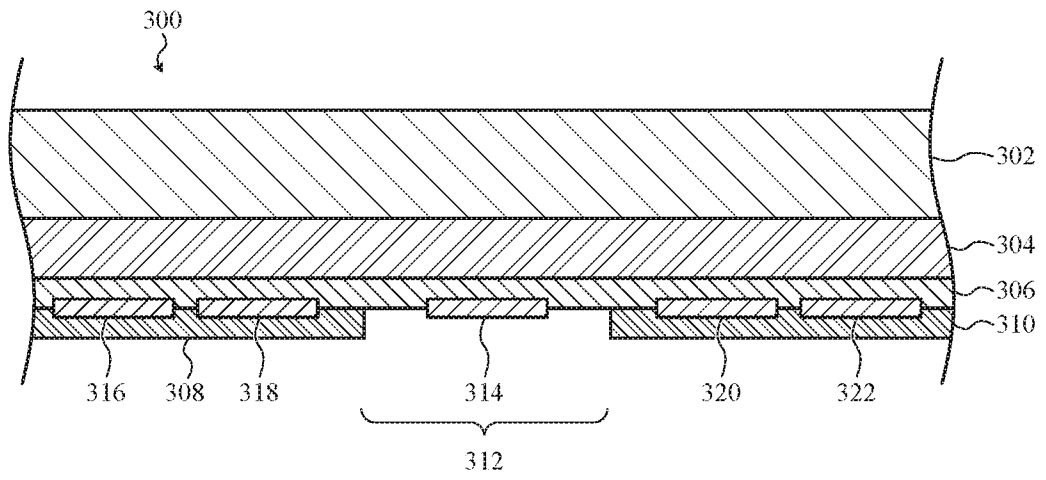


FIG. 3A

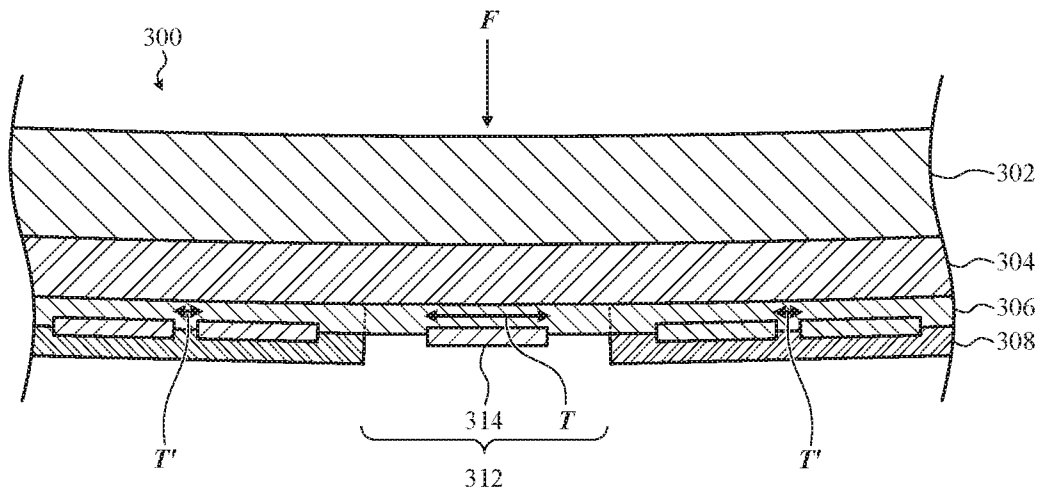


FIG. 3B

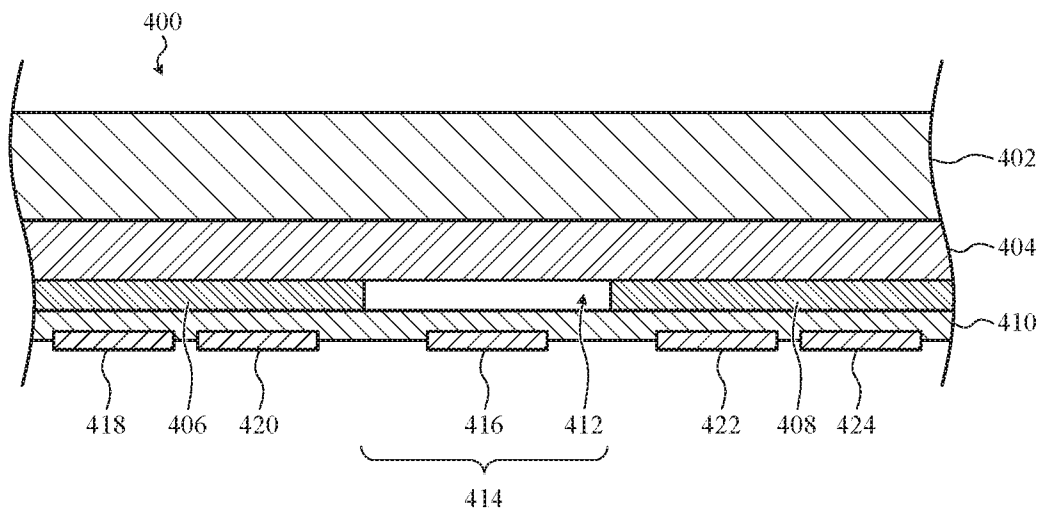


FIG. 4

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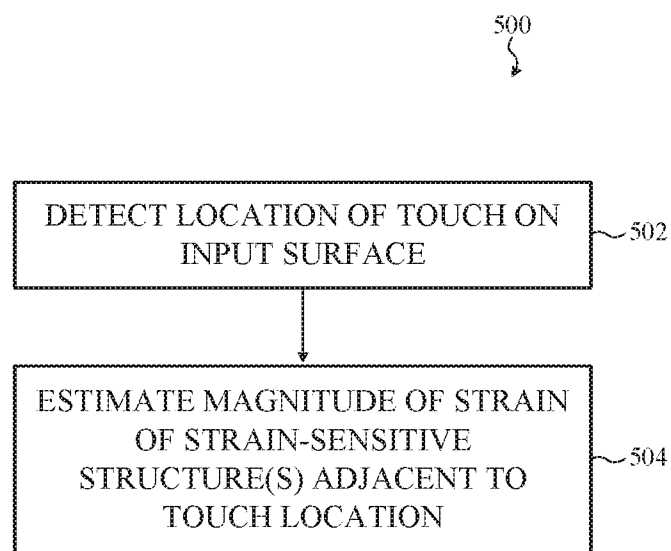


FIG. 5

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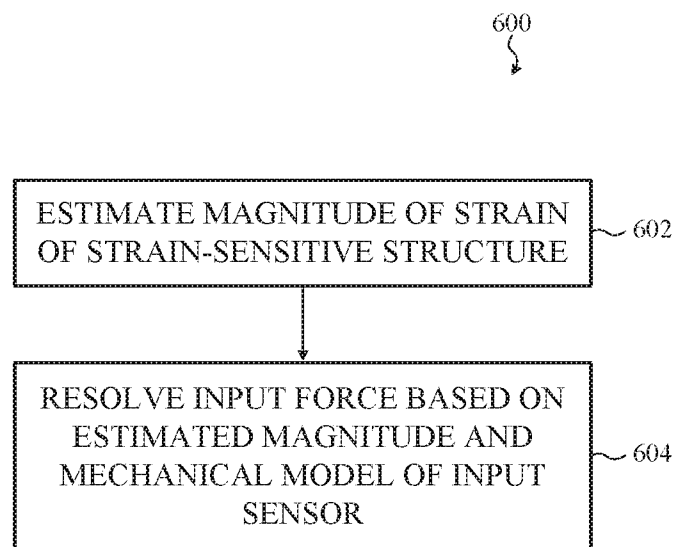


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/013559

A. CLASSIFICATION OF SUBJECT MATTER
 INV. G01L1/20 G06F3/041 G06F3/045 H01L27/32
 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)
 G06F G01L H01L

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	EP 0 388 346 A2 (IBM [US]) 19 September 1990 (1990-09-19) the whole document	1-11, 19-23
X	WO 2014/149023 A1 (RINAND SOLUTIONS LLC [US]) 25 September 2014 (2014-09-25) the whole document	1,12-19

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
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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
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- "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 29 March 2017	Date of mailing of the international search report 01/06/2017
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 Schambach, Philip

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/013559

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