A transparent force sensor for detecting an applied force on a surface of a device. The transparent force sensor includes a transparent force-sensitive film having an array of strain-relief features oriented along a first direction. The transparent force-sensitive film is formed from a transparent piezoelectric material that exhibits a substantially reduced net charge when strained along a primary direction. The force sensor also includes a display element disposed on one side of the transparent force-sensitive film.
FIG. 1
FIG. 6
TRANSPARENT FORCE SENSOR WITH STRAIN RELIEF

CROSS-REFERENCE TO RELATED APPLICATIONS


TECHNICAL FIELD

This application generally relates to force sensing and, in particular, to force sensing using a transparent force-sensitive film having one or more strain-relief features.

BACKGROUND

Mobile devices typically include a display screen and one or more components for providing user input to the device. In some cases, it may be advantageous for the user to provide touch input on a surface that overlays the display or other portion of the device. Some traditional touch sensors are configured to detect the presence and location of a touch on a surface using capacitive sensing techniques. However, many traditional touch sensors are not able to determine the magnitude or degree of force associated with a touch.

SUMMARY

One example embodiment includes a transparent force sensor for detecting a force on a surface of a device. The applied force may be due to a touch on an exterior surface of the device. The transparent force sensor may include a transparent force-sensitive film having an array of slit features oriented along a first direction. The transparent force-sensitive film may be formed from a transparent piezoelectric material that exhibits a substantially reduced net charge when strained along a first primary direction. The sensor may also include a display element disposed along a first direction. The sensor may include a top electrode disposed above the first transparent force-sensitive film, a middle electrode disposed below the first transparent force-sensitive film, and a bottom electrode disposed below the second transparent force-sensitive film. In some example embodiments, the sensor also includes a first optically-clear adhesive disposed between the top electrode and the first transparent force-sensitive film; and a second optically-clear adhesive disposed between the middle electrode and the first transparent force-sensitive film.

In some embodiments, the sensor includes a cover disposed above the first transparent force-sensitive film; and a display element disposed below the second transparent force-sensitive film, wherein the second transparent force-sensitive film is disposed below the first transparent force-sensitive film. The sensor may also include a top electrode disposed above the first transparent force-sensitive film, a middle electrode disposed below the first transparent force-sensitive film, and a bottom electrode disposed below the second transparent force-sensitive film. In some example embodiments, the sensor also includes a first optically-clear adhesive disposed between the top electrode and the first transparent force-sensitive film; and a second optically-clear adhesive disposed between the middle electrode and the first transparent force-sensitive film.

In some embodiments, the sensor includes sense circuitry electrically coupled to the top, middle, and bottom electrodes. The sense circuitry may be configured to detect a change in an electrical property of the first and second transparent force-sensitive films due to the force on the device. In some embodiments, the electrical property is an electrical charge.
sensitive film is configured to produce a charge when strained perpendicular to the second direction. In some cases, the sense circuitry is configured to measure a magnitude of the touch.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 depicts an example electronic device having a force sensor incorporated with a display element.

[0012] FIGS. 2A-C depict an example of charge characteristics for a transparent force-sensing film having strain-direction dependent charge polarity.

[0013] FIGS. 3A-B depict a force-sensitive films having an array of strain-relief features substantially oriented along a Y-direction.


[0015] FIGS. 5A-C depict examples of force-sensitive films integrated with a display stack.

[0016] FIG. 6 depicts components of an example electronic device.

DETAILED DESCRIPTION

[0017] In the following description of examples, reference is made to the accompanying drawings in which it is shown by way of illustration specific examples that can be practiced. It is to be understood that other examples can be used and structural changes can be made without departing from the scope of the various examples.

[0018] The examples provided herein can be used to detect and measure the force of a user’s touch on a device. In particular, the examples include devices and systems for detecting an amount and/or location of a force applied to a device using a force-sensitive film. One example system can include a transparent force-sensitive film for generating an electric charge in response to a deformation of the film. Some embodiments relate to force-sensors that include one or more layers formed from a transparent force-sensitive film for detecting an amount of a force applied to a device. In one example, a transparent force-sensitive film is integrated with, or disposed relative to, a display element of an electronic device. The electronic device may be, for example, a mobile phone, a wearable electronic device, a health monitoring device, a tablet computing device, a computer display, a computing input device (such as a touch pad, keyboard or mouse), a touch pad or screen, one or more buttons, and so on. In some cases, a transparent or non-transparent force-sensitive film is integrated with a non-display component to form a touch-sensitive surface on the surface of an enclosure or other surface of the device. In some embodiments, the force-sensitive film is integrated with a touch pad, touch panel, or other touch-sensitive surface of a device. In one example, the force-sensitive film is integrated with a touch pad of a notepad computer system.

[0019] Generally and broadly, a touch may be sensed on a display, enclosure, or other surface of an electronic device using a force sensor, which determines a force of the touch. The estimated magnitude or degree of the force may be used as an input signal or input data to the electronic device. This may permit multiple different inputs through a single touch or input device, such that the response and/or output of the device may vary with the input force. Accordingly, and for example, this may permit a first force exerted on a given point to be interpreted as a first input type or command, while a second force (different in amount from the first) at the same point may be interpreted as a second input type or command. The device’s responses or outputs may thus differ in response to the two inputs, even though they occur at the same point and may use the same input device.

[0020] The transparent force-sensitive film is typically a compliant material that exhibits an electrical property that is variable in response to deformation or deflection of the film. The transparent force-sensitive film may be formed from a piezoelectric, piezo-resistive, resistive, or other strain-sensitive materials. Transparent resistive films can be formed by coating a substrate with a transparent conductive material. Potential transparent conductive materials include, for example, polyethyleneoxythiophene (PEDOT), indium tin oxide (ITO), carbon nanotubes, graphene, silver nanowire, other metallic nanowires, and the like. Potential substrate materials include, for example, glass or transparent polymers like polyethylene terephthalate (PET) or cyclo-olefin polymer (COP). Typically, when a piezo-resistive or resistive film is strained, the resistance of the film changes as a function of the strain. The resistance can be measured with an electrical circuit. In this way, a transparent piezo-resistive or resistive film can be used in a similar fashion as a strain gauge. If transparency is not required, then other film materials may be used, including, for example, Constantan and Karma alloys for the conductive film and a polyimide may be used as a substrate. Nontransparent applications include force sensing on track pads or the back of display elements.

[0021] In some embodiments, the transparent force-sensitive film exhibits a different charge polarity depending on the direction along which the film is strained. As explained in more detail below with respect to FIGS. 2A-C, in some cases, the film may exhibit a substantially zero net charge when the film is bent or deflected up or down along a primary direction. In some cases, the film may exhibit a substantially reduced net charge when strained along a primary direction. For example, the film may exhibit a negative that is substantially less when strained in the primary direction as compared to other directions.

[0022] In some cases, the film may exhibit a strain-direction dependent charge polarity. For example, the film may exhibit a charge having a polarity that is dependent on the direction of the bend with respect to the primary direction. In particular, the charge may have a first polarity when the film is bent up at a first angle with respect to the primary direction and have a second, opposite polarity when the film is bent up at an angle that is, for example, in the opposite direction to the first angle. In one illustrative example, the primary direction may be oriented approximately 45 degrees from an X- and Y-directions (which are perpendicular to each other). Bending the film up along the X-direction may result in a surface charge having a first polarity (e.g., positive or negative). Bending the film up along the Y-direction (perpendicular to the X-direction) may result in a surface charge having a second, opposite polarity (e.g., negative or positive). Example transparent films that exhibit these properties include polylactide polymers, such as poly-L-lactide (PLLA) and poly-D-lactide (PDLA) polymers. In general, transparent and non-transparent force-sensitive films may be referred to herein as “force-sensitive films” or simply “films.”

[0023] In some embodiments, the force-sensitive film is patterned into an array of lines, pixels, or other geometric elements herein referred to as film elements. The regions of
the force-sensitive film or the film elements may also be connected to sense circuitry using electrically conductive traces or electrodes. In general, the force-sensitive film exhibits a measurable change in an electrical property in response to a force being applied to the device. In one example, as a force is applied to the device, one or more of the film elements is deflected or deformed. Sense circuitry, which is in electrical communication or otherwise electrically connected to the one or more film elements or film electrodes, is configured to detect and measure the change in the electrical property of the film due to the deflection. Based on the measured electrical property of the film, an estimated amount of force can be computed. In some cases, the estimated force may represent the magnitude of a touch on the device and be used as an input to a graphical user interface or other aspect of the device.

[0024] In some cases, the force-sensitive film is patterned into pixel elements, each pixel element including an array of traces generally oriented along one direction. This configuration may be referred to as a piezo-resistive or resistive strain gauge configuration. In general, in this configuration the force-sensitive film is a material whose resistance changes in response to strain. The change in resistance may be due to a change in the geometry resulting from the applied strain. For example, an increase in length combined with decrease in cross-sectional area may occur in accordance with Poisson's effect. The change in resistance may also be due to a change in the inherent resistivity of the material due to the applied strain. For example, the applied strain may make it easier or harder for electrons to transition through the material. The overall effect is for the total resistance to change with strain due to the applied force. Also, in a piezo-resistive or resistive strain gauge configuration, each pixel may be formed from a pattern of the force-sensitive film, aligned to respond to strain along a particular axis. For example, if strain along an x-axis is to be measured, the pixel should have majority of its trace length aligned with the x-axis.

[0025] In some embodiments, the force-sensitive film may be formed from a solid sheet of material and is in electrical communication with a pattern of electrodes disposed on one or more surfaces of the force-sensitive film. The electrodes may be used, for example, to electrically connect a region of the solid sheet of material to sense circuitry. This configuration may be referred to as a piezo-strain configuration. In this configuration, the force-sensitive film may generate a charge when strained. The force-sensitive film may also generate different amounts of charge depending on the degree of the strain. In some cases, the overall total charge is a superposition of the charge generated due to strain along various axes.

[0026] One or more force-sensitive films may be integrated with or attached to a display element of a device, which may include other types of sensors. In one typical embodiment, the display element also includes a touch sensor configured to detect the location of one or more touches. Using a touch sensor and the transparent force-sensitive film(s) in accordance with some embodiments described herein, the location and magnitude of a touch and a force of a touch on a display element of a device can be estimated.

[0027] FIG. 1 depicts an example electronic device 100 having a force sensor integrated into a display element 110. In this example, the electronic device 100 includes a display element 110 mounted in a device housing 101. The display element 110 may be generally referred to as a display and is used to present visual content to the user of the electronic device 100. The display element 110 may include a variety of devices, such as a liquid-crystal display (LCD), a light-emitting diode (LED) display, an organic light-emitting diode (OLED) display, or the like. As explained in more detail below, the electronic device also includes one or more transparent force-sensitive layers 150 that are integrated with the display element 110. In some cases, the display element 110 is disposed on one side of, or relative to, the one or more transparent force-sensitive layers. The one or more force-sensitive layers may be attached to a surface of the display element 110 via one or more other layers including, for example, pressure sensitive adhesive layers, plastic layers, glass layers, conductive layers, or other materials. Also, as described in more detail below with respect to FIGS. 5A-C, more than one force-sensitive film may be used to form a force sensor that is incorporated with the display element 110 of the electronic device 100.

[0028] As previously mentioned, the transparent force-sensing film may exhibit a different charge polarity depending on the direction along which the film is strained. FIGS. 2A-C depict an example of charge characteristics for a transparent force-sensing film (film 200) having strain-direction dependent charge polarity. In the following examples, the film 200 is a PLa piezoelectric film that has been drawn along a primary direction, as indicated by the tensor, primary direction 210 shown in FIGS. 2A-C. In some cases, the orientation of the primary direction is due to a drawing process that substantially aligns the polymer chains of the film along a single (primary) direction.

[0029] As shown in FIGS. 2A-B, the film 200 produces a surface charge having a different polarity depending on the direction of the strain with respect to the primary direction 210. In this example, the film 200 produces a positive charge (+) on the top surface of the film 200 in response to the film 200 being bent downward along the X-direction. A negative charge (–) is also produced on the bottom surface of film 200 in response to this deflection.

[0030] As shown in FIG. 2B, the charge polarity is reversed when the film 200 is bent upward along the Y-direction. Specifically, the film 200 produces a negative charge (–) on the top surface of the film 200 in response to the film 200 being bent downward along the Y-direction. A positive charge (+) is also produced on the bottom surface of film 200 in response to this deflection. While FIGS. 2A-B depict the charge characteristics of the film 200 when bent downward, a similar reverse polarity will result when the film 200 is bent upward along either the X- or Y-directions.

[0031] In this example, if the film 200 is bent upward or downward along the primary direction 210, a zero net charge is produced. In some cases, the film 200 exhibits a substantially reduced net charge when strained along the primary direction 210. The uniaxial strain characteristics of the film 200 may be due to the orientation of the polymer chains, which are substantially aligned with the primary direction 210. The primary direction 210 is depicted in FIGS. 2A-C as being approximately 45 degrees from both the X- and Y-directions, which are substantially perpendicular to each other and generally oriented along the edge of the rectangular sheet. However, this is merely exemplary in nature and in other embodiments the primary direction 210 may be along a different orientation with respect to the X- and Y-directions and the film 200 may be formed from a non-rectangular, curved, or differently shaped sheet.

[0032] Furthermore, as shown in FIG. 2C, if the film 200 is bent downward in both the X- and Y-directions, the opposite
charges that are created may substantially cancel each other out. In this example, a substantially equal bend in both the X- and Y-directions results in a zero or substantially zero net charge on both the top and bottom surfaces of the film 200. The resulting shape of this deflection may be described as a dome shape, canopy shape, concave shape, or convex shape, depending on the context of the description.

[0033] The zero net charge property of the film 200 as depicted in FIG. 2C may be undesirable if the film 200 in used as a force-sensitive film in a touch sensor application. For example, a touch incident on a surface of the device may deform the film into a generally concave shape or depression. Because the resulting charge is substantially net zero (or substantially reduced by the net charge effect) the sensing electronics coupled to the film may not be able to detect the occurrence of the touch and/or the magnitude of the force of the touch.

[0034] One solution to this problem may be to provide an array of strain-relief features oriented along one direction of the force-sensitive film. FIGS. 3A-B and FIGS. 4A-B depict force-sensitive films that have an array of strain-relief features substantially oriented along either the X- or Y-directions. By including one or more strain-relief features in the force-sensitive film, strain in the film may be substantially isolated to a single direction. As described in more detail below with respect to the sensor configurations of FIGS. 5A-C, one or more force-sensitive films having strain-relief features may be used to detect the occurrence and magnitude of the force of a touch without the limitations described above with respect to FIG. 2C.

[0035] FIGS. 3A-B depict a force-sensitive film (film 300) formed from a piezoelectric material that exhibits a zero or substantially reduced net charge when strained along a primary direction 310. As shown in FIG. 3A, the film 300 may include an array of strain-relief features 302 that are formed as slot features. While the strain-relief features 302 are depicted as slot features, other types of features may also be used. For example, the features may be formed as recessed channel features, perforated hole features, or formed as other types of gaps in the material that substantially relieve strain along one or more directions in the film.

[0036] As a result of the strain-relief features 302, the film 300 may exhibit a net charge along a first direction and a zero, substantially zero, or substantially reduced net charge along a different, second direction. As shown in FIG. 3A, the film 300 has strain-relief features that are substantially oriented along a Y-direction. If the film 300 is bent upward along the Y-direction, a negative surface charge (−) is produced on the top surface of the film 300 and a positive surface charge (+) is produced on the bottom surface of the film 300. Similarly, a bend upward along the Y-direction will result in a positive surface charge on the top surface and a negative surface charge on the bottom surface of the film 300.

[0037] As shown in FIG. 3B, if the film 300 is bent downward along the X-direction, a zero, substantially zero, or substantially reduced net charge is produced on the top and bottom surfaces of the film 300. Thus, the strain-relief features can be used to isolate the films response to deflections that are substantially along a single direction (in this case the Y-direction). As a result, deflections that occur in both an X- and Y-direction will not result in a zero net charge as discussed above with respect to FIG. 2C. This may be advantageous when detecting or measuring the magnitude of a touch force that results in a concave dome-shaped deflection in the film 300.

[0038] A similar configuration is depicted in FIGS. 4A-B only for a film 400 having strain-relief features 402 oriented along the X-direction (instead of the Y-direction). FIGS. 4A-B also depict a force-sensitive film (film 400) formed from a piezoelectric material that exhibits a zero or substantially reduced net charge when strained along a primary direction 410 (in the absence of strain-relieving features). As shown in FIGS. 4A-B, a bend or deflection of the film 400 along the X-direction results in a positive (or negative) charge on a surface of the film 400. As shown in FIG. 4B, a bend or deflection of the film along the Y-direction results in a zero or substantially zero net charge on the surface of the film 400. Thus, in this example, the strain response of the film 400 may be substantially isolated along the X-direction.

[0039] One or more force-sensitive films as described with respect to FIGS. 3A-B and FIGS. 4A-B may be integrated into a force sensor configured to detect and/or measure the magnitude of the force of a touch. In one typical embodiment, the force-sensitive film is integrated with, or placed adjacent to, portions of a display element of a device, herein referred to as a “display stack” or simply a “stack.” A force-sensitive film may be integrated with a display stack by, for example, being attached to a substrate or sheet that is attached to the display stack. Alternatively, the force-sensitive film may be placed within the display stack in certain embodiments. Examples of a force-sensitive film that is integrated with a display stack are provided below, with respect to FIGS. 5A-C. Although the following examples are provided with respect to force-sensitive film integrated with a display stack, in other embodiments, the force-sensitive film may be incorporated with a portion of the device other than the display stack. For example, a similar force-sensitive film configuration may be integrated with a non-display element, such as a track pad, touch pad, or other touch-sensitive surface of the device.

[0040] FIG. 5A depicts an example of a force-sensitive film integrated into a display stack 500. In this example, the display stack 500 includes a two-force-sensitive films 510, 520 that are incorporated with a display element 501. As discussed above, the display element 501 may include, for example an LCD display, an LED display, an OLED display, or the like. In some cases, the display stack 500 is attached directly to a surface of the display element 501. However, in other examples, there may be additional components or layers between the display element 501 and other components of the display stack depicted in FIG. 5A. Furthermore, one or more other components or layers may be disposed on the top of the display stack 500, including, for example, a cover glass layer, another sensor layer, an optical conditioning layer, or other component layers.

[0041] The two-force-sensitive films 510, 520 are formed from a piezoelectric material that, in an unrelieved sheet form, exhibits a zero or substantially reduced net charge when strained along a primary direction (519, 529). In this example, the (unrelieved) piezoelectric material exhibits a strain-direction dependent charge polarity. In this example both of the force-sensitive films 510, 520 include strain-relief features that are oriented in different directions from each other. In particular, force-sensitive film 510 includes an array of strain-relief features that are substantially oriented along a Y-direction and the force-sensitive film 520 includes an array of strain-relief features that are substantially oriented along an
X-direction. As discussed above with respect to FIGS. 3A-B and FIGS. 4A-B, using a film having strain-relief features oriented along one direction may help isolate the strain response of the film in that direction. Accordingly, the force-sensitive film 510, having strain-relief features substantially aligned with the Y-axis can be used to measure strain that occurs primarily in the Y-direction and isolate strain that occurs in directions transverse to the direction of the strain-relief features. Similarly, the force-sensitive film 520, having strain-relief features along the X-axis can be used to measure strain that occurs primarily in the X-direction while eliminating or minimizing strain along directions that are transverse to the direction of the strain-relief features.

In this example, the primary directions 519, 529 of the two force-sensitive films 510, 520 are also oriented differently from each other. In particular, the force-sensitive film 510 is placed in the stack 500 with the primary direction 519 generally oriented -45 degrees from the Y-axis. The other force-sensitive film 520 is placed in the stack 500 with the primary direction 529 generally oriented +45 degrees from the Y-axis. This configuration results in the force-sensitive films 510, 520 having the same electric field direction when strained. As a result, the middle electrodes 522b and 512a may be connected or electrically coupled within the sensor. While the primary directions 519 and 529 are depicted in FIG. 5A as being generally oriented at +/-45 degrees, the primary directions may be in different orientations if the middle electrodes 522b and 512a are independently connected within the sensor. Furthermore, in some cases, it may not be necessary to have both electrodes 522b and 512a, if, for example, there is sufficient capacitive coupling within the stack 500.

In some cases, it may be desirable to measure the strain in both the X- and Y-directions. For example, the sum of the strain in the X- and Y-directions may represent a more robust and reproducible indication of the force applied to the top surface of the stack when boundary conditions may vary. For example, if the stack (in sheet form) is supported on opposing side edges, the stack will primarily bend and exhibit strain along the unsupported axis. Thus, if only the side edges are supported, the stack will be nonzero only along an axis that is substantially orthogonal to the side edges.

The two force-sensitive films 510, 520 may be used to detect and measure the magnitude of a force on the display stack 500. In particular, the two force-sensitive films 510, 520, as configured in the stack 500 FIG. 5A, may be used to detect a concave depression caused by a touch on the surface of the display stack 500. Furthermore, by using two force-sensitive films 510, 520 having strain relief features that are oriented transverse to each other, the response of the sensor to some deflections may be improved. For example, the use of two force-sensitive films 510, 520 may improve the reliability of sensor which may be subjected to one or more boundary conditions, as discussed above.

As shown in FIG. 5A, the stack 500 includes other components or layers that are arranged in an example configuration. In stack 500, optically clear adhesive (OCA) layers 511a, 511b are disposed on either side of the force-sensitive film 510. Similarly, two OCA layers 521a, 521b are disposed on either side of the other force-sensitive film 520. The OCA layers 511a-b and 521a-b are used to bond or join the adjacent layers to form the stack 500.

As shown in FIG. 5A, the stack 500 also includes a pair of electrode layers for each force-sensitive film. In particular, two electrode layers 512a and 512b are disposed on either side of the force-sensitive film 510. Similarly, two other electrode layers 522a, 522b are disposed on either side of the other force-sensitive film 520. The electrode layers 512a-b and 522a-b may be operatively coupled to sense circuitry that is configured to detect a change in an electrical property, such as charge or current, produced by the deflection of the force-sensitive films 510, 520. The electrode layers 512a-b and 522a-b may be formed from a transparent conductive material, such as indium tin oxide (ITO) layer deposited or formed on a substrate. In this example, the electrode layers 512a-b are formed on respective substrate layers 513a-b, and the electrode layers 522a-b are formed on respective substrate layers 523a-b. The substrate layers 513a-b and 523a-b may be formed from a polyethylene terephthalate (PET) sheet or other transparent sheet material. In this example, an additional OCA layer 515 is used to bond the top and bottom components of the stack 500 together. In some embodiments, the substrate 523a may form the cover of the display stack. In other embodiments, the substrate 523a is attached via one or more other layers to a separate cover element.
to as described above with respect to FIG. 5A, both of the force-sensitive films 570, 580 are formed from a piezoelectric material that exhibits a zero or substantially reduced net charge when strained along a primary direction (579, 589).

Also, similar to the two previous examples, each of the force-sensitive films 570, 580 includes an array of strain-relief features that are oriented transverse to each other. Thus, stack 560 may also be used to detect and measure the magnitude of the force of a touch on the stack 560.

[0051] In this example, the two force-sensitive films 570, 580 share a common electrode layer 592, which is formed on substrate layer 593. The common electrode layer 592 may be used as a common electrical ground or reference layer. Alternatively, the outer electrode layers 572 and 582 may be used as ground layers and shield the internal components of the stack 560 from electrical interference. This configuration further reduces the number of layers that are required to form a stack and also eliminates the number of electrode layers that need to be formed. Thus, the stack 560 of FIG. 5C may have a reduced thickness as compared to the stack 500 of FIG. 5A and stack 530 of FIG. 5B.

[0052] As shown in FIG. 5C, the stack 560 also includes OCA layers 571a and 571b disposed on either side of the force-sensitive film 570. Similarly, OCA layers 581a and 581b are disposed on either side of the other force-sensitive film 580. The stack 560 also includes electrode layer 572 and shared electrode layer 592 disposed on either side of the force-sensitive film 570. Similarly, electrode layer 582 and shared electrode layer 592 are disposed on either side of the other force-sensitive film 580. The bottom electrode layer 572 is formed on substrate layer 573 and the top electrode layer 582 is formed on substrate layer 583. The OCA, electrode, and substrate layers may be formed using materials and techniques similar to those described above with respect to stack 500 of FIG. 5A. In some embodiments, the upper substrate 583 may form the cover of the display stack 560. In other embodiments, the upper substrate 583 is attached via one or more other layers to a separate cover element.

[0053] FIG. 6 depicts components of an example electronic device 600. The schematic representation depicted in FIG. 6 may correspond to components of the portable electronic devices described above, including the device 100 depicted in FIG. 1. However, FIG. 6 may also more generally represent other types of devices that are configured to use a force sensor.

For example, the electronic device 600 may represent a subset of components for a mobile phone, a wearable electronic device, a health monitoring device, a tablet computing device, a notebook computer, or a desktop computer.

[0054] As shown in FIG. 6, a device 600 includes a processing unit 602 operatively connected to computer memory 604 and computer-readable media 606. The processing unit 602 may be operatively connected to the memory 604 and computer-readable media 606 components via an electronic bus or bridge. The processing unit 602 may include one or more computer processors or microcontrollers that are configured to perform operations in response to computer-readable instructions. The processing unit 602 may include the central processing unit (CPU) of the device. Additionally or alternatively, the processing unit 602 may include other processors within the device including application specific integrated circuits (ASIC) and other microcontroller devices.

[0055] The memory 604 may include a variety of types of non-transitory computer-readable storage media, including, for example, read access memory (RAM), read-only memory (ROM), erasable programmable memory (e.g., EPROM and EEPROM), or flash memory. The memory 604 is configured to store computer-readable instructions, sensor values, and other persistent software elements. Computer-readable media 606 also includes a variety of types of non-transitory computer-readable storage media including, for example, a hard-drive storage device, solid state storage device, portable magnetic storage device, or other similar devices. The computer-readable media 606 may also be configured to store computer-readable instructions, sensor values, and other persistent software elements.

[0056] In this example, the processing unit 602 is operable to read computer-readable instructions stored on the memory 604 and/or computer-readable media 606. The computer-readable instructions may adapt the processing unit 602 to detect or control the sensing and display operations described above with respect to FIG. 7. The computer-readable instructions may be provided as a computer-program product, software application, or the like.

[0057] As shown in FIG. 6, the device 100 also includes a display 608 and an input device 610. The display 608 may include a liquid-crystal display (LCD), organic light emitting diode (OLED) display, light emitting diode (LED) display, organic electroluminescence (OEL) display, or other type of display element. If the display 608 is an LCD, the display may also include a backlight component that can be controlled to provide variable levels of display brightness. If the display 608 is an OLED or LED type display, the brightness of the display may be controlled by controlling the electrical signal that is provided to display elements.

[0058] The input device 610 is configured to provide user input to the device 100. The input device 610 may represent devices that are configured to provide user input in addition to the force sensor 620 of the device 600, which may also be generally characterized as input devices. The input device 610 may include, for example, touch button, keyboard, key pad, or other touch input device. The device 600 may include other input devices, including, for example, power button, volume buttons, home buttons, scroll wheels, and camera buttons.

[0059] As shown in FIG. 6, the device 100 also includes a force sensor 620 that may be configured to detect and measure a force applied to a surface of the device. In accordance with some embodiments described herein, the force sensor 620 may include at least one transparent force-sensitive film that is configured to deflect relative to each other in response to a force applied to a surface of the device. Example force-sensitive films are described above with respect to FIGS. 2A-C, 3A-B, and 4A-B. In accordance with some embodiments described herein, the force sensor 620 may include one or more force-sensitive films that are incorporated into a display stack and configured to detect a touch on the cover (glass) of the display. Example display stacks having an incorporated force sensor are described above with respect to the embodiments depicted in FIGS. 5A-C.

[0060] As shown in FIG. 6, the device 600 also includes sense circuitry 630 that is operatively coupled to the force sensor 620. In some embodiments, the sense circuitry 630 is configured to detect a change in an electrical property of one or more transparent force-sensitive films of the force sensor 620 due to the force on the device. For example, the sense circuitry 630 may be operatively coupled to a transparent force-sensitive film via one or more electrodes and include circuitry that is configured to detect a change in charge on a
surface of the transparent force-sensitive film. The circuitry may include components that may function as charge accumulator or electrical current integrators that may be configured to amplify small changes in current. The circuitry may also include one or more analog to digital converter components for converting an analog charge or voltage signal into a digital signal or output. The sense circuitry 630 may also include memory and one or more programmable components that are used to operate the force sensor 620 and communicate an output of the sense circuitry 630 to the processing unit 602 and/or the memory 604 of the device 600.

[0061] While the present disclosure has been described with reference to various embodiments, it will be understood that these embodiments are illustrative and that the scope of the disclosure is not limited to them. Many variations, modifications, additions, and improvements are possible. More generally, embodiments in accordance with the present disclosure have been described in the context of particular embodiments. Functionality may be separated or combined in procedures differently in various embodiments of the disclosure or described with different terminology. These and other variations, modifications, additions, and improvements may fall within the scope of the disclosure as defined in the claims that follow.

We claim:

1. A transparent force sensor for detecting a force of a touch on a surface of a device, the transparent force sensor comprising:
   a transparent force-sensitive film having an array of slit features oriented along a first direction, wherein the transparent force-sensitive film is formed from a piezoelectric material that exhibits a substantially reduced net charge when strained along a primary direction;

2. The transparent force sensor of claim 1, further comprising: a display element disposed on one side of the transparent force-sensitive film.

3. The transparent force sensor of claim 1, wherein the piezoelectric material exhibits a strain-direction dependent charge polarity.

4. The transparent force sensor of claim 1, wherein the piezoelectric material exhibits a positive charge when bent upward along a first strain direction and exhibits a negative charge when bent upward along a second strain direction that is substantially perpendicular to the first strain direction.

5. The transparent force sensor of claim 1, wherein the piezoelectric material is a poly-β-L-lactide (PBLA) or poly-D-lactide (PDLA) polymer film material.

6. The transparent force sensor of claim 1, further comprising:
   a first electrode disposed above the transparent force-sensitive film;
   a second electrode disposed below the transparent force-sensitive film; and
   sense circuitry electrically coupled to the first and second electrodes, wherein the sense circuitry is configured to detect a change in an electrical property of the transparent force-sensitive film due to the force on the device.

7. The transparent force sensor of claim 6, wherein the electrical property is an electrical charge.

8. A transparent force sensor for detecting a force applied to a device, the transparent force sensor comprising:
   a cover forming a portion of an exterior surface of the device; a transparent force-sensitive film disposed below the cover and having an array of strain-relief features oriented along a first direction, wherein the transparent force-sensitive film is formed from a piezoelectric material that exhibits a substantially reduced net charge when strained along a primary direction, and a display element disposed below the transparent force-sensitive film.

9. The transparent force sensor of claim 8, wherein the strain-relief features are slit features oriented along the first direction.

10. The transparent force sensor of claim 8, wherein the strain-relief features are recessed channel features oriented along the first direction.

11. The transparent force sensor of claim 8, wherein the strain-relief features are perforated features that are arranged along the first direction.

12. A transparent force sensor for detecting a force of a touch on a device, the transparent force sensor comprising:
   a first transparent force-sensitive film having an array of slit features oriented along a first direction, wherein the transparent force-sensitive film is formed from a piezoelectric material that exhibits a substantially reduced net charge when strained along a first primary direction; and
   a second transparent force-sensitive film having an array of slit features oriented along a second direction, wherein the second transparent force-sensitive film is formed from a piezoelectric material that exhibits a substantially reduced net charge when strained along a secondary primary direction.

13. The transparent force sensor of claim 12, wherein the first direction is substantially perpendicular to the second direction.

14. The transparent force sensor of claim 12, wherein the first primary direction is substantially perpendicular to the second primary direction.

15. The transparent force sensor of claim 12, wherein the first direction is approximately 45 degrees from the first primary direction and the second direction is approximately 45 degrees from the second primary direction.

16. The transparent force sensor of claim 12, further comprising:
   a cover disposed above the first transparent force-sensitive film; and
   a display element disposed below the second transparent force-sensitive film, wherein the second transparent force-sensitive film is disposed below the first transparent force-sensitive film.

17. The transparent force sensor of claim 12, further comprising:
   a top electrode disposed above the first transparent force-sensitive film;
   a middle electrode disposed below the first transparent force-sensitive film;
   a bottom electrode disposed below the second transparent force-sensitive film; and
   sense circuitry electrically coupled to the top, middle, and bottom electrodes, wherein the sense circuitry is configured to detect a change in an electrical property of the first and second transparent force-sensitive films due to the force on the device.

18. The transparent force sensor of claim 17, wherein the first transparent force-sensitive film is configured to produce a charge when strained perpendicular to the first direction,
and the second transparent force-sensitive film is configured to produce a charge when strained perpendicular to the second direction.

19. The transparent force sensor of claim 17, wherein the sense circuitry is configured to measure a magnitude of the touch.

20. The transparent force sensor of claim 17, further comprising:
   a first optically-clear adhesive disposed between the top electrode and the first transparent force-sensitive film;
   and
   a second optically-clear adhesive disposed between the middle electrode and the first transparent force-sensitive film.