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(54) **ELECTRONIC DEVICES WITH MULTI-LAYER COVER LAYERS**

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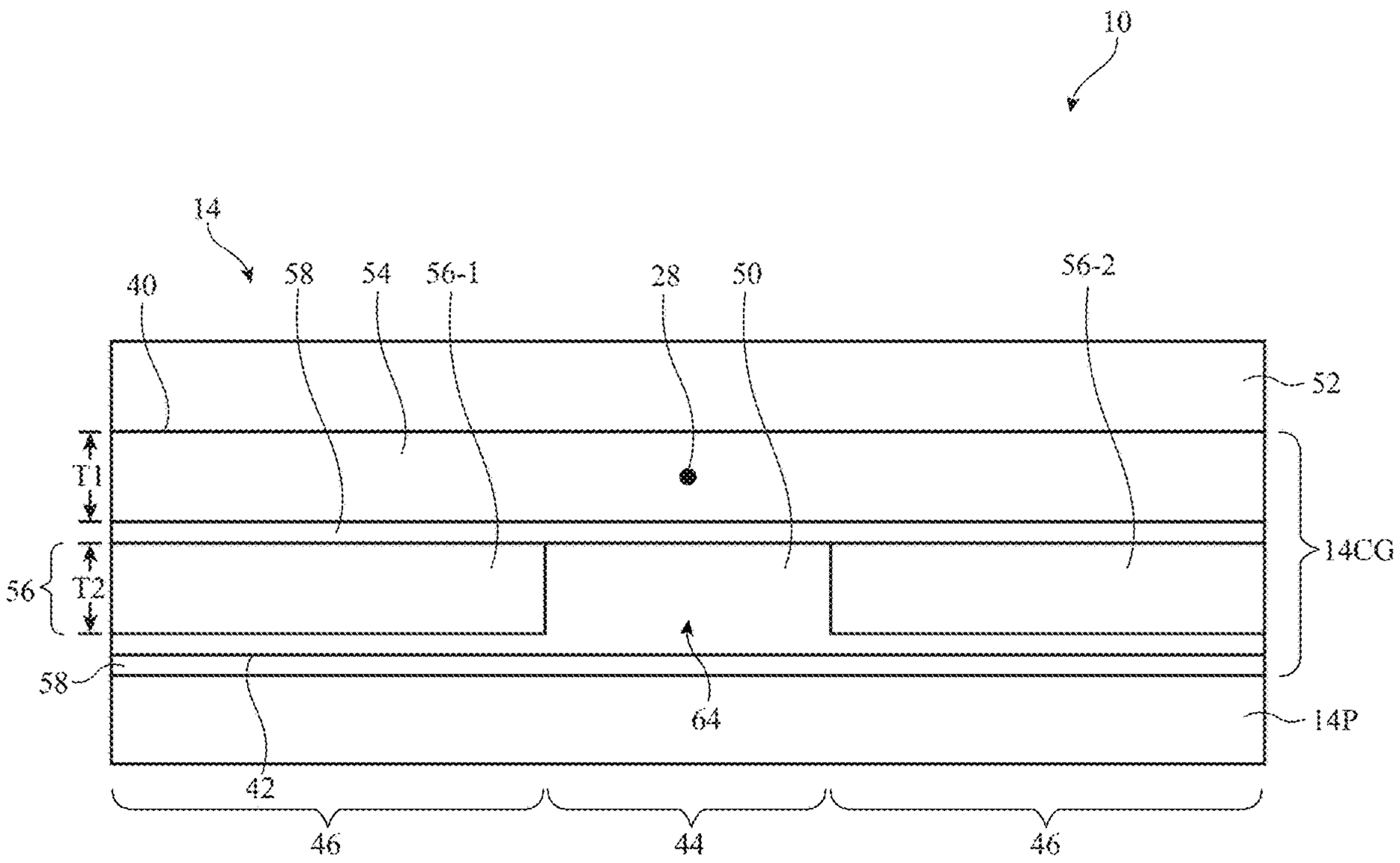
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B32B 17/10	(2006.01)

(52) **U.S. Cl.**

CPC ***G06F 1/1652*** (2013.01); ***B32B 7/022*** (2019.01); ***B32B 17/10064*** (2013.01); ***B32B 17/10155*** (2013.01); *B32B 2307/412* (2013.01); *B32B 2315/08* (2013.01); *B32B 2457/206* (2013.01)

(57) **ABSTRACT**

A foldable electronic device may bend about a bend axis. The device may include a flexible display panel and a display cover layer overlapping the flexible display panel. The flexible display panel and the display cover layer may bend along the bend axis as the device is folded. The display cover layer may be formed from first and second glass layers. The first glass layer may have first and second planar portions joined by a third portion that bends about the bend axis. The second glass layer may have third and fourth portions that respectively overlap the first and second planar portions and that are separated by a gap overlapping the bend axis. The second glass layer may have a higher modulus of elasticity, lower compressive stress, and/or a greater thickness than the first glass layer to provide additional display protection.



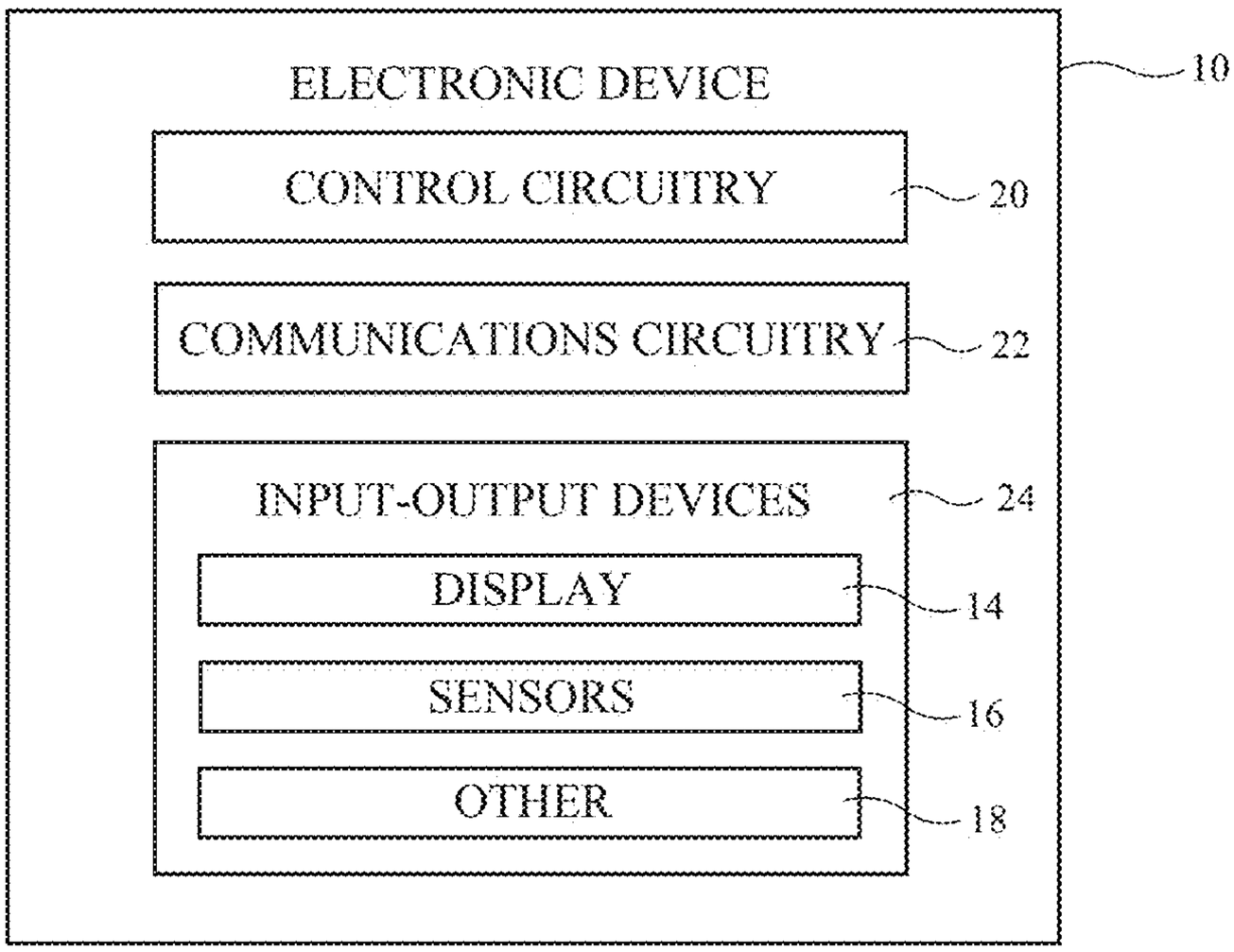

ELECTRONIC DEVICE
10
CONTROL CIRCUITRY
20
COMMUNICATIONS CIRCUITRY
22
INPUT-OUTPUT DEVICES
24
DISPLAY
14
SENSORS
16
OTHER
18

FIG. 1

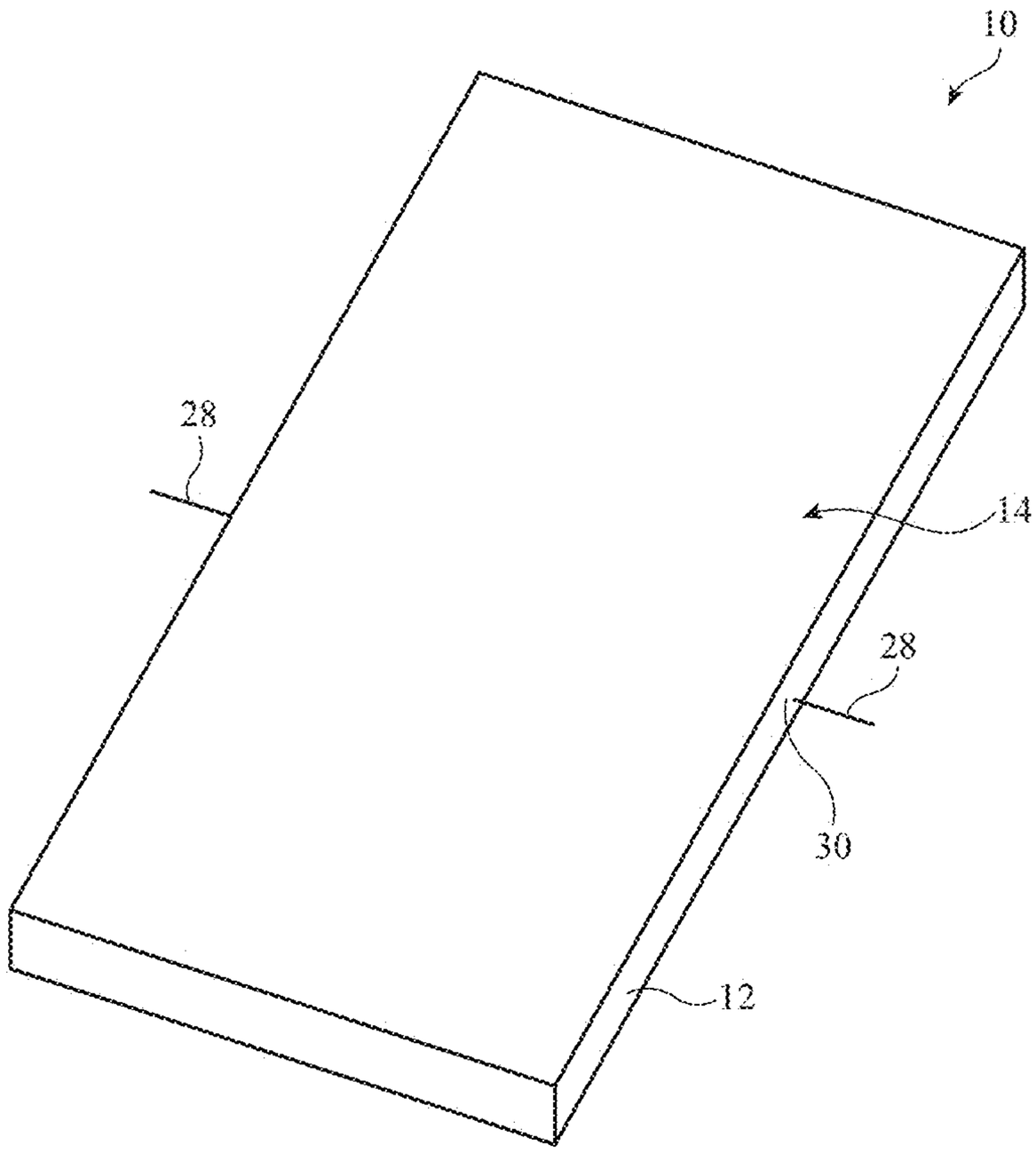


FIG. 2

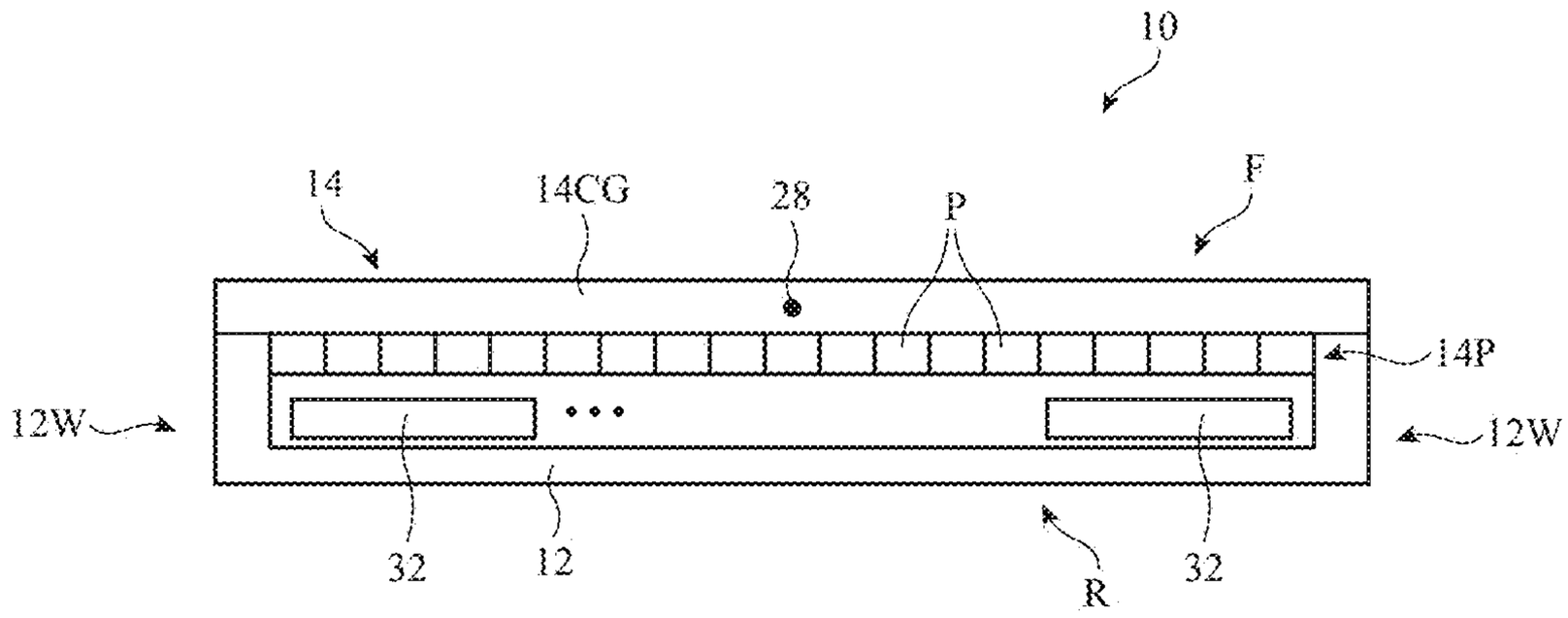


FIG. 3

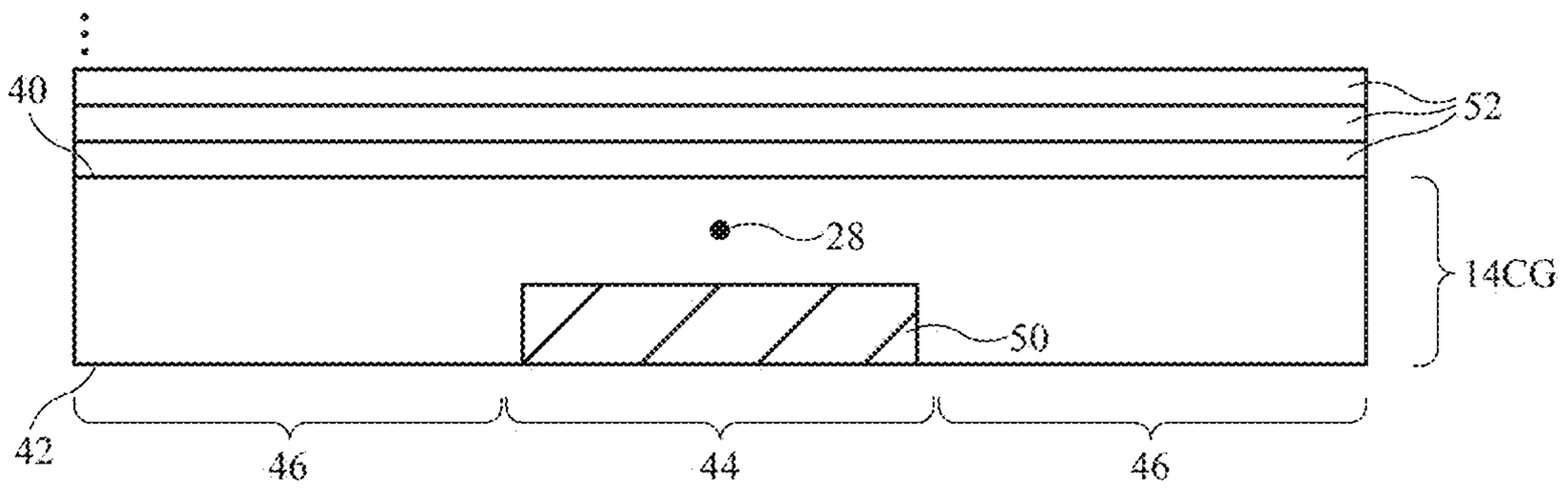


FIG. 4

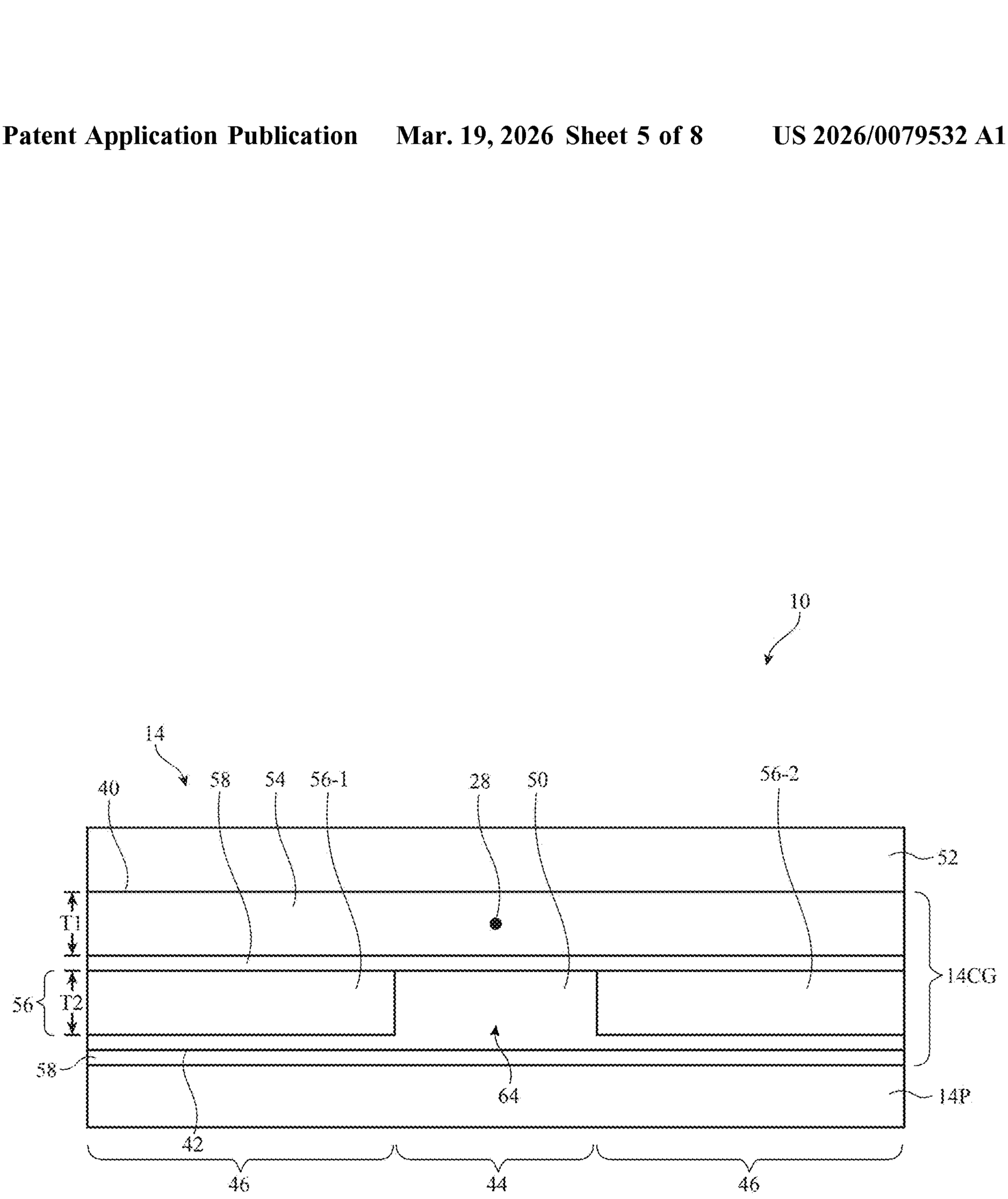


FIG. 5

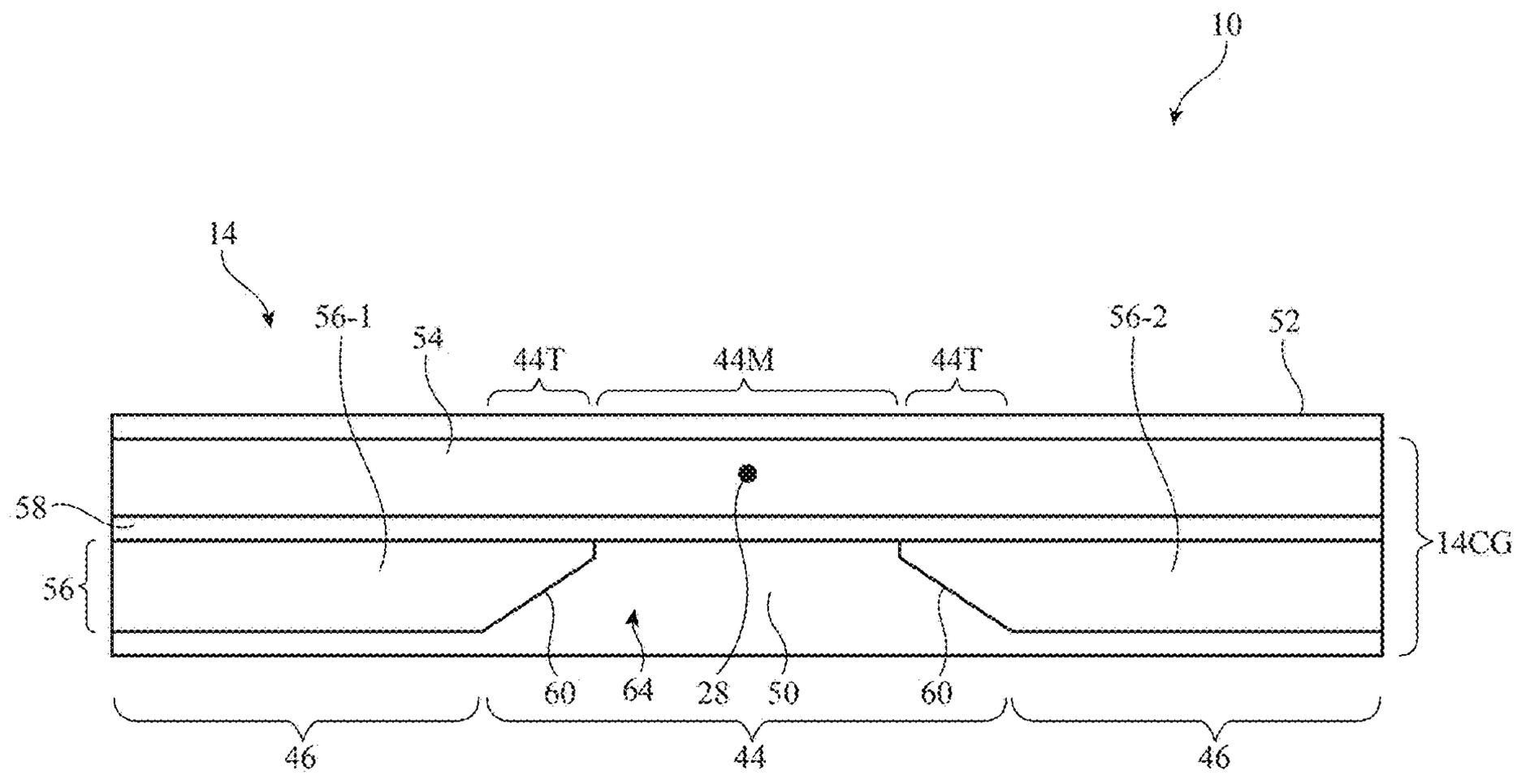


FIG. 6

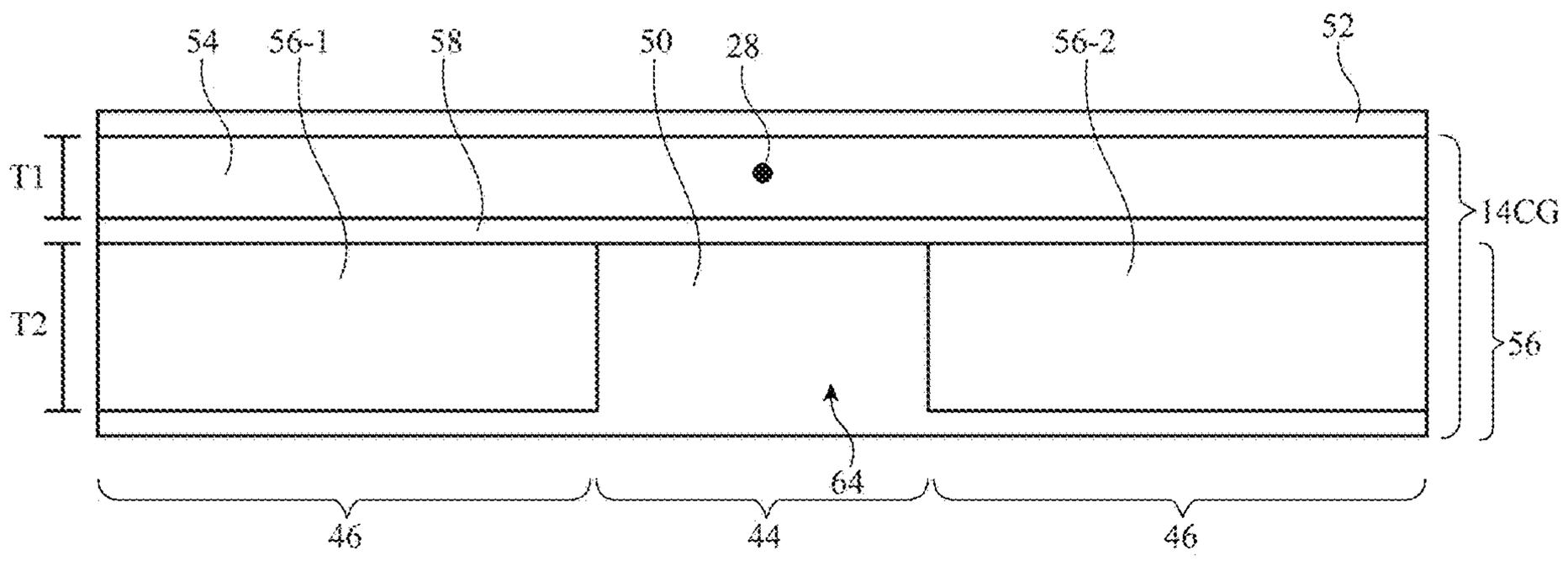


FIG. 7

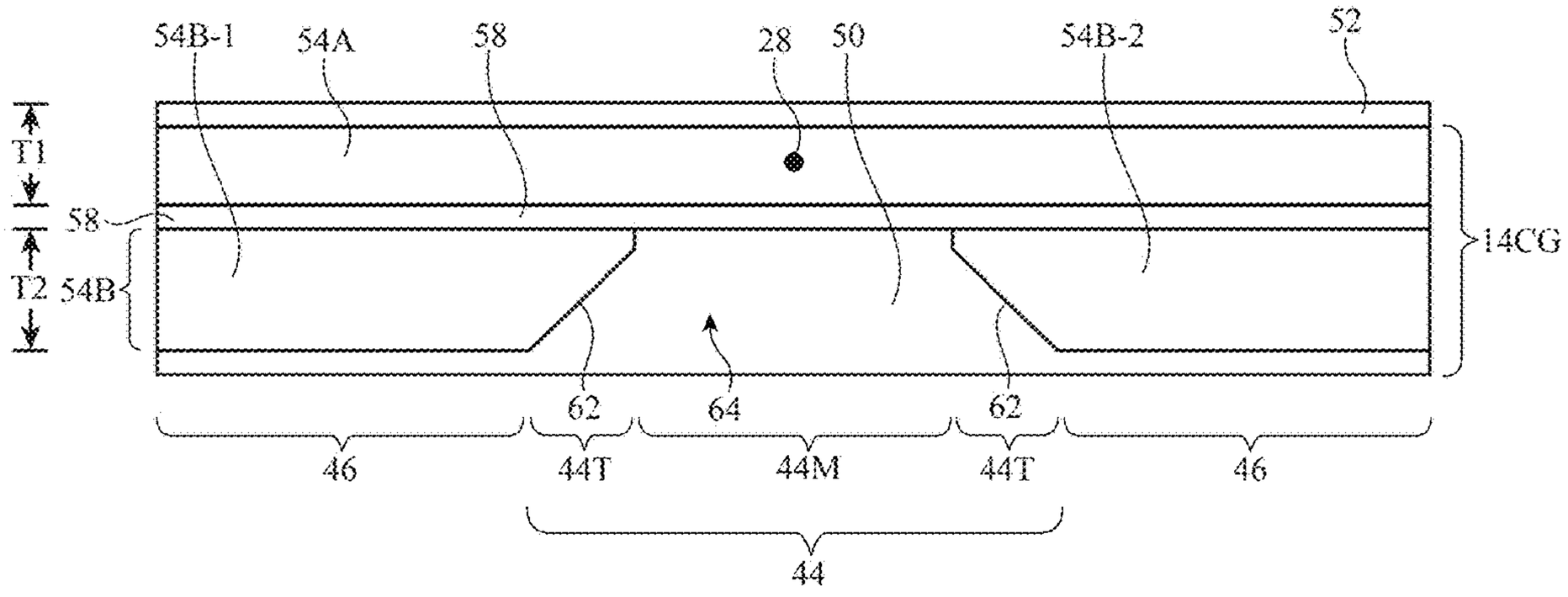

54B-1
54A
58
28
50
54B-2
52
T1
58
T2
54B
14CG
62
64
62
46
44T
44M
44T
46
44

FIG. 8

ELECTRONIC DEVICES WITH MULTI-LAYER COVER LAYERS

[0001] This application claims the benefit of U.S. provisional Ser. No. 63/695,744 , filed Sep. 17, 2024, which is hereby incorporated by reference herein in its entirety.

FIELD

[0002] This relates generally to electronic devices, and, more particularly, to electronic devices with displays.

BACKGROUND

[0003] Electronic devices often have displays. Portability may be a concern for some devices, which tends to limit available real estate for displays.

SUMMARY

[0004] An electronic device may be provided with a foldable housing that allows the device to fold and unfold about a bend axis. A flexible display may be mounted in the foldable housing. The flexible display may have an array of pixels forming a display panel. The display panel may be configured to bend along the bend axis as the device is folded.

[0005] The display panel may display images that are viewable through a transparent display cover layer that overlaps the display panel. The display cover layer may be formed from first and second glass layers. The first glass layer may have first and second planar portions joined by a third portion that bends about the bend axis. The second glass layer may have third and fourth portions that respectively overlap the first and second planar portions and that are separated by a gap overlapping the bend axis. The second glass layer may have a higher modulus of elasticity, lower compressive stress, and/or a greater thickness than the first glass layer to provide additional display protection.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1** is a schematic diagram of an illustrative electronic device in accordance with some embodiments.

[0007] FIG. **2** is a perspective view of an illustrative electronic device with a display in accordance with some embodiments.

[0008] FIG. **3** is a side view of an illustrative electronic device in accordance with some embodiments.

[0009] FIG. **4** is a side view of an illustrative cover layer having a hinge region with a thickness that is less than the thickness of other portions of the cover layer in accordance with some embodiments.

[0010] FIG. **5** is a side view of an illustrative display having a cover layer with a first layer that extends across a hinge axis and a second layer that has a gap aligned with the hinge axis in accordance with some embodiments.

[0011] FIG. **6** is a side view of an illustrative cover layer having a first type of glass that extends across a hinge axis and a second type of glass that has a gap aligned with the hinge axis and that has regions of variable thickness in accordance with some embodiments.

[0012] FIG. **7** is a side view of an illustrative cover layer having a first layer that extends across a hinge axis and a second layer that has a gap aligned with the hinge axis and that has a different thickness than the first layer in accordance with some embodiments.

[0013] FIG. **8** is a side view of an illustrative cover layer having a first layer of a first type of glass that extends across a hinge axis and a second layer of the first type of glass that has a gap aligned with the hinge axis and that has regions of variable thickness in accordance with some embodiments.

DETAILED DESCRIPTION

[0014] Electronic devices may be provided with displays. Displays may be used for displaying images for users. Displays may be formed from arrays of light-emitting diode pixels or other pixels. For example, a device may have an organic light-emitting diode display or a display formed from an array of micro-light-emitting diodes (e.g., diodes formed from crystalline semiconductor dies).

[0015] A schematic diagram of an illustrative electronic device having a display is shown in FIG. **1**. Device **10** may be a cellular telephone, tablet computer, laptop computer, wristwatch device or other wearable device, a television, a stand-alone computer display or other monitor, a computer display with an embedded computer (e.g., a desktop computer), a system embedded in a vehicle, kiosk, or other embedded electronic device, a media player, or other electronic equipment. Configurations in which device **10** is a cellular telephone, tablet computer, or other portable electronic device may sometimes be described herein as an example. This is illustrative. Device **10** may, in general, be any suitable electronic device with a display.

[0016] Device **10** may include control circuitry **20**. Control circuitry **20** may include storage and processing circuitry for supporting the operation of device **10**. The storage and processing circuitry may include storage such as nonvolatile memory (e.g., flash memory or other electrically-programmable-read-only memory configured to form a solid state drive), volatile memory (e.g., static or dynamic random-access-memory), etc. Processing circuitry in control circuitry **20** may be used to gather input from sensors and other input devices and may be used to control output devices. The processing circuitry may be based on one or more microprocessors, microcontrollers, digital signal processors, baseband processors and other wireless communications circuits, power management units, audio chips, application specific integrated circuits, etc. During operation, control circuitry **20** may use a display and other output devices in providing a user with visual output and other output.

[0017] To support communications between device **10** and external equipment, control circuitry **20** may communicate using communications circuitry **22**. Circuitry **22** may include antennas, radio-frequency transceiver circuitry (wireless transceiver circuitry), and other wireless communications circuitry and/or wired communications circuitry. Circuitry **22**, which may sometimes be referred to as control circuitry and/or control and communications circuitry, may support bidirectional wireless communications between device **10** and external equipment over a wireless link (e.g., circuitry **22** may include radio-frequency transceiver circuitry such as wireless local area network transceiver circuitry configured to support communications over a wireless local area network link, near-field communications transceiver circuitry configured to support communications over a near-field communications link, cellular telephone transceiver circuitry configured to support communications over a cellular telephone link, or transceiver circuitry configured to support communications over any other suitable wired or

wireless communications link). Wireless communications may, for example, be supported over a Bluetooth® link, a WiFi® link, a wireless link operating at a frequency between 6 GHz and 300 GHz, a 60 GHz link, or other millimeter wave link, cellular telephone link, wireless local area network link, personal area network communications link, or other wireless communications link. Device **10** may, if desired, include power circuits for transmitting and/or receiving wired and/or wireless power and may include batteries or other energy storage devices. For example, device **10** may include a coil and rectifier to receive wireless power that is provided to circuitry in device **10**.

[0018] Device **10** may include input-output devices such as devices **24**. Input-output devices **24** may be used in gathering user input, in gathering information on the environment surrounding the user, and/or in providing a user with output. Devices **24** may include one or more displays such as display **14**. Display **14** may be an organic light-emitting diode display, a liquid crystal display, an electrophoretic display, an electrowetting display, a plasma display, a microelectromechanical systems display, a display having a pixel array formed from crystalline semiconductor light-emitting diode dies (sometimes referred to as microLEDs), and/or other display. Configurations in which display **14** is an organic light-emitting diode display or microLED display are sometimes described herein as an example.

[0019] Display **14** may have an array of pixels configured to display images for a user. The pixels may be formed as part of a display panel that is bendable. This allows device **10** to be folded and unfolded about a bend axis. For example, a flexible (bendable) display in device **10** may be folded so that device **10** may be placed in a compact shape for storage and may be unfolded when it is desired to view images on the display.

[0020] Sensors **16** in input-output devices **24** may include force sensors (e.g., strain gauges, capacitive force sensors, resistive force sensors, etc.), audio sensors such as microphones, touch and/or proximity sensors such as capacitive sensors (e.g., a two-dimensional capacitive touch sensor integrated into display **14**, a two-dimensional capacitive touch sensor overlapping display **14**, and/or a touch sensor that forms a button, trackpad, or other input device not associated with a display), and other sensors. If desired, sensors **16** may include optical sensors such as optical sensors that emit and detect light, ultrasonic sensors, optical touch sensors, optical proximity sensors, and/or other touch sensors and/or proximity sensors, monochromatic and color ambient light sensors, image sensors, fingerprint sensors, temperature sensors, sensors for measuring three-dimensional non-contact gestures ("air gestures"), pressure sensors, sensors for detecting position, orientation, and/or motion (e.g., accelerometers, magnetic sensors such as compass sensors, gyroscopes, and/or inertial measurement units that contain some or all of these sensors), health sensors, radio-frequency sensors, depth sensors (e.g., structured light sensors and/or depth sensors based on stereo imaging devices that capture three-dimensional images), optical sensors such as self-mixing sensors and light detection and ranging (lidar) sensors that gather time-of-flight measurements, humidity sensors, moisture sensors, gaze tracking sensors, and/or other sensors. In some arrangements, device **10** may use sensors **16** and/or other input-output devices to gather user input. For example, buttons may be used to gather button press input, touch sensors overlapping displays can be used for gathering user touch screen input, touch pads may be used in gathering touch input, microphones may be used for gathering audio input, accelerometers may be used in monitoring when a finger contacts an input surface and may therefore be used to gather finger press input, etc.

[0021] If desired, electronic device **10** may include additional components (see, e.g., other devices **18** in input-output devices **24**). The additional components may include haptic output devices, audio output devices such as speakers, light-emitting diodes for status indicators, light sources such as light-emitting diodes that illuminate portions of a housing and/or display structure, other optical output devices, and/or other circuitry for gathering input and/or providing output. Device **10** may also include a battery or other energy storage device, connector ports for supporting wired communication with ancillary equipment and for receiving wired power, and other circuitry.

[0022] FIG. **2** is a perspective view of electronic device **10** in an illustrative configuration in which device **10** is a portable electronic device such as a cellular telephone or tablet computer. As shown in FIG. **2**, device **10** may have a display such as display **14**. Display **14** may cover some or all of the front face of device **10**. Touch sensor circuitry such as two-dimensional capacitive touch sensor circuitry may be incorporated into display **14**.

[0023] Display **14** may be mounted in housing **12**. Housing **12** may form front and rear housing walls, sidewall structures, and/or internal supporting structures (e.g., a frame, an optional midplate member, etc.) for device **10**. Glass structures, transparent polymer structures, and/or other transparent structures that cover display **14** and other portions of device **10** may provide structural support for device **10** and may sometimes be referred to as housing structures. For example, a transparent housing portion such as a glass or polymer housing structure that covers and protects a pixel array in display **14** may serve as a display cover layer for the pixel array while also serving as a housing wall on the front face of device **10**. In configurations in which a display cover layer is formed from glass, the display cover layer may sometimes be referred to as a display cover glass or display cover glass layer. The portions of housing **12** on the sidewalls and rear wall of device **10** may be formed from glass or other transparent structures and/or opaque structures. Sidewalls and rear wall structures may be formed as extensions to the front portion of housing **12** (e.g., as integral portions of the display cover layer) and/or may include separate housing wall structures.

[0024] Housing **12** may have flexible structures (e.g., bendable housing wall structures) and/or hinge structures such as hinge **30**. Hinge **30** may have a hinge axis aligned with device bend axis **28**. Hinge **30** and/or flexible housing structures that overlap bend axis **28** may allow housing **12** to bend about bend axis **28**. For example, housing **12** may have a first portion on one side of bend axis **28** and a second portion on an opposing side of bend axis **28** and these two housing portions may be coupled by hinge **30** for rotational motion about axis **28**.

[0025] As housing **12** is bent about bend axis **28**, the flexibility of display **14** allows display **14** to bend about axis **28**. In an illustrative configuration, housing **12** and display **14** may bend by **180°**. This allows display **14** to be folded back on itself (with first and second outwardly-facing portions of display **14** facing each other). The ability to place

device **10** in a folded configuration in this way may help make device **10** compact so that device **10** can be stored efficiently. When it is desired to view images on display **14**, device **10** may be unfolded about axis **28** to place device **10** in the unfolded configuration of FIG. **2**. This allows display **14** to lie flat and allows a user to view flat images on display **14**. The ability to fold display **14** onto itself allows device **10** to exhibit an inwardly folding behavior. Display **14** may be sufficiently flexible to allow device **10** to be folded outwardly and/or inwardly.

[0026] Device **10** of FIG. **2** has a rectangular outline (rectangular periphery) with four corners. As shown in FIG. **2**, a first pair of parallel edges (e.g., the left and right edges of device **10** in the example of FIG. **2**) may be longer than a second pair of parallel edges (e.g., the upper and lower edges of device **10** of FIG. **2**) that are oriented at right angles to the first pair of parallel edges. In this type of configuration, housing **12** is elongated along a longitudinal axis that is perpendicular to bend axis **28**. Housing **12** may have other shapes, if desired (e.g., shapes in which housing **12** has a longitudinal axis that extends parallel to bend axis **28**). With an arrangement of the type shown in FIG. **2**, the length of device **10** along its longitudinal axis may be reduced by folding device **10** about axis **28**.

[0027] FIG. **3** is a cross-sectional side view of an illustrative foldable electronic device. Device **10** of FIG. **3** may bend about bend axis **28**. Bend axis **28** may be aligned with display cover layer **14**CG or other structures in device **10**. For example, bend axis **28** may pass through a portion of display cover layer **14**CG or may be located above or below layer **14**CG.

[0028] As shown in FIG. **3**, display **14** includes an array of pixels P forming display panel **14**P under an inwardly facing surface of display cover layer **14**CG. Display panel **14**P may be, for example, a flexible organic light-emitting diode display or a microLED display in which light-emitting pixels are formed on a flexible substrate layer (e.g., a flexible layer of polyimide or a sheet of other flexible polymer). Flexible support layer(s) for display **14** may also be formed from flexible glass, flexible metal, and/or other flexible structures.

[0029] Display cover layer **14**CG may be formed from polymer, glass, crystalline materials such as sapphire, other materials, and/or combinations of these materials. To enhance flexibility, a portion of layer **14**CG that overlaps bend axis **28** may be locally thinned (e.g., this portion may be thinned relative to portions of layer **14**CG that do not overlap bend axis **28**). The thickness of layer **14**CG (e.g., the non-thinned portions of layer **14**CG) may be 50-200 microns, 70-150 microns, 100-200 microns, 100-600 microns, at least 100 microns, at least 200 microns, less than 600 microns, less than 400 microns, less than 250 microns, less than 150 microns, less than 100 microns, at least 50 microns, or other suitable thickness.

[0030] In the example of FIG. **3**, housing **12** has a portion on rear face R that forms a rear housing wall and has side portions forming sidewalls **12**W. The rear housing wall of housing **12** may form a support layer for components in device **10**. Housing **12** may also have one or more interior supporting layers (e.g., frame structures such as an optional midplate, etc.). These interior supporting layers and the rear housing wall may have first and second portions that are coupled to opposing sides of a hinge that is aligned with bend axis **28** (see, e.g., hinge **30** of FIG. **2**) or may be sufficiently flexible to bend around bend axis **28**.

[0031] Electrical components **32** may be mounted in the interior of device **10** (e.g., between display **14** and the rear of housing **12**. Components **32** may include circuitry of the type shown in FIG. **1** (e.g., control circuitry **20**, communications circuitry **22**, input-output devices **24**, batteries, etc.). Display **14** may be mounted on front face F of device **10**. When device **10** is folded about axis **28**, display cover layer **14**CG, display panel **14**P, and the other structures of device **10** that overlap bend axis **28** may flex and bend to accommodate folding.

[0032] If desired, the outer and/or inner surfaces of display cover layer **14**GC may be provided with coatings. These coatings may include, for example, antireflection coatings, anti-scratch coatings, anti-smudge coatings, and/or other coating layers. Consider, as an example, the cross-sectional side view of display cover layer **14**CG of FIG. **4**. As shown in FIG. **4**, display cover layer may have an outer surface (outwardly facing surface) such as surface **40** and an opposing inner surface (inwardly facing surface) such as surface **42**. A strip-shaped region of display cover layer **14**CG that overlaps and runs parallel to bend axis **28** may have a locally reduced thickness (e.g., a groove or other recess that runs parallel to bend axis **28** may be formed in layer **14**CG to form locally reduced thickness portion **44** of layer **14**CG). Locally reduced thickness portion **44** of layer **14**CG may be thinner than other portions of layer **14**CG such as portions **46** (which may be, for example, planar glass layer portions of layer **14**CG). The presence of reduced thickness portion **44** in display cover layer **14**CG may facilitate bending of display cover layer **14**CG about bend axis **28**.

[0033] To help planarize inner surface **42** and thereby facilitate mounting of display panel **14**P against inner surface **42** (e.g., with a layer of adhesive), the elongated recess (groove) in the inner surface of layer **14**CG that forms thinned portion **44** may be filled with a polymer such as polymer **50**. Polymer **50** may be sufficiently flexible to bend about bend axis **28** when device **10** is opened and closed. The refractive index of polymer **50** may be matched to that of display cover layer **14**CG to help minimize light reflections (e.g., by incorporating inorganic nanoparticles in polymer **50**). For example, at a wavelength of 500 nm, the refractive index of polymer **50** may differ from that of layer **14**CG by less than 0.15, less than 0.1, or less than 0.05 (as examples).

[0034] Coating layers **52** may optionally be formed on outer surface **40**. Coating layers **52** may include, for example, anti-scratch layers (sometimes referred to as hard coats), protective polymer layers, anti-smudge layers, anti-fog layers, antireflection layers, anti-static layers, adhesion layers, and/or other coatings. In some configurations, each of these functions may be implemented using a separate respective coating layer. In other configurations, a single layer may serve multiple functions. In general, coatings such as coatings **52** may be formed on outer surface **40** and/or inner surface **42**. In the illustrative configuration of FIG. **4**, coatings **52** are formed on outer surface **40**.

[0035] Coatings **52** may be provided in any suitable order. As one example, the lowermost coating of coatings **52** (e.g., a coating layer formed directly on surface **40** of FIG. **4**) may be a hard coat or other anti-scratch layer that helps prevent scratches that could damage layer **14**CG. An antireflection coating may be formed on top of the anti-scratch layer. The

antireflection layer may be a thin-film interference filter antireflection coating containing a stack of thin-film layers such as dielectric sublayers of alternating refractive index. One of the thin-film layers may be a conductive layer such as a transparent semiconductor layer (e.g., an indium tin oxide layer) that serves as an antistatic layer. An anti-smudge coating or anti-fog coating may be formed on top of the antireflection layer. Anti-smudge coatings (e.g., hydrophobic polymer coatings) may help reduce fingerprints and other undesired marks on the surfaces of display **14**. An example of an anti-smudge coating is a fluoropolymer coating (e.g., a fluoropolymer formed from evaporated perfluoropolyether) that serves as an oleophobic layer. Fluoropolymers can be adhered to underlying coating layers using an intervening adhesion layer.

[0036] In some configurations, cover layer **14**CG may be a single, monolithic piece of glass that includes a locally reduced thickness portion **44** that is thinned relative to portions **46** of cover layer **14**CG (e.g., non-bending portions of cover layer **14**CG that do not overlap hinge axis **28** and that do not need to bend). In other configurations, cover layer **14**CG may be formed from multiple layers of transparent material such as glass, plastic, sapphire, or other suitable transparent material. This type of arrangement is illustrated in FIG. **5**.

[0037] As shown in FIG. **5**, display **14** of device **10** may include cover layer **14**CG interposed between display panel **14**P and one or more coatings **52**. Cover layer **14**CG may include one or more overlapping transparent layers such as first transparent layer **54** and second transparent layer **56**. First transparent layer **54** (sometimes referred to as outer transparent layer **54** or outer glass layer **54**) and second transparent layer **56** (sometimes referred to as inner transparent layer **56** or inner glass layer **56**) may be formed from glass, plastic, sapphire, or any other suitable transparent material. A first adhesive layer **58** may be used to attach inner layer **56** to outer layer **54**, and a second adhesive layer **58** may be used to attach inner layer **56** to display panel **14**P.

[0038] Outer layer **54** may extend across fold axis **28** and may have uniform thickness T**1** across regions **46** and **44**. For example, thickness T**1** of outer layer **54** may be less than 100 microns, less than 200 microns, less than 400 microns, or greater than 400 microns. Thickness T**1** of outer layer **54** may be sufficiently small to permit outer layer **54** to bend in region **44** overlapping hinge axis **28**.

[0039] Inner layer **56** may include first and second portions **56-1** and **56-2** in regions **46** separated by gap **64** in region **44**. Gap **64** may be a recess that extends partway through layer **56** or may be a through-hole that extends entirely through layer **56**. Gap **64** may overlap hinge axis **28**, thereby allowing first portion **56-1** to rotate relative to second portion **56-2** of layer **56** as display **14** is folded and unfolded. First and second portions **56-1** and **56-2** of layer **56** may have uniform thickness T**2**. Thickness T**2** may be equal to or different than thickness T**1** of layer **54**. For example, thickness T**2** may be less than 100 microns, less than 200 microns, less than 400 microns, or greater than 400 microns. Since layer **56** includes gap **64** overlapping hinge axis **28** and does not need to bend, layer **56** may have a greater thickness than layer **54**, if desired.

[0040] To help planarize inner surface **42** and thereby facilitate mounting of display panel **14**P against inner surface **42** (e.g., with a layer of adhesive), the elongated recess (groove) in the inner surface of layer **14**CG that forms thinned portion **44** may be filled with a polymer such as polymer **50**. Polymer **50** may be sufficiently flexible to bend about bend axis **28** when device **10** is opened and closed. The refractive index of polymer **50** may be matched to that of display cover layer **14**CG to help minimize light reflections (e.g., by incorporating inorganic nanoparticles in polymer **50**). For example, at a wavelength of 500 nm, the refractive index of polymer **50** may differ from that of inner layer **56** by less than 0.15, less than 0.1, or less than 0.05 (as examples). Polymer **50** may be located only in gap **64** or may also be present as a thin layer between display panel **14**P and inner layer **56**.

[0041] In some arrangements, which are sometimes described herein as an example, outer layer **54** may be a first type of glass and inner layer **56** may be a second type of glass having one or more different properties than outer glass **54**. For example, inner layer **56** may have a higher modulus of elasticity than outer layer **54**, may exhibit lower compressive stress than outer layer **54**, may have a greater thickness than outer layer **54**, may have a different refractive index than outer layer **54** (e.g., a refractive index that more closely matches that of polymer **50**), and/or may have other properties that differ from those of outer layer **54**. The presence of layer **56** in regions **46** may help protect display panel **14**P from damage during operation of device **10**. For example, if a sharp object or drop event causes damage to outer layer **54**, the presence of a stiffer layer such as inner layer **56** behind outer layer **54** may help prevent the damage from reaching display panel **14**P. This allows outer layer **54** to be sufficiently thin to achieve the desired bending radius of cover layer **14**CG. Additionally, since layers **54** and **56** are separate layers (as opposed to a monolithic piece of glass with variable thickness), outer glass layer **54** may be formed with uniform thickness across regions **46** and **44**, which helps prevent variations in the amount of expansion that occurs across portions **46** and **44** of layer **54** during ion exchange.

[0042] It may be desirable to configure the cross-sectional profile of inner layer **56** of display cover layer **14**CG to help avoid distortion of the image on display panel **14**P due to changes in the refraction of light from thickness variations and/or gaps such as gap **64**. As shown in FIG. **6**, for example, inner layer **56** may include tapered edges such as tapered edges **60** on opposing sides of gap **64**. Tapered edges **60** of inner glass layer **56** may provide locally reduced thickness region **44** of cover glass **14**CG with varying thickness portions **44**T. Portions **44**T may be tapered and characterized by smoothly and gradually varying thicknesses. Portions **44**T may be located at the outer edges of locally reduced thickness region **44** and may provide layer **14**CG with a gradual transition between the thinnest part of region **44** (e.g., portion **44**M of portion **44** of cover layer **14**CG, where outer glass layer **54** overlaps gap **64** and does not overlap any portion of inner glass layer **56**) and the thicker portions of layer **14**CG such as portions **46** (e.g., where outer glass layer **54** overlaps non-thinned portions of inner glass layer **56**). By gradually changing the thickness of inner glass layer **56**, undesired visual artifacts and stress concentration features may be avoided.

[0043] In addition to or instead of forming inner layer **56** with a higher modulus of elasticity than outer layer **54**, inner layer **56** may be provided with a greater thickness than outer layer **54** to provide additional display protection without inhibiting bending in region **44** where cover layer **14**CG

overlaps bend axis **28**. This type of arrangement is illustrated in FIG. **7**. As shown in FIG. **7**, outer layer **54** may have thickness T**1** and inner layer **56** may have thickness T**2**. Thickness T**2** may be greater than thickness T**1** (e.g., thickness T**2** may be 5% greater than thickness T**1**, 10% greater than thickness T**1**, 25% greater than thickness T**1**, 50% greater than thickness T**1**, more than 50% greater than thickness T**1**, less than 50% greater than thickness T**1**, etc.).

[0044] In the example of FIG. **8**, display cover layer **14**CG includes multiple layers such as first transparent layer **54**A and second transparent layer **54**B. First transparent layer **54**A (sometimes referred to as outer transparent layer **54**A or outer glass layer **54**A) and second transparent layer **54**B (sometimes referred to as inner transparent layer **54**B or inner glass layer **54**B) may be formed from glass, plastic, sapphire, or any other suitable transparent material. Adhesive layer **58** may be used to attach inner layer **54**B to outer layer **54**A. An additional adhesive layer may be used to attach inner layer **54**B to display panel **14**P (FIGS. **3** and **4**).

[0045] Outer layer **54**A may extend across fold axis **28** and have uniform thickness T**1** across regions **46** and **44**. For example, thickness T**1** of outer layer **54**A may be less than 100 microns, less than 200 microns, less than 400 microns, or greater than 400 microns. Thickness T**1** of outer layer **54**A may be sufficiently small to permit outer layer **54**A to bend in region **44** overlapping hinge axis **28**.

[0046] Inner layer **54**B may include first and second portions **54**B-**1** and **54**B-**2** in regions **46** separated by gap **64** in region **44**. Gap **64** may be a recess that extends partway through layer **54**B or may be a through-hole that extends entirely through layer **54**B. Gap **64** may overlap hinge axis **28**, thereby allowing first portion **54**B-**1** to move relative to second portion **54**B-**2** of layer **54**B as display **14** is folded and unfolded. First and second portions **54**B-**1** and **54**B-**2** of layer **54**B may have uniform thickness T**2**, or may have a variable thickness with tapered edges on opposing sides of gap **64**. Thickness T**2** may be equal to or different than thickness T**1** of layer **54**A. For example, thickness T**2** may be less than 100 microns, less than 200 microns, less than 400 microns, or greater than 400 microns. Since layer **54**B includes gap **64** overlapping hinge axis **28** and does not need to bend, layer **54**B may have a greater thickness than layer **54**A, if desired.

[0047] If desired, gap **64** may be filled with a polymer such as polymer **50**. Polymer **50** may be sufficiently flexible to bend about bend axis **28** when device **10** is opened and closed. The refractive index of polymer **50** may be matched to that of display cover layer **14**CG to help minimize light reflections (e.g., by incorporating inorganic nanoparticles in polymer **50**). For example, at a wavelength of 500 nm, the refractive index of polymer **50** may differ from that of inner layer **54**B by less than 0.15, less than 0.1, or less than 0.05 (as examples). Polymer **50** may be located only in gap **64** or may also be present as a thin layer between display panel **14**P and inner layer **54**B.

[0048] In the example of FIG. **8**, outer layer **54**A and inner layer **54**B are formed from the same type of glass. For example, outer layer **54**A and inner layer **54**B may have the same modulus of elasticity, may exhibit the same amount of compressive stress, and/or may have the same refractive index. The presence of layer **54**B in regions **46** may help protect display panel **14**P from damage during operation of device **10**. For example, if a sharp object or drop event causes damage to outer layer **54**A, the presence of inner layer **54**B may help prevent the puncture from reaching display panel **14**P. This allows outer layer **54**A to be sufficiently thin to achieve the desired bending radius of cover layer **14**CG. Additionally, since layers **54**A and **54**B are separate layers (as opposed to a monolithic piece of glass with variable thickness), outer glass layer **54**A may be formed with uniform thickness across regions **46** and **44**, which helps prevent variations in the amount of expansion that occurs across portions **46** and **44** of layer **54**A during ion exchange.

[0049] As shown in FIG. **8**, inner layer **54**B may include tapered edges such as tapered edges **62** on opposing sides of gap **64**. Tapered edges **62** of inner glass layer **54**B may provide locally reduced thickness region **44** of cover glass **14**CG with varying thickness portions **44**T. Portions **44**T may be tapered and characterized by smoothly and gradually varying thicknesses. Portions **44**T may be located at the outer edges of locally reduced thickness region **44** and may provide layer **14**CG with a gradual transition between the thinnest part of region **44** (e.g., portion **44**M of portion **44** of cover layer **14**CG, where outer glass layer **54**A overlaps gap **64** and does not overlap any portion of inner glass layer **54**B) and the thicker portions of layer **14**CG such as portions **46** (e.g., where outer glass layer **54**A overlaps non-thinned portions of inner glass layer **54**B). By gradually changing the thickness of inner glass layer **54**B, undesired visual artifacts and stress concentration features may be avoided. This is merely illustrative. If desired, inner glass layer **54**B may have uniform thickness and may not include any tapered edges (e.g., similar to layer **56** of FIG. **5**).

[0050] As described above, one aspect of the present technology is the gathering and use of information such as information from input-output devices. The present disclosure contemplates that in some instances, data may be gathered that includes personal information data that uniquely identifies or can be used to contact or locate a specific person. Such personal information data can include demographic data, location-based data, telephone numbers, email addresses, twitter ID's, home addresses, data or records relating to a user's health or level of fitness (e.g., vital signs measurements, medication information, exercise information), date of birth, username, password, biometric information, or any other identifying or personal information.

[0051] The present disclosure recognizes that the use of such personal information, in the present technology, can be used to the benefit of users. For example, the personal information data can be used to deliver targeted content that is of greater interest to the user. Accordingly, use of such personal information data enables users to calculated control of the delivered content. Further, other uses for personal information data that benefit the user are also contemplated by the present disclosure. For instance, health and fitness data may be used to provide insights into a user's general wellness or may be used as positive feedback to individuals using technology to pursue wellness goals.

[0052] The present disclosure contemplates that the entities responsible for the collection, analysis, disclosure, transfer, storage, or other use of such personal information data will comply with well-established privacy policies and/or privacy practices. In particular, such entities should implement and consistently use privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining personal infor-

mation data private and secure. Such policies should be easily accessible by users and should be updated as the collection and/or use of data changes. Personal information from users should be collected for legitimate and reasonable uses of the entity and not shared or sold outside of those legitimate uses. Further, such collection/sharing should occur after receiving the informed consent of the users. Additionally, such entities should consider taking any needed steps for safeguarding and securing access to such personal information data and ensuring that others with access to the personal information data adhere to their privacy policies and procedures. Further, such entities can subject themselves to evaluation by third parties to certify their adherence to widely accepted privacy policies and practices. In addition, policies and practices should be adapted for the particular types of personal information data being collected and/or accessed and adapted to applicable laws and standards, including jurisdiction-specific considerations. For instance, in the United States, collection of or access to certain health data may be governed by federal and/or state laws, such as the Health Insurance Portability and Accountability Act (HIPAA), whereas health data in other countries may be subject to other regulations and policies and should be handled accordingly. Hence different privacy practices should be maintained for different personal data types in each country.

[0053] Despite the foregoing, the present disclosure also contemplates embodiments in which users selectively block the use of, or access to, personal information data. That is, the present disclosure contemplates that hardware and/or software elements can be provided to prevent or block access to such personal information data. For example, the present technology can be configured to allow users to select to "opt in" or "opt out" of participation in the collection of personal information data during registration for services or anytime thereafter. In another example, users can select not to provide certain types of user data. In yet another example, users can select to limit the length of time user-specific data is maintained. In addition to providing "opt in" and "opt out" options, the present disclosure contemplates providing notifications relating to the access or use of personal information. For instance, a user may be notified upon downloading an application ("app") that their personal information data will be accessed and then reminded again just before personal information data is accessed by the app.

[0054] Moreover, it is the intent of the present disclosure that personal information data should be managed and handled in a way to minimize risks of unintentional or unauthorized access or use. Risk can be minimized by limiting the collection of data and deleting data once it is no longer needed. In addition, and when applicable, including in certain health related applications, data de-identification can be used to protect a user's privacy. De-identification may be facilitated, when appropriate, by removing specific identifiers (e.g., date of birth, etc.), controlling the amount or specificity of data stored (e.g., collecting location data at a city level rather than at an address level), controlling how data is stored (e.g., aggregating data across users), and/or other methods.

[0055] Therefore, although the present disclosure broadly covers use of information that may include personal information data to implement one or more various disclosed embodiments, the present disclosure also contemplates that the various embodiments can also be implemented without the need for accessing personal information data. That is, the various embodiments of the present technology are not rendered inoperable due to the lack of all or a portion of such personal information data.

[0056] The foregoing is merely illustrative and various modifications can be made to the described embodiments. The foregoing embodiments may be implemented individually or in any combination.

What is claimed is:

1. An electronic device, comprising:

a foldable housing that is configured to bend about a bend axis;

a flexible display panel that overlaps the bend axis; and

a display cover layer that overlaps the flexible display panel, wherein the display cover layer comprises:

a first glass layer that extends across the bend axis; and

a second glass layer having a gap aligned with the bend axis.

2. The electronic device defined in claim **1** wherein the second glass layer has a higher modulus of elasticity than the first glass layer.

3. The electronic device defined in claim **1** wherein the second glass layer exhibits lower compressive stress than the first glass layer.

4. The electronic device defined in claim **1** wherein the first glass layer has uniform thickness.

5. The electronic device defined in claim **4** wherein the second glass layer comprises first and second portions with uniform thickness and wherein the gap separates the first portion from the second portion.

6. The electronic device defined in claim **4** wherein the second glass layer comprises first and second portions having respective first and second tapered edges on opposing sides of the gap.

7. The electronic device defined in claim **4** wherein the second glass layer is thicker than the first glass layer.

8. The electronic device defined in claim **1** further comprising an adhesive layer that attaches the second glass layer to the first glass layer.

9. The electronic device defined in claim **8** further comprising an additional adhesive layer that attaches the second glass layer to the flexible display panel.

10. The electronic device defined in claim **1** further comprising a transparent polymer that fills the gap.

11. The electronic device defined in claim **1** wherein the first and second glass layers have the same modulus of elasticity.

12. A display, comprising:

a flexible display having first and second display regions that fold relative to one another about a fold axis; and

a cover layer through which the flexible display displays images, the cover layer comprising:

an outer glass layer comprising first and second portions respectively overlapping the first and second display regions and joined by a third portion that bends about the fold axis, wherein the outer glass layer has uniform thickness across the first, second, and third portions; and

an inner glass layer comprising third and fourth portions respectively overlapping the first and second display regions and separated by a gap that overlaps the fold axis.

13. The display defined in claim **12** further comprising:

a first adhesive layer interposed between the inner and outer glass layers; and

a second adhesive layer interposed between the inner glass layer and the flexible display.

14. The display defined in claim **12** wherein the third and fourth portions each have a tapered edge facing the gap.

15. The display defined in claim **12** wherein the third and fourth portions each have uniform thickness.

16. The display defined in claim **12** wherein the inner glass layer has a higher modulus of elasticity than the outer glass layer.

17. The display defined in claim **12** wherein the inner glass layer exhibits lower compressive stress than the outer glass layer.

18. A foldable display cover layer, comprising:

a first glass layer comprising first and second planar portions joined by a third portion that bends about a fold axis, wherein the first glass layer has uniform thickness across the first, second, and third portions; and

a second glass layer comprising third and fourth portions respectively overlapping the first and second portions of the first glass layer, wherein the third and fourth portions are separated by a gap that overlaps the fold axis, wherein the second glass layer has at least one property that is different from the first glass layer, and wherein the at least one property is selected from the group consisting of: modulus of elasticity, compressive stress, and thickness.

19. The foldable display cover layer defined in claim **18** further comprising a transparent polymer in the gap.

20. The foldable display cover layer defined in claim **18** wherein the third and fourth portions each have a tapered edge facing the gap.

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