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(54) **INTEGRATED PIXEL DISPLAY AND TOUCH SENSOR**

(56) **References Cited**

U.S. PATENT DOCUMENTS

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4,814,760 A 3/1989 Johnston et al.

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6,995,550 B2 2/2006 Jacobson et al.

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7,663,607 B2 2/2010 Hotelling

7,864,503 B2 1/2011 Chang

7,875,814 B2 1/2011 Chen

7,920,129 B2 4/2011 Hotelling

(Continued)

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FOREIGN PATENT DOCUMENTS

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WO WO 2009/131292 10/2009

WO WO 2009/133503 11/2009

WO WO 2012/129247 9/2012

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OTHER PUBLICATIONS

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US 2016/0132167 A1 May 12, 2016

E. Yilmaz, U.S. Appl. No. 12/859,874, Response to Non-Final Office Action dated Feb. 12, 2016.

E. Yilmaz, U.S. Appl. No. 12/859,874, Final Office Action dated Jun. 2, 2016.

U.S. Appl. No. 61/454,936, filed Mar. 21, 2011, Myers.

U.S. Appl. No. 61/454,950, filed Mar. 21, 2011, Lynch.

U.S. Appl. No. 61/454,894, filed Mar. 21, 2011, Rothkopf.

(Continued)

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(57) **ABSTRACT**

In one embodiment, an apparatus includes one or more display layers within a display stack, the one or more display layers include a plurality of crystals configured to adjust a polarization of light passing through the one or more display layers. The apparatus includes a reference voltage layer that provides the one or more display layers with a reference voltage. The apparatus includes a plurality of pixel-drive electrodes that adjust the polarization of the light passing through the one or more display layers by adjusting an electrical potential between the plurality of pixel-drive electrodes and the reference voltage layer. The pixel-drive electrodes provide drive signals for a touch sensor and the reference voltage layer provides sense signals.

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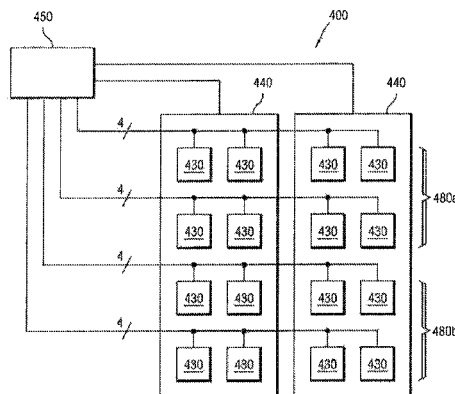
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(56)

References Cited

U.S. PATENT DOCUMENTS

8,031,094	B2	10/2011	Hotelling	
8,031,174	B2	10/2011	Hamblin	
8,040,326	B2	10/2011	Hotelling	
8,049,732	B2	11/2011	Hotelling	
8,179,381	B2	5/2012	Frey	
8,217,902	B2	7/2012	Chang	
8,581,860	B2	11/2013	Meng	
8,624,845	B2	1/2014	Grivna	
8,723,824	B2	5/2014	Myers	
2008/0012835	A1*	1/2008	Rimon	..... G06F 3/038 345/173
2008/0048989	A1	2/2008	Yoon et al.	
2008/0062139	A1	3/2008	Hotelling et al.	
2008/0062147	A1	3/2008	Hotelling et al.	
2008/0143689	A1	6/2008	Foo et al.	
2008/0238894	A1	10/2008	Ng et al.	
2008/0309627	A1*	12/2008	Hotelling	..... G02F 1/134363 345/173
2008/0309635	A1	12/2008	Matsuo	
2009/0109522	A1	4/2009	Paolini et al.	
2009/0315854	A1	12/2009	Matsuo	
2010/0044122	A1	2/2010	Sleeman et al.	
2010/0045632	A1	2/2010	Yilmaz et al.	
2010/0079384	A1	4/2010	Grivna	
2010/0148993	A1	6/2010	Lee	
2010/0149108	A1	6/2010	Hotelling et al.	
2010/0194707	A1	8/2010	Hotelling et al.	
2011/0007011	A1	1/2011	Mozdzyń	
2011/0025635	A1	2/2011	Lee	
2011/0025639	A1	2/2011	Trend et al.	
2011/0031042	A1	2/2011	Wu	
2011/0038030	A1	2/2011	Roosendaal et al.	
2011/0109566	A1	5/2011	Meng	
2011/0109622	A1	5/2011	Son et al.	
2011/0254802	A1	10/2011	Philipp	
2011/0310459	A1	12/2011	Gates et al.	
2012/0044190	A1	2/2012	Yilmaz	
2012/0242588	A1	9/2012	Myers	
2012/0242592	A1	9/2012	Rothkopf	

2012/0243151	A1	9/2012	Lynch
2012/0243719	A1	9/2012	Franklin
2013/0076612	A1	3/2013	Myers

OTHER PUBLICATIONS

E. Yilmaz, U.S. Appl. No. 12/859,874, Non-final Office Action, dated Oct. 11, 2012.

E. Yilmaz, U.S. Appl. No. 12/859,874, Amendment to Non-final Office Action, dated Feb. 11, 2013.

E. Yilmaz, U.S. Appl. No. 12/859,874, Final Office Action, dated Jun. 5, 2013.

E. Yilmaz, U.S. Appl. No. 12/859,874, RCE and Amendment, dated Sep. 5, 2013.

E. Yilmaz, U.S. Appl. No. 12/859,874, Non-final Office Action, dated Sep. 15, 2014.

E. Yilmaz, U.S. Appl. No. 12/859,874, Amendment to Non-final Office Action, dated Mar. 15, 2015.

E. Yilmaz, U.S. Appl. No. 12/859,874, Non-final Office Action, dated Apr. 20, 2015.

E. Yilmaz, U.S. Appl. No. 12/859,874, Amendment to Non-final Office Action, dated Jul. 20, 2015.

E. Yilmaz, U.S. Appl. No. 12/859,874, Non-final Office Action, dated Aug. 12, 2015.

E. Yilmaz, U.S. Appl. No. 13/715,677, Non-final Office Action, dated Oct. 9, 2014.

E. Yilmaz, U.S. Appl. No. 13/715,677, Amendment to Non-final Office Action, dated Feb. 9, 2015.

E. Yilmaz, U.S. Appl. No. 13/715,677, Final Office Action, dated Mar. 4, 2015.

E. Yilmaz, U.S. Appl. No. 13/715,677, Amendment to Final Office Action, dated May 4, 2015.

E. Yilmaz, U.S. Appl. No. 13/715,677, Applicant Initiated Interview Summary, dated May 4, 2015.

E. Yilmaz, U.S. Appl. No. 13/715,677, Notice of Allowance, dated Sep. 18, 2015.

E. Yilmaz, U.S. Appl. No. 12/859,874, Request for Continued Examination and Amendment filed Oct. 3, 2016.

E. Yilmaz, U.S. Appl. No. 12/859,874, Non-final Office Action dated Nov. 9, 2016.

E. Yilmaz, U.S. Appl. No. 12/859,874, Response to Non-final Office Action dated Feb. 9, 2017.

\* cited by examiner

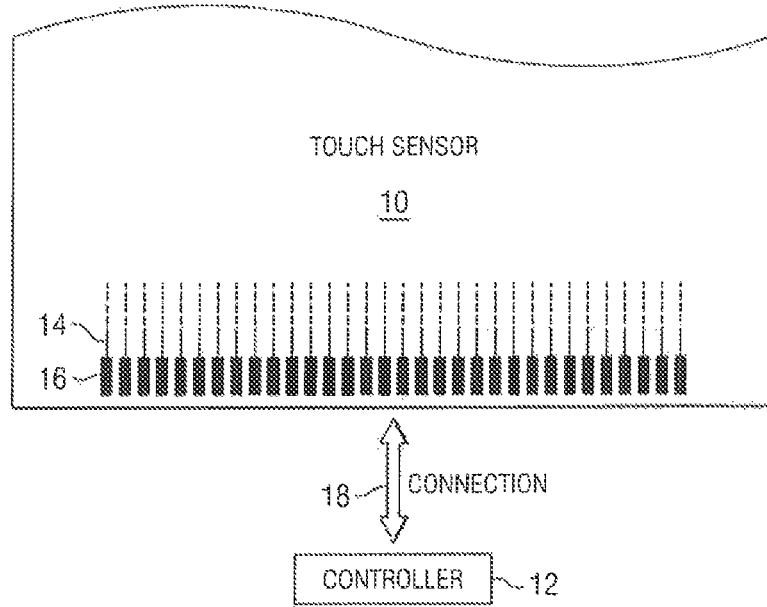


FIG. 1

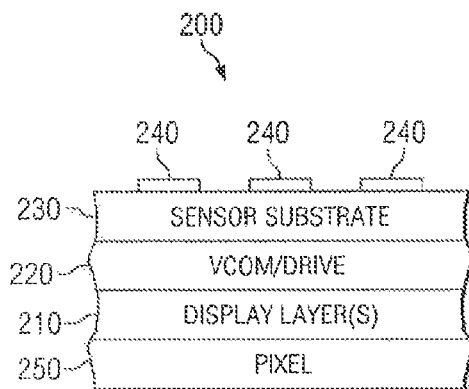


FIG. 2

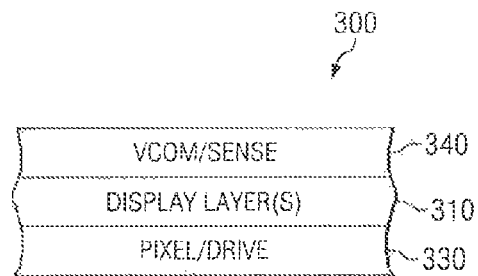


FIG. 3

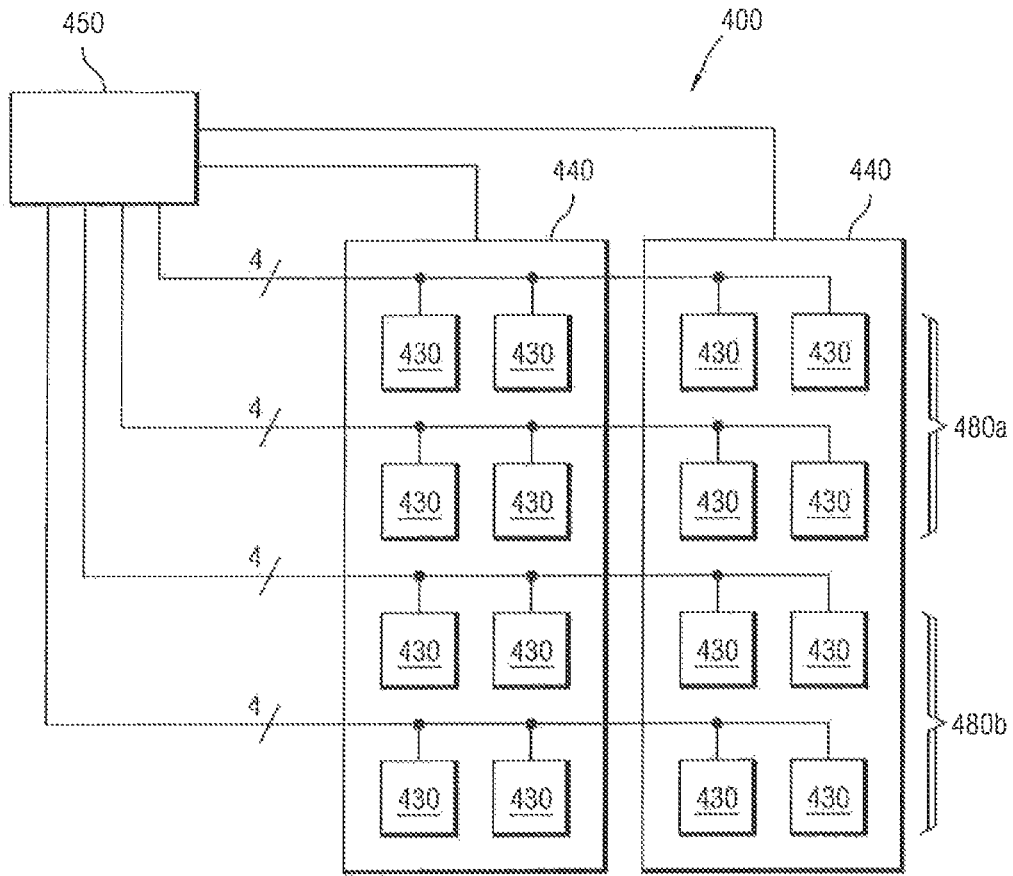


FIG. 4

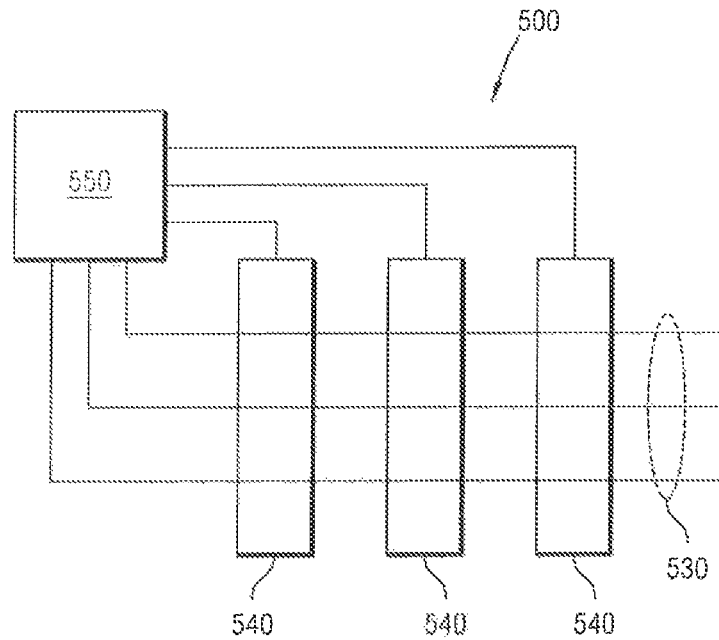


FIG. 5

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# INTEGRATED PIXEL DISPLAY AND TOUCH SENSOR

## RELATED APPLICATION

This application claims the benefit, under 35 U.S.C. §120, as a divisional of U.S. patent application Ser. No. 13/715,677, filed Dec. 14, 2012, which is incorporated herein by reference.

## TECHNICAL FIELD

This disclosure generally relates to integrated pixel displays and touch sensors.

## BACKGROUND

A touch sensor may detect the presence and location of a touch or the proximity of an object (such as a user's finger or a stylus) within a touch-sensitive area of the touch sensor overlaid on a display screen, for example. In a touch-sensitive-display application, the touch sensor may enable a user to interact directly with what is displayed on the screen, rather than indirectly with a mouse or touch pad. A touch sensor may be attached to or provided as part of a desktop computer, laptop computer, tablet computer, personal digital assistant (PDA), smartphone, satellite navigation device, portable media player, portable game console, kiosk computer, point-of-sale device, or other suitable device. A control panel on a household or other appliance may include a touch sensor.

There are a number of different types of touch sensors, such as (for example) resistive touch screens, surface acoustic wave touch screens, and capacitive touch screens. Herein, reference to a touch sensor may encompass a touch screen, and vice versa, where appropriate. When an object touches or comes within proximity of the surface of the capacitive touch screen, a change in capacitance may occur within the touch screen at the location of the touch or proximity. A touch-sensor controller may process the change in capacitance to determine its position on the touch screen.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an example touch sensor with an example controller.

FIG. 2 illustrates a profile view of a portion of an example touch screen in which a pixel layer provides a pixel-drive signal to a display layer of a LCD, and a reference voltage layer provides the display layer of the LCD with a reference voltage and provides an integrated touch sensor with a drive signal.

FIG. 3 illustrates a profile view of a portion of an example touch screen in which a pixel-drive layer provides a pixel-drive signal to a display layer of a LCD and a drive signal to an integrated touch sensor, and a reference voltage layer provides a reference voltage for the display layer of the LCD and provides a sense signal to a touch screen controller.

FIG. 4 illustrates an overhead view of an example touch screen in which pixel-drive electrodes provide a display portion of a touch screen with a pixel-drive signal and provide an integrated touch sensor of the touch screen with a drive signal.

FIG. 5 illustrates an overhead view of an example touch screen in which a reference voltage layer provides a display

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portion of a touch screen with a reference voltage and provides an integrated touch sensor of the touch screen with a drive signal.

## DESCRIPTION OF EXAMPLE EMBODIMENTS

FIG. 1 illustrates an example touch sensor **10** with an example touch-sensor controller **12**. Touch sensor **10** and touch-sensor controller **12** may detect the presence and location of a touch or the proximity of an object within a touch-sensitive area of touch sensor **10**. Herein, reference to a touch sensor may encompass both the touch sensor and its touch-sensor controller, where appropriate. Similarly, reference to a touch-sensor controller may encompass both the touch-sensor controller and its touch sensor, where appropriate. Touch sensor **10** may include one or more touch-sensitive areas, where appropriate. Touch sensor **10** may include an array of drive and sense electrodes (or an array of electrodes of a single type) disposed on one or more substrates, which may be made of a dielectric material and/or may be included in a display stack. Herein, reference to a touch sensor may encompass both the electrodes of the touch sensor and the substrate(s) that they are disposed on, where appropriate. Alternatively, where appropriate, reference to a touch sensor may encompass the electrodes of the touch sensor, but not the substrate(s) that they are disposed on.

An electrode (whether a drive electrode or a sense electrode) may be an area of conductive material forming a shape, such as for example a disc, square, rectangle, thin line, other suitable shape, or suitable combination of these. One or more cuts in one or more layers of conductive material may (at least in part) create the shape of an electrode, and the area of the shape may (at least in part) be bounded by those cuts. In particular embodiments, the conductive material of an electrode may occupy approximately 100% of the area of its shape. As an example and not by way of limitation, an electrode may be made of indium tin oxide (ITO) and the ITO of the electrode may occupy approximately 100% of the area of its shape (sometimes referred to as 100% fill), where appropriate. In particular embodiments, the conductive material of an electrode may occupy substantially less than 100% of the area of its shape. As an example and not by way of limitation, an electrode may be made of fine lines of metal or other conductive material (FLM) such as for example copper, silver, or a copper- or silver-based material and the fine lines of conductive material may occupy approximately 5% of the area of its shape in a hatched, mesh, or other suitable pattern. Herein, reference to FLM encompasses such material, where appropriate. Although this disclosure describes or illustrates particular electrodes made of particular conductive material forming particular shapes with particular fills having particular patterns, this disclosure contemplates any suitable electrodes made of any suitable conductive material forming any suitable shapes with any suitable fill percentages having any suitable patterns.

Where appropriate, the shapes of the electrodes (or other elements) of a touch sensor may constitute in whole or in part one or more macro-features of the touch sensor. One or more characteristics of the implementation of those shapes (such as, for example, the conductive materials, fills, or patterns within the shapes) may constitute in whole or in part one or more micro-features of the touch sensor. One or more macro-features of a touch sensor may determine one or more characteristics of its functionality, and one or more micro-

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features of the touch sensor may determine one or more optical features of the touch sensor, such as transmittance, refraction, or reflection.

A mechanical stack may contain the substrate (or multiple substrates) and the conductive material forming the drive or sense electrodes of touch sensor **10**. In certain embodiments, the conductive material used for the drive or sense electrodes may also be used for a portion of the display screen (e.g., the same conductive material may be used for the sense electrodes of a touch sensor and for the reference voltage layer of a display screen). In some embodiments, the mechanical stack may be within or comprise a portion of a display stack configured to generate images. As an example and not by way of limitation, the mechanical stack may include a first layer of optically clear adhesive (OCA) beneath a cover panel of a display stack. The cover panel may be clear and made of a resilient material suitable for repeated touching, such as for example glass, polycarbonate, or poly(methyl methacrylate) (PMMA). This disclosure contemplates any suitable cover panel made of any suitable material. The first layer of OCA may be disposed between a layer or substrate of the display stack and the substrate with the conductive material forming the drive or sense electrodes. The substrate with the conductive material may provide a benefit or feature in producing an image (e.g., it may be a layer or substrate found in a typical, non-touch, display stack) or it may be a layer added specifically to provide a substrate on which the electrodes are formed. In some embodiments, the mechanical stack may also include a second layer of OCA. In some embodiments, the mechanical stack may also include a dielectric layer (which may be made of polyethylene terephthalate (PET) or another suitable material, similar to the substrate with the conductive material forming the drive or sense electrodes). As an alternative, where appropriate, a thin coating of a dielectric material may be applied instead of the second layer of OCA and/or the dielectric layer. The second layer of OCA may be disposed between the substrate with the conductive material making up the drive or sense electrodes and the dielectric layer, and the dielectric layer may be disposed between the second layer of OCA and another layer of the display stack. As an example only and not by way of limitation, the cover panel may have a thickness of approximately 1 mm; the first layer of OCA may have a thickness of approximately 0.05 mm; the substrate with the conductive material forming the drive or sense electrodes may have a thickness of approximately 0.05 mm; the second layer of OCA may have a thickness of approximately 0.05 mm; and the dielectric layer may have a thickness of approximately 0.05 mm. Although this disclosure describes a particular mechanical stack with a particular number of particular layers made of particular materials and having particular thicknesses, this disclosure contemplates any suitable mechanical stack with any suitable number of any suitable layers made of any suitable materials and having any suitable thicknesses.

In particular embodiments, the drive or sense electrodes in touch sensor **10** may be made of ITO in whole or in part. In particular embodiments, the drive or sense electrodes in touch sensor **10** may be made of fine lines of metal or other conductive material. As an example and not by way of limitation, one or more portions of the conductive material may be copper or copper-based and have a thickness of approximately 5  $\mu\text{m}$  or less and a width of approximately 10  $\mu\text{m}$  or less. As another example, one or more portions of the conductive material may be silver or silver-based and similarly have a thickness of approximately 5  $\mu\text{m}$  or less and a

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width of approximately 10  $\mu\text{m}$  or less. This disclosure contemplates any suitable electrodes made of any suitable material.

Touch sensor **10** may implement a capacitive form of touch sensing. In a mutual-capacitance implementation, touch sensor **10** may include an array of drive and sense electrodes forming an array of capacitive nodes. A drive electrode and a sense electrode may form a capacitive node. The drive and sense electrodes forming the capacitive node may come near each other, but not make electrical contact with each other. Instead, the drive and sense electrodes may be capacitively coupled to each other across a space between them. A pulsed or alternating voltage applied to the drive electrode (by touch-sensor controller **12**) may induce a charge on the sense electrode, and the amount of charge induced may be susceptible to external influence (such as a touch or the proximity of an object). When an object touches or comes within proximity of the capacitive node, a change in capacitance may occur at the capacitive node and touch-sensor controller **12** may measure the change in capacitance. By measuring changes in capacitance throughout the array, touch-sensor controller **12** may determine the position of the touch or proximity within the touch-sensitive area(s) of touch sensor **10**.

In a self-capacitance implementation, touch sensor **10** may include an array of electrodes of a single type that may each form a capacitive node. When an object touches or comes within proximity of the capacitive node, a change in self-capacitance may occur at the capacitive node and touch-sensor controller **12** may measure the change in capacitance, for example, as a change in the amount of charge needed to raise the voltage at the capacitive node by a pre-determined amount. As with a mutual-capacitance implementation, by measuring changes in capacitance throughout the array, touch-sensor controller **12** may determine the position of the touch or proximity within the touch-sensitive area(s) of touch sensor **10**. This disclosure contemplates any suitable form of capacitive touch sensing, where appropriate.

In particular embodiments, one or more drive electrodes may together form a drive line running horizontally or vertically or in any suitable orientation. Similarly, one or more sense electrodes may together form a sense line running horizontally or vertically or in any suitable orientation. In particular embodiments, drive lines may run substantially perpendicular to sense lines. Herein, reference to a drive line may encompass one or more drive electrodes making up the drive line, and vice versa, where appropriate. Similarly, reference to a sense line may encompass one or more sense electrodes making up the sense line, and vice versa, where appropriate.

Touch sensor **10** may have drive and sense electrodes disposed in a pattern on one side of a single substrate. In such a configuration, a pair of drive and sense electrodes capacitively coupled to each other across a space between them may form a capacitive node. For a self-capacitance implementation, electrodes of only a single type may be disposed in a pattern on a single substrate. In addition or as an alternative to having drive and sense electrodes disposed in a pattern on one side of a single substrate, touch sensor **10** may have drive electrodes disposed in a pattern on one side of a substrate and sense electrodes disposed in a pattern on another side of the substrate. Moreover, touch sensor **10** may have drive electrodes disposed in a pattern on one side of one substrate and sense electrodes disposed in a pattern on one side of another substrate. In such configurations, an intersection of a drive electrode and a sense electrode may form a capacitive node. Such an intersection may be a

location where the drive electrode and the sense electrode “cross” or come nearest each other in their respective planes. The drive and sense electrodes do not make electrical contact with each other—instead they are capacitively coupled to each other across a dielectric at the intersection. Although this disclosure describes particular configurations of particular electrodes forming particular nodes, this disclosure contemplates any suitable configuration of any suitable electrodes forming any suitable nodes. Moreover, this disclosure contemplates any suitable electrodes disposed on any suitable number of any suitable substrates in any suitable patterns.

As described above, a change in capacitance at a capacitive node of touch sensor **10** may indicate a touch or proximity input at the position of the capacitive node. Touch-sensor controller **12** may detect and process the change in capacitance to determine the presence and location of the touch or proximity input. Touch-sensor controller **12** may then communicate information about the touch or proximity input to one or more other components (such one or more central processing units (CPUs)) of a device that includes touch sensor **10** and touch-sensor controller **12**, which may respond to the touch or proximity input by initiating a function of the device (or an application running on the device) associated with it. Although this disclosure describes a particular touch-sensor controller having particular functionality with respect to a particular device and a particular touch sensor, this disclosure contemplates any suitable touch-sensor controller having any suitable functionality with respect to any suitable device and any suitable touch sensor.

Touch-sensor controller **12** may be one or more integrated circuits (ICs), such as for example general-purpose microprocessors, microcontrollers, programmable logic devices or arrays, or application-specific ICs (ASICs). In particular embodiments, touch-sensor controller **12** comprises analog circuitry, digital logic, and digital non-volatile memory. In particular embodiments, touch-sensor controller **12** is disposed on a flexible printed circuit (FPC) bonded to the substrate of touch sensor **10**. The FPC may be active or passive, where appropriate. In particular embodiments, multiple touch-sensor controllers **12** are disposed on the FPC. Touch-sensor controller **12** may include a processor unit, a drive unit, a sense unit, a display unit, and a storage unit. The drive unit may supply drive signals to the drive electrodes of touch sensor **10**. The sense unit may sense charge at the capacitive nodes of touch sensor **10** and provide measurement signals to the processor unit representing capacitances at the capacitive nodes. The processor unit may control the supply of drive signals to the drive electrodes by the drive unit and process measurement signals from the sense unit to detect and process the presence and location of a touch or proximity input within the touch-sensitive area(s) of touch sensor **10**. The processor unit may also track changes in the position of a touch or proximity input within the touch-sensitive area(s) of touch sensor **10**. The storage unit may store programming for execution by the processor unit, including programming for controlling the drive unit to supply drive signals to the drive electrodes, programming for processing measurement signals from the sense unit, and other suitable programming, where appropriate. Although this disclosure describes a particular touch-sensor controller having a particular implementation with particular components, this disclosure contemplates any suitable touch-sensor controller having any suitable implementation with any suitable components.

Tracks **14** of conductive material disposed on the substrate of touch sensor **10** may couple the drive or sense electrodes of touch sensor **10** to connection pads **16**, also disposed on the substrate of touch sensor **10**. As described below, connection pads **16** facilitate coupling of tracks **14** to touch-sensor controller **12**. Tracks **14** may extend into or around (e.g. at the edges of) the touch-sensitive area(s) of touch sensor **10**. Particular tracks **14** may provide drive connections for coupling touch-sensor controller **12** to drive electrodes of touch sensor **10**, through which the drive unit of touch-sensor controller **12** may supply drive signals to the drive electrodes. Other tracks **14** may provide sense connections for coupling touch-sensor controller **12** to sense electrodes of touch sensor **10**, through which the sense unit of touch-sensor controller **12** may sense charge at the capacitive nodes of touch sensor **10**. Tracks **14** may be made of fine lines of metal or other conductive material. As an example and not by way of limitation, the conductive material of tracks **14** may be copper or copper-based and have a width of approximately 100  $\mu\text{m}$  or less. As another example, the conductive material of tracks **14** may be silver or silver-based and have a width of approximately 100  $\mu\text{m}$  or less. In particular embodiments, tracks **14** may be made of ITO in whole or in part in addition or as an alternative to fine lines of metal or other conductive material. Although this disclosure describes particular tracks made of particular materials with particular widths, this disclosure contemplates any suitable tracks made of any suitable materials with any suitable widths. In addition to tracks **14**, touch sensor **10** may include one or more ground lines terminating at a ground connector (which may be a connection pad **16**) at an edge of the substrate of touch sensor **10** (similar to tracks **14**).

Connection pads **16** may be located along one or more edges of the substrate, outside the touch-sensitive area(s) of touch sensor **10**. As described above, touch-sensor controller **12** may be on an FPC. Connection pads **16** may be made of the same material as tracks **14** and may be bonded to the FPC using an anisotropic conductive film (ACF). Connection **18** may include conductive lines on the FPC coupling touch-sensor controller **12** to connection pads **16**, in turn coupling touch-sensor controller **12** to tracks **14** and to the drive or sense electrodes of touch sensor **10**. This disclosure contemplates any suitable connection **18** between touch-sensor controller **12** and touch sensor **10**.

FIG. 2 illustrates a profile view of a portion of an example touch screen in which a pixel layer provides a pixel-drive signal to a display layer of a LCD, and a reference voltage layer provides the display layer of the LCD with a reference voltage and provides an integrated touch sensor with a drive signal. Touch screen **200** includes a stack of layers that provide both an image, via a display portion, and touch sensing, via an integrated touch sensor. The display portion of touch screen **200** is configured to provide images through a two-dimensional array of pixels. The touch sensor is configured to determine a relative location of a touch input within touch screen **200**. The depicted layers of touch screen **200** are display layer(s) **210**, reference voltage layer **220**, sensor substrate **230**, sense electrodes **240**, and pixel layer **250**. Additional layers of touch screen **200** are not depicted. For example, touch screen **200** may include one or more layers, materials, and/or components above sense electrodes **240**, below pixel layer **250**, and/or in-between any of the other depicted layers of touch screen **200**.

Display layer(s) **210** may include pixels which provide images for touch screen **200**. Display layer(s) **210** may include any suitable number of layers of touch screen **200**.

For example, display layer(s) **210** may include a single display layer or more than one display layer. In some embodiments, display layer(s) **210** may be a liquid crystal layer that adjusts a polarization of light passing through the layer. In some embodiments, display layer(s) **210** may be the liquid crystal layer and any combination of one or more glass substrate layers with electrodes and/or one or more polarizing filter layers. In some embodiments, display layer(s) **210** may include VCOM layer(s) and/or pixel layer(s).

The color of the pixels of display layer(s) **210** may be determined, in part, based on an electrical potential between a pixel layer **250** and reference voltage layer **220**. The reference voltage may be referred to as a common voltage or VCOM. In addition to providing a reference voltage for display layer(s) **210**, reference voltage layer **220** may also provide the drive signal for a touch sensor. For example, in the embodiment depicted in FIG. 2, the touch sensor portion of touch screen **200** may include sense electrodes **240**, sensor substrate **230**, and reference voltage layer **220**. In such an embodiment, reference voltage layer **220** may act as the drive electrodes of a touch sensor. This may allow the same layer, reference voltage layer **220**, to provide both a reference voltage for display layer(s) **210** and a drive signal for a touch sensor.

Reference voltage layer **220** may be electrically conductive so as to provide both the reference voltage and the drive signal. In certain embodiments, the reference voltage layer **220** may comprise ITO. In some embodiments, reference voltage layer **220** may include fine lines of metal. The fine lines of metal may be used to provide both the reference voltage for display layer(s) **210** as well as the drive signals for the touch sensor. In some embodiments, the fine lines of metal may be arranged in a mesh configuration. In some embodiments, the fine lines of metal may be electrically isolated drive lines that are all pulsed simultaneously to provide the reference voltage for display layer(s) **210**. In some embodiments, the fine lines of metal may be electrically isolated drive lines that are each pulsed one at a time to provide drive signals to sense electrodes **240**. In some embodiments, instead of pulsing each of the electrically isolated drive lines one at a time to provide drive signals to sense electrodes **240**, two or more of the electrically isolated drive lines (such as, for example, two of the electrically isolated drive lines, three of the electrically isolated drive lines, or any other number of the electrically isolated drive lines) may be pulsed simultaneously to provide drive signals to sense electrodes **240**.

In the depicted embodiment, sensor substrate **230** is located between sense electrodes **240** and reference voltage layer **220**. In some embodiments, sensor substrate **230** may comprise an additional layer that would not be found in a traditional non-touch sensitive LCD display stack. In some such embodiments, sensor substrate **230** may comprise non-birefringent material. The use of a non-birefringent material may avoid undesirable twisting of the light passing through the material. In some embodiments, sensor substrate **230** may comprise an existing layer that would be found in a traditional non-touch sensitive LCD display stack. For example, sensor substrate **230** may be a color filter layer of an LCD display stack. In some embodiments, sensor substrate **230** may comprise multiple layers.

Pixel layer **250** may be configured to change the characteristics of the crystals within display layer(s) **210** (e.g., to change the image to be displayed by touch screen **200**). In particular embodiments, pixel layer **250** may comprise a two-dimensional array of pixel electrodes. The size of the

two-dimensional array of pixel electrodes may correspond to the number of display pixels of touch screen **200** (e.g., each pixel to be displayed may have its own respective pixel electrode(s)). In some embodiments, each pixel electrode may be individually controlled to generate an image.

Although the depicted embodiment includes an LCD display stack, other embodiments may comprise other types of display stacks (e.g., any display stack that includes a reference voltage layer). For example, in some embodiments, an organic light emitting diode (OLED) display stack may be used for touch screen **200**.

FIG. 3 illustrates a profile view of a portion of an example touch screen in which a pixel-drive layer provides a pixel-drive signal to a display layer of a LCD and a drive signal to an integrated touch sensor, and a reference voltage layer provides a reference voltage for the display layer of the LCD and provides a sense signal to a touch screen controller. Similar to touch screen **200**, touch screen **300** provides both an image and touch sensitivity. In FIG. 3, touch screen **300** may include several layers. The depicted layers of touch screen **300** include voltage layer **340**, display layer(s) **310**, and pixel-drive layer **330**. Additional layers of touch screen **300** are not depicted. For example, touch screen **300** may include one or more layers, materials, and/or components above voltage layer **340**, below pixel-drive layer **330**, and/or in-between any of the other depicted layers of touch screen **300**.

In the embodiment depicted in FIG. 3, the drive and sense electrodes of a touch sensor are implemented through pixel-drive layer **330** and reference voltage layer **340**, respectively. These layers also provide their traditional functionality for display layer(s) **310**. For example, pixel-drive layer **330** may be configured to change the characteristics of the crystals within display layer(s) **310** (e.g., to change the image to be displayed by touch screen **300**) and may be configured to provide a drive signal for a touch sensor; and reference voltage layer **340** may be configured to provide a reference voltage for display layer(s) **310** and may be configured to provide sense signals to a touch screen controller (i.e., where the sense signals are provided by the reference voltage layer **340** as a result of the drive signals provided to the reference voltage layer **340** by pixel-drive layer **330**). In addition, in the depicted embodiment, display layer(s) **310** may also act as the sensor substrate for the touch sensor.

In particular embodiments, pixel-drive layer **330** may comprise a two-dimensional array of pixel-drive electrodes. The size of the two-dimensional array of pixel-drive electrodes may correspond to the number of display pixels of touch screen **300** (e.g., each pixel to be displayed may have its own respective pixel-drive electrode). While the pixel-drive electrodes may be individually controlled to generate an image, in some embodiments they may be grouped together to provide drive signals for the touch sensor. For example, one or more rows of pixel-drive electrodes may be used collectively as a single drive electrode (e.g., the same drive signal may be sent to all the pixel-drive electrodes within one or more rows pixel-drive electrodes).

In some embodiments, one or both of pixel-drive layer **330** and reference voltage layer **340** may comprise fine lines of metal. In particular embodiments, the fine lines of metal for pixel-drive layer **330** and/or reference voltage layer **340** may be arranged in a mesh fashion. In some embodiments, fine lines of metal may be connected between the pixel-drive electrodes and a touch screen controller. Although the depicted embodiment includes an LCD display stack, other embodiments may comprise other types of display stacks



(e.g., any display stack that includes a reference voltage layer). For example, in some embodiments, an organic light emitting diode (OLED) display stack may be used for touch screen **300**.

FIG. 4 illustrates an overhead view of an example touch screen in which pixel-drive electrodes provide a display portion of a touch screen with a pixel-drive signal and provide an integrated touch sensor of the touch screen with a drive signal. In the depicted embodiment, touch screen **400** comprises a four-by-four display with an integrated two-by-two touch sensor. The four-by-four display comprises the individual pixels of display layer(s) (not depicted). Each pixel of the display has its own associated pixel-drive electrode **430**. These pixel-drive electrodes **430** are grouped into subsets of pixel-drive electrodes **430** to form drive electrodes **480**. The two-by-two touch sensor comprises sense electrodes **440** and the two subsets of pixel-drive electrodes **430** that form drive electrodes **480**. In order to form drive electrodes **480**, pixel-drive electrodes **430** are arranged into two subsets (drive electrode **480a** and drive electrode **480b**), each subset comprises a two-by-four array of pixel-drive electrodes **430**. Controller **450** is separately connected to each pixel-drive electrode **430** and thus may treat pixel-drive electrodes **430** as separate entities when generating an image and collectively (as subsets) when generating a drive signal to determine a location of a touch input. In this embodiment, the sensor substrate (not shown), is located between sense electrodes **440** and drive electrodes **480**.

In the depicted embodiment, touch screen controller **450** is connected to sense electrodes **440** as well as the individual pixel-drive electrodes **430** that form drive electrodes **480**. This may allow touch screen controller **450** to both adjust the pixel-drive signal to control the image generated by touch screen **400** and to manage the drive signal for the touch sensor used to determine the relative location of a touch input. Because pixel-drive electrodes **430** are used for both the touch sensor functionality and for creating the displayed image, touch screen controller **450** may need to synchronize how and when it sends pixel-drive signals and drive signals.

While the pixel-drive electrodes have been grouped together in rows in the depicted embodiment, some embodiments may group the pixel-drive electrodes into clusters (e.g., two-by-two clusters) or may not group them together at all. For example, sense electrodes **440** may separately detect a touch input based on a change in the charge, capacitance, or electrical potential from each of the individual pixel-drive electrodes.

FIG. 5 illustrates an overhead view of an example touch screen in which a reference voltage layer provides a display portion of a touch screen with a reference voltage and provides an integrated touch sensor of the touch screen with a drive signal. In FIG. 5, touch screen **500** includes touch screen controller **550** coupled to drive electrodes **530** and sense electrodes **540**. Drive electrodes **530** may be spaced so as to provide a reference voltage for a display layer(s) (not depicted). Drive electrodes **530** may also be configured to provide drive signals to a touch sensor. In some embodiments, drive electrodes **530** may be oriented perpendicularly to the orientation of sense electrodes **540**. In some embodiments, drive electrodes **530** may be made of fine lines of metal. Touch screen controller **550** may use drive electrodes **530** to provide drive signals for a touch sensor and to provide a reference voltage for a display layer(s) (e.g., display layer(s) **210** of an LCD display stack). As discussed above with respect to FIG. 4, touch screen controller **550**

may synchronize the reference voltage and the drive signals being sent over drive electrodes **530**. Touch screen controller **550** may then use the sense signal provided by sense electrodes **540** to determine a relative location of a touch input.

Although FIGS. 1-5 have been described above as including particular components, the systems of FIGS. 1-5 may include any combination of any of the described components and any of the options or features described herein, as would be understood by one of ordinary skill in the art based upon the teachings of the disclosure. For example and not by way of limitation, any of the options or features described herein may be utilized in combination with the illustrated embodiments of FIGS. 1-5 and/or any number of the other options or features also described herein as would be understood by one of ordinary skill in the art based upon the teachings of the disclosure.

Herein, reference to a computer-readable non-transitory storage medium may include a semiconductor-based or other integrated circuit (IC), such as for example a field-programmable gate array (FPGA) or an application-specific IC (ASIC), a hard disk, an HDD, a hybrid hard drive (HHD), an optical disc, an optical disc drive (ODD), a magneto-optical disc, a magneto-optical drive, a floppy disk, a floppy disk drive (FDD), magnetic tape, a holographic storage medium, a solid-state drive (SSD), a RAM-drive, a SECURE DIGITAL card, a SECURE DIGITAL drive, another suitable medium, or a suitable combination of these, where appropriate. A computer-readable non-transitory storage medium may be volatile, non-volatile, or a combination of volatile and non-volatile, where appropriate.

Herein, "or" is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A or B" means "A, B, or both," unless expressly indicated otherwise or indicated otherwise by context. Moreover, "and" is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A and B" means "A and B, jointly or severally," unless expressly indicated otherwise or indicated otherwise by context.

This disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Moreover, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative.

What is claimed is:

1. An apparatus, comprising:

- one or more display layers within a display stack, the one or more display layers comprising a plurality of pixels configured to display an image;
- a reference voltage layer configured to provide the one or more display layers with a reference voltage; and
- a plurality of pixel-drive electrodes configured to adjust the polarization of the light passing through the one or more display layers by adjusting an electrical potential between the plurality of pixel-drive electrodes and the reference voltage layer, the plurality of pixel-drive electrodes arranged in a plurality of rows of pixel-drive

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electrodes, each row of pixel-drive electrodes comprising multiple pixel-drive electrodes coupled together; wherein:  
 the plurality of pixel-drive electrodes are further configured to provide a plurality of drive signals for a touch sensor;  
 the reference voltage layer is further configured to provide sense signals, the reference voltage layer comprising a plurality of electrodes configured to provide the sense signals for the touch sensor;  
 the one or more display layers are between the reference voltage layer and the plurality of pixel-drive electrodes; and  
 the plurality of pixel-drive electrodes are arranged in a plurality of subsets, each subset comprising multiple rows of the plurality of rows of pixel-drive electrodes that collectively provide a drive signal for the touch sensor, a particular electrode of the plurality of electrodes of the reference voltage layer spanning multiple subsets of the plurality of subsets of pixel-drive electrodes and spanning two or more pixel-drive electrodes in each row of pixel-drive electrodes of the multiple subsets of the plurality of subsets of pixel-drive electrodes.

2. The apparatus of claim 1, wherein the reference voltage layer comprises fine lines of metal.

3. The apparatus of claim 1, wherein the plurality of pixel-drive electrodes comprises a two-dimensional array of pixel-drive electrodes.

4. The apparatus of claim 1, further comprising a touch screen controller coupled to the reference voltage layer and the plurality of pixel-drive electrodes, the touch screen controller configured to adjust the electrical potential at each of the plurality of pixel-drive electrodes to generate an image and to generate a drive signal used to determine a location of a touch input based on the sense signals from the reference voltage layer.

5. The apparatus of claim 1, further comprising a touch screen controller coupled to the reference voltage layer and the plurality of pixel-drive electrodes, the touch screen controller configured to adjust the electrical potential at each of the plurality of pixel-drive electrodes to generate an image.

6. The apparatus of claim 1, wherein the plurality of pixel-drive electrodes arranged in the plurality of subsets are individually controlled to generate an image.

7. The apparatus of claim 1, wherein the display stack is a liquid crystal display (LCD) stack.

8. The apparatus of claim 1, wherein the display stack is an organic light emitting diode (OLED) display stack.

9. The apparatus of claim 1, wherein the pixel-drive electrodes comprise a plurality of electrically isolated drive lines that are configured to each be pulsed one at a time to provide drive signals to the touch sensor.

10. The apparatus of claim 1, wherein the pixel-drive electrodes comprise a plurality of electrically isolated drive lines, wherein two or more of the plurality of electrically isolated drive lines are configured to be pulsed simultaneously to provide drive signals to the plurality of sense electrodes.

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11. An apparatus, comprising:  
 one or more display layers within a display stack, the one or more display layers comprising a plurality of pixels configured to display an image;  
 a touch sensor comprising a plurality of sense electrodes and a plurality of drive electrodes, the touch sensor configured to detect a touch input;  
 a reference voltage layer comprising a plurality of electrically isolated drive lines configured to:  
 provide a reference voltage for the one or more display layers; and  
 provide sense signals from the plurality of sense electrodes; and  
 a plurality of pixel-drive electrodes comprising fine lines of metal arranged in a mesh configuration, the plurality of pixel-drive electrodes arranged in a plurality of rows of pixel-drive electrodes, each row of pixel-drive electrodes comprising multiple pixel-drive electrodes coupled together, the plurality of pixel-drive electrodes configured to:  
 adjust the polarization of the light passing through the one or more display layers by adjusting an electrical potential between the plurality of pixel-drive electrodes and the reference voltage layer; and  
 provide a plurality of drive signals for the drive electrodes;

wherein:  
 the one or more display layers are between the reference voltage layer and the plurality of pixel-drive electrodes; and  
 the plurality of pixel-drive electrodes are arranged in a plurality of subsets, each subset comprising multiple rows of the plurality of rows of pixel-drive electrodes that collectively provide a drive signal for the touch sensor, a particular drive line of the plurality of electrically isolated drive lines of the reference voltage layer spanning multiple subsets of the plurality of subsets of pixel-drive electrodes and spanning two or more pixel-drive electrodes in each row of pixel-drive electrodes of the multiple subsets of the plurality of subsets of pixel-drive electrodes.

12. The apparatus of claim 11, wherein the plurality of pixel-drive electrodes are configured to adjust the polarization of light passing through the one or more display layers by pulsing the pixel-drive electrodes individually to generate a pixel-drive signal and the pixel-drive electrodes are pulsed simultaneously to provide drive signals for the touch sensor.

13. The apparatus of claim 11, wherein the plurality of pixel-drive electrodes are configured to adjust the polarization of light passing through the one or more display layers by pulsing the pixel-drive electrodes simultaneously to generate a pixel-drive signal and the pixel-drive electrodes are pulsed individually to provide drive signals for the touch sensor.

14. The apparatus of claim 11, wherein the drive electrodes are oriented perpendicularly to the orientation of the sense electrodes.

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