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- (54) **FLEXIBLE IMAGE DISPLAY DEVICE**
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(57) **ABSTRACT**

A flexible image display device includes a window substrate, a polarizing plate, and a touch panel, wherein a distance between a neutral plane and a lower surface of the touch panel based on a visible side during bending is 34% or less to an entire thickness of the flexible image display device. The flexible image display device has excellent flexibility and may significantly reduce a defect rate due to a damage of the touch panel by minimizing the damage of the touch panel even if repeatedly applying bending fatigue thereto.

12 Claims, 3 Drawing Sheets

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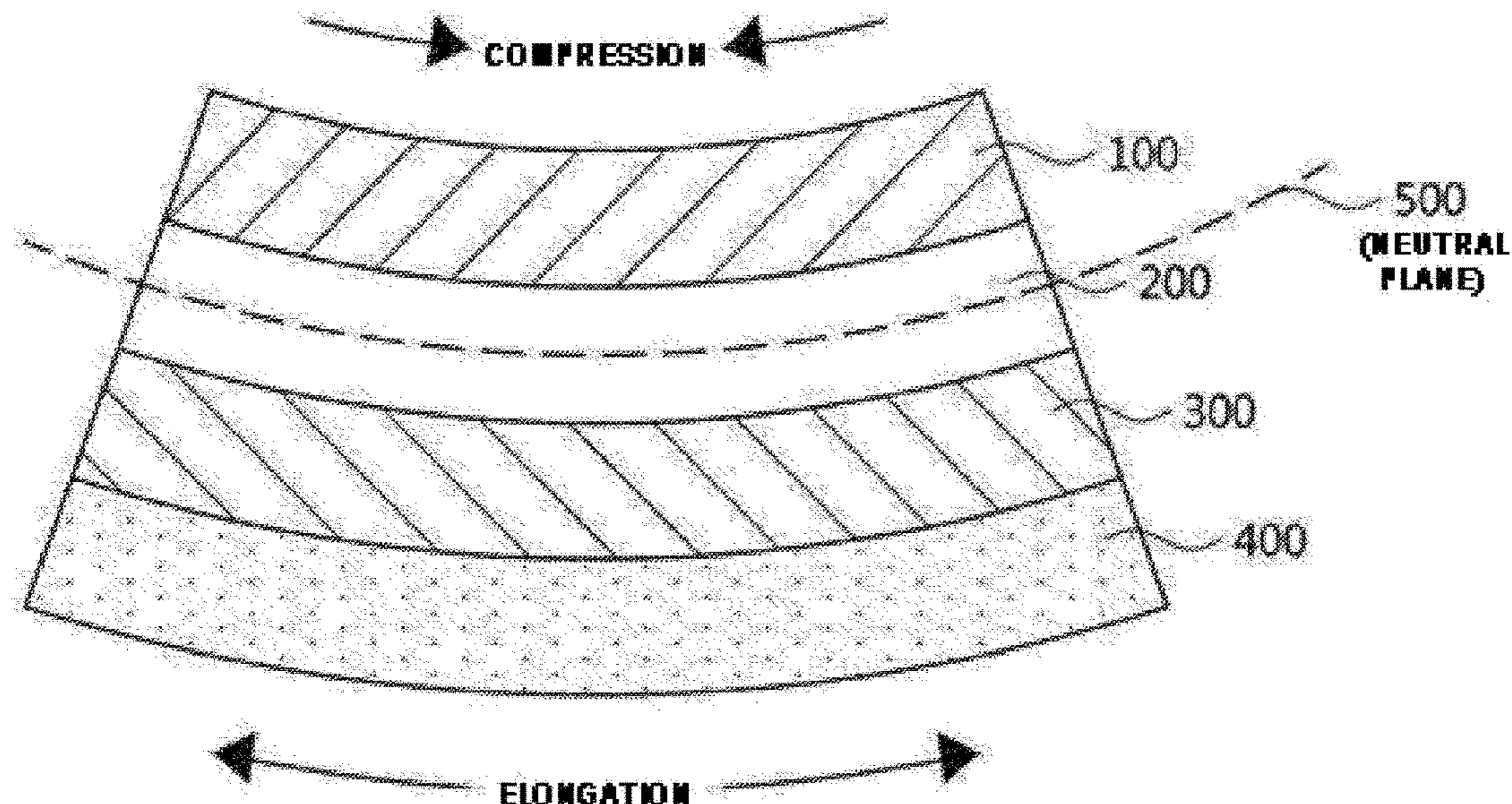
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FIG. 1

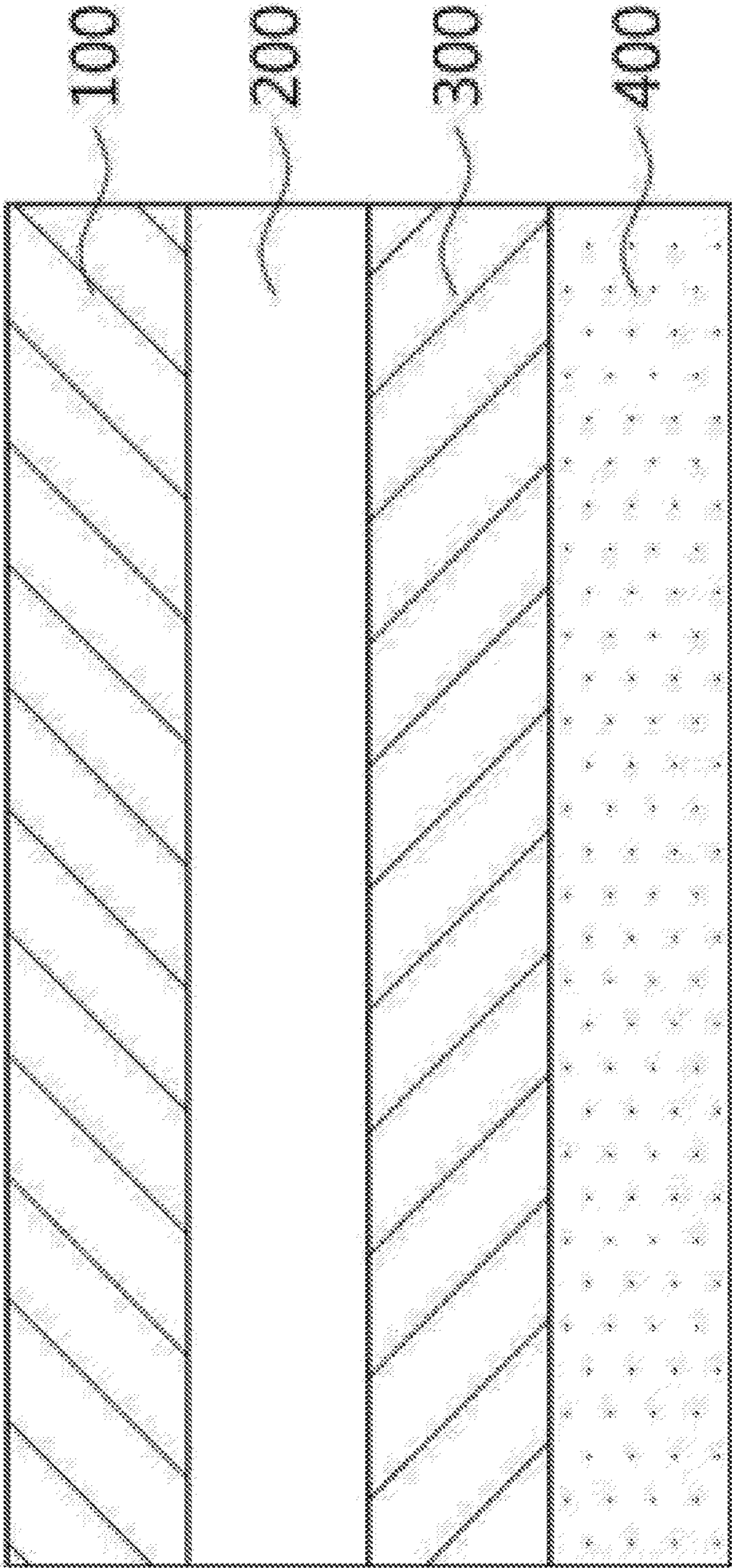


FIG. 2

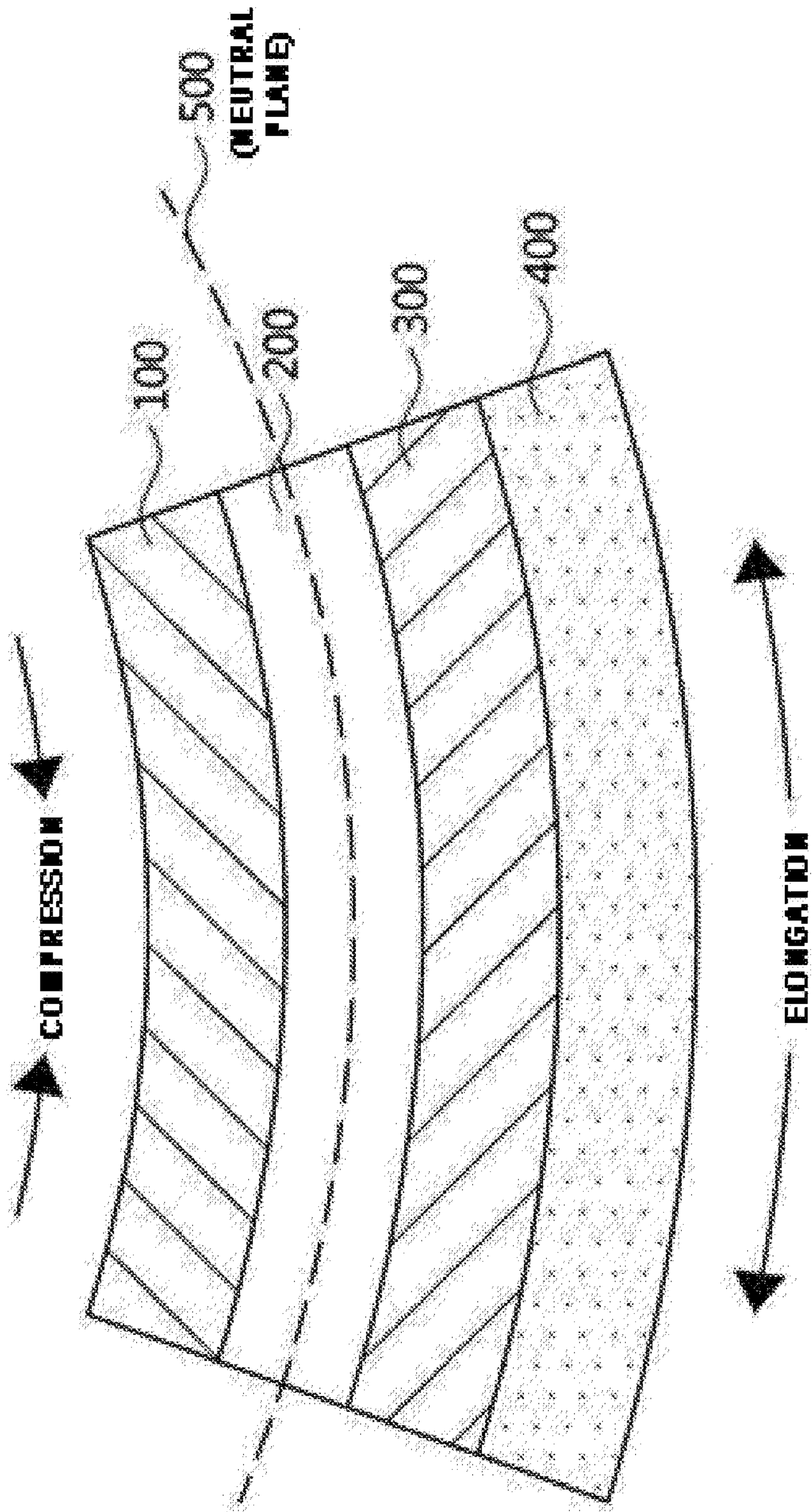
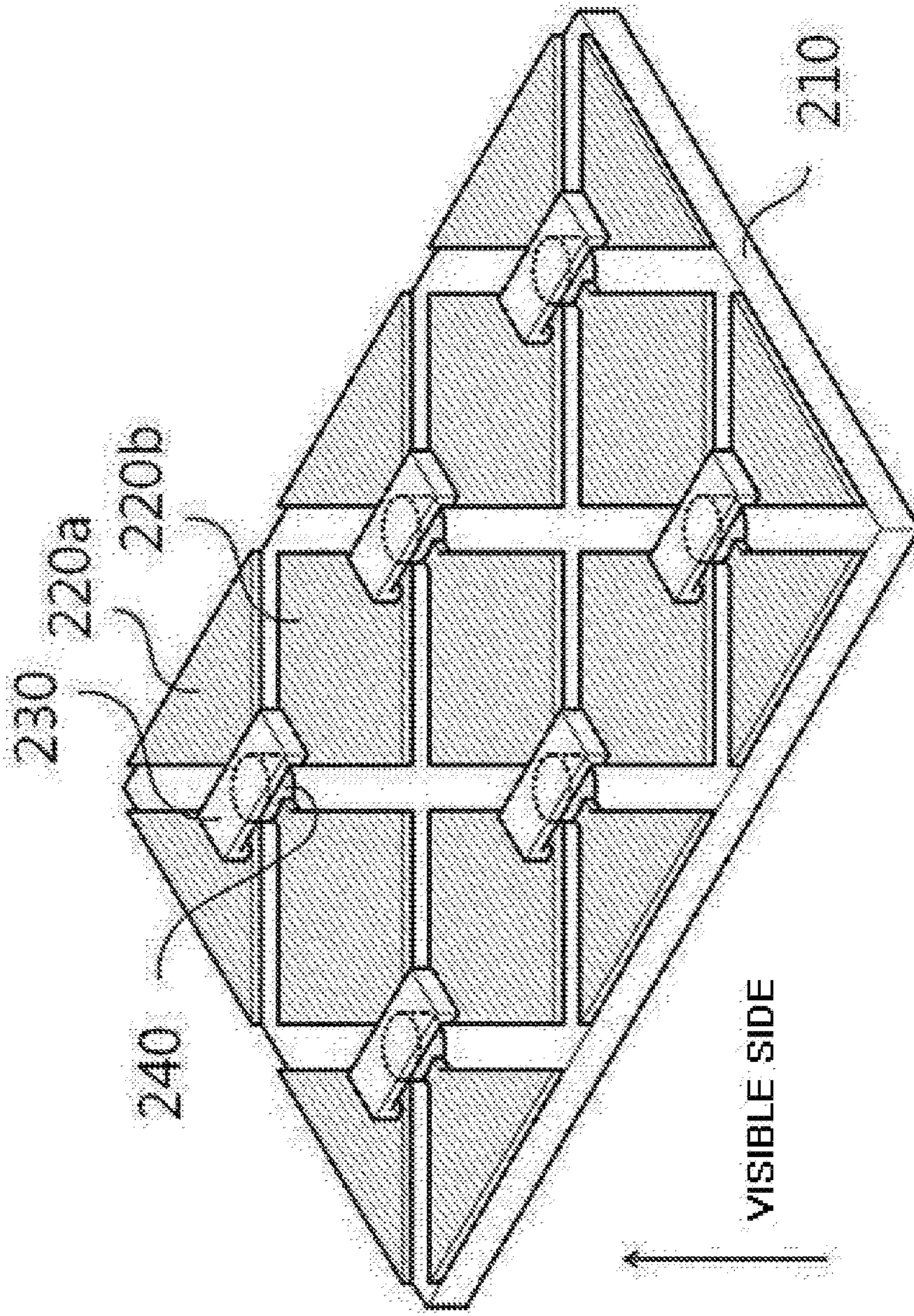


FIG. 3



FLEXIBLE IMAGE DISPLAY DEVICE

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the priority of Korean Patent Application No. 10-2015-0163452 filed on Nov. 20, 2015, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a flexible image display device.

2. Description of the Related Art

Generally, a flexible image display device is a device in which a display part is formed on a flexible substrate to add flexibility thereto, and has a very useful advantage of being able to be used by bending a shape thereof as necessary.

Meanwhile, recently, almost all display devices tend to be configured to be operated by a touch operation of a user. For this, the flexible image display device is provided with a flexible touch panel capable of being flexibly bent, similar to a main body.

However, since a wiring layer made of a conductive material such as indium-tin-oxide (ITO) is formed in the flexible touch panel, there have been a lot of cases of cracks occurring in the wiring layer during an operation of bending the flexible touch panel.

That is, when bending the flexible image display device, there have frequently been cases of cracks occurring due to the wiring layer of the touch screen panel having a relatively low flexibility such that it could not stand a deformation thereof.

Thereby, in severe cases, the wiring layer is broken, resulting in a driving failure. Therefore, in order to prevent an occurrence of failure in a product, measures to resolve the above-described problem are required.

Korean Patent Laid-Open Publication No. 2014-0120510 discloses a flexible substrate, a flexible image display device, and a method of manufacturing the same, however, it did not suggest an alternative idea to solve the above-described problems.

SUMMARY

It is an aspect of the present invention to provide a flexible image display device capable of preventing an occurrence of curved cracks in a touch panel.

The above aspect of the present invention will be achieved by the following characteristics:

(1) A flexible image display device including: a window substrate, a polarizing plate, and a touch panel, wherein a distance between a neutral plane and a lower surface of the touch panel based on a visible side during bending is 34% or less to an entire thickness of the flexible image display device.

(2) The flexible image display device according to the above (1), further including a display panel disposed on a side opposite to the window substrate based on the polarizing plate and the touch panel.

(3) The flexible image display device according to the above (2), wherein a thickness between an upper surface of the window substrate and a lower surface of the display panel is 500 μm or less.

(4) The flexible image display device according to the above (2), wherein the window substrate has a thickness thicker than a total thickness of the polarizing plate, the touch panel and the display panel, and an elastic modulus larger than an elastic modulus of a laminate of the polarizing plate, the touch panel and the display panel.

(5) The flexible image display device according to the above (2), wherein the window substrate, the touch panel and the display panel have an elastic modulus of 2 GPa to 7 GPa, respectively, and the polarizing plate has an elastic modulus of 7 GPa or less.

(6) The flexible image display device according to the above (2), wherein optical clear adhesive layers are located between the window substrate and the polarizing plate, and between the touch panel and the display panel.

(7) The flexible image display device according to the above (1), wherein a substrate of the touch panel has a toughness of 2,000 Mpa % or more.

(8) The flexible image display device according to the above (1), wherein the touch panel satisfies Equation 1 below:

$$\left(\frac{\text{Toughness of touch panel substrate/Stress applied to the touch panel during bending}}{\geq 9\%}\right) \quad [\text{Equation 1}]$$

(wherein the stress is a stress applied to the touch panel when bending the flexible image display device with a radius of curvature of 2.5 mm at a speed of 40 times/minute at room temperature by repeating 300,000 times).

(9) The flexible image display device according to the above (2), wherein the window substrate, the polarizing plate, the touch panel and the display panel are laminated in this order.

(10) The flexible image display device according to the above (9), wherein the substrate of the touch panel has a front retardation of ± 2.5 nm or less.

(11) The flexible image display device according to the above (2), wherein the window substrate, the touch panel, the polarizing plate and the display panel are laminated in this order.

The flexible image display device of the present invention has excellent flexibility and may minimize a damage of the touch panel even if repeatedly applying bending fatigue thereto. Thereby, a defect rate due to the damage of the touch panel may be significantly reduced.

BRIEF DESCRIPTION OF THE DRAWING

The above and other objects, features and other advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic cross-sectional view of a flexible image display device according to an embodiment of the present invention;

FIG. 2 is a schematic cross-sectional view of the flexible image display device according to the embodiment of the present invention during bending; and

FIG. 3 is a schematic plan view of a touch panel in the flexible image display device according to the embodiment of the present invention during bending.

DETAILED DESCRIPTION

The present invention discloses a flexible image display device including: a window substrate, a polarizing plate, and a touch panel, wherein a distance between a neutral plane and a lower surface of the touch panel based on a visible side during bending is 34% or less to an entire thickness of the flexible image display device. Thereby, the flexible image display device has excellent flexibility and may significantly reduce a defect rate due to a damage of the touch panel by minimizing the damage of the touch panel even if repeatedly applying bending fatigue thereto.

Hereinafter, the present invention will be described in detail.

A flexible image display device of the present invention includes a window substrate **100**, a polarizing plate **300**, and a touch panel **200**, wherein a distance between a neutral plane and a lower surface of the touch panel **200** based on a visible side during bending is 34% or less to an entire thickness of the flexible image display device.

The window substrate **100** is not made of a rigid material such as a conventional glass, and preferably, is made of a transparent material having flexible properties, for example, a material such as polymethyl methacrylate (PMMA), acryl, polyester (PET), polyimide (PI), or the like.

The window substrate **100** has, for example, an elastic modulus of 2 GPa to 7 GPa, preferably, 2.3 GPa to 6 GPa, and more preferably, 5 GPa to 6 GPa. If the elastic modulus thereof is less than 2 GPa, it is difficult to achieve a high pencil hardness to cause a difficulty in sufficiently protecting the display panel. If the elastic modulus thereof exceeds 7 GPa, flexibility thereof may be decreased.

A thickness of the window substrate **100** is not particularly limited and may be, for example, 40 to 150 μm . If the thickness thereof is less than 40 μm , it is difficult to achieve a high pencil hardness to cause a difficulty in sufficiently protecting the display panel. If the thickness thereof exceeds 150 μm , the thickness is increased, such that bending properties in a small radius may not be satisfied.

The flexible image display device of the present invention may further include a display panel **400**. Hereinafter, an embodiment in a case of further including the display panel **400** will be described, but it is not limited thereto.

Also, the display panel **400** is a display panel having flexible properties, and may be implemented as an organic electroluminescence display panel.

As an example, the organic electroluminescence display panel is a self-emitting device, and does not need to include a backlight unit unlike the existing liquid crystal display panel. Therefore, by using polyimide (PI), polycarbonate (PC), polyethersulphone (PES), polyethylene terephthalate (PET), polyethylenenaphthalate (PEN), polyarylate (PAR) fiber glass reinforced plastic (FRP), or the like, the display panel **400** may have flexible properties.

The display panel **400** may have an elastic modulus of 2 GPa to 7 GPa, and preferably, 2.5 GPa to 6 GPa. If the elastic modulus thereof is less than 2 GPa, luminescence performance may be deteriorated or the display device may be aged due to transmittance of oxygen or water vapor resulting from the increased gas permeability. If the elastic modulus exceeds 7 GPa, flexibility thereof may be decreased.

A thickness of the display panel **400** is not particularly limited and may be, for example, 20 to 40 μm . If the

thickness thereof is less than 20 μm , luminescence performance may be deteriorated or the display device may be aged due to transmittance of oxygen or water vapor resulting from the increased gas permeability. If the thickness thereof exceeds 40 μm , flexibility thereof may be decreased to cause failure of the display device during bending.

The polarizing plate **300** and the touch panel **200** may be disposed between the window substrate **100** and the display panel **400**.

FIG. 3 is a plan view of the touch panel **200** according to the embodiment of the present invention.

The touch panel **200** is classified into an active area (AA) and a non-active area (NA) located at an outer portion of the active area. The active area is an area corresponding to an area (display part) in which an image is displayed in the display panel **400**, and an area of detecting touch of a user. The non-active area is an area corresponding to an area (non-display part) in which the image is not displayed in the display device. FIG. 3 illustrates only the active area as an example.

The touch panel **200** may include: a substrate **210** having flexible properties; a sensing pattern **220** formed in the active area of the substrate **210**; and sensing lines (not illustrated) which are formed in the non-active area of the substrate **210** to connect the sensing pattern **220** with an external driving circuit (not illustrated) through a pad part (not illustrated).

The substrate **210** having flexible properties may include, for example, polyester films such as polyethylene terephthalate, polyethylene isophthalate, polybutylene terephthalate, etc.; cellulose films such as diacetylcellulose, triacetylcellulose, etc.; polycarbonate films; acryl films such as polymethyl (meth)acrylate, polyethyl (meth)acrylate, etc.; styrene films such as polystyrene, acrylonitrile-styrene copolymer, etc.; polyolefin films such as cycloolefin, cycloolefin copolymer, polynorbornene, polypropylene, polyethylene, ethylene-propylene copolymer, etc.; vinyl chloride films; polyamide films such as nylon, aromatic polyamide, etc.; polyimide films; sulfone films; polyetherketone films; polyphenylene sulfide films; vinyl alcohol films; vinylidene chloride films; vinyl butyral films; allylate films; polyoxymethylene films; urethane films; epoxy films; silicon films, and the like.

It is preferable that a substrate of the touch panel **200** has a toughness of 2,000 Mpa % or more, in terms of suppressing cracks in the touch panel **200**. More preferably, the substrate may have a toughness of 2,000 MPa % to 30,000 MPa %.

The sensing pattern **220** may include a first pattern **220a** formed in a first direction and a second pattern **220b** formed in a second direction, as illustrated in FIG. 3.

The first pattern **220a** and the second pattern **220b** are disposed in different directions from each other. For example, the first direction may be an X-axis direction, and the second direction may be a Y-axis direction orthogonal to the first direction, but it is not limited thereto.

In this regard, the first and second patterns **220a** and **220b** are formed in the same layer of the substrate, and the respective patterns thereof have to be electrically connected with each other to detect the touched point. However, each unit patterns the first pattern **220a** are connected with each other through connection parts thereof while unit patterns of the second pattern **220b** are separated from each other in an island form, thereby additional bridge electrodes **230** are needed to electrically connect the unit patterns of second pattern **220b** with each other.

Any transparent electrode material known in the related art may be used for the sensing pattern **220** without particular limitation thereof. For example, indium-tin oxide (ITO), indium-zinc oxide (IZO), zinc oxide (ZnO), indium-zinc-tin oxide (IZTO), cadmium-tin oxide (CTO), poly(3,4-ethylenedioxythiophene) (PEDOT), carbon nanotube (CNT), graphene, etc., may be used, which may be used alone or in combination of two or more thereof. Preferably, the indium-tin oxide (ITO) is used. Metals used in the metal wire are not particularly limited but may include, for example, silver (Ag), gold, aluminum, copper, iron, nickel, titanium, tellurium, chromium, etc., which are used alone or in combination of two or more thereof.

The bridge electrodes **230** electrically connect the separated unit patterns of the second pattern **220b**.

The bridge electrode **230** may be made of the same material as the sensing pattern **220**, and may be made of, for example, molybdenum, silver, aluminum, copper, palladium, gold, platinum, zinc, tin, titanium, or an alloy of two or more thereof.

The first pattern **220a** and the second pattern **220b** have to be insulated from each other, an insulation layer **240** is formed between the sensing pattern **220** and the bridge electrode **230**.

As illustrated in FIG. 3, the insulation layer **240** may be formed only between a connection part of the first pattern **220a** and the bridge electrode **230**, and may be formed in a structure of a layer covering the sensing pattern **220**. In a case of the layered structure, the bridge electrode **230** may connect the unit patterns of the second pattern **220b** through contact holes foiled in the insulation layer **240**.

In addition, the touch panel **200** may satisfy Equation 1 below:

$$\left(\frac{\text{Toughness of touch panel substrate}}{\text{Stress applied to the touch panel during bending}}\right) \geq 9\% \quad [\text{Equation 1}]$$

(wherein the stress is a stress applied to the touch panel when bending the flexible image display device with a radius of curvature of 2.5 mm at a speed of 40 times/minute at room temperature by repeating 300,000 times).

When the touch panel **200** satisfies Equation 1, it has excellent crack resistance against continuous bending fatigue.

As used herein, the term "room temperature" means the range of temperatures that people tend to prefer for indoor settings. The range is approximately between 15° C. (59° F.) and 30° C. (86° F.).

The polarizing plate **300** may be a configuration including a polarizer alone, or the polarizer and a protective film adhered to at least one surface thereof.

The polarizer may be any polarizer used in the related art, and for example, prepared by a process such as swelling, dyeing, cross-linking, drawing, washing, drying a polyvinyl alcohol film, or the like.

The protective film used herein may be any film so long as it has excellent properties such as transparency, mechanical strength, thermal stability, moisture-shielding properties, isotropic properties, or the like. In particular, polyester films such as polyethylene terephthalate, polyethylene isophthalate, polybutylene terephthalate, etc.; cellulose films such as diacetylocellulose, triacetylcellulose, etc.; polycarbonate films; acryl films such as polymethyl (meth)acrylate, polyethyl (meth)acrylate, etc.; styrene films such as polystyrene, acrylonitrile-styrene copolymer, etc.; polyolefin films such as cycloolefin, cycloolefin copolymer, polynorbornene, polypropylene, polyethylene, ethylene-propylene copolymer, etc.; vinyl chloride films; polyamides films such as

nylon, aromatic polyamide, etc.; imide films; sulfone films; polyetherketone films; polyphenylene sulfide films; vinyl alcohol films; vinylidene chloride films; vinyl butyral films; allylate films; polyoxymethylene films; urethane films; epoxy films; silicon films, or the like, may be used. In particular, the cellulose film having a surface saponified using alkali or the like is preferably used among the above compounds, in consideration of polar properties or durability. The protective film may also have an optical compensation function such as a retardation function.

The protective film is adhered to one surface of the polarizer when using as the polarizing plate **300**. In this case, adhesion facilitating treatment for improving adhesiveness may be executed on a surface to be adhered to the polarizer.

The adhesion facilitating treatment is not particularly limited so long as it can improve adhesiveness between the polarizer and the protective film, and may include drying treatment such as primer treatment, plasma treatment, corona treatment, etc.; chemical treatment such as alkalination (saponification) treatment; low pressure UV treatment, or the like.

The polarizing plate **300** may have an elastic modulus of 7 GPa or less. If the elastic modulus exceeds 7 GPa, flexibility thereof may be decreased. In terms of expressing an appropriate hardness or excellent flexibility, the polarizing plate may have an elastic modulus of 2 GPa to 7 GPa, and preferably 2 GPa to 5.5 GPa.

A thickness of the polarizing plate **300** is not particularly limited and may be, for example, 100 μm or less. If the thickness thereof exceeds 100 μm, flexibility thereof may be decreased. Within the above range, the polarizing plate may have a thickness of 5 μm to 100 μm, for example.

In the flexible image display device of the present invention, the window substrate **100** has a thickness thicker than a total thickness of the polarizing plate **300**, the touch panel **200** and the display panel **400**. In addition, the window substrate **100** may have an elastic modulus larger than an elastic modulus of a laminate of the polarizing plate **300**, the touch panel **200** and the display panel **400**. In this case, the flexible image display device may express excellent flexibility while reducing a thickness thereof, thus being preferable.

It is preferable that the flexible image display device of the present invention may have a thickness of 500 μm or less between an upper surface of the window substrate **100** and a lower surface of the display panel **400**. For example, the thickness thereof may be 100 μm to 400 μm, but it is not limited thereto.

A distance between a neutral plane and a lower surface of the touch panel based on a visible side during bending is 34% or less to an entire thickness of the flexible image display device.

The neutral plane means a point in which no compressive stress or tensile stress acts during bending the flexible image display device. For example, when the flexible image display device is bent as illustrated in FIG. 2, the compressive stress acts on an inside of the curved curvature and the tensile stress acts on an outside thereof. Therefore, a direction in which the stress acts is gradually changed from the inside of the curvature toward the outside thereof, and at a critical point, there exists a transition point in which neither the compressive stress nor the tensile stress acts, and this transition point becomes the neutral plane (NP).

The tensile stress more greatly affects an occurrence of cracks than the compressive stress, and the largest tensile stress is applied to the lower surface of the touch panel **200**. Accordingly, when the distance between the neutral plane

TABLE 2

Comparative Example 3	Comparative Example 4	Example 7	Example 8	Example 9	Example 10	Example 11	Example 12
Window substrate	Window substrate	Window substrate	Window substrate	Window substrate	Window substrate	Window substrate	Window substrate
152 μm	152 μm	152 μm	152 μm	152 μm	152 μm	152 μm	152 μm
OCA layer	OCA layer	OCA layer	OCA layer	Touch panel	Touch panel	Touch panel	OCA layer
100 μm	85 μm	50 μm	50 μm	27 μm	27 μm	27 μm	50 μm
Polarizing plate	Polarizing plate	Polarizing plate	Polarizing plate	OCA layer	OCA layer	OCA layer	Touch panel
41 μm	41 μm	41 μm	41 μm	50 μm	50 μm	50 μm	27 μm
Touch panel	Touch panel	Touch panel	Touch panel	Polarizing plate	Polarizing plate	Polarizing plate	Polarizing plate
27 μm	27 μm	27 μm	27 μm	41 μm	41 μm	41 μm	41 μm
OCA layer	OCA layer	OCA layer	OCA layer	OCA layer	OCA layer	OCA layer	OCA layer
50 μm	80 μm	100 μm	100 μm	100 μm	100 μm	100 μm	100 μm
Display panel	Display panel	Display panel	Display panel	Display panel	Display panel	Display panel	Display panel
20 μm	20 μm	20 μm	20 μm	20 μm	20 μm	20 μm	20 μm

In particular, a polyimide substrate which includes a finger print-preventing layer and a hard coating layer sequentially laminated on one surface thereof and has an elastic modulus of 6 GPa was used as a window substrate, a silicon OCA layer having an elastic modulus of 0.1 MPa at -20° C. to 80° C. was used as an upper adhesive layer, a polarizing plate which includes a triacetylcellulose protective film, having a thickness of 20 μm adhered on both surfaces of a polyvinyl alcohol polarizer having a thickness of 7 μm, and has an elastic modulus of 4.5 GPa was used as a polarizing plate.

As a touch panel, a touch panel which includes an ITO sensing pattern having a thickness of 40 nm on a triacetylcellulose (TAC) and cycloolefin (COP) substrate (retardation of ± 2.5 nm or less), and a polyethylene terephthalate (PET) substrate (retardation of 125 nm), an insulation layer having a thickness of 2 μm on the sensing pattern, and an ITO bridge pattern having a thickness of 170 nm on the insulation layer, and has an elastic modulus of 4.5 GPa was used.

A silicon OCA layer having an elastic modulus of 0.1 MPa at -20° C. to 80° C. was used as a lower adhesive layer, and a flexible OLED having an elastic modulus of 5.0 GPa was used as a display panel.

A portion in which the optical clear adhesive (OCA) layer is not present therebetween among the members of each layer includes an acryl adhesive layer having a thickness of 2.5 μm, respectively.

Experimental Example

(1) Calculation of Neutral Plane

A neutral plane was calculated according to Equations 2 and 3 below.

$$\sigma = \frac{E}{R} \cdot Z \quad [\text{Equation 2}]$$

(wherein, σ is a stress applied during bending, E is Young's Modulus, R is a radius of curvature, and Z is a neutral plane).

$$Z = \frac{\sum_{i=1}^n E_i d_i^2 + 2 \sum_{i=2}^n \left(E_i d_i \sum_{j=1}^{i-1} d_j \right)}{2 \sum_{i=1}^n E_i d_i} \quad [\text{Equation 3}]$$

(wherein, n is the number of layers, d is a thickness of individual layers, and E is Young's Modulus).

(2) Assessment of Touch Properties Before Bending

A test was performed using a capacitance tester, and the touch properties before bending were determined in such a manner that, if a gap difference in numerals of an entire node is less than 20%, it is determined to be good (OK), and if the gap difference in numerals of the entire node is 20% or more, it is determined to be not good (NG).

(3) Experiment for Repeated Bending Fatigue

An experiment for analysis of repeated bending fatigue was assessed using a folding tester (DLMLH-FS, YUASA Co.) An adhesion sample had a size of 100 mm \times 10 mm, and the sample was mounted in the tester, then assessment was conducted with a radius of curvature of 2.5 R at a speed of 40 times/minute by repeating 250,000 times.

For assessment, the repeated bending fatigue was determined in such a manner that, if there is no crack and a touch operation is reliably performed, it is determined to be good (OK), and if cracks are confirmed and the touch operation is not performed, it is determined to be not good (NG).

In cases of Comparative Examples 3 and 4, and Examples 7 to 12 in the experiment, a polyimide film (that plays a role of a rear cover at the time of being actually applied to products) having a thickness of 50 μm was further adhered to a lower surface of the display panel using an acryl adhesive layer having a thickness of 2.5 μm, and then the experiment was performed.

(4) Experiment for Ball Drop

A steel ball used in the test had a weight of 500 g, and a diameter (R) of 2 cm. The experiment was performed by dropping the steel ball from a height of 15 cm on the display device of the examples and comparative examples, and impact resistance was determined in such a manner that, if there is no crack and the touch operation is reliably performed, it is determined to be good (OK), and if cracks are

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confirmed and the touch operation is not performed, it is determined to be not good (NG).

(5) Assessment of Touch Properties

Touch properties were determined in such a manner that, if a gap difference between before and after of the bending assessment or the ball drop experiment is less than 20%, it is determined to be good (OK), and if the gap difference is 20% or more, it is determined to be not good (NG).

(6) Display Quality

a* and b* values depending on a viewing angle were measured using DMS-803 (Instrument Systems).

The measured angle and evaluation standards are as follows:

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θ ; 0-60°/Φ; 0, 45, 90 and 135°, based on a main viewing angle of display panel

If each numeral of a* and b* is 7 or less, it is determined to be good (OK)

If each numeral of a* and b* is 10 or more, it is determined to be not good (NG)

If both of a* and b* are 0, a complete black anti-reflective function may be expressed without light leakage, thereby display quality is improved. When using a PET film as a touch substrate of the touch panel disposed on the lower side of the polarizing plate, black does not occur in the touch panel.

TABLE 3

Section	Comparative	Comparative	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
	Example 1	Example 2						
Touch panel substrate	COP	COP	TAC	PET	COP	TAC	PET	PET
Toughness of touch panel substrate (MPa %)	500	1300	2500	13855	2000	2500	13855	13855
Total thickness (μm) (Thickness of acrylic adhesive layer is omitted)	370	385	370	370	370	370	370	370
Distance between upper surface of window substrate and neutral plane (μm)	146	127	123	123	117	118	119	125
Distance between neutral plane and lower surface of touch panel (μm)	152	161	125	125	42	41	40	82
Distance between neutral plane and lower surface of display panel (μm)	224	258	247	247	250	249	248	245
Stress applied to touch panel (MPa)	375	396	309	309	102	100	99	203
Stress applied to touch panel substrate (MPa)	571	205	307	311	93	113	131	221
Tensile stress (MPa)	0	0	0	0	0	0	0	0
Toughness of touch panel substrate (MPa %)/Stress applied to touch panel (MPa)	1%	3%	8%	45%	20%	25%	140%	68%
Toughness of touch panel substrate (MPa %)/Stress applied to touch panel substrate (MPa)	1%	6%	8%	45%	21%	22%	106%	63%
Distance between the neutral plane and lower surface of touch panel based on visible side/Total thickness (%)	41	42	34	34	11	11	11	22
Touch properties before bending	OK	OK	OK	OK	OK	OK	OK	OK
Repeated bending fatigue	NG	NG	OK	OK	OK	OK	OK	OK
Ball drop	NG	NG	OK	OK	OK	OK	OK	OK
Touch properties	NG	NG	OK	OK	OK	OK	OK	OK
Display quality	OK	OK	OK	NG	OK	OK	OK	OK

TABLE 4

Section	Comparative	Comparative	Example 7	Example 8	Example 9	Example 10	Example 11	Example 12
	Example 3	Example 4						
Touch panel substrate	COP	COP	TAC	PET	COP	TAC	PET	PET
Toughness of touch panel substrate (MPa %)	500	1300	2500	13855	2000	2500	13855	13855
Total thickness (μm) (Thickness of acrylic adhesive layer is omitted)	390	405	390	390	390	390	390	390
Distance between upper surface of window substrate and neutral plane (μm)	162	147	141	141	136	137	137	143

TABLE 4-continued

Section	Comparative Example 3	Comparative Example 4	Example 7	Example 8	Example 9	Example 10	Example 11	Example 12
Distance between neutral plane and lower surface of touch panel (μm)	136	141	107	107	23.1	22.3	22.0	64
Distance between neutral plane and lower surface of display panel (μm)	228	258	249	249	251	250	250	247
Stress applied to touch panel (MPa)	336	347	264	264	57	55	54	158
Stress applied to touch panel substrate (MPa)	519	182	269	273	54	80	93	182
Tensile stress (MPa)	457	516	498	498	502	501	500	495
Toughness of touch panel substrate (MPa %)/Stress applied to touch panel (MPa)	1%	4%	9%	53%	35%	45%	256%	88%
Toughness of touch panel substrate (MPa %)/Stress applied to touch panel substrate (MPa)	1%	7%	9%	51%	37%	31%	149%	76%
Distance between the neutral plane and lower surface of touch panel based on visible side/Total thickness (%)	35	35	27	27	6	6	6	16
Touch properties before bending	OK	OK	OK	OK	OK	OK	OK	OK
Repeated bending fatigue	NG	NG	OK	OK	OK	OK	OK	OK
Ball drop	NG	NG	OK	OK	OK	OK	OK	OK
Touch properties	NG	NG	OK	OK	OK	OK	OK	OK
Display quality	OK	OK	OK	NG	OK	OK	OK	OK

As a result of the experiment, it could be seen that the flexible image display devices of the examples had a distance between the neutral plane and the lower surface of the touch panel based on the visible side during bending was 34% or less to an entire thickness of the flexible image display device, and exhibited no occurrence of cracks due to the repeated bending fatigue.

However, in a case of the flexible image display devices of the comparative examples, cracks occurred due to the repeated bending fatigue.

What is claimed is:

1. A flexible image display device comprising:

a window substrate;

a polarizing plate; [and]

a touch panel between the window substrate and the polarizing plate, wherein a distance between a neutral plane and a lower surface of the touch panel based on a visible side during bending is 34% or less to an entire thickness of the flexible image display device[.]; and a display panel disposed on a side opposite to the window substrate based on the polarizing plate and the touch panel,

wherein a substrate of the touch panel has a toughness of 2,000 MPa % or more; and

the window substrate, the touch panel and the display panel have an elastic modulus of 2 GPa to 7 GPa, respectively, and the polarizing plate has an elastic modulus of 7 GPa or less.

[2. The flexible image display device according to claim 1, further comprising a display panel disposed on a side opposite to the window substrate based on the polarizing plate and the touch panel.]

3. The flexible image display device according to claim [2] 1, wherein a thickness between an upper surface of the window substrate and a lower surface of the display panel is 500 μm or less.

4. The flexible image display device according to claim [2] 1, wherein the window substrate has a thickness thicker

than a total thickness of the polarizing plate, the touch panel and the display panel, and an elastic modulus larger than an elastic modulus of a laminate of the polarizing plate, the touch panel and the display panel.

[5. The flexible image display device according to claim 2, wherein the window substrate, the touch panel and the display panel have an elastic modulus of 2 GPa to 7 GPa, respectively, and the polarizing plate has an elastic modulus of 7 GPa or less.]

[6. The flexible image display device according to claim 2, wherein optical clear adhesive layers are located between the window substrate and the polarizing plate, and between the touch panel and the display panel.]

[7. The flexible image display device according to claim 2, wherein the window substrate, the polarizing plate, the touch panel and the display panel are laminated in this order.]

[8. The flexible image display device according, to claim 7, wherein the substrate of the touch panel has a front retardation of ± 2.5 nm or less.]

9. The flexible image display device according to claim [2] 1, wherein the window substrate, the touch panel, the polarizing plate and the display panel are laminated in this order.

10. The flexible image display device according to claim 1, wherein the touch panel satisfies Equation 1 below:

$$\left(\frac{\text{Toughness of touch panel substrate/Stress applied to the touch panel during bending}}{\text{Stress applied to the touch panel during bending}}\right) > 9\% \quad [\text{Equation 1}]$$

wherein the stress is a stress applied to the touch panel when bending the flexible image display device with a radius of curvature of 2.5 mm at a speed of 40 times/minute at room temperature by repeating 300,000 times.

11. A flexible image display device comprising:

a window substrate;

a touch panel, wherein a distance between a neutral plane and a lower surface of the touch panel based on a

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visible side during bending is 34% or less to an entire thickness of the flexible image display device, and a substrate of the touch panel has a toughness of 2,000 MPa % or more;

a polarizing plate between the window substrate and the touch panel; and

a display panel disposed on a side opposite to the window substrate based on the polarizing plate and the touch panel,

wherein a thickness between an upper surface of the window substrate and a lower surface of the display panel is 500 μm or less.

12. The flexible image display device according to claim 11, wherein the window substrate has a thickness thicker than a total thickness of the polarizing plate, the touch panel and the display panel, and an elastic modulus larger than an elastic modulus of a laminate of the polarizing plate, the touch panel and the display panel.

13. The flexible image display device according to claim 11, wherein the window substrate, the touch panel and the display panel have an elastic modulus of 2 GPa to 7 GPa, respectively, and the polarizing plate has an elastic modulus of 7 GPa or less.

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14. The flexible image display device according to claim 11, wherein optical clear adhesive layers are located between the window substrate and the polarizing plate, and between the touch panel and the display panel.

15. The flexible image display device according to claim 11, wherein the window substrate, the polarizing plate, the touch panel and the display panel are laminated in this order.

16. The flexible image display device according to claim 15, wherein the substrate of the touch panel has a front retardation of ±2.5 nm or less.

17. The flexible image display device according to claim 11, wherein the touch panel satisfies Equation 1 below:

$$\frac{\text{(Toughness of touch panel substrate/Stress applied to the touch panel during bending)}}{9\%} \quad \text{[Equation 1]}$$

wherein the stress is a stress applied to the touch panel when bending the flexible image display device with a radius of curvature of 2.5 mm at a speed of 40 times/minute at room temperature by repeating 300,000 times.

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