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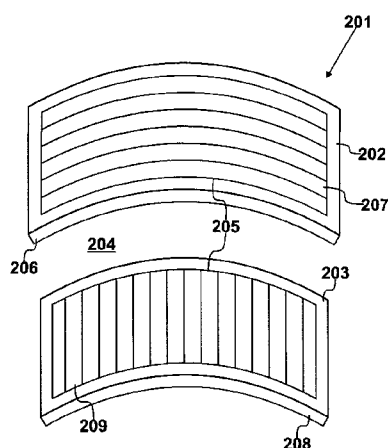
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(57) Abstract: A flexible sensor (201) comprises a first conductive layer (202) and a second conductive layer (203). The first conductive layer and the second conductive layer define a sensing region (205) for determining an interaction, such as a mechanical interaction. The first conductive layer comprises a first substrate (206) having a plurality of conductive rows (207) printed thereon and the second conductive layer comprises a second substrate (208) having a plurality of columns (209) printed thereon. The first conductive layer and the second conductive layer are constrained by a constraining means (505) which holds the two layers together but permits movement of the layers perpendicular to each other in the sensing region.

Fig. 2



Flexible Sensor

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from United Kingdom Patent Application No. 1616751.2, filed October 1st, 2016, the whole contents of which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

The present invention relates to a flexible sensor and method of manufacturing a flexible sensor.

Sensors are known to be used in a wide variety of applications and industries. In particular, sensors which provide touch capabilities in response to mechanical interactions such as pressure are often used in applications such as in electronic devices to provide touchscreens, buttons or similar. Standard matrix sensors typically include two separate substrates which include conductive materials in order to provide an indication of force or position values with the substrates being constrained to prevent movement of the substrates relative to each other.

A problem that occurs with sensors of this type is that, even if the substrates are made to be flexible, bending of the sensor (and substrates) results in compression on the inner surface of each substrate as it bends. Bending of the sensor (and substrates) also results in elongation on the outer surface of each substrate as it bends. This leads to the substrates making contact with each other thereby creating a conduction path resulting in false triggering or a start resistance being induced into the sensor from the residual stresses activated during bending. Furthermore, any induced start resistance is also uneven and thus difficult to predict due to its dependence on the radius of curvature of the bend.

In addition, for relatively thin substrates, instead of experiencing compression on the inner surface and elongation on the outer surface, the substrate buckles about the inner surface. Similarly, the buckling creates a pressure point where the substrates contact which results in a start

resistance and corresponding stress to the sensor.

BRIEF SUMMARY OF THE INVENTION

According to an aspect of the present invention, there is provided a flexible sensor, comprising: a first conductive layer; and a second conductive layer; said first conductive layer and said second conductive layer define a sensing region for determining a mechanical interaction; wherein said first conductive layer comprises a first substrate having a plurality of conductive rows printed thereon; said second conductive layer comprises a second substrate having a plurality of conductive columns printed thereon; and said first conductive layer and said second conductive layer are constrained by a constraining means so as to maintain said first conductive layer and said second conductive layer together while permitting movement of the layers perpendicular to each other in said sensing region.

According to a further aspect of the present invention, there is provided a method of manufacturing a flexible sensor, comprising the steps of: providing a first conductive layer and a second conductive layer, said first conductive layer and said second conductive layer defining a sensing region for determining a mechanical interaction, said first conductive layer comprising a first substrate and said second conductive layer comprising a second substrate; printing a plurality of conductive rows on said first substrate; printing a plurality of conductive columns on said second substrate; constraining said first conductive layer and said second conductive layer by a constraining means such that said first conductive layer and said second conductive layer are maintained together while being permitted to move perpendicular to each other in said sensing region.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Figure 1 shows an example application utilising a flexible sensor on a curved electronic device;

Figure 2 shows an exploded view of conductive layers of a flexible sensor;

Figure 3 shows a cross-sectional exploded view of conductive layer of

a flexible sensor;

Figure 4 shows the arrangement of a sensing region of a flexible sensor;

Figure 5 shows a flexible sensor in isolation;

5 Figure 6A shows a first substrate comprising a pin;

Figure 6B shows a second substrate comprising a slot;

Figure 6C shows first and second substrates being constrained by a constraining means.

10 Figure 7A shows a cross-sectional view of a flexible sensor in an inactive configuration;

Figure 7B shows a cross-sectional view of the flexible sensor of Figure 6A in an arcuate configuration;

Figure 8A shows a cross-sectional view of a flexible sensor on application of a mechanical interaction;

15 Figure 8B shows a cross-sectional view of the flexible sensor of Figure 8A in an arcuate configuration on application of a mechanical interaction;

Figure 9 shows a flexible sensor in an example embodiment;

Figure 10 shows a tablet computer folded into a storage configuration;

20 Figure 11 shows a cross-sectional view of a flexible sensor suspended in an enclosure; and

Figure 12 shows the flexible sensor of Figure 11 in an arcuate configuration.

Figure 1

25 An example embodiment showing the use of a flexible sensor in a typical environment is shown in Figure 1. A user **101** is shown watching a television **102**.

30 Television **102** is substantially curved and includes hinged members such as hinged member **103**, which can be moved around to enhance the user's **101** viewing experience. Television **102** also has a screen **104** which comprises a flexible sensor which has touch capabilities such that user **101** may interact by pressing screen **104** to provide an instruction or select data.

The flexible sensor incorporated into screen **104** is substantially similar as is herein described and allows hinged member **103** to be moved effectively without incurring undue stresses or false triggering to the sensor thereby preventing reduced capacity to any touch capabilities of screen **104**.
5 Thus, user **101** is able to adjust television **102** as desired in order to view more of screen **104** of television **102** or adjust the angle it is being viewed at. Additionally, user **101** can continue to utilise the touch capacity of the television even as the screen is flexed. The flexible sensor utilised in this example will now be described in the following Figures.

10 **Figure 2**

A flexible sensor **201** in accordance with an aspect of the present invention is shown in a partially exploded view Figure 2. Flexible sensor **201** comprises a first conductive layer **202** and a second conductive layer **203**. In this diagrammatic illustration, first conductive layer **202** and second
15 conductive layer **203** are shown in an exploded form such that there is a gap **204** between them. It is appreciated that, in practice, first conductive layer **202** and second conductive layer **203** are positioned closer together than shown and in some embodiments, gap **204** is negligible.

In combination, conductive layer **202** and conductive layer **203**
20 combine to define a sensing region **205** which is used for determining an interaction. In an embodiment, this interaction is a mechanical interaction such as a force or pressure applied by means of a finger or stylus press. In alternative embodiments, the interaction may be chemical, electro-magnetic or from ionising radiation.

25 As can be seen in Figure 2, conductive layer **202** comprises a substrate **206** which includes a plurality of conductive rows **207** printed onto the substrate.

In a similar way, conductive layer **203** comprises substrate **208** onto
30 which a plurality of conductive columns **209** are printed. The conductive rows and columns are configured to cooperate in the manner of a matrix sensor

as will be described further in Figure 3.

In the example, substrates **206** and **208** are made from polyethylene terephthalate (PET). Each of the PET substrates are typically one hundred microns (100 μm) thick. In an alternative embodiment however, substrates **206** and **208** are manufactured from polyimide, which, in an embodiment, is typically around twelve microns (12 μm) in thickness.

Figure 3

Figure 3 shows a sensing region arrangement **205** in diagrammatic form. Sensing region **205** is defined by conductive layer **202** and conductive layer **203** of which a portion of each is shown in the illustration of Figure 3.

Conductive layer **202** comprises a plurality of conductive rows **207** and conductive layer **203** comprises a plurality of conductive columns **209**. Each row is electrically insulated from the others, and similarly, each column is electrically insulated from the others.

In this example, the sensing region **205** is provided by a matrix of eight rows, indicated as R1 to R8, and eight columns, indicated by C1 to C8. A matrix sensor of this type can be utilised to detect mechanical interactions and determine positional and extent properties of that mechanical interaction. It is appreciated that, in alternative embodiments, interactions may be made by chemical, electro-magnetic or ionising radiation means and suitable sensing region arrangements are made.

With respect to the use of the terminology “rows” and “columns”, it is appreciated that rows **207** and columns **209** are positioned parallel to one another within the first conductive layer **202** and second conductive layer **203** respectively. The plurality of rows are also positioned substantially perpendicularly to the plurality of columns, albeit in separate planes relating to the first conductive layer **202** and the second conductive layer **203** respectively.

In order to determine positional properties, each row is configured to allow electrical potential gradient to be established along it between a first terminal at one end of any one of the rows and a second terminal at the

opposite end of the row. For example, an electrical potential gradient is established along row R4 between end **301** and end **302**. Similarly, each column is configured to allow an electrical potential gradient to be established between a first end and a second end of column, such as first end **303** and second end **304** of column C3. Positional properties, for example at point X, can then be determined in a substantially conventional manner.

Figure 4

In the embodiment of Figure 4, conductive rows **207** and conductive columns **209** combine to define a sensing region **205** which is used to determine a mechanical interaction via connection to an electrical circuit so as to determine positional and/or extent properties of a mechanical interaction. This is calculated through use of the conductive materials which are applied to the substrate as will now be described.

Figure 4 shows conductive layer **202** and conductive layer **203** in a diagrammatic cross-sectional exploded view. Conductive layer **202** comprises substrate **206** which is overprinted with a plurality of conductive rows **207**. Conductive rows **207** comprise a layer of silver-loaded ink **401** and a layer of carbon loaded ink **402**. In manufacture, the PET substrate **206** is printed initially with the silver ink **401** before being overprinted with conductive carbon **402**.

In a similar manner, conductive layer **203** comprises a PET substrate **208** which is overprinted with a layer of silver-loaded ink **403** which is then overprinted with a conductive carbon loaded ink **404**. Conductive layer **203** further comprises a substance **405** which exhibits a variable resistivity. In an embodiment, the resistivity of substance **405** is dependent on pressure applied to conductive layer **203**.

In the embodiment described, substance **405** is a quantum tunnelling material such as QTC (RTM) in an ink format as supplied by the present applicant, Peratech Holdco Limited, Brompton-on-Swale, United Kingdom.

Quantum tunnelling material **405** is overprinted over the conductive carbon ink **404** with each of the conductive layers of silver **403**, carbon **404** and quantum tunnelling material **405** in combination forming the plurality of conductive columns **209**.

5 It is appreciated that, in alternative embodiments, the quantum tunnelling material is printed on substrate **206** and forms part of conductive layer **202** rather than conductive layer **203**. It is further appreciated that in a further embodiment both conductive layer **202** and conductive layer **203** both comprise layers of quantum tunnelling material.

10 The silver ink provides a high conductivity and may typically have a sheet resistance of around zero point four ohms ($0.4\ \Omega$). In contrast the carbon ink provides a sheet resistance in the region of four hundred ohms ($400\ \Omega$) but prints as a relatively smooth surface thereby providing improved contact between the layers.

15 **Figure 5**

A flexible sensor **501** is shown in isolation in a plan view in Figure 5 with conductive layer **202** overlaying conductive layer **203**. Conductive layers **202** and **203** have now been placed in substantially close proximity to form the substantially thin flexible sensor **501**. Conductive layer **202** and
20 conductive layer **203** define sensing region **205** for determining an interaction, in this example a mechanical interaction by means of a force applied. Sensing region **205** comprises the plurality of rows **207** and plurality of columns **209** of conductive layer **202** and conductive layer **203** respectively.

25 At a first end **502** of sensor **501**, conductive layers **202** and **203** are constrained by means of a pressure sensitive adhesive (PSA) which adheres substrate **206** and substrate **208** together. At first end **502**, flexible sensor **501** is further provided with electrical connectors **503** and **504** which are connected to conductive layers **202** and **203** respectively. Thus, in this way,
30 the electrical potential gradient previously described in Figure 3 can be

established and processed to determine positional and extent properties of a mechanical interaction in a conventional manner.

Flexible sensor **501** includes a constraining means **505** which is configured to maintain conductive layer **202** and conductive layer **203** together. Constraining means **505** is positioned along a first edge **506** and a second edge **507** of sensor **501**. However, while it is appreciated that the constraining means is configured to hold substrates **206** and **208** together, constraining means **505** does not constrain the flexible sensor **201** in the sensing region **205**.

In this illustrated embodiment, constraining means **505** comprises a plurality of pins on substrate **206** and a plurality of corresponding slots on substrate **208**. In this way, substrates **206** and **208** are loosely connected so as to maintain conductive layer **202** and conductive layer **203** together without restricting movement of the layers. The construction of constraining means **505** will be described further with respect to Figure 6.

Figures 6A, 6B and 6C

The construction of constraining means **505** is illustrated in greater detail with respect to Figures 6A, 6B and 6C. Figure 6A shows a portion of conductive layer **202** comprising substrate **206**. A pin **601**, in the form of a t-shaped profile which has been scored into substrate **206** is positioned between edge **507** and the plurality of rows **207**. The T-shaped profile **602** is cut through substrate **206** with line **603** providing a hinge where the substrate is uncut thereby enabling t-shaped profile **602** to be moved about hinge **603** and away from the main portion of substrate **206**.

Figure 6B shows a portion of conductive layer **203** comprising substrate **208**. Substrate **208** comprises a slot **604** which has been cut into substrate **208** to present an aperture. Slot **604** is positioned in a relative position to pin **601** of substrate **206**, between edge **507** and plurality of columns **209**.

Thus, when substrates **206** and **208** are combined and positioned in

close proximity, pin **601** and slot **604** can be combined in the manner of Figure 6C. Thus, in Figure 6C, t-shaped profile **602** is hinged and pushed through slot **604** to constrain substrates **206** and **208** together. In the embodiment of Figure 5, it is appreciated that a plurality of slots and pins are
5 utilised along edge **507**.

It is further appreciated that in alternative embodiments, other arrangements may be used for the constraining means. For example, clamps, clips, adhesives or other fastenings can be utilised provided they maintain conductive layers **202** and **203** together without constraining
10 sensing region **205**. Furthermore, alternative shapes to the t-shaped profile and rectangular shaped slot may also be utilised.

Thus, in this example, the constraining means passes through the layers thereby restricting movement of the substrates in a first and second direction, that is, in the two planes parallel to Figures 5 and 6, but does not
15 restrict them in a third direction perpendicular to the plane of these Figures. Thus, conductive layer **202** and conductive layer **203** are able to move independently of each other in this direction. Thus, in sensing region **205** conductive layers **202** and **203** are configured to be able to slide over each other when sensor **501** is flexed or bent. This will be described further in
20 Figure 7.

Figure 7A and Figure 7B

A diagrammatic illustration showing conductive layers **202** and **203** is shown in Figures 7A and 7B.

Figure 7A shows flexible sensor **501** in an inactive configuration
25 whereby conductive layer **202** is positioned substantially parallel to conductive layer **203** with a relatively small air gap between them. It is appreciated, however, that while Figure 6A shows the two conductive layers having an air gap therebetween, in alternative embodiments, conductive layer **202** and conductive layer **203** may be in contact, but, with reference to
30 the configuration of Figure 7A, conduction is not permitted between the

layers in this inactive configuration.

As described previously in Figure 5, conductive layers **202** and **203** are loosely constrained at edges **506** and **507** and the constraining means acts to prevent conductive layers **202** and **203** from becoming separated. In this way, conductive layers **202** and **203** also remain sufficiently aligned to enable positional and extent properties to be determined. Referring now to Figure 7B, sensor **501** has been flexed or bent into a substantially arcuate or curved shape such that conductive layer **203** forms a radius of curvature indicated at r_1 and conductive layer **202** forms a radius of curvature r_2 .

In known sensors, this curvature results in the inner surface **701** of conductive layer **203** being subjected to compressive forces which causes the inner surface to wrinkle or buckle. This in turn leads to undesirable contact between conductive layer **203** and conductive layer **202**. In a similar way, the outer surface **702** of conductive layer **202** stretches. However, the constraining means described in Figures 5 and 6 mean that conductive layer **202** and conductive layer **203** are permitted to move relative to each other in the direction of the centre of the radius r_1 . Thus, conductive layer **202** and conductive layer **203** has additional freedom of movement enabling the gap to be maintained between the two layers thereby preventing false triggering and the induction of a start resistance between the two layers.

Figure 8A and Figure 8B

Sensor **501** is shown further in Figures 8A and 8B in similar orientations to those of Figures 7A and 7B. Figure 8A shows conductive layer **202** and conductive layer **203** when a mechanical interaction is applied, which in this case is a force being applied by a finger **801**. When the force is applied in this configuration conductive layers **202** and **203** are forced together to provide conduction through the layers.

Thus, by utilising electrical connectors to provide connection to an electrical circuit, position and extent properties can be determined as required by means of conventional processing equipment.

In a similar manner, in the curved orientation of Figure 8B when a force is applied by finger **802**, conductive layer **202** and conductive layer **203** are forced together to provide a point of mechanical interaction at **803** whereby conductive layers **202** and **203** touch to provide conduction through the layers.

In this way, for a given force applied by finger **801** and finger **802** being substantially equal, the reading from sensor **201** will be substantially similar in both the configuration of Figure 8A and the configuration of Figure 8B.

Figure 9

An alternative flexible sensor **901** in accordance with an aspect of the present invention is shown in Figure 9. Flexible sensor **901** is substantially similar in operation and construction as flexible sensors **201** and **501** previously described. Flexible sensor **901** comprises a first conductive layer **902** and second conductive layer **903** which define a sensing region for determining a mechanical interaction. Conductive layer **902** and conductive layer **903** are configured to move independently of each other in the sensing region **904** such that when sensor **901** is bent or flexed the sensor does not false trigger or induce stresses in the substrates of the conductive layers. Sensor **901** includes constraining means **905** which is positioned along a first edge **906** and a second edge **907**. In the embodiment, the constraining means comprises a plurality of pins positioned around edges **906** and **907** on conductive layer **902** and a plurality of slots positioned around edges **906** and **907** on conductive layer **903**. In this embodiment, the plurality of pins and plurality of slots are substantially similar to those described in Figure 6. It is appreciated, however, that other constraining means may be used that allow for flexibility in the sensing region in at least one direction.

In this embodiment, the flexible sensor **901** is constrained along a centre point **908** by a pressure sensitive adhesive (PSA). In this way, in the region **909** surrounding centre line **908** the layers are constrained and do not

move independently of each other. This effectively creates two sensing regions **904A** and **904B** whereby, in either sensing region **904A** or **904B**, determination of a mechanical interaction can be made when the sensor **901** is being flexed. Region **909** is adhered and electrical connectors **910** are included in this region. Thus, the maximum positional integrity is maintained across the flexible sensor **901**. In this way, a minimum amount of flexible sensing region is lost due to the electrical connectors.

Figure 10

An application utilising the flexible sensor as previously described may be that of providing a tablet computer. A tablet computer comprises a touchscreen which utilises a flexible sensor, such as flexible sensor **201**. A user may use the tablet computer in a manner such that a flexible sensor of touchscreen is in a similar configuration to that shown previously in Figures 7A and 8A, wherein the flexible sensor is in a substantially flat configuration. However, tablet computer is configured to be flexible such that should a user wish to adjust the angle of the touchscreen for example, this can be done without damaging the touch capabilities of the sensor. In this way, a user is free to repeatedly adjust the touchscreen angle as desired without losing functionality of the flexible sensor therein.

Once a user has finished using tablet computer, it may be desirable to put the computer into storage. A tablet computer is shown in Figure 10 in a flexible mode, whereby it is bent to produce a radius of curvature **1101** as illustrated. Thus, a user may choose to fold tablet in the manner shown in Figure 10, such that the tablet can be stored at half its usual cross-sectional area as shown at **1002**. However, due to the nature of the flexible sensor described herein, the conductive layers of the touchscreen are not put under any undue stresses while in storage and do not incur a start resistance while being stored as the conductive layers are permitted to move across each other and flex to a greater degree than conventional force sensors.

Figure 11

A further embodiment of the flexible sensor as previously described

herein is shown in Figure 12 in a cross sectional side view. Flexible sensor **1101** comprises a first conductive layer **1102** and a second conductive layer **1103**. In this embodiment, first conductive layer **1102** and second conductive layers **1103** are contained within an enclosure **1104** and are suspended in a free floating configuration within enclosure **1104**. Conductive layers **1102** and **1103** are substantially similar to those as described in Figures 2 and 3 previously and together provide a sensing region for determining positional and/or extent properties in response to a mechanical interaction such as a finger press or force applied.

Enclosure **1104** comprises a protective layer **1105** which is constrained to an electronic device **1106** by means of a pressure sensitive adhesive **1107**.

In this embodiment, electronic device **1106** is a display, such as the television **102** in Figure 1 or a tablet computer similar to that shown in Figure **10**. Electronic device **1106** is configured to be flexible. Protective layer **1105** is mounted directly to electronic device **1106** however, it is appreciated that conductive layer **1102** and conductive layer **1103** are not directly connected to the electronic device **1106**.

In Figure 12, electronic device **1106** is shown in a substantially flat configuration whereby flexible sensor **1101** is in an inactive configuration without conduction between conductive layer **1102** and conductive layer **1103**. However, electronic device **1106** is able to flex to form an arcuate configuration as is shown and described further with respect to Figure 13.

Figure 12

Flexible sensor **1101** is shown further in Figure 13 in an arcuate configuration when mounted to electronic device **1106**. Electronic device **1106** has been flexed such that the front surface **1201** of electronic device **1206** forms a curved face in the manner of television **102** of Figure 1. When a force **1202** is applied to the front surface **1201**, conductive layers **1102** and **1103** are brought together in a similar way to that as previously described

with reference to Figure 8A and 8B. Thus, when a force is not applied, conductive layers **1102** and **1103** are flexed but inactive such that conduction is not permitted between conductive layers **1102** and **1103**. However when a force **1302** is applied to front surface **1301** curved conductive layers **1102** and **1103** are brought together such that conduction occurs between conductive layer **1103** and **1102**.

Thus, stress is not imparted to the conductive layers **1102** and **1103** while in the configuration Figure 12 or Figure **13**. However, when force **1202** is applied, conductive layers **1202** and **1203** connect to provide conduction through the layers.

Thus, the invention provides a solution to the aforesaid problems experienced with bendable or curved sensors by avoiding compression on the inside of the conductive layers which leads to the undesirable buckling and false triggering.

CLAIMS

1. A flexible sensor, comprising:

a first conductive layer; and

a second conductive layer;

5 said first conductive layer and said second conductive layer define a sensing region for determining a mechanical interaction; wherein

said first conductive layer comprises a first substrate having a plurality of conductive rows printed thereon;

10 said second conductive layer comprises a second substrate having a plurality of conductive columns printed thereon; and

said first conductive layer and said second conductive layer are constrained by a constraining means so as to maintain said first conductive layer and said second conductive layer together while permitting movement of the layers perpendicular to each other in said sensing region.

15

2. The flexible sensor of claim 1, wherein said first conductive layer and said second conductive layer are constrained by said constraining means in a first direction and a second direction parallel to said first conductive layer and said second conductive layer respectively.

20

3. The flexible sensor of claim 1, wherein at least one of said first substrate and said second substrate comprises a substance that exhibits a variable resistivity and said resistivity is dependent upon pressure applied to said second layer.

25

4. The flexible sensor of claim 3, wherein said substance is a quantum tunnelling composite.

5. The flexible sensor of claims 1, wherein each said conductive row comprises at least one of silver-loaded ink or carbon loaded ink.

30

6. The flexible sensor of claims 1, wherein each said conductive column comprises at least one of silver-loaded ink or carbon loaded ink.

5 7. The flexible sensor of claim 1, wherein said constraining means comprises a plurality of slots on one of said first conductive layer and said second conductive layer, and a plurality of corresponding pins on the other of said first conductive layer and said second conductive layer.

10 8. The flexible sensor of claim , wherein said first conductive layer and said second conductive layer are suspended in a free floating configuration within an enclosure.

15 9. The flexible sensor of claim 8, wherein said enclosure is attached to an electronic device.

10 10. The flexible sensor of claim 9, wherein said electronic device is a display.

20 11. The flexible sensor of claim 9, wherein said electronic device is substantially curved.

12. A method of manufacturing a flexible sensor, comprising the steps of:

25 providing a first conductive layer and a second conductive layer, said first conductive layer and said second conductive layer defining a sensing region for determining a mechanical interaction, said first conductive layer comprising a first substrate and said second conductive layer comprising a second substrate;

printing a plurality of conductive rows on said first substrate;

30 printing a plurality of conductive columns on said second substrate;

constraining said first conductive layer and said second conductive layer by a constraining means such that said first conductive layer and said second conductive layer are maintained together while being permitted to move perpendicular to each other in said sensing region.

5

13. The method of claim 12, further comprising the step of: suspending said first conductive layer and said second conductive layer in a free floating configuration within an enclosure.

10

14. The method of claim 13, further comprising the step of: attaching said enclosure to an electronic device.

15

15. The method of claim 12, wherein said step of positioning includes the steps of: constraining said first conductive layer and said second conductive layer by said constraining means in a first direction and a second direction parallel to said first conductive layer and said second conductive layer respectively.

20

16. The method of claim 12, further comprising the step of: printing a substance that exhibits a variable resistivity onto said first substrate.

17. The method of claim 16, wherein said substance is a quantum tunnelling ink.

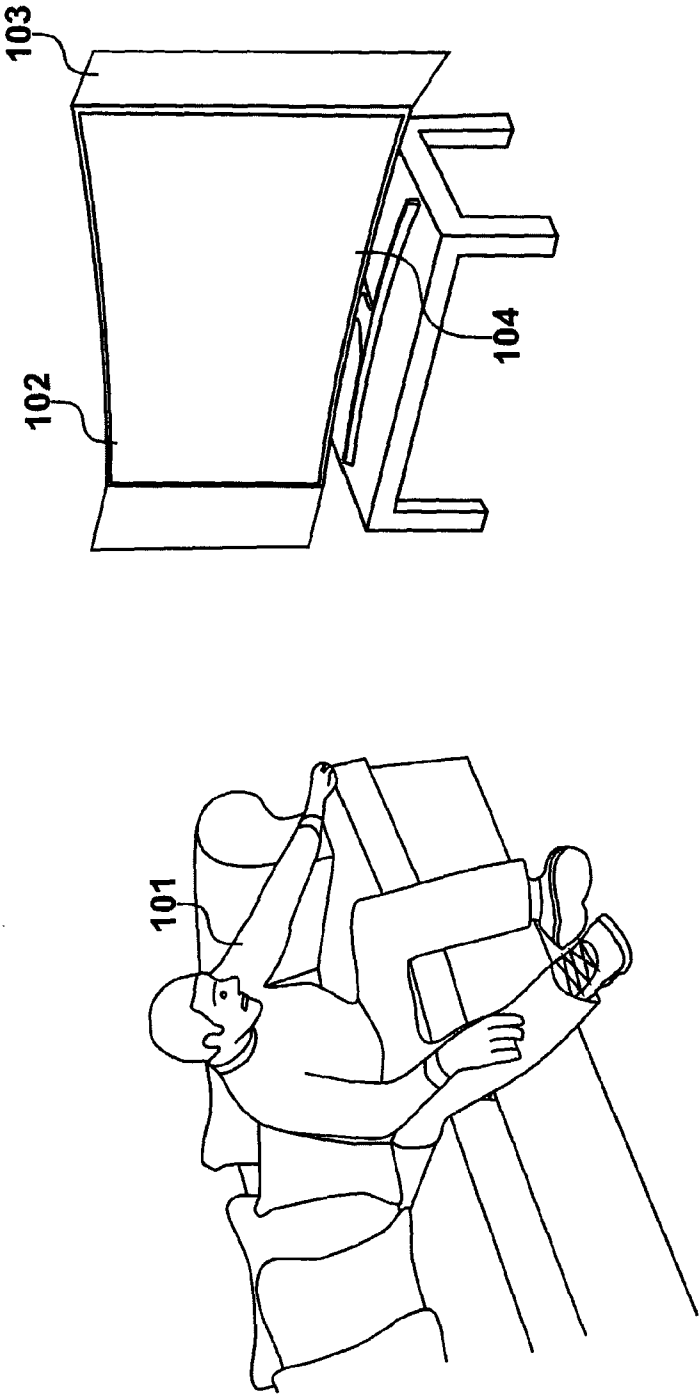
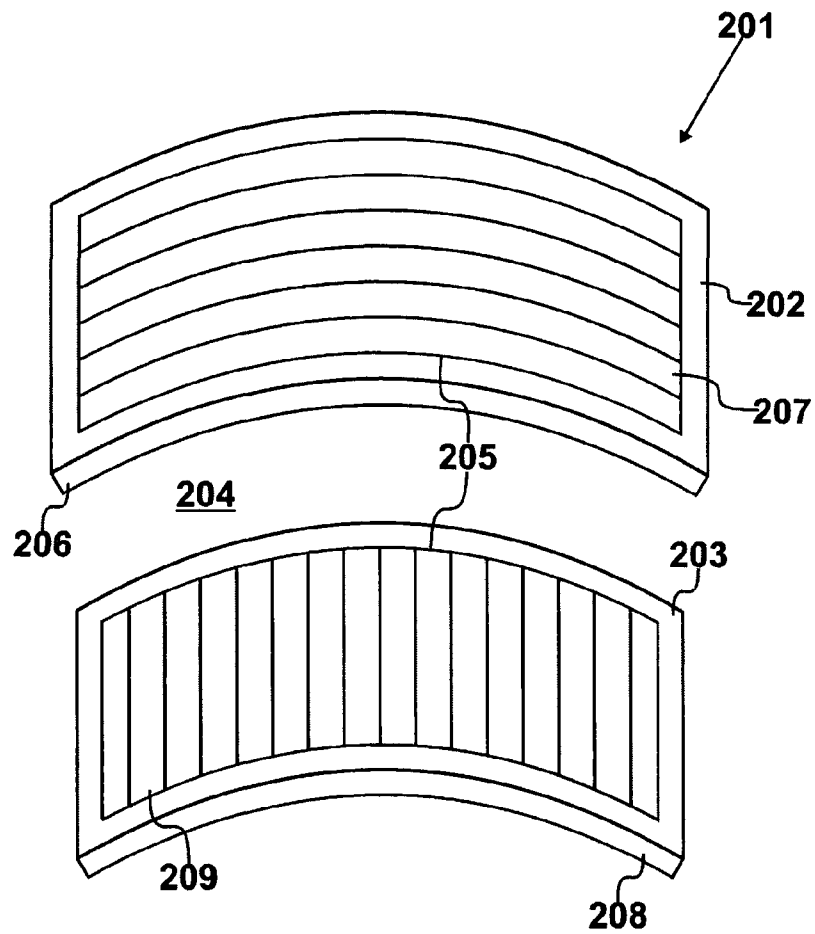


Fig. 1

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*Fig. 2*

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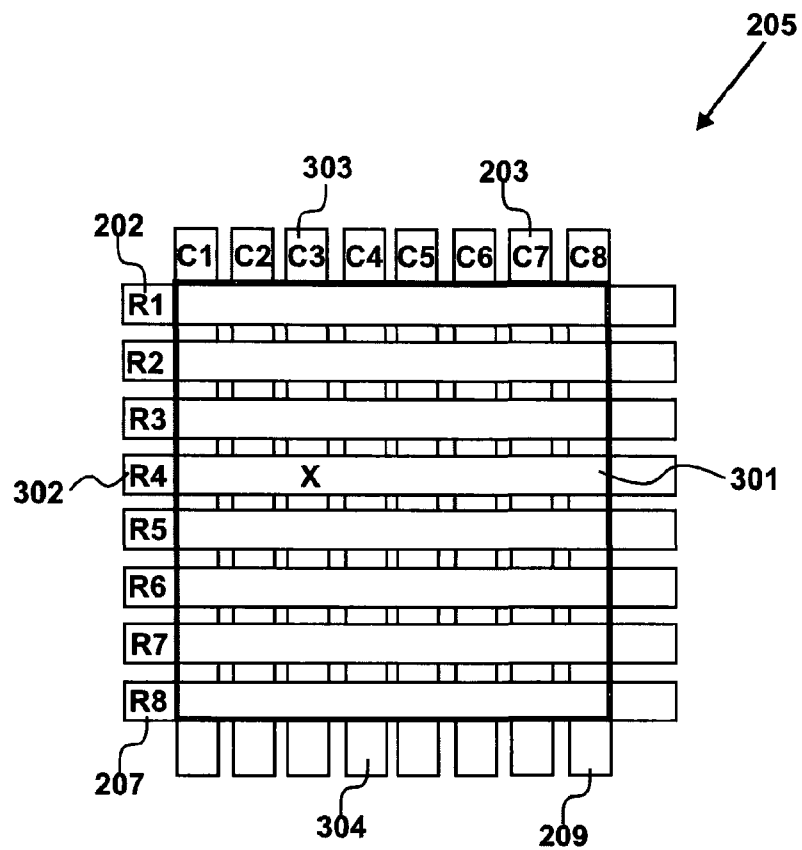


Fig. 3

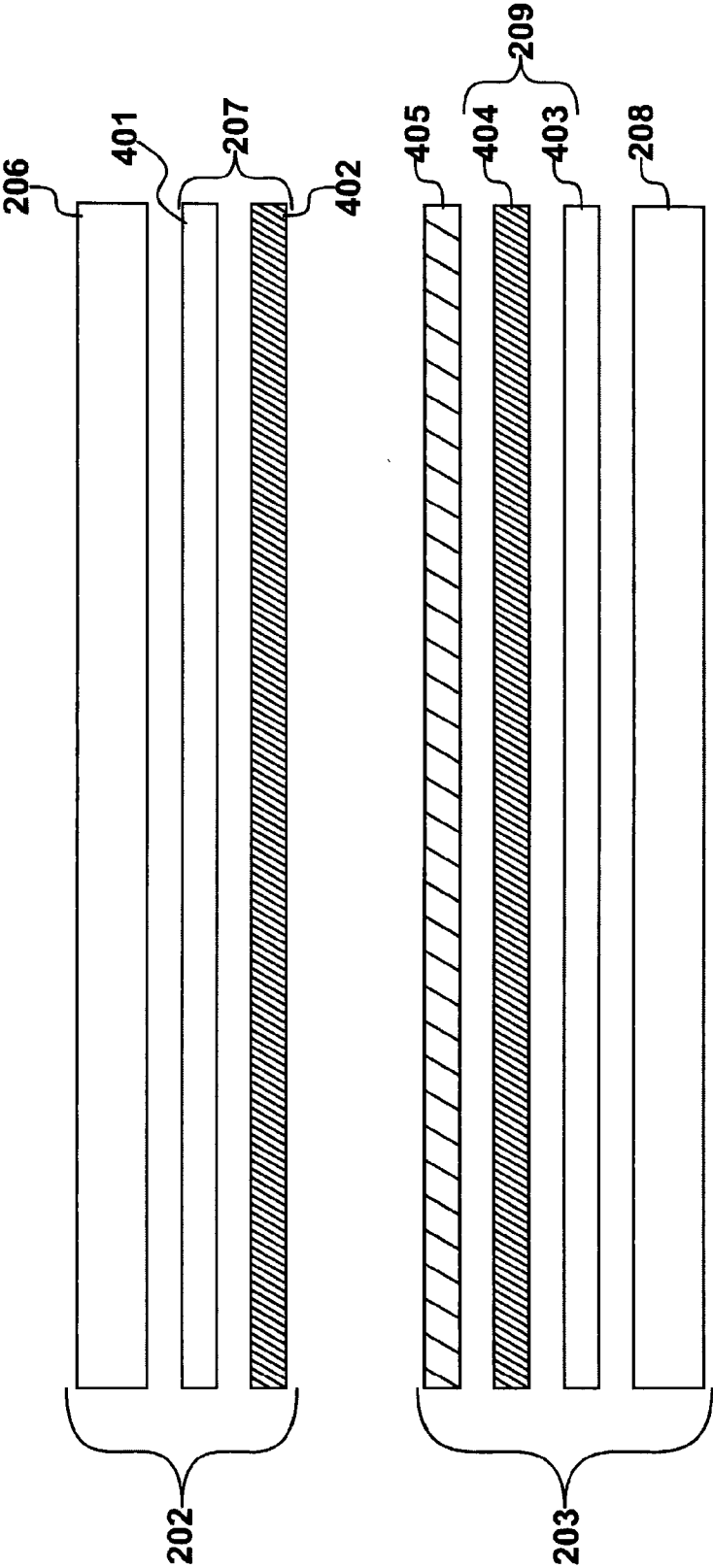


Fig. 4

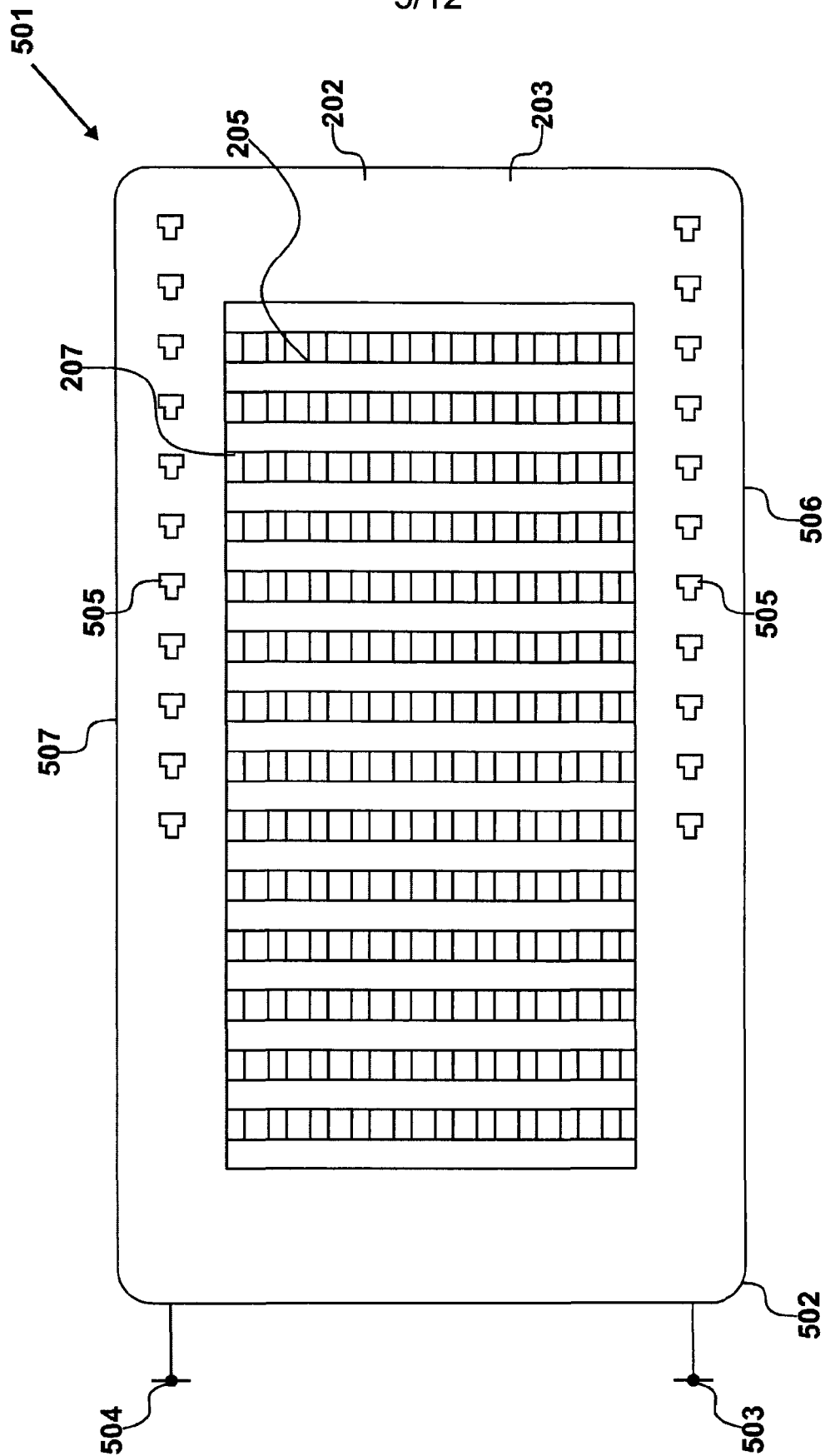
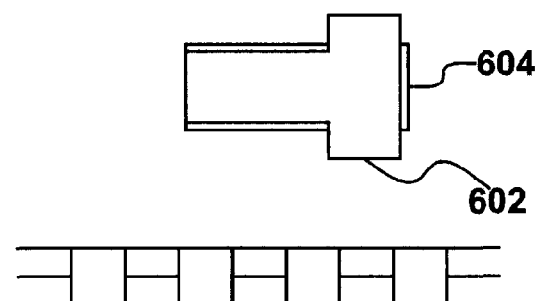
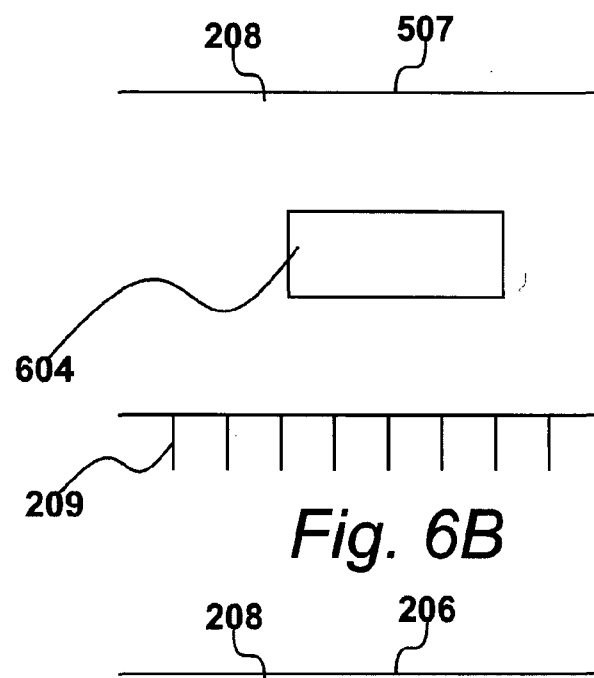
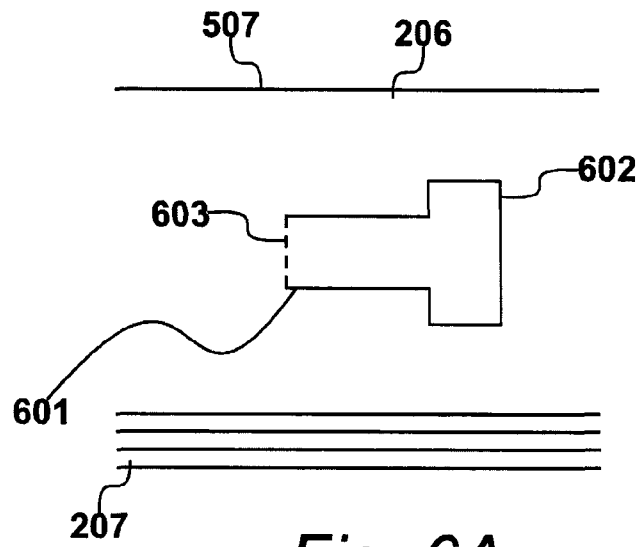


Fig. 5

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Fig. 7A

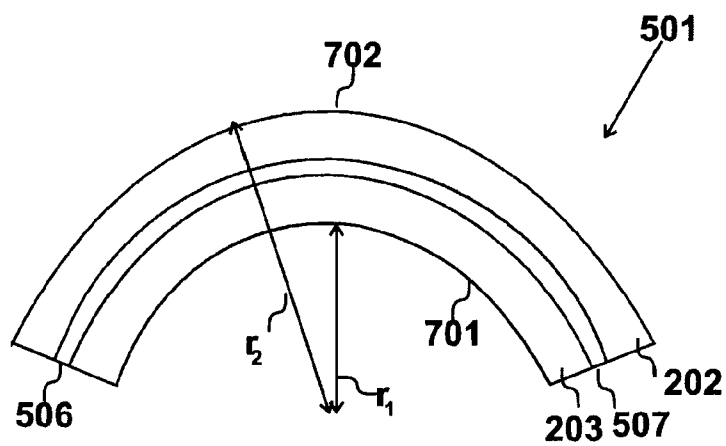


Fig. 7B

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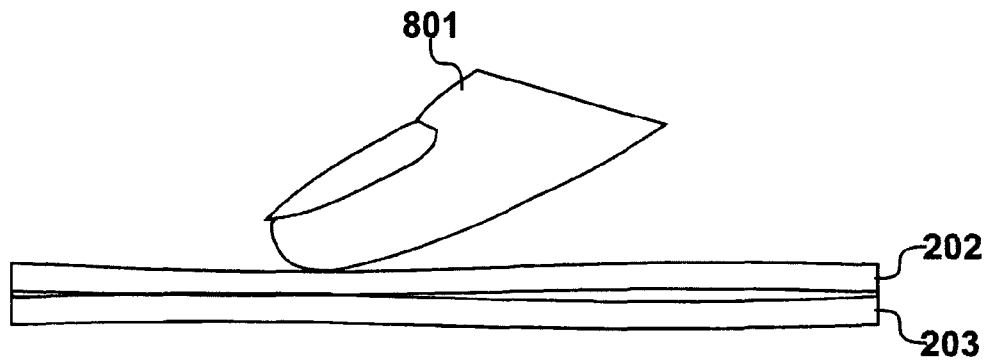


Fig. 8A

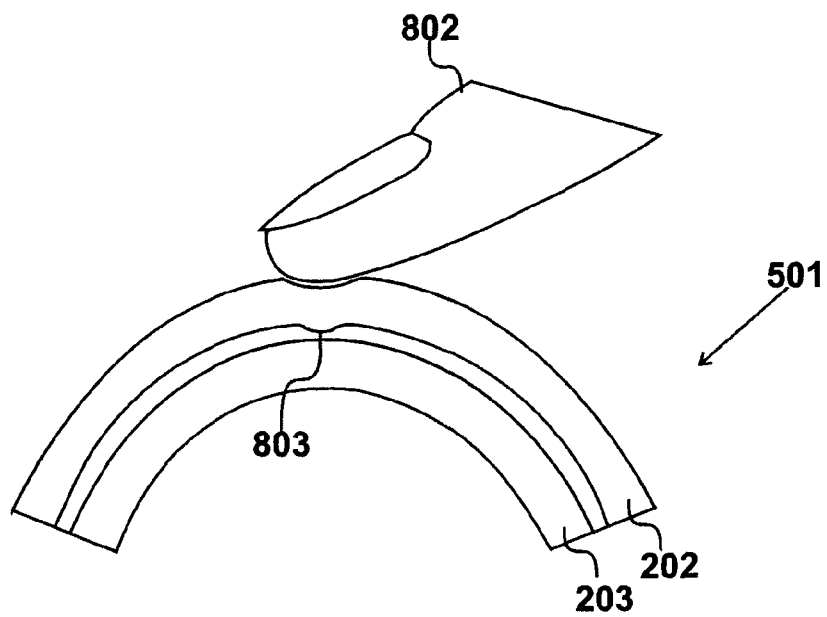


Fig. 8B

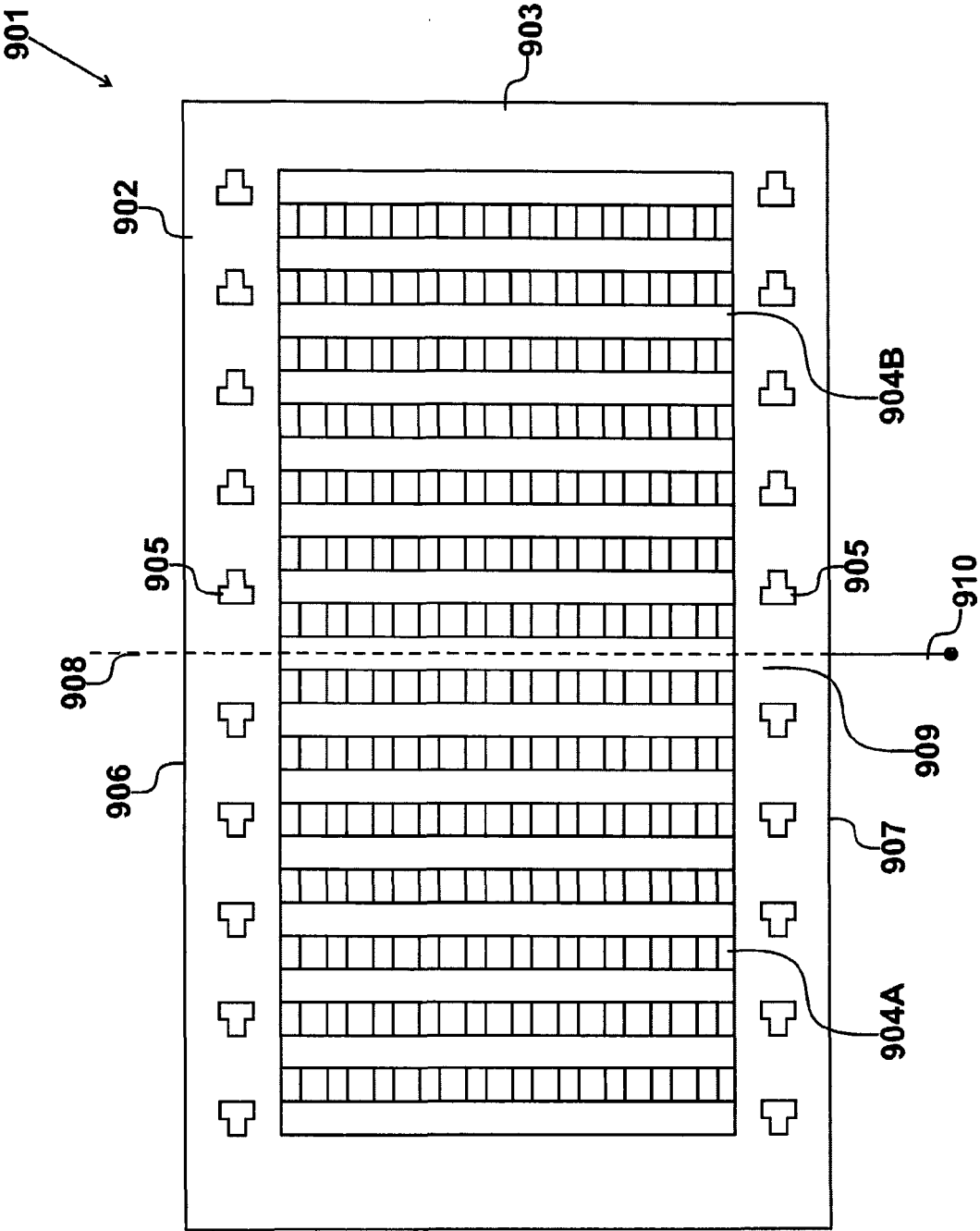


Fig. 9

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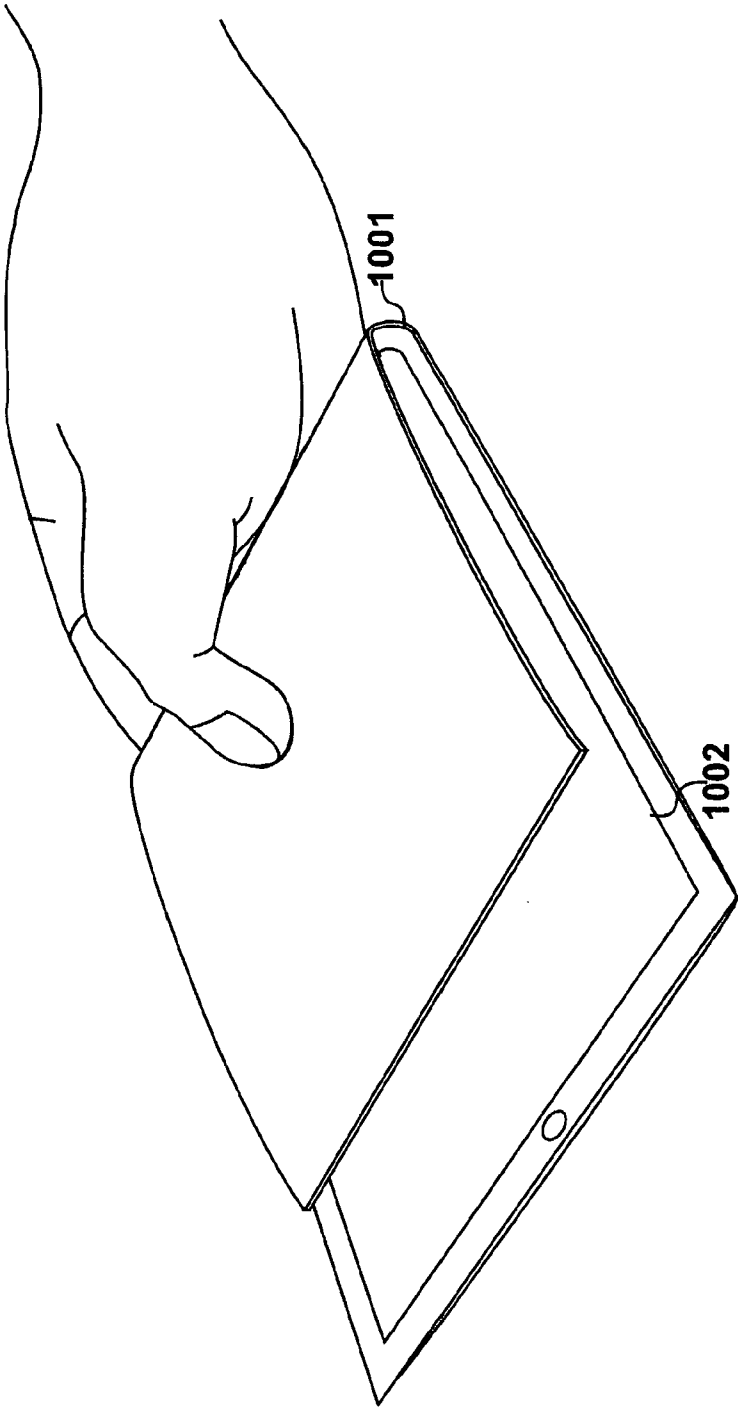


Fig. 10

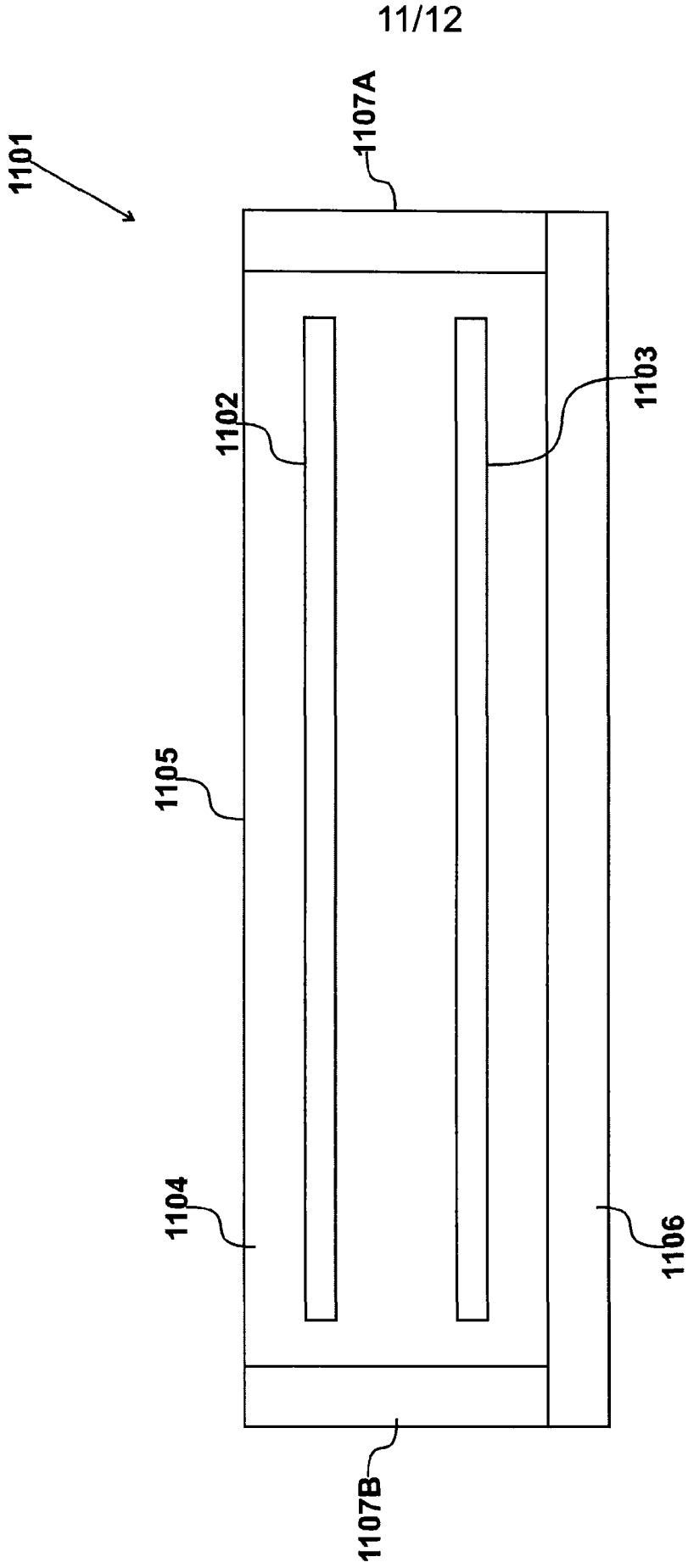


Fig. 11

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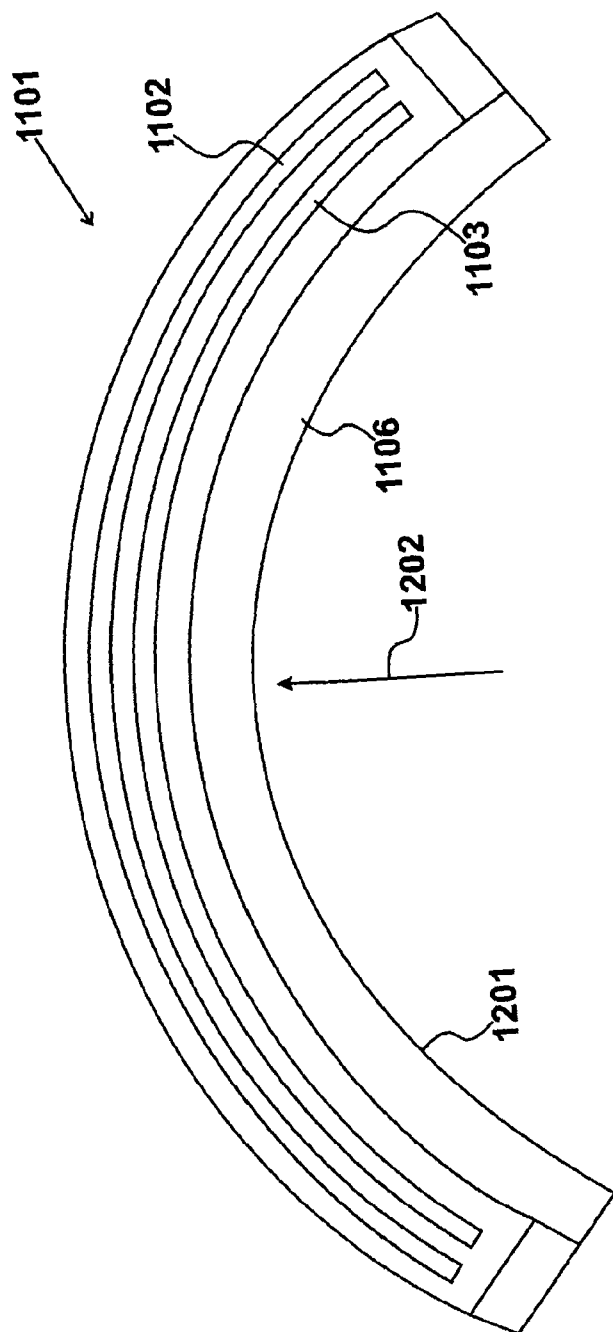


Fig. 12