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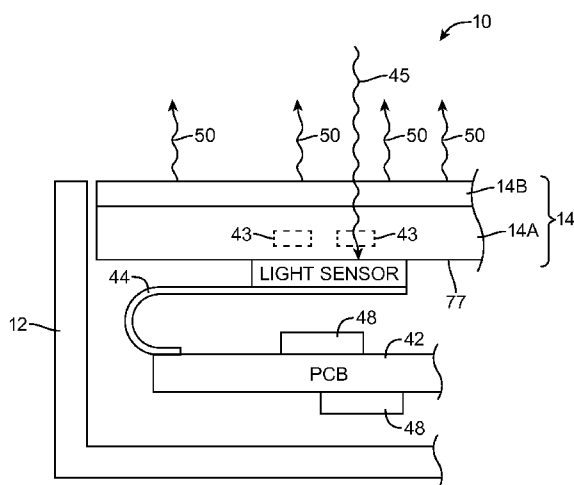


FIG. 6

(57) Abstract: An electronic device is provided with a display and a light sensor that receives light that passes through the display. The display includes features that increase the amount of light that passes through the display. The features may be translucency enhancement features that allow light to pass directly through the display onto a light sensor mounted behind the display or may include a light-guiding layer that guides light through the display onto a light sensor mounted along an edge of the display. The translucency enhancement features may be formed in a reflector layer or an electrode layer for the display. The translucency enhancement features may include microperforations in a reflector layer of the display, a light-filtering reflector layer of the display, or a reflector layer of the display that passes a portion of the light and reflects an additional portion of the light.

Electronic Devices With Light Sensors And Displays

This application claims priority to United States patent application No. 13/732,966 filed January 2, 2013, which is hereby incorporated by reference herein in its entirety.

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Background

This relates generally to electronic devices and, more particularly, to electronic devices with displays and light sensors.

10 Electronic devices often include displays. For example, cellular telephones and portable computers often include displays for presenting information to a user.

 Electronic devices also often include light sensors. For example, an electronic device may include an ambient light sensor that senses the amount of light in the environment surrounding the device. The brightness of display images generated by the display is sometimes adjusted based on the amount of ambient light. For example, in bright sunlight, the display brightness may be increased and in a dark room, the display brightness can be decreased.

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 In a typical device, the display emits display

light from a first side and has an opposing side that is opaque or reflective for preventing light from leaking into the device. These opaque display structures also block light that originates outside of the device such as ambient light from passing through the display.

Additional space is therefore commonly provided within a device enclosure to accommodate a light sensor that receives light through a transparent portion of the enclosure.

This type of additional space for a common display and light sensor package can result in an undesirable increase in the size and thickness of the device.

It would therefore be desirable to be able to provide improved displays for electronic devices with light sensors and displays.

Summary

An electronic device is provided with a display mounted in an electronic device housing. The electronic device is also provided with one or more light sensors that receive light through at least a portion of the display.

The light sensor may be implemented as an ambient light sensor, a proximity sensor, ultraviolet light sensor, infrared light sensor, thin-film solar cell, a photoplethysmograph, or other light sensor.

The display includes translucency enhancement features and/or light-guiding features that allow light that originates outside the device to pass through the display onto the light sensor.

The display may be an organic light-emitting diode display, a liquid crystal display or a display that

incorporates other types of display pixel technology.

The translucency enhancement features may include a translucent reflective layer that reflects display light generated by the display while passing at least some ambient light, microperforations in one or more display layers that allow ambient light to pass through the display layers, modified display traces that allow light to pass onto the light sensor or other suitable translucency enhancement features that increase the transparency of the display in comparison with conventional displays.

The light-guiding features may include a light-guiding layer in the display that guides light to a light sensor that is mounted along an edge of the light-guiding layer.

The light sensor can be mounted behind the display and configured to receive light through the translucent display or the light sensor can be mounted along an edge of the display and receive light that is guided to the light sensor by the light-guiding layer of the display.

Further features, their nature and various advantages will be more apparent from the accompanying drawings and the following detailed description of the preferred embodiments.

Brief Description of the Drawings

FIG. 1 is a perspective view of an illustrative electronic device such as a laptop computer with a light sensor that receives light through a display in accordance with an embodiment.

FIG. 2 is a perspective view of an illustrative electronic device such as a handheld electronic device

with a light sensor that receives light through a display in accordance with an embodiment.

FIG. 3 is a perspective view of an illustrative electronic device such as a tablet computer with a light
5 sensor that receives light through a display in accordance with an embodiment.

FIG. 4 is a perspective view of an illustrative electronic device such as a computer display with a light
10 sensor that receives light through a display in accordance with an embodiment.

FIG. 5 is a schematic diagram of an illustrative electronic device with a light sensor and a display in accordance with an embodiment.

FIG. 6 is a cross-sectional side view of a
15 portion of an illustrative electronic device having a light sensor mounted behind an enhanced translucency display in accordance with an embodiment.

FIG. 7 is a cross-sectional side view of a portion of an illustrative electronic device having a
20 light sensor mounted along an edge of a display that includes a light-guiding layer that guides light to the light sensor in accordance with an embodiment.

FIG. 8 is a diagram of an illustrative top-emission organic light-emitting diode display having
25 translucency enhancement features that allow light to pass through the display onto a light sensor in accordance with an embodiment.

FIG. 9 is a diagram of an illustrative bottom-emission organic light-emitting diode display having
30 translucency enhancement features that allow light to pass through the display onto a light sensor in accordance with an embodiment.

FIG. 10 is a diagram of an illustrative liquid

crystal display having translucency enhancement features that allow light to pass through the display onto a light sensor in accordance with an embodiment.

FIG. 11 is a diagram of an illustrative
5 reflective display layer having microperforations that enhance the translucency of the reflective display layer in accordance with an embodiment.

FIG. 12 is a diagram of an illustrative top-emission organic light-emitting diode display having a
10 light-guiding layer that guides light onto a light sensor mounted along an edge of the display in accordance with an embodiment.

FIG. 13 is a diagram of an illustrative bottom-emission organic light-emitting diode display having a
15 light-guiding layer that guides light onto a light sensor mounted along an edge of the display in accordance with an embodiment.

FIG. 14 is a diagram of an illustrative liquid crystal display having a light-guiding layer that guides
20 light onto a light sensor mounted along an edge of the display in accordance with an embodiment.

FIG. 15 is a top view of an illustrative light-guiding layer showing how the light-guiding layer may guide light onto a light sensor mounted along an edge of
25 the light-guiding layer in accordance with an embodiment.

FIG. 16 is a top view of an illustrative display circuitry layer showing how translucency enhancement features may include thinned conductive traces on the display circuitry layer in accordance with an embodiment.

FIG. 17 is a top view of an illustrative display circuitry layer showing how translucency enhancement features may include conductive traces having curved portions that deviate from a straight path to allow light

to pass through the conductive traces onto a light sensor in accordance with an embodiment.

Detailed Description

5 Electronic devices are provided with displays and light sensors. The display includes features that allow light to pass through the display onto the one or more light sensors. The features that allow light to pass through the display onto the one or more light sensors may
10 include translucency enhancement features that enhance the translucency of the display and/or light-guiding structures that guide light through the display onto the light sensors. Illustrative electronic devices that have displays and light sensors are shown in FIGS. 1, 2, 3, and
15 4.

 Electronic device 10 of FIG. 1 has the shape of a laptop computer and has upper housing 12A and lower housing 12B with components such as keyboard 16 and touchpad 18. Device 10 has hinge structures 20 to allow
20 upper housing 12A to rotate in directions 22 about rotational axis 24 relative to lower housing 12B. Display 14 such as an enhanced translucency display is mounted in upper housing 12A. Upper housing 12A, which may sometimes be referred to as a display housing or lid, is placed in a
25 closed position by rotating upper housing 12A towards lower housing 12B about rotational axis 24. Light sensors 40 such as ambient light sensors are mounted behind a portion of display 14. Light sensors 40 may be ambient
light sensors, proximity sensors, ultraviolet light
30 sensors, infrared light sensors, thin-film solar cells, photoplethysmograph (PPG) sensors, or other light sensor that sense the amount of light falling on the light sensor through the translucent display 14. Each light sensor 40

may include one or more photosensitive elements such as one or more photodiodes that generate electrical signals in response to incident light. Light sensors that are implemented as proximity sensors may also include a light-emitting component such as a light-emitting diode that emits light through a translucency enhancement feature and/or a light-guiding layer of the display.

FIG. 2 shows an illustrative configuration for electronic device 10 in which device 10 is implemented as a handheld device such as a cellular telephone, music player, gaming device, navigation unit, or other compact device. In this type of configuration for device 10, housing 12 has opposing front and rear surfaces. Display 14 is mounted on a front face of housing 12. Display 14 may have an exterior layer such as a rigid transparent layer that includes openings for components such as button 26 and speaker port 28.

In the example of FIG. 3, electronic device 10 is a tablet computer. In electronic device 10 of FIG. 3, housing 12 has opposing planar front and rear surfaces. Display 14 is mounted on the front surface of housing 12. As shown in FIG. 3, display 14 has an external layer with an opening to accommodate button 26.

FIG. 4 shows an illustrative configuration for electronic device 10 in which device 10 is a computer display or a computer that has been integrated into a computer display. With this type of arrangement, housing 12 for device 10 is mounted on a support structure such as stand 27. Display 14 is mounted on a front face of housing 12.

In some configurations, peripheral portions of display 14 are provided with a partially or completely opaque masking layer. As shown in FIGS. 1, 2, 3, and 4,

display 14 may be characterized by a central active region such as active region AA in which an array of display pixels is used in displaying information for a user. An inactive region such as inactive border region IA
5 surrounds active region AA. In the examples of FIGS. 1, 2, 3, and 4, active region AA has a rectangular shape. Inactive region IA has a rectangular ring shape that surrounds active region AA (as an example). Portions of display 14 in inactive region IA may be covered with a
10 partially opaque masking material such as a layer of black ink (e.g., a polymer filled with carbon black) or a layer of partially opaque metal. The masking layer helps hide components in the interior of device 10 in inactive region IA from view by a user.

15 In the examples of FIGS. 1, 2, 3, and 4, four light sensors 40 are mounted behind portions of display 14 in active area AA and four additional ambient light sensors 40 are mounted behind portions of display 14 in inactive area IA. However, this is merely illustrative.
20 If desired, device 10 may include more than four light sensors 40 in active area AA, less than four light sensors 40 in active area AA, more than four light sensors 40 in inactive area IA, less than four light sensors 40 in inactive area IA, a light sensor 40 that extends behind
25 substantially all of active area AA, behind substantially all of inactive area IA, or behind substantially all of active area AA and inactive area AA.

Light sensors 40 that are located in inactive area IA may be mounted alongside an edge of display 14. A
30 light-guiding layer in display 14 may guide light from outside of device 10 to the light sensor mounted along the edge of the display. In this way, a light sensor is provided that can be mounted separately from an outer

transparent layer of a device (i.e., a light sensor can be formed in the interior of the device). However, this is merely illustrative. If desired, light sensors 40 may be mounted directly behind display 14 in active area AA.

5 Display 14 includes translucency enhancement features that allow light to pass through display 14 onto the light sensor 40 that is mounted directly behind the display.

 The configurations for device 10 that are shown
10 in FIGS. 1, 2, 3, and 4 are merely illustrative. In general, electronic device 10 may be a laptop computer, a computer monitor containing an embedded computer, a tablet computer, a cellular telephone, a media player, or other handheld or portable electronic device, a smaller device
15 such as a wrist-watch device, a pendant device, a headphone or earpiece device, or other wearable or miniature device, a television, a computer display that does not contain an embedded computer, a gaming device, a navigation device, an embedded system such as a system in
20 which electronic equipment with a display is mounted in a kiosk or automobile, equipment that implements the functionality of two or more of these devices, or other electronic equipment.

 Housing 12 of device 10, which is sometimes
25 referred to as a case, is formed of materials such as plastic, glass, ceramics, carbon-fiber composites and other fiber-based composites, metal (e.g., machined aluminum, stainless steel, or other metals), other materials, or a combination of these materials. Device 10
30 may be formed using a unibody construction in which most or all of housing 12 is formed from a single structural element (e.g., a piece of machined metal or a piece of molded plastic) or may be formed from multiple housing

structures (e.g., outer housing structures that have been mounted to internal frame elements or other internal housing structures).

Display 14 may be a touch-sensitive display that includes a touch sensor or may be insensitive to touch. Touch sensors for display 14 may be formed from an array of capacitive touch sensor electrodes, a resistive touch array, touch sensor structures based on acoustic touch, optical touch, or force-based touch technologies, or other suitable touch sensor components.

Displays for device 10 may, in general, include image pixels formed from light-emitting diodes (LEDs), organic LEDs (OLEDs), plasma cells, electrowetting pixels, electrophoretic pixels, liquid crystal display (LCD) components, or other suitable image pixel structures. In some situations, it may be desirable to use OLED components to form display 14, so configurations for display 14 in which display 14 is an organic light-emitting diode display are sometimes described herein as an example. Other types of display technology may be used in device 10, if desired.

A schematic diagram of device 10 is shown in FIG. 5. As shown in FIG. 5, electronic device 10 includes control circuitry such as storage and processing circuitry 400. Storage and processing circuitry 400 includes one or more different types of storage such as hard disk drive storage, nonvolatile memory (e.g., flash memory or other electrically-programmable-read-only memory), volatile memory (e.g., static or dynamic random-access-memory), etc. Processing circuitry in storage and processing circuitry 400 is used in controlling the operation of device 10. The processing circuitry may be based on a processor such as a microprocessor and other integrated

circuits.

With one suitable arrangement, storage and processing circuitry 400 is used to run software on device 10 such as internet browsing applications, email applications, media playback applications, operating system functions, software for capturing and processing images, software for implementing functions associated with gathering and processing sensor data, etc.

Input-output circuitry 32 is used to allow data to be supplied to device 10 and to allow data to be provided from device 10 to external devices.

Input-output circuitry 32 can include wired and wireless communications circuitry 34. Communications circuitry 34 may include radio-frequency (RF) transceiver circuitry formed from one or more integrated circuits, power amplifier circuitry, low-noise input amplifiers, passive RF components, one or more antennas, and other circuitry for handling RF wireless signals. Wireless signals can also be sent using light (e.g., using infrared communications).

Input-output circuitry 32 of FIG. 5 includes input-output devices 36 such as buttons, joysticks, click wheels, scrolling wheels, a touch screen such as translucent display 14, other touch sensors such as track pads or touch-sensor-based buttons, vibrators, audio components such as microphones and speakers, image capture devices such as a camera module having an image sensor and a corresponding lens system, keyboards, status-indicator lights, tone generators, key pads, and other equipment for gathering input from a user or other external source and/or generating output for a user.

Sensors 38 of FIG. 5 include a light sensor such as an ambient light sensor for gathering information on

ambient light levels. Sensors 38 also include other light sensor components such as proximity sensor components. Proximity sensor components in device 10 can include capacitive proximity sensor components, infrared-light-based proximity sensor components, proximity sensor components based on acoustic signaling schemes, solar cell light sensor technology, or other proximity sensor equipment. Sensors 38 may also include a pressure sensor, a temperature sensor, an accelerometer, a gyroscope, and other circuitry for making measurements of the environment surrounding device 10.

It can be challenging to mount electrical components such as the components of FIG. 5 within an electronic device. To facilitate mounting of components in housing 12 of device 10, sensors 38 may be configured to receive light through a portion of a display having translucency enhancement features and/or light-guiding features that increase the amount of light that passes through the display onto the light sensor.

Storage and processing circuitry 400 samples voltages, electrical charges, or other electrical light sensor signals from light sensors 40 of sensors 38. Storage and processing circuitry 400 converts the sampled signals into ambient light intensities. Storage and processing circuitry 400 controls other aspects of the operation of device 10 using the converted ambient light intensities. For example, storage and processing circuitry can increase or decrease the display light from the device display based on the ambient light intensity.

FIG. 6 is a cross-sectional view of a portion of device 10 with a light sensor such as light sensor 40 that is mounted adjacent to inner surface 77 of display 14 having translucency enhancement features 43. Device 10

also includes a circuitry such as printed circuit board 42 and a flexible printed circuit 44 that electrically couples light sensor 40 to printed circuit board (PCB) 42. Circuitry associated with printed circuit board 42 (e.g.,
5 internal circuitry, circuitry on a surface of PCB 42, and/or integrated circuitry such as circuit components 48 mounted to a surface of PCB 42) controls the operation of display 14 and light sensor 40. PCB 42 and components 48 may, for example, form some or all of storage and
10 processing circuitry 400 of FIG. 5.

Light signals such as ambient light intensity signals gathered using light sensor 40 in response to light 45 are routed to printed circuit board 42 through flexible printed circuit 44. Flexible printed circuit 44
15 is attached to a portion of sensor 40 using electrical coupling material (e.g., anisotropic conductive film (ACF), solder, or other electrically conductive adhesive material). An opposing end of flexible printed circuit 44 is attached to a portion of PCB 42 using electrical
20 coupling material (e.g., anisotropic conductive film (ACF), solder, or other electrically conductive adhesive materials, or mechanical connector structures).

Display 14 may include multiple display layers such as layers 14A and 14B. Display layer 14B may include
25 a transparent coverlayer (e.g., a sheet of transparent plastic or glass) and, if desired, a touch-sensitive layer and/or other display layers such as protective films, anti-reflection coatings, anti-glare coatings, anti-smudge coatings, etc. A touch-sensitive layer may include
30 transparent electrodes formed from, for example, indium tin oxide or other transparent or translucent conductive material. Touch-sensor circuitry may include capacitive touch-sensor technology, resistive touch-sensor

technology, force-based touch-sensor technology or other touch-sensor technology for gathering user touch input.

Display layer 14A may include multiple layers for generating display images for display 14. Display
5 layer 14A may include image generating structures such as light-emitting diodes (LEDs), organic LEDs (OLEDs), plasma cells, electrowetting pixels, electrophoretic pixels, liquid crystal display (LCD) components, backlight structures, or other suitable image pixel structures.

10 As shown in FIG. 6, translucency enhancement features 43 may be features of display 14 that allow light 45 from outside of device 10 to be transmitted directly through display 14 onto light sensor 40. Translucency enhancement features of this type may allow less than 1
15 percent, less than 0.5 percent, less than 0.2 percent, less than 0.05 percent, less than 0.02 percent, greater than 0.01 percent, greater than 0.02 percent, greater than 0.1 percent between 0.05 and 1 percent, between 0.05 percent and 3 percent or less than 5 percent of light 45
20 to pass through features 43.

Translucency enhancement features 43 may include openings in a display layer (e.g., microperforations in a reflective layer of a display), a partially transmissive reflector layer (e.g., a reflective layer that reflects a
25 portion of the light that is incident on it while passing a relatively smaller portion of the incident light or a reflective layer that reflects light such as display light 50 having a first set of wavelengths such as visible wavelengths while passing light of a second, different set
30 of wavelengths such as infrared and/or ultraviolet wavelengths), or other structures that allow a relatively larger portion of incident light to pass through as compared with conventional displays.

Translucency enhancement features 43 may be formed in localized portions of display 14 as in the example of FIG. 6 or may extend across some or all of display 14. In configurations in which features 43 are
5 formed in localized portions of display 14, a larger fraction of ambient light 45 may pass through features 43 than the fraction that passes through other portions of display 14. In configurations in which features 43 extend across substantially all of display 14, display 14 may be
10 a translucent display that allows a measurable fraction of external light 45 to pass through the display onto a sensor such as sensor 40.

The translucency enhancement features of FIG. 6 are merely illustrative. As shown in FIG. 7, display 14
15 may be provided with one or more light-guiding structures such as light-guiding layer 52 of display 14 that guide light through at least a portion of the display to a light sensor such as light sensor 40. In the example of FIG. 7, light sensor 40 is mounted adjacent to edge 120 of display
20 layers 14A. In this type of configuration, light 45 enters display 14 through outer surface 56 and is redirected along layer 52 onto sensor 40. Light-guiding layer 52 may include wave-guide structures, light-focusing structures, optical films such as wave-guide films or film
25 stacks that redirect light based on reflections at refractive index changes between films in the stack, beam steering films, geometric light-guiding structures, corrugated light-guiding structures, or other light-guiding structures.

30 As examples, layer 52 may include a first planar layer of transparent material and a curved layer of transparent material attached to the planar layer that guides light in a direction parallel to the planar layer

or layer 52 may include a pair of transparent layers having planar outer surfaces and interfacing corrugated interior surfaces that guide light in a direction parallel to the planar outer surfaces using reflections at the
5 interfacing corrugated interior surfaces.

FIGS. 8, 9, 10, and 11 show examples of arrangements in which display 14 includes translucency enhancement features that allow light from outside of device 10 to be transmitted directly through display 14
10 onto a light sensor. FIGS. 12, 13, and 14 show examples of arrangements in which display 14 includes a light-guiding layer that guides light through the display to a light sensor that mounted adjacent the display.

FIG. 8 is a cross-sectional view of a light
15 sensor 40 that that receives light 45 through display layers 14A that are implemented as a top-emission organic light emitting diode (OLED) display. FIG. 9 is a cross-sectional view of a light sensor 40 that that receives light 45 through display layers 14A that are implemented
20 as a bottom-emission organic light emitting diode (OLED) display. FIG. 10 is a cross-sectional view of a light sensor 40 that that receives light 45 through display layers 14A that are implemented as a liquid crystal display (LCD).

25 In a configuration for display 14 of the type shown in FIG. 8, layers 14A include an outer layer such as layer 60. Outer layer 60 may include a protective film and/or one or more light-polarizing layers such as a linear polarizer and/or a circular polarizer. Layers 14A
30 include a layer of organic light-emitting material such as organic emissive layer 66 that is interposed between electrode layers 64 and 68. Electrode layer 64 may be a partially transmissive electrode layer such as a cathode

layer that allows display light 50 to pass through the electrodes.

Organic emissive layer 66 may be formed from organic plastics such as polyfluorene or other organic emissive materials. Electrode layer 64 is covered by barrier layer 62. Barrier layer 62 may be formed from a layer plastic, a glass layer, a thin-film encapsulation layer formed from a material such as silicon nitride, a layered stack of alternating polymer and ceramic materials, or other suitable material for forming a barrier layer that protects organic emissive layer 66 from environmental exposure by preventing water and oxygen from reaching organic emissive materials within layer 66.

Electrode layer 68 may be a reflective or partially reflective electrode layer such as an anode layer. An array of thin-film transistors (TFTs) may be formed throughout some or all of layer 68. The thin-film transistors may be formed from semiconductors such as amorphous silicon, polysilicon, or compound semiconductors (as examples). Layer 68 may include reflective material or opaque masking material (e.g., black ink) on thin film-transistors in layer 68 that helps prevent the thin-film transistors from being viewed by a viewer such as viewer 80 viewing display 14 in direction 82. If desired, a layer of transparent dielectric material such as dielectric layer 70 may be formed on a surface of electrode layer 68. Dielectric layer 70 may help planarize the surface of electrode layer 68 or may be a dielectric spacer layer for display 14. However, this is merely illustrative. If desired, display layer 14A may be formed without dielectric layer 70.

An additional barrier layer such as barrier layer 72 is formed over electrode layer 68 and dielectric

layer 72. In configurations in which layers 14A are provided without dielectric layer 70, barrier layer 72 may be formed directly on electrode layer 68. Barrier layer 72 may be formed from a layer of metal foil, metal foil
5 covered with plastic, other metal structures, a glass layer, a thin-film encapsulation layer formed from a material such as silicon nitride, a layered stack of alternating polymer and ceramic materials, or other suitable material for encapsulating organic emissive layer
10 66 and electrode layer 68.

Substrate layer 74 (e.g., a layer of plastic or glass) is attached to barrier layer 72. A reflective layer such as reflector 76 may be attached to substrate
15 74. Reflective layer 76 reflects light that is emitted from organic emissive layer 66 in the direction of reflector 76 back out of display layers 14A to be viewed by a viewer such as viewer 80.

As shown in FIG. 8, one or more light sensors 40 may be mounted adjacent to a surface such as surface 77 of
20 reflector 76. Light 45 such as ambient light passes through translucency enhancement features 43 in display layer 14A onto light sensors 40. In the example of FIG. 8, translucency enhancement features 43 are formed in reflector layer 76 and electrode/TFT layer 68. However,
25 this is merely illustrative. If desired display 14 may include translucency enhancement features in any location in display 14.

Translucency enhancement features 43 in reflector layer 76 may include openings such as
30 microperforations (i.e., perforations that allow light to pass through but that are too small to be seen with the human eye when no light shines through the perforations) or regions of modified transparency in reflector layer 76.

For example, translucency enhancement features 43 may be portions of reflector 76 that are formed from translucent material that reflects a portion of the light that is incident on it while passing a relatively smaller portion of the incident light or features 43 may be portions of reflector 76 that are formed from a material that reflects light such as display light 50 having a first set of wavelengths such as visible wavelengths while passing light of a second, different set of wavelengths such as infrared and/or ultraviolet wavelengths (as examples).

Translucency enhancement features 43 may be formed in localized portions of reflector 76 as in the example of FIG. 8 or may extend across some or all of reflector 76 (e.g., reflector 76 may be substantially all formed from a material that is partially translucent or that allows light having a given range of wavelengths such as infrared wavelengths and/or ultraviolet wavelengths to pass while reflecting light of other wavelengths).

Translucency enhancement features in electrode/TFT layer 68 may include microperforations in layer 68, portions of layer 68 that are formed from a translucent material, portions of layer 68 that are formed from a material that passes light having a given range of wavelengths (e.g., infrared wavelengths and/or ultraviolet wavelengths) while reflecting light of other wavelengths, or may include portions of opaque conductive structures such as conductive traces that are modified to allow light to pass through or between the conductive traces. Modified conductive traces may include locally thinned conductive traces or rerouted conductive traces (as examples). As shown in FIG. 8, features 43 in layer 68 may be aligned with features 43 in layer 76 so that light such as light 45 may pass through the aligned translucency

enhancement features in multiple display layers onto one or more of light sensors 40.

Light absorbing material 78 is formed on surface 77 of reflector 76. Light absorbing material may include
5 light-absorbing ink such as infrared absorbing ink that prevents light from reflecting from sensors 40 back through display layers 14A. Material 78 on surface 77 helps prevent user 80 from viewing light sensor 40. Material 78 may include one or more openings 79 aligned
10 with features 43 that allow light to pass through the openings onto sensors 40.

In a configuration for display 14 of the type shown in FIG. 9, light sensors 40 receive light 45 through translucency enhancement features 43 in a bottom-emission
15 light emitting diode display (i.e., an OLED display that emits light through a substrate layer). In the example of FIG. 9, a first surface of substrate layer 74 is attached to outer layer 60 and a second, opposing surface of substrate 74 is attached to barrier layer 72. Optional
20 dielectric layer 70 is attached to barrier layer 72 and electrode layer 64 is attached to dielectric layer 70. In configurations in which display layers 14A are provided without dielectric layer 70, barrier layer 72 may be formed directly on electrode layer 64. Organic emissive
25 layer 66 is sandwiched between electrode layers 64 and 68 and emits display light 50 through electrode layer 64 and other display layers 14A. Barrier layer 62 is formed on electrode layer 68 and reflector layer 76 is attached to barrier layer 62.

30 One or more light sensors 40 is mounted adjacent to surface 77 of reflector 76 and receives light such as light 45 through translucency enhancement features 43 in reflector layer 76, electrode layer 68, and/or other

layers of display layers 14A.

In a configuration for display 14 of the type shown in FIG. 10, light sensors 40 receive light 45 through translucency enhancement features 43 in a liquid crystal display (LCD) formed from liquid crystal display cell 84 and backlight structures 86. Liquid crystal layer 92 of LCD cell 84 is formed between color filter layer 90 and thin-film transistor layer 94. Layers 90 and 94 may be formed on a transparent substrate such as a sheet of glass. Liquid crystal layer 92, color filter layer 90, and thin-film transistor layer 94 are sandwiched between light polarizing layers such as upper polarizer 88 and lower polarizer 96.

Backlight structures 86 may include a light guide plate such as light guide plate 100. Light guide plate 100 may be formed from a transparent material such as clear glass or plastic that guides light using internal reflections within plate 100. During operation of backlight structures 86, a light source such as light source 102 may generate light 103. Light source 102 may be, for example, an array of light-emitting diodes.

Light 103 from light source 102 may be coupled into an edge of light guide plate 100 and may be distributed in dimensions X and Y throughout light guide plate 100 due to the principle of total internal reflection. Light guide plate 100 may include light-scattering features such as pits or bumps. The light-scattering features may be located on an upper surface and/or on an opposing lower surface of light guide plate 100.

Light 103 that scatters upwards in direction Z from light guide plate 100 may serve as display light 50 for display 14. Light 103 that scatters downwards may be

reflected back in the upwards direction by reflector 76. Reflector 76 may be formed from a reflective material such as metal, a layer of white plastic or may be formed from a translucent material that allows some of light 45 to pass
5 while reflecting other portions of light 45.

Backlight structures 86 may include optical films 98 (e.g., diffuser layers, compensation films for enhancing off-axis viewing, and brightness enhancement films (also sometimes referred to as turning films) for
10 collimating backlight).

Light sensor 40 may be attached to interior surface 77 of a reflector such as reflector 76 that is implemented in backlight unit 86 and may receive ambient light through upper polarizer 88, color filter layer 90,
15 liquid crystal layer 92, thin-film transistor layer 94, lower polarizer layer 96, and backlight unit 86. Backlight unit 86, thin-film transistor layer 94 and/or other portions of a liquid crystal display of the type shown in FIG. 10 may include features 43 that enhance the
20 transmission of light 45 through display layers 14A to sensor 40.

As described above in connection with FIG. 8, translucency enhancement features 43 in reflector layer 76 may include openings such as microperforations (i.e.,
25 perforations that allow light to pass through but that are too small to be seen with the human eye when light does not shine through the perforations) or regions of modified transparency in reflector layer 76.

Translucency enhancement features 43 may be
30 formed in localized portions of reflector 76 or may extend across some or all of reflector 76.

Translucency enhancement features 43 in thin-film transistor layer 94 may include microperforations in

layer 94, partially translucent portions of layer 94, portions of layer 94 that pass light having a given range of wavelengths (e.g., infrared and/or ultraviolet wavelengths) while reflecting light of other wavelengths (e.g., visible wavelengths), or may include portions of opaque conductive structures such as conductive traces that are modified to allow light to pass through the conductive traces. Modified conductive traces may include locally thinned conductive traces or rerouted conductive traces (as examples). Features 43 in layer 94 may be aligned with features 43 in layer 76 so that light such as light 45 may pass through the aligned translucency enhancement features onto one or more of light sensors 40.

FIG. 11 is cross-sectional view of a portion of reflector 76 showing how translucency enhancement features 43 may be formed from openings such as microperforations 104 in reflector 76. Microperforations 104 pass through reflector 76 from a first surface to an opposing second surface of reflector 76. Openings 104 may include openings in masking material 78. Microperforations 104 may be laser-drilled openings in layer 76 (as an example). If desired, microperforations such as microperforations 104 may be formed in other layers of display 14 (e.g., one or more additional display layers of display layers 14A and/or one or more of display layers 14B). Microperforations 104 may be formed in a localized portion of reflector 76 or may be formed across substantially all of reflector 76.

FIG. 12 is a cross-sectional view of a light sensor 40 that that receives light 45 through a light-guiding layer of display layers 14A that are implemented as a top-emission OLED display. FIG. 13 is a cross-sectional view of a light sensor 40 that that receives

light 45 through a light-guiding layer of display layers 14A that are implemented as a bottom-emission OLED display. FIG. 14 is a cross-sectional view of a light sensor 40 that receives light 45 through a light-guiding layer of display layers 14A that are implemented as an LCD display.

In a configuration for display 14 of the type shown in FIG. 12, a top-emission OLED display of the type shown in FIG. 8 is provided with an additional layer such as light-guide layer 52. Light-guide layer 52 is attached to barrier layer 72 using a layer of transparent adhesive such as optically clear adhesive layer 108. Substrate 74 is attached to an opposing surface of light-guide layer 52 and to reflective layer 76. Light 45 that passes through organic emissive layer 66 and enters light-guide layer 52 is guided within layer 52 (e.g., along the x-y plane of FIG. 12) onto a light sensor 40 that is mounted adjacent to edge 120 of display layers 14A (e.g., adjacent to an edge of light-guide layer 52).

During manufacturing and assembly operations, a temporary substrate such as a plastic sheet may be attached to display layers 14A at location 124. After assembly of display layers 60, 62, 64, 66, 68, 70, and 72 on the temporary substrate, the temporary substrate may be removed and light-guide layer 52 may be attached at location 124 using adhesive 108.

In a configuration for display 14 of the type shown in FIG. 13, a bottom-emission OLED display of the type shown in FIG. 9 is provided with an additional layer such as light-guide layer 52. Light-guide layer 52 is attached to barrier layer 72 using a layer of transparent adhesive such as optically clear adhesive layer 108. Substrate 74 is attached to an opposing surface of light-

guide layer 52 and to outer layer 60. Light 45 that enters light-guide layer 52 is guided within layer 52 (along the x-y plane of FIG. 13) onto a light sensor 40 that is mounted adjacent to edge 120 of display layers 14A (e.g., adjacent to an edge of light-guide layer 52). Display light 50 passes through light-guide layer 52 and out of display layers 14A to be viewed by viewer 80 in direction 82.

In a configuration for display 14 of the type shown in FIG. 14, an LCD display of the type shown in FIG. 10 is provided with an additional layer such as light-guide layer 52. Light-guide layer 52 is interposed between LCD cell 84 and backlight structures 86. However, this is merely illustrative. If desired, light-guide layer 52 may be formed behind backlight unit 86 or may be formed between two other layers of LCD cell 84 or backlight structures 86. In the example of FIG. 14, light 45 that enters light-guide layer 52 after passing through LCD cell 84 is guided within layer 52 (e.g., along the x-y plane of FIG. 14) onto a light sensor 40 that is mounted adjacent to edge 120 of display layers 14A (e.g., adjacent to an edge of light-guide layer 52). Display light 50 that is generated by backlight structures 86 passes through light-guide layer 52, through LCD cell 84, and out of display layers 14A to be viewed by viewer 80 in direction 82.

In the examples of FIGS. 12, 13, and 14, device 10 includes a light sensor mounted along edge 120 of display 14 that receives light through light-guide layer 52, and two light sensors mounted adjacent to interior surface 77 of display 14 that receive light through translucency enhancement features 43. However this is merely illustrative. In various other possible

combinations, device 10 may be provided with a single light sensor mounted adjacent to surface 77, three or more light sensors mounted adjacent to surface 77 or no light sensors mounted adjacent to surface 77. Device 10 may include more than one light sensor mounted adjacent to edge 120 or may be provided without any light sensors mounted adjacent to edge 120.

In order to minimize the effect of display light 50 on light detection operations using light sensors 40, the light sensors may be provided with light-filtering structures such as light-filtering films that prevent display light from reaching the sensors, light sensor data may be gathered during blanking periods in which display 14 is not generating display light, or display light signals may be removed from light sensor data using software applications that access stored display light data associated with known features of the display light (e.g., known display light wavelengths, known display light intensities or known display light emission cycles).

FIG. 15 is a top view of a light guide layer such as light-guide layer 52 (e.g., light-guide layer 52 of any of FIGS. 7, 12, 13, or 14). In the example of FIG. 15, light-guide layer 52 includes internal light guiding structures 128 (e.g., geometric features, corrugated features, etc.) that guide light that is incident on light-guide layer 52 along directions 130 onto light sensor 40 mounted along edge 120. Light-guide layer 52 may include a coating layer 125 on edge 120 that prevents light from exiting light-guide layer 52. Coating 125 may have an opening such as opening 126 that allows light to exit from edge 120 through opening 126 onto light sensor 40.

FIG. 16 is a top view of a portion of a display

circuitry layer having translucency enhancement features formed from modified conductive traces on the circuitry layer. Display circuitry layer 110 may be a portion of electrode/TFT layer 68 of any of FIGS. 8, 9, 12, or 13, may be a portion of TFT layer 94 of either of FIGS. 10 or 14, or may be any other layer of display 14 having conductive traces such as traces 112. Conductive traces 112 may be formed from opaque conductive material such as metal (e.g., copper).

In the example of FIG. 16, translucency enhancement features 43 are formed from thinned portions 114 of selected conductive traces 112. Thinned portions 114 are formed over light sensor 40 so that light may pass between thinned portions 114 onto sensor 40. Layer 110 includes conductive traces 112 having thinned portions 114 and conductive traces 112 that have a substantially constant thickness along the length of the trace.

The modified conductive traces of FIG. 16 are merely illustrative. If desired, conductive traces on layer 110 may be modified in other ways to allow light to pass through conductive traces 112 onto light sensor 40.

In the example of FIG. 17, traces 112 include curved portions 116 that reroute the traces on layer 110 so that the traces avoid overlapping light sensor 40. In this way, curved portions 116 of layer 110 allow light to pass between curved portions 116 of traces 112 onto light sensor 40. Layer 110 includes conductive traces 112 having curved portions 116 and conductive traces 112 that extend along substantially straight paths on layer 110.

In accordance with an embodiment, an electronic device is provided that includes an enhanced translucency display having at least one translucency enhancement feature that allows light to pass through the enhanced

translucency display, the display has an outer surface and an opposing inner surface, and a light sensor adjacent to the opposing inner surface, the light sensor is configured to receive the light that passes through the translucency enhancement feature.

In accordance with another embodiment, the light sensor includes an ambient light sensor that senses ambient light that passes through the translucency enhancement feature of the enhanced translucency display.

In accordance with another embodiment, the display includes a light-reflecting layer and the translucency enhancement feature includes at least a portion of the light-reflecting layer that reflects a first portion of the ambient light while passing a second portion of the ambient light.

In accordance with another embodiment, the first portion of the ambient light has a first range of wavelengths and the second portion of the ambient light has a second range of wavelengths that is different from the first range of wavelengths.

In accordance with another embodiment, the first range of wavelengths includes visible wavelengths and the second range of wavelengths includes at least infrared wavelengths.

In accordance with another embodiment, the first and second portions of the ambient light have a common range of wavelengths.

In accordance with another embodiment, the second portion of the ambient light includes at least one percent of the ambient light.

In accordance with another embodiment, the electronic device includes masking material interposed between the light sensor and the opposing inner surface.

In accordance with another embodiment, the display includes a light-reflecting layer and the translucency enhancement feature includes a plurality of microperforations in the light-reflecting layer.

5 In accordance with another embodiment, the display includes a circuitry layer and the translucency enhancement feature includes modified conductive traces that allow the light to pass between the modified conductive traces onto the light sensor.

10 In accordance with another embodiment, the modified conductive traces include conductive traces having thinned portions that are formed over light sensor.

In accordance with another embodiment, the modified conductive traces include conductive traces
15 having curved portions that reroute the conductive traces around a portion of the circuitry layer that covers the light sensor.

In accordance with an embodiment, an electronic device is provided that includes a display having a light-
20 guiding layer, and a light sensor adjacent to an edge of the display, the light sensor receives light that passes through at least a portion of the light-guiding layer onto the light sensor.

In accordance with another embodiment, the
25 display includes a layer of organic emissive material interposed between the light-guiding layer and an outer surface of the display.

In accordance with another embodiment, the display includes a layer of organic emissive material and
30 the light-guiding layer is interposed between the layer of organic emissive material and an outer surface of the display.

In accordance with another embodiment, the

display includes a layer of liquid crystal material interposed between the light-guiding layer and an outer surface of the display.

5 In accordance with another embodiment, the display further includes a light-guide plate that distributes display light for the display and the light-guiding layer is interposed between the light-guide plate and an outer surface of the display.

10 In accordance with another embodiment, the electronic device includes masking material formed on an edge of the light-guiding layer, the masking material includes an opening adjacent to the light sensor that allows light to pass from the light-guiding layer onto the light sensor.

15 In accordance with an embodiment, an electronic device is provided that includes a display that generates display images to be displayed to a user of the electronic device, the display includes an outer surface, an inner surface, and an edge, a first light sensor mounted
20 adjacent to the inner surface of the display that receives light that passes through the outer surface and the inner surface of the display, and a second light sensor mounted adjacent to the edge of the display that receives light that passes through the outer surface and edge of the
25 display.

In accordance with another embodiment, the display includes at least one translucency enhancement feature that allows the light that passes through the outer surface and the inner surface of the display to pass
30 through one or more display layers of the display.

In accordance with another embodiment, the display further includes a light-guide layer that guides the light that passes through the outer surface and the

edge of the display through the light-guide layer to the edge of the display.

In accordance with another embodiment, the display includes a light-guide layer that guides the light
5 that passes through the outer surface and the edge of the display through the light-guide layer to the edge of the display.

The foregoing is merely illustrative and various modifications can be made by those skilled in the art
10 without departing from the scope and spirit of the described embodiments. The foregoing embodiments may be implemented individually or in any combination.

What is Claimed is:

1. An electronic device, comprising:
an enhanced translucency display having at least one translucency enhancement feature that allows light to pass through the enhanced translucency display, wherein the display has an outer surface and an opposing inner surface; and
a light sensor adjacent to the opposing inner surface, wherein the light sensor is configured to receive the light that passes through the translucency enhancement feature.
2. The electronic device defined in claim 1 wherein the light sensor comprises an ambient light sensor that senses ambient light that passes through the translucency enhancement feature of the enhanced translucency display.
3. The electronic device defined in claim 2 wherein the display comprises a light-reflecting layer and wherein the translucency enhancement feature comprises at least a portion of the light-reflecting layer that reflects a first portion of the ambient light while passing a second portion of the ambient light.
4. The electronic device defined in claim 3 wherein the first portion of the ambient light has a first range of wavelengths and wherein the second portion of the ambient light has a second range of wavelengths that is different from the first range of wavelengths.
5. The electronic device defined in claim 4 wherein the first range of wavelengths comprises visible

wavelengths and wherein the second range of wavelengths comprises at least infrared wavelengths.

6. The electronic device defined in claim 3 wherein the first and second portions of the ambient light have a common range of wavelengths.

7. The electronic device defined in claim 6 wherein the second portion of the ambient light comprises at least one percent of the ambient light.

8. The electronic device defined in claim 1, further comprising masking material interposed between the light sensor and the opposing inner surface.

9. The electronic device defined in claim 1 wherein the display comprises a light-reflecting layer and wherein the translucency enhancement feature comprises a plurality of microperforations in the light-reflecting layer.

10. The electronic device defined in claim 1 wherein the display comprises a circuitry layer and wherein the translucency enhancement feature includes modified conductive traces that allow the light to pass between the modified conductive traces onto the light sensor.

11. The electronic device defined in claim 10 wherein the modified conductive traces comprise conductive traces having thinned portions that are formed over light sensor.

12. The electronic device defined in claim 10 wherein the modified conductive traces comprise conductive traces having curved portions that reroute the conductive traces around a portion of the circuitry layer that covers the light sensor.

13. An electronic device, comprising:
a display having a light-guiding layer; and
a light sensor adjacent to an edge of the display, wherein the light sensor receives light that passes through at least a portion of the light-guiding layer onto the light sensor.

14. The electronic device defined in claim 13 wherein the display comprises a layer of organic emissive material interposed between the light-guiding layer and an outer surface of the display.

15. The electronic device defined in claim 13 wherein the display comprises a layer of organic emissive material and wherein the light-guiding layer is interposed between the layer of organic emissive material and an outer surface of the display.

16. The electronic device defined in claim 13 wherein the display comprises a layer of liquid crystal material interposed between the light-guiding layer and an outer surface of the display.

17. The electronic device defined in claim 16 wherein the display further comprises a light-guide plate that distributes display light for the display and wherein the light-guiding layer is interposed between the light-

guide plate and an outer surface of the display.

18. The electronic device defined in claim 13, further comprising masking material formed on an edge of the light-guiding layer, wherein the masking material includes an opening adjacent to the light sensor that allows light to pass from the light-guiding layer onto the light sensor.

19. An electronic device, comprising:

a display that generates display images to be displayed to a user of the electronic device, wherein the display includes an outer surface, an inner surface, and an edge;

a first light sensor mounted adjacent to the inner surface of the display that receives light that passes through the outer surface and the inner surface of the display; and

a second light sensor mounted adjacent to the edge of the display that receives light that passes through the outer surface and edge of the display.

20. The electronic device defined in claim 19 wherein the display comprises at least one translucency enhancement feature that allows the light that passes through the outer surface and the inner surface of the display to pass through one or more display layers of the display and wherein the display further comprises a light-guide layer that guides the light that passes through the outer surface and the edge of the display through the light-guide layer to the edge of the display.

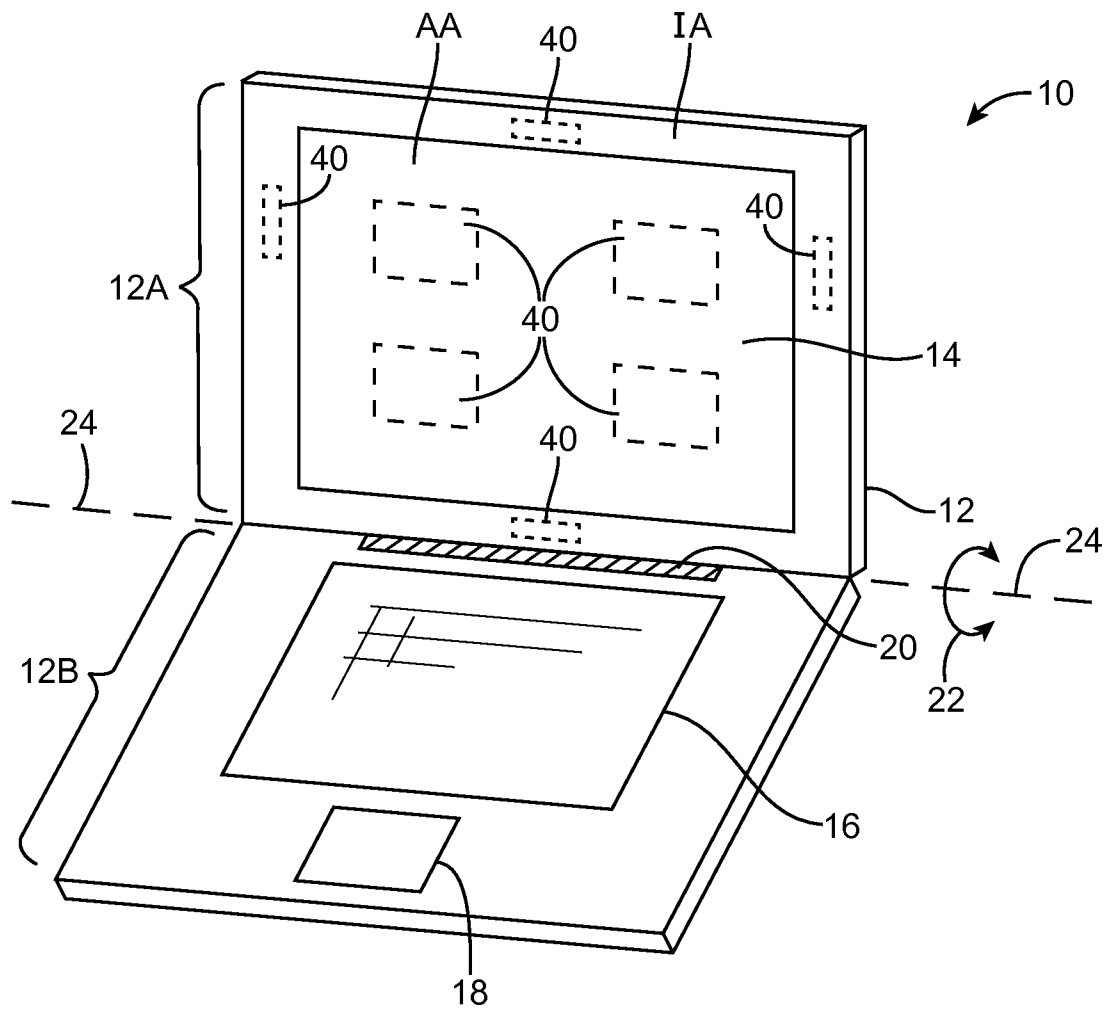


FIG. 1

2 / 16

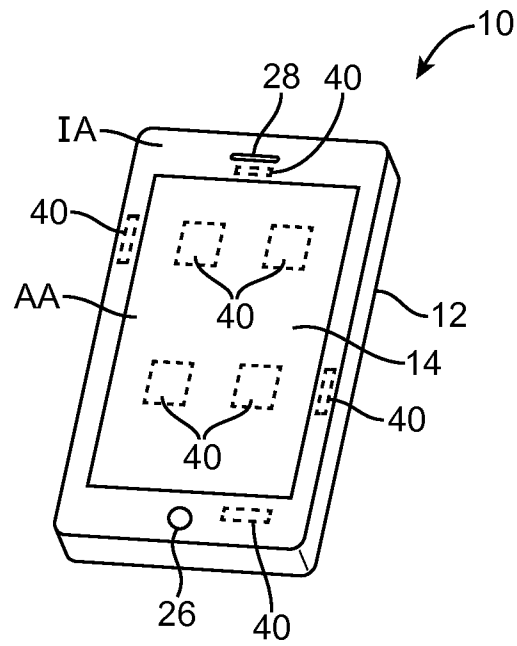


FIG. 2

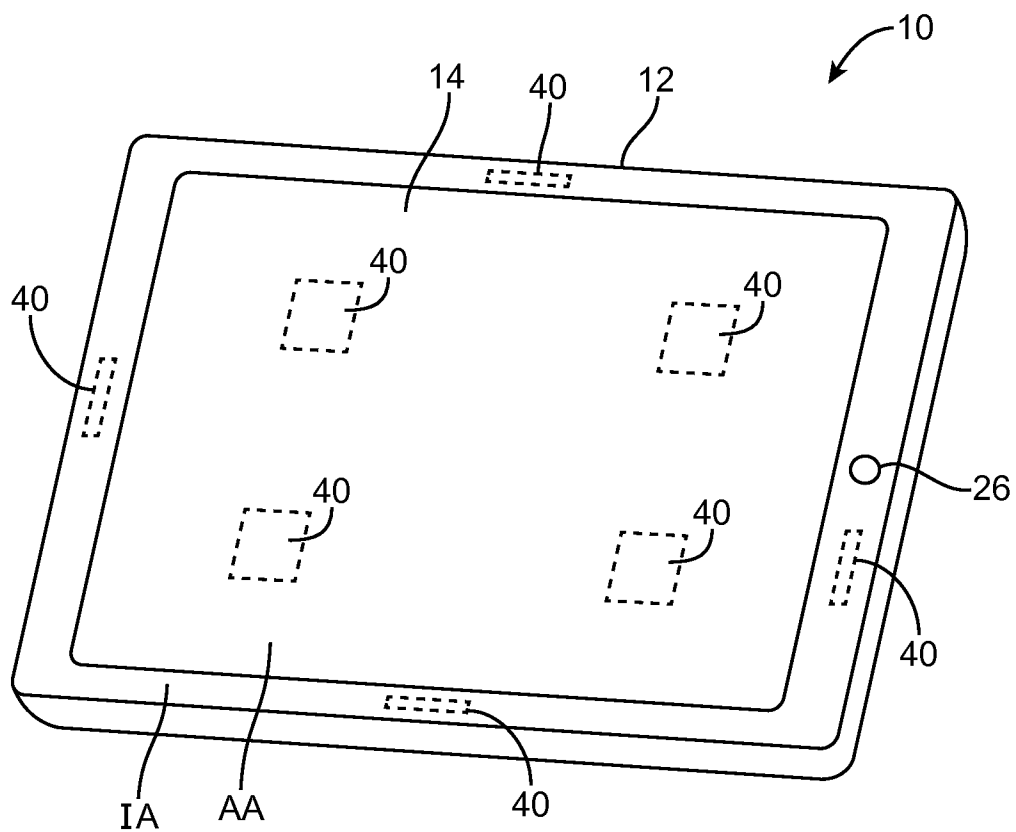


FIG. 3

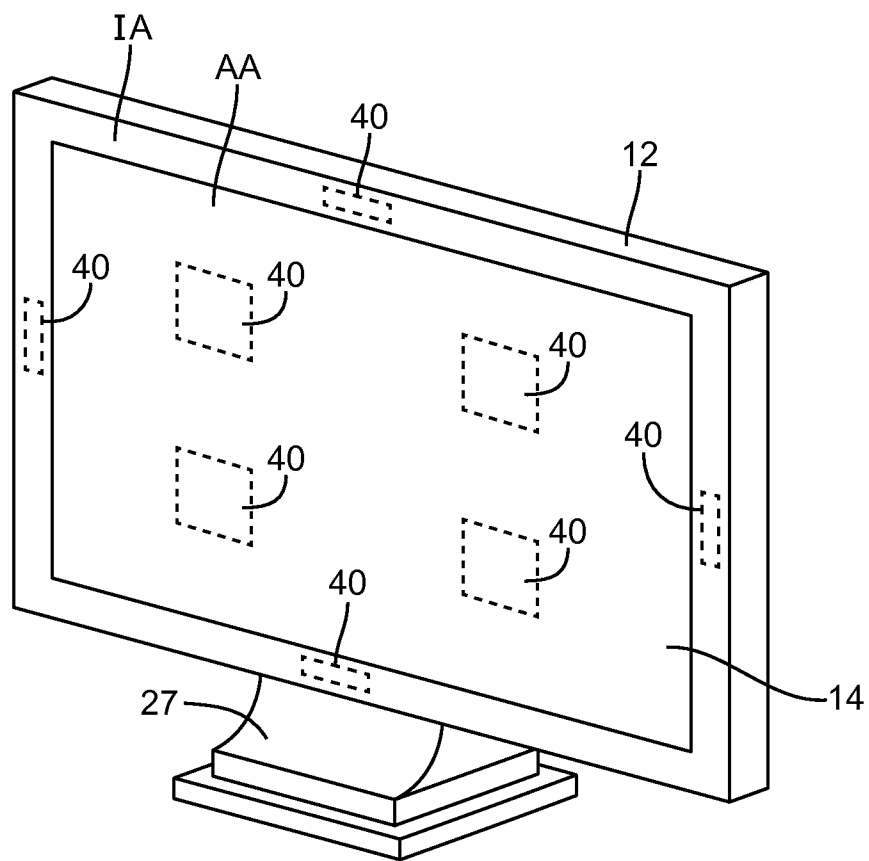


FIG. 4

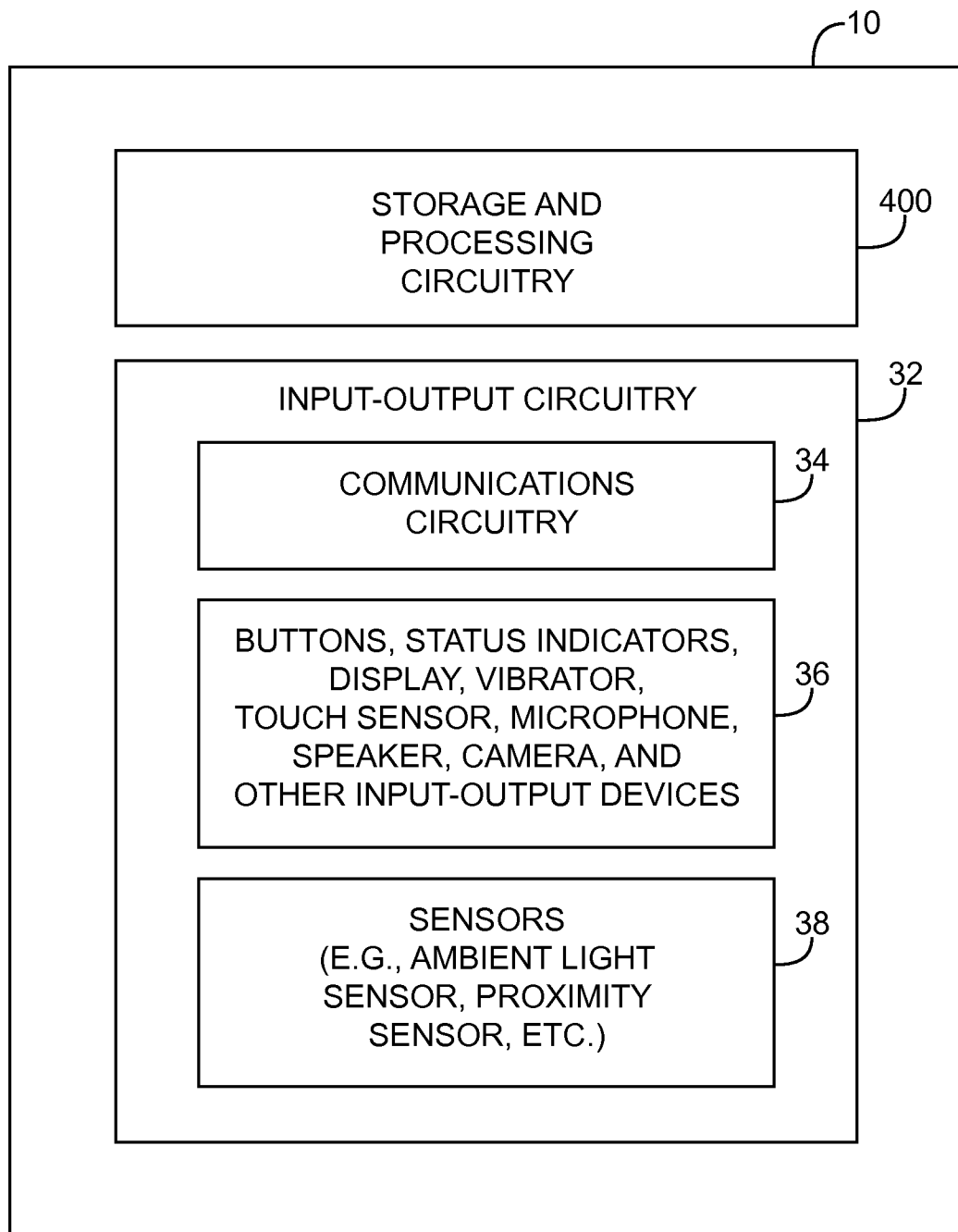


FIG. 5

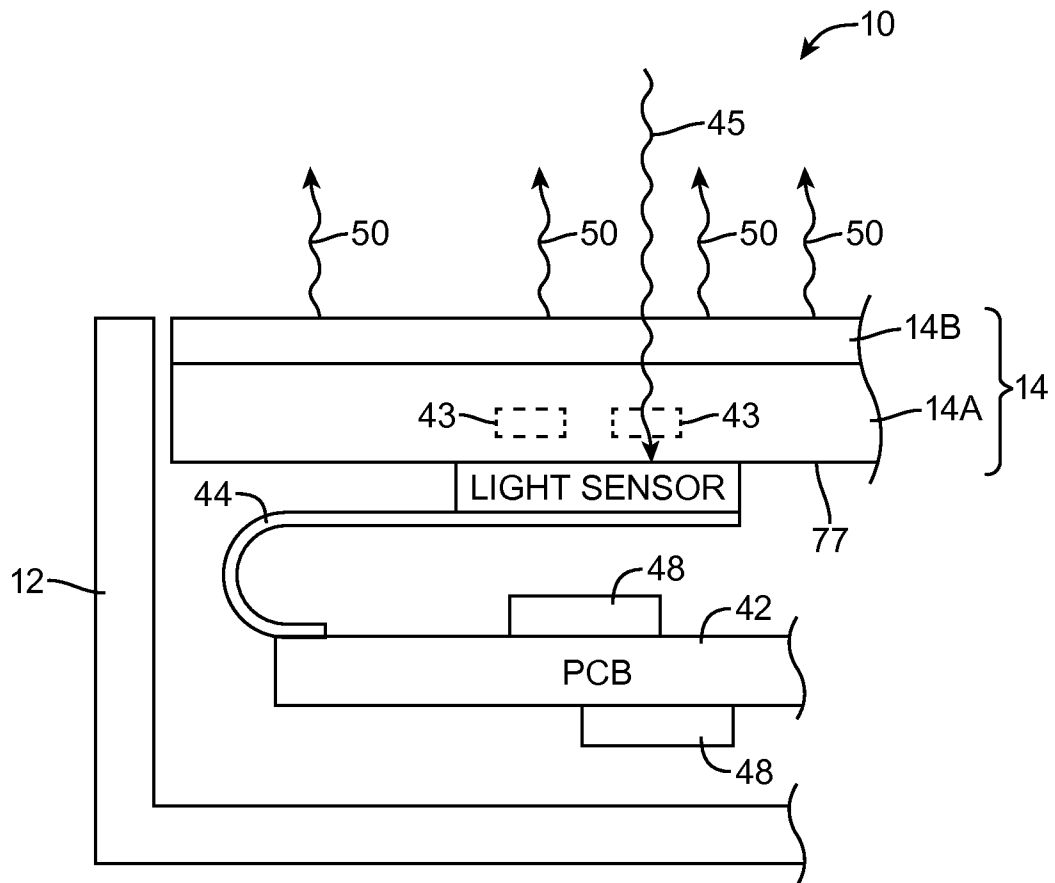


FIG. 6

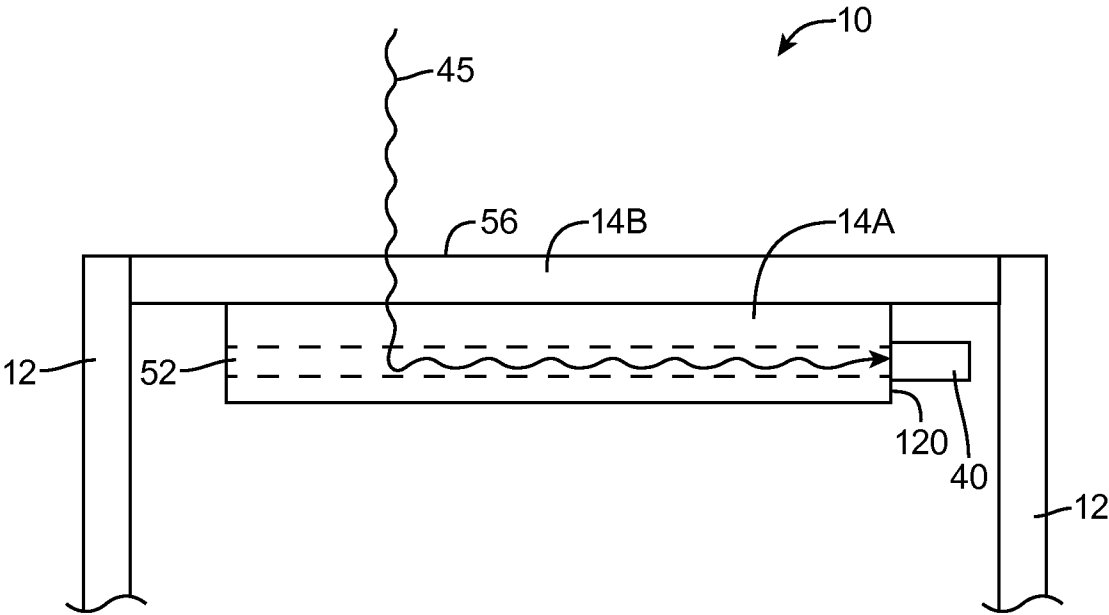


FIG. 7

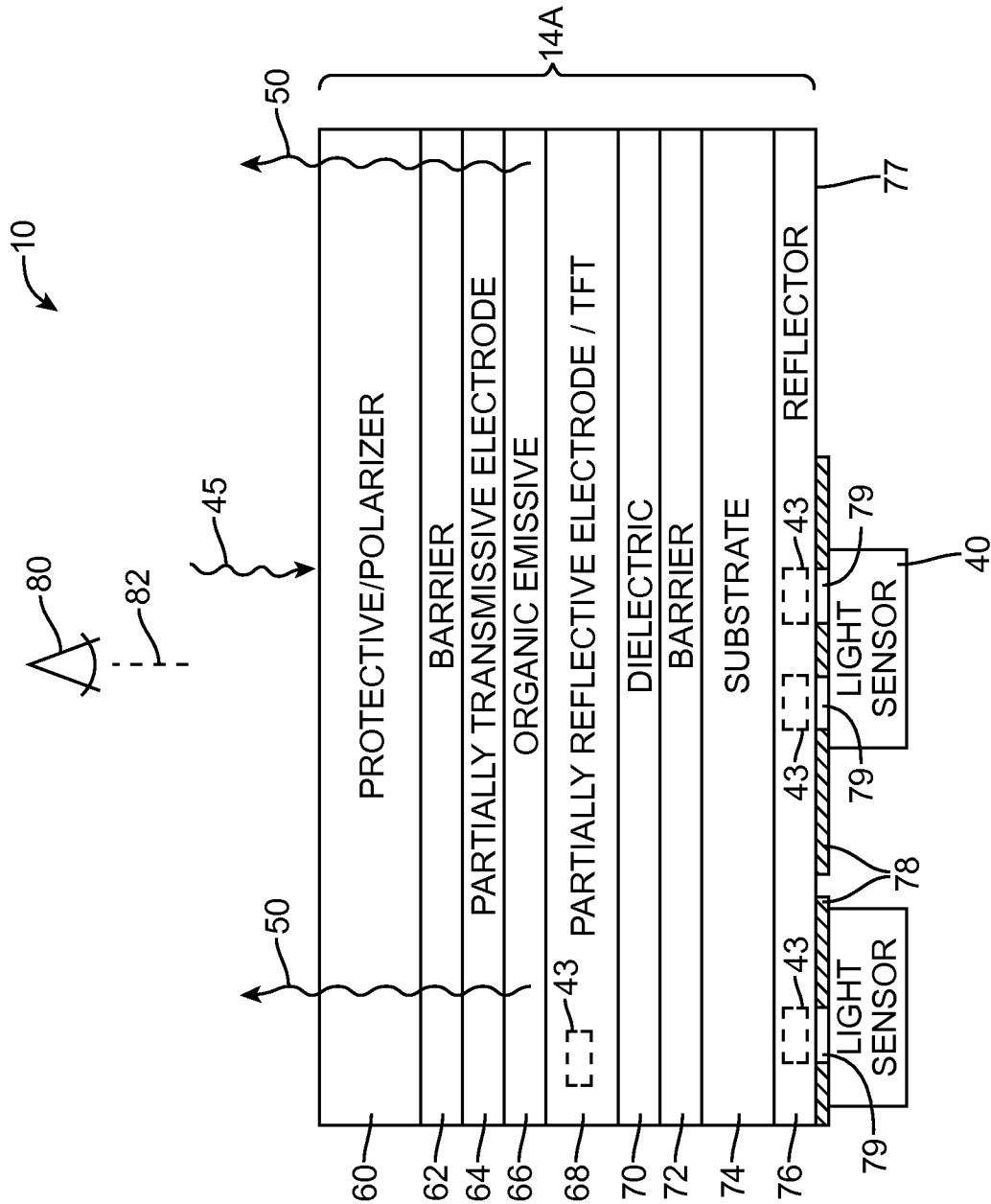


FIG. 8

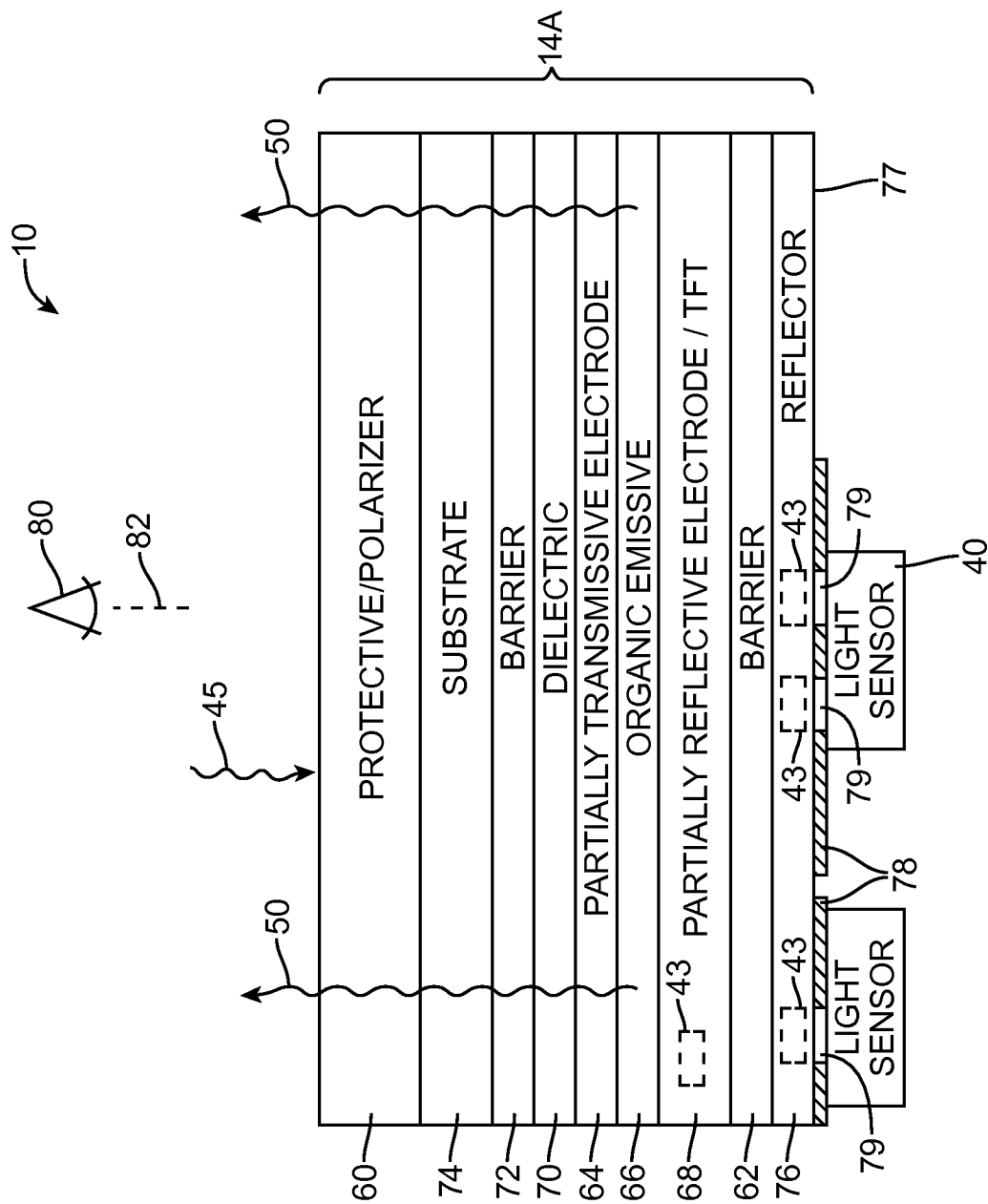


FIG. 9

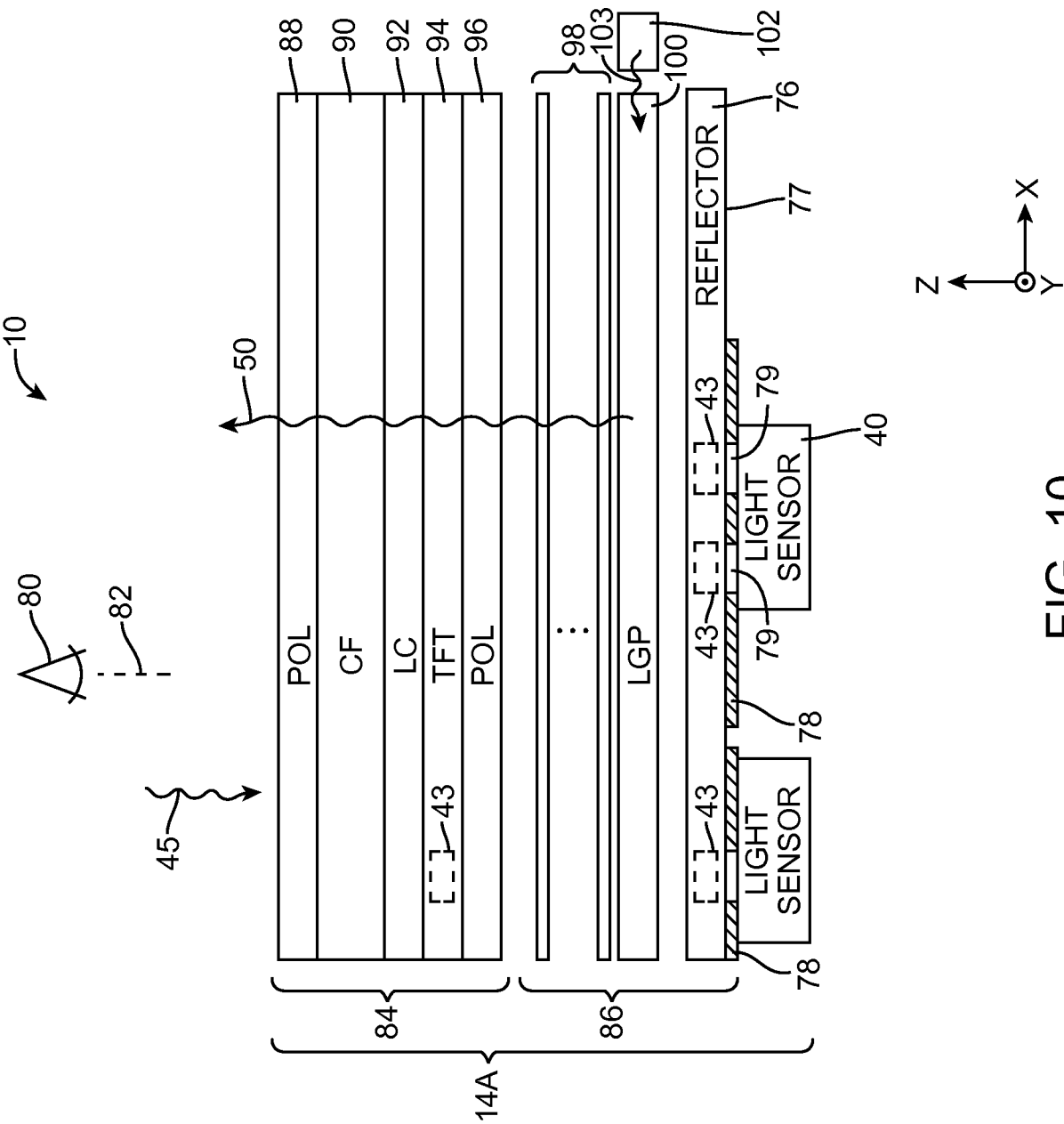


FIG. 10

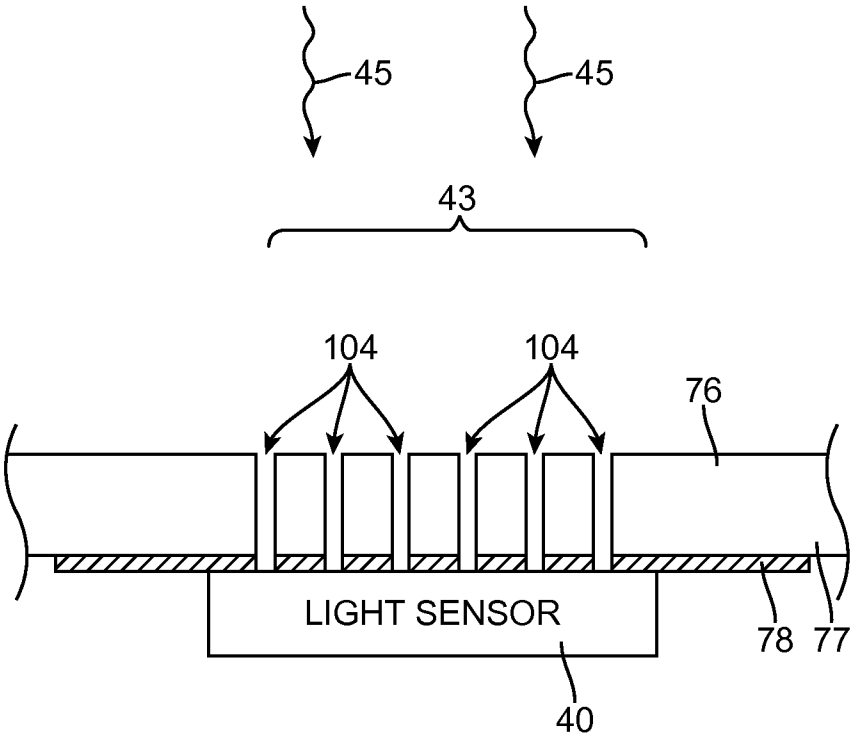


FIG. 11

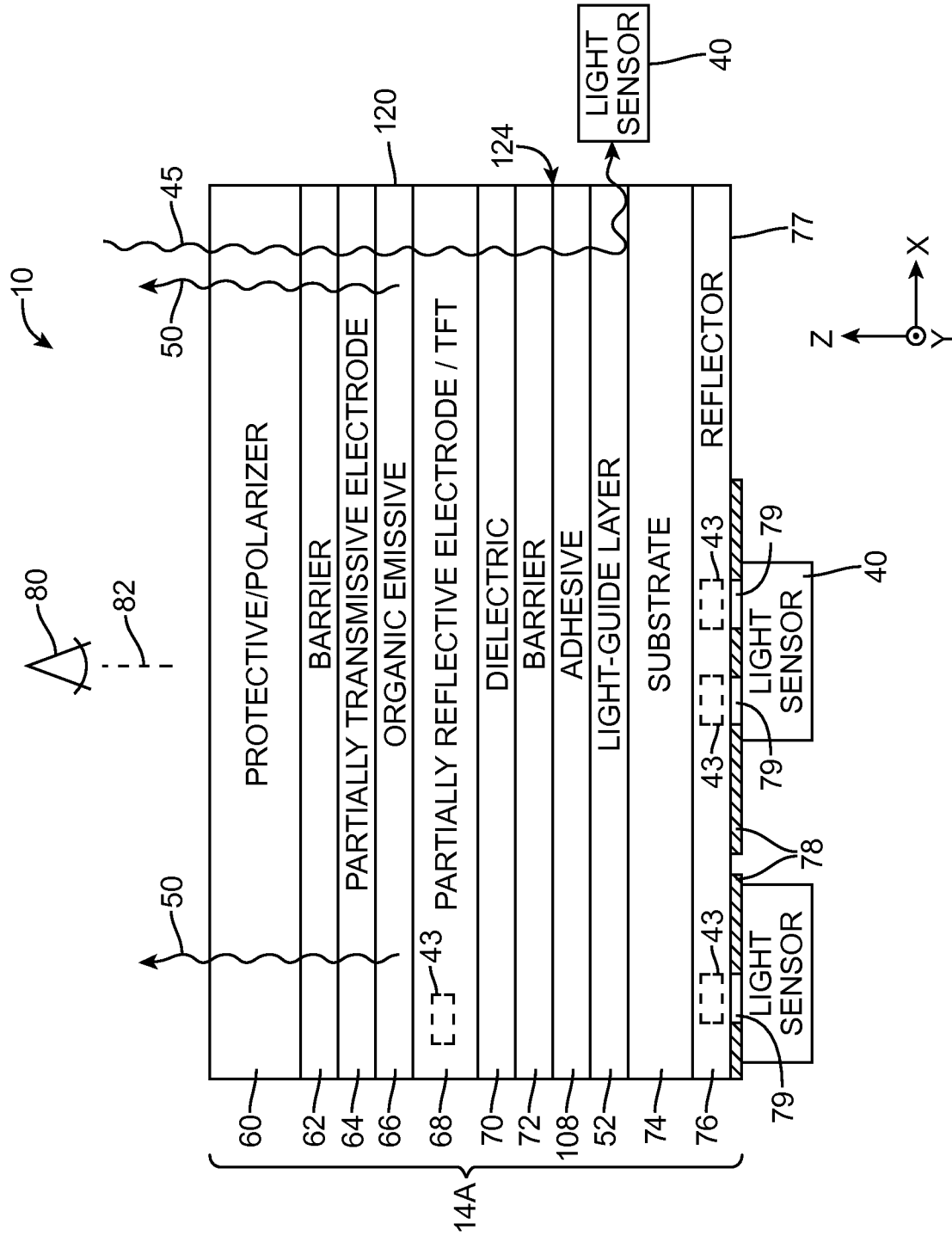


FIG. 12

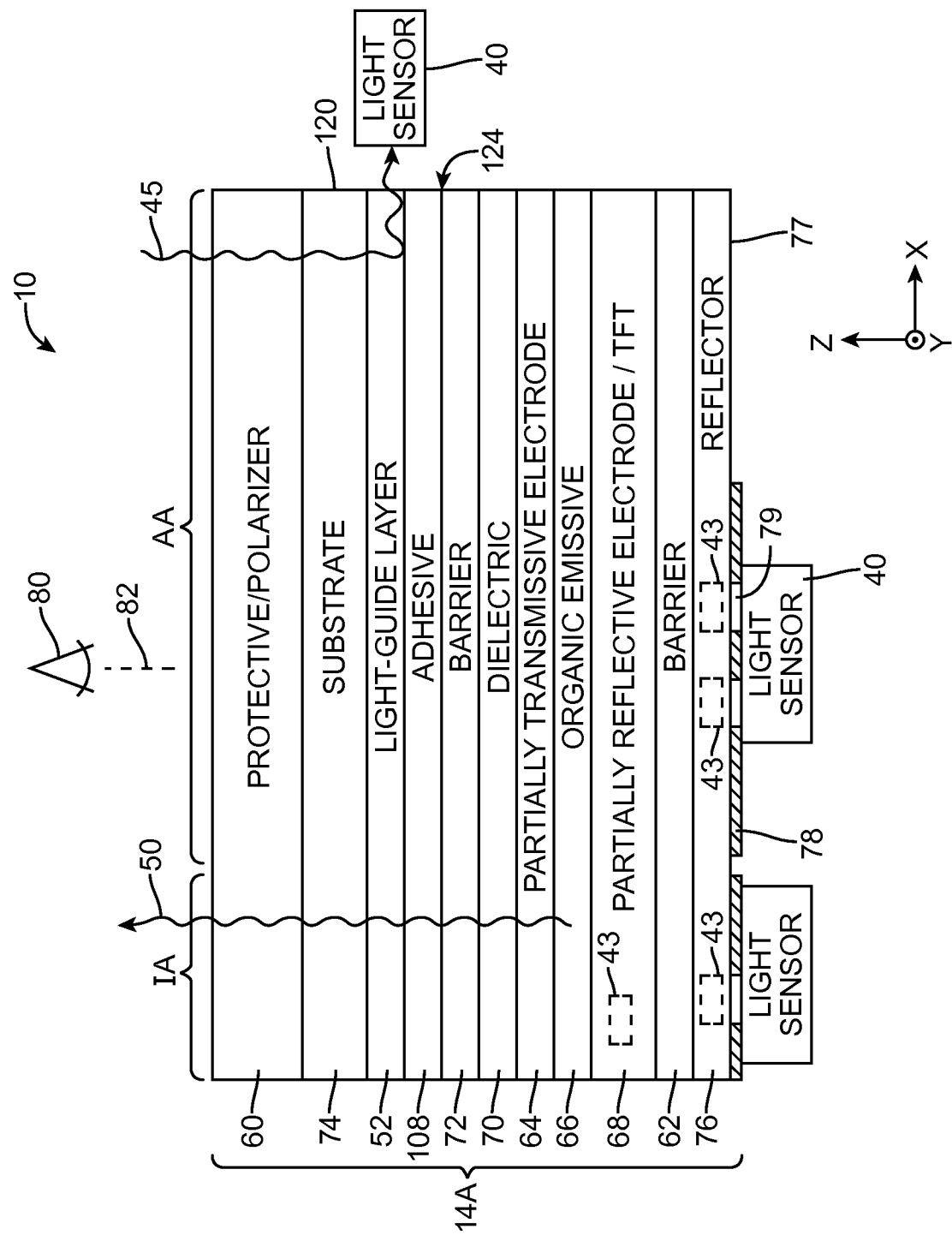


FIG. 13

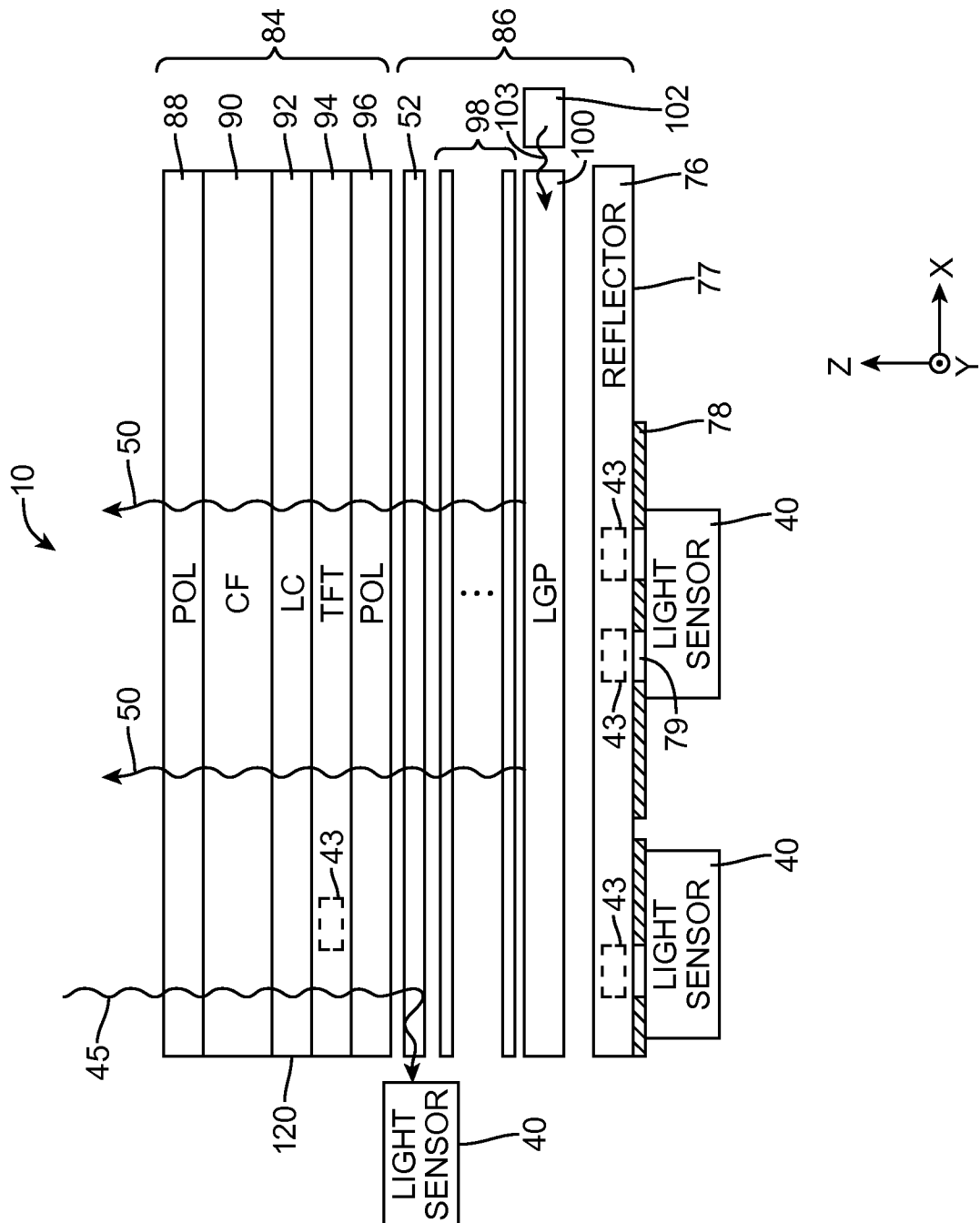


FIG. 14

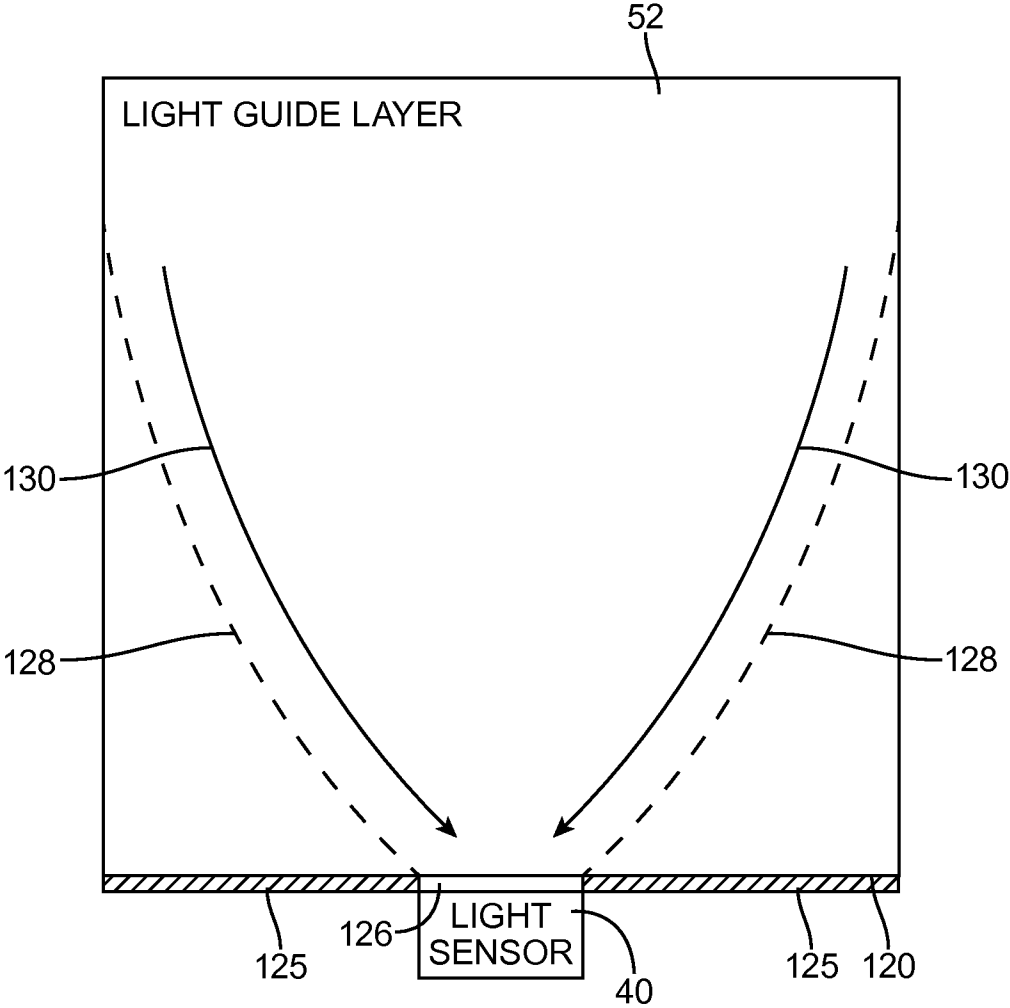


FIG. 15

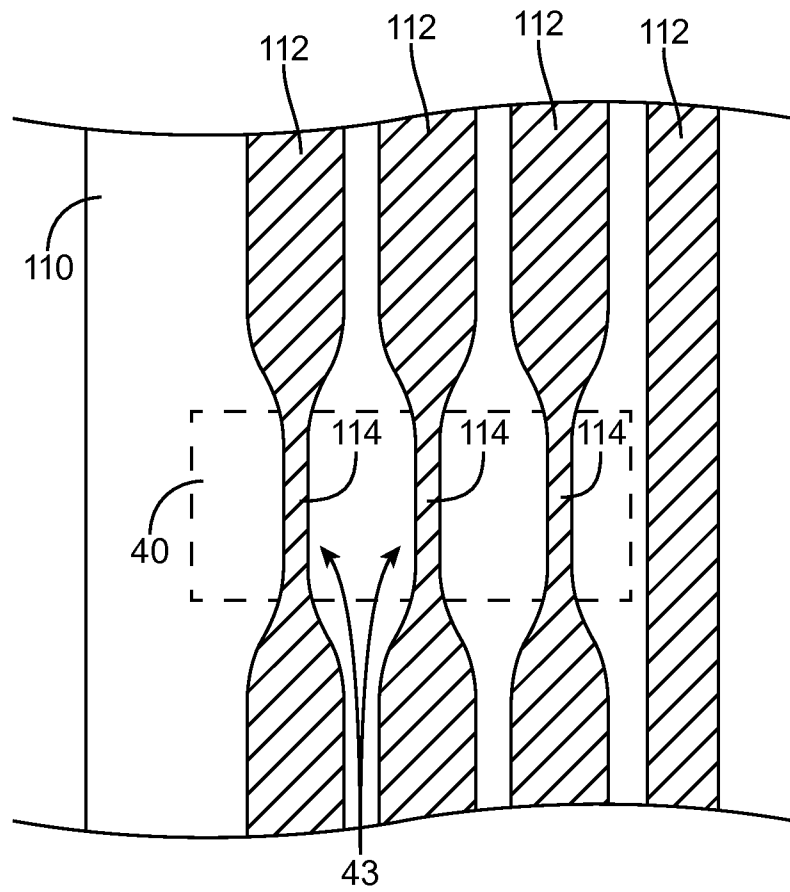


FIG. 16

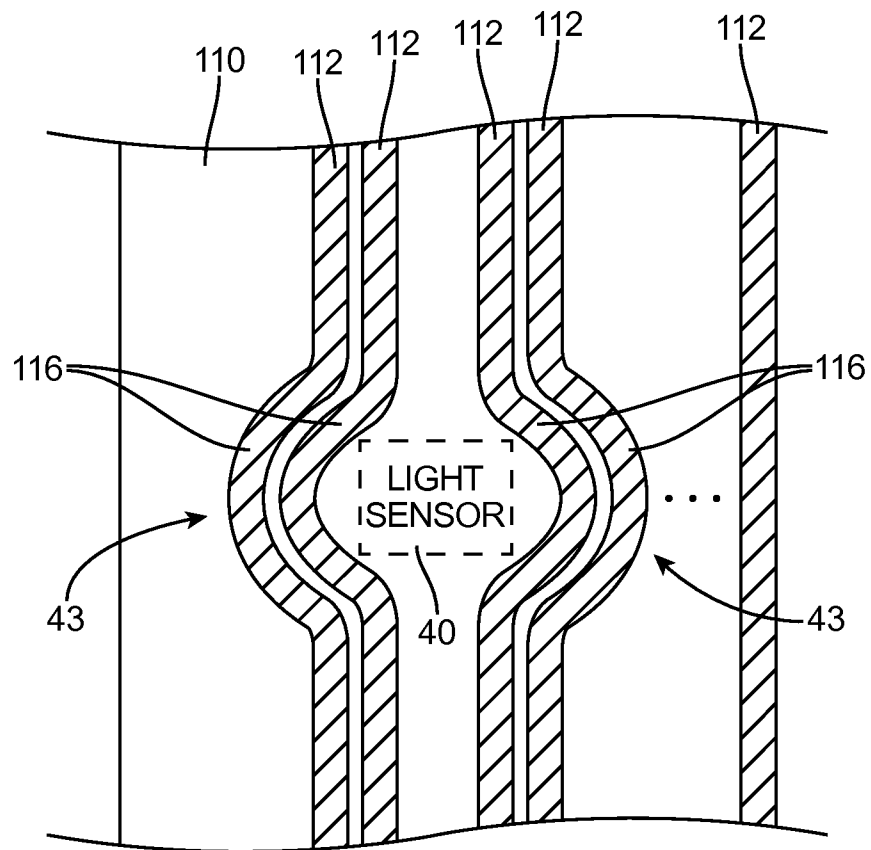


FIG. 17