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Cok

(54) **MICRO-WIRE ELECTRODES WITH EQUI-POTENTIAL DUMMY MICRO-WIRES**

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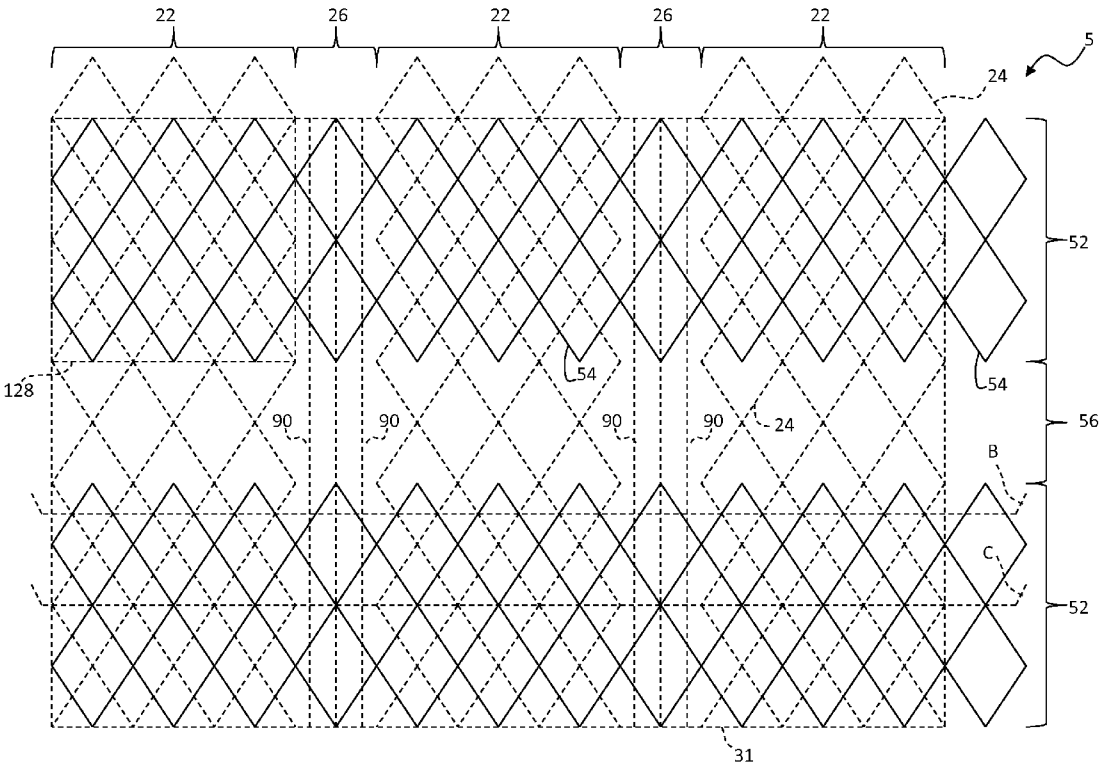
G06F 3/044 (2006.01)

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

CPC ***G06F 1/16*** (2013.01); ***G06F 3/044*** (2013.01); *G06F 2203/04112* (2013.01); *G06F 2203/04103* (2013.01)

(57) **ABSTRACT**

A micro-wire multi-electrode structure having an area of substantially uniform optical density includes a plurality of spatially separated patterned electrodes located in an electrode layer in the area. Each electrode includes a plurality of patterned conductive electrically connected electrode micro-wires. One or more patterned equi-potential electrically conductive dummy micro-wires in the area are located substantially along equi-potential lines between adjacent electrodes and are electrically isolated from the electrode micro-wires so that the area has a substantially uniform optical density. An unpatterned conductive layer is located in the area in electrical contact with the electrode micro-wires and the dummy micro-wires.



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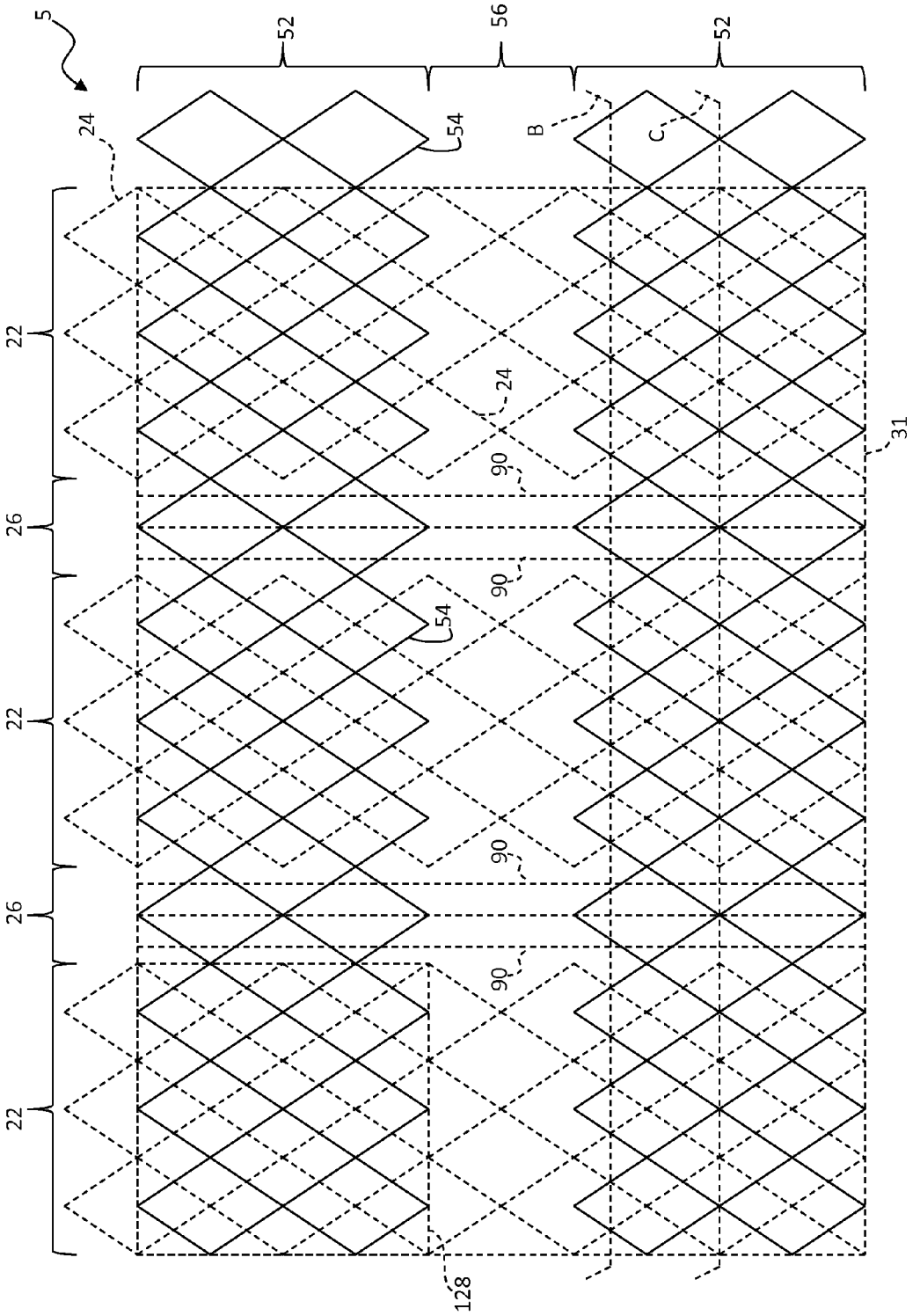

FIG. 1A

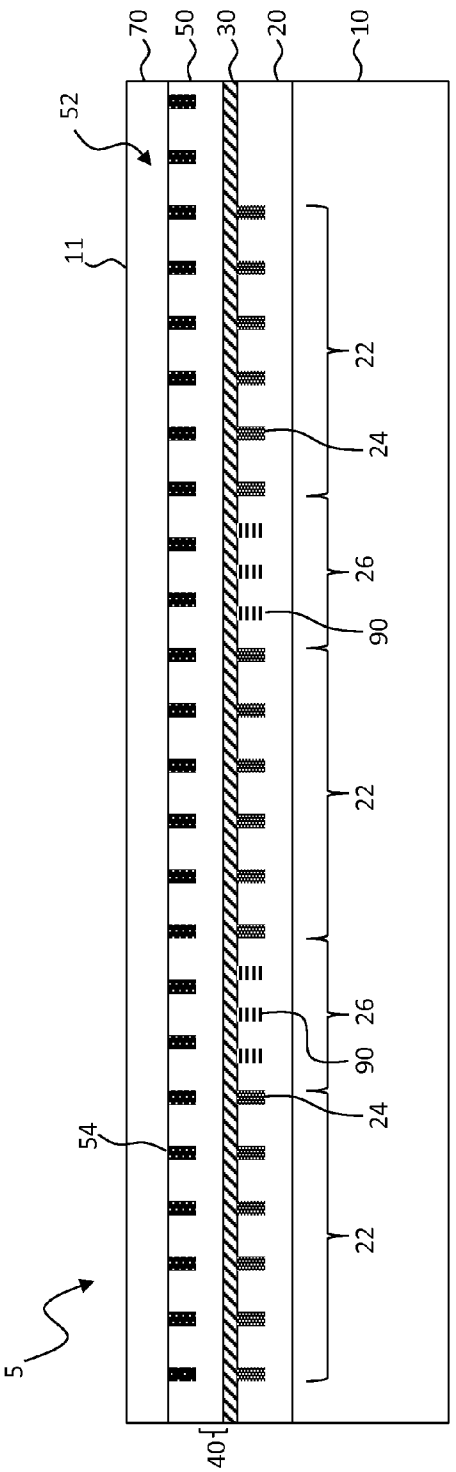
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FIG. 1B

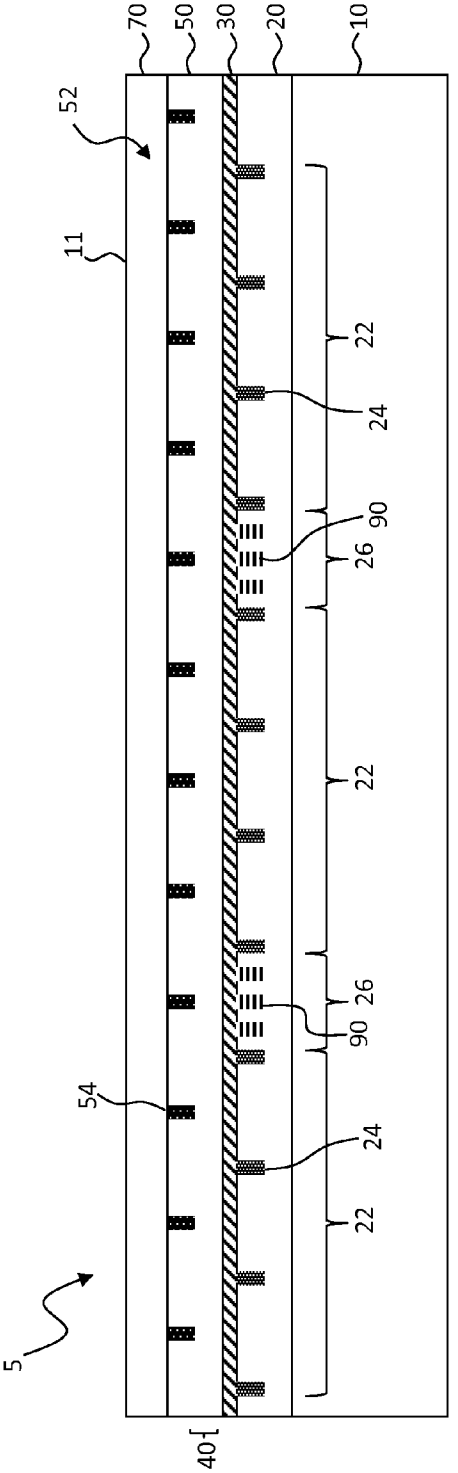
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FIG. 1C

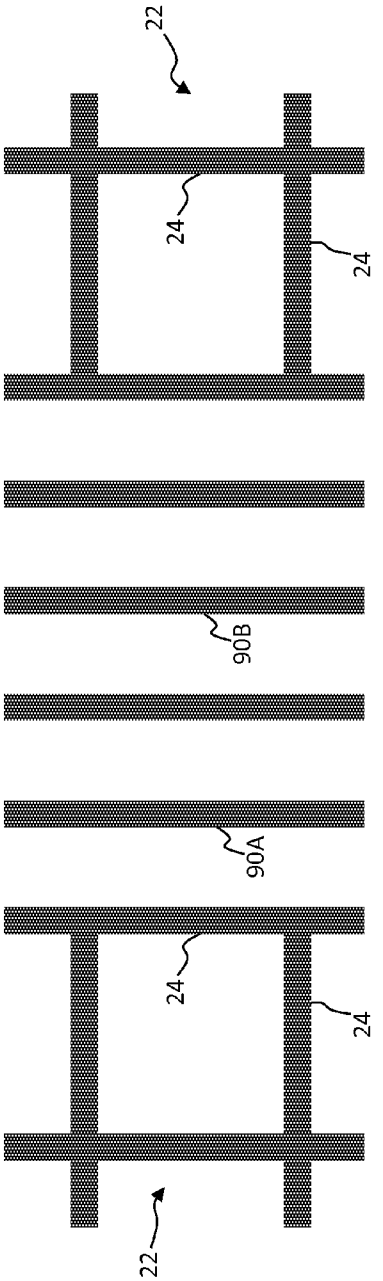

FIG. 2A

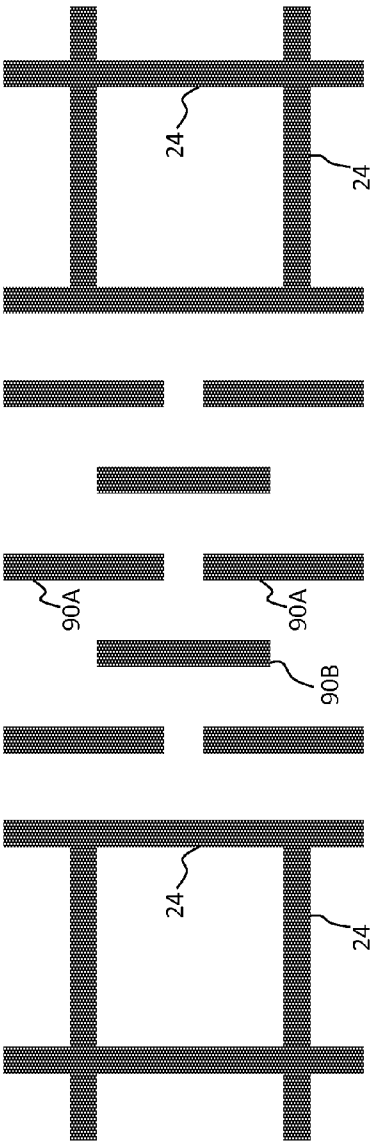

FIG. 2B

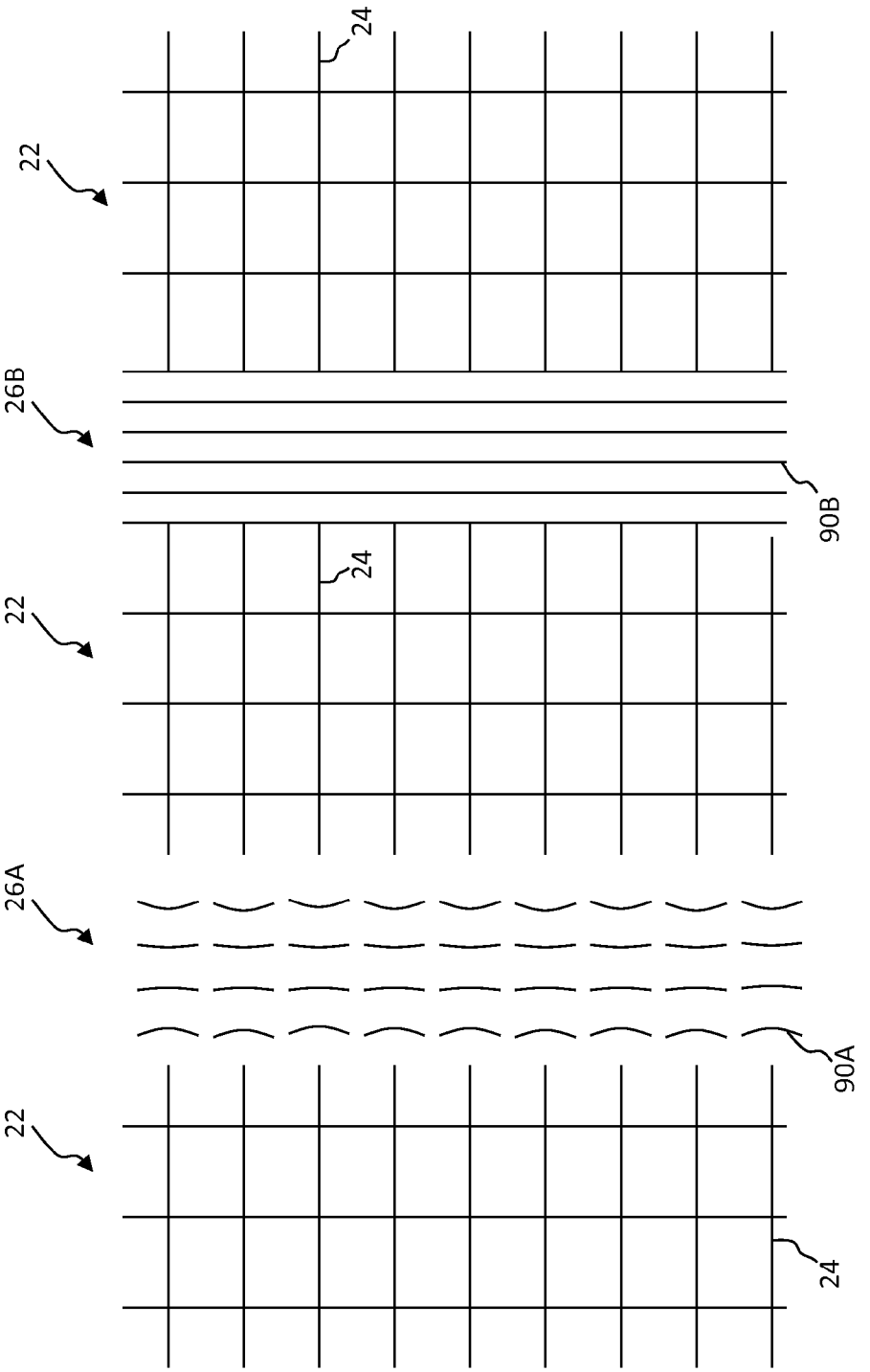

FIG. 3

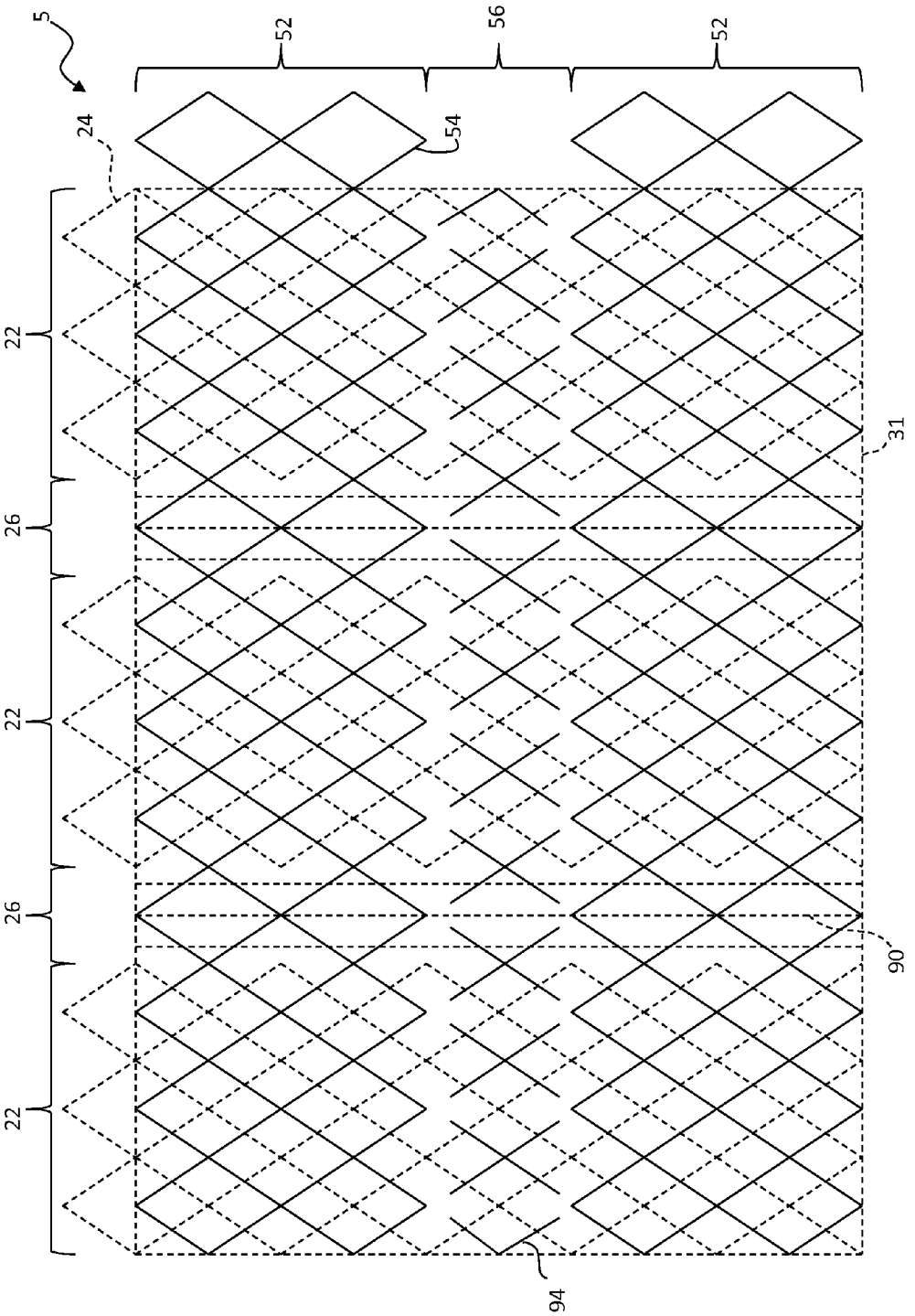

FIG. 4

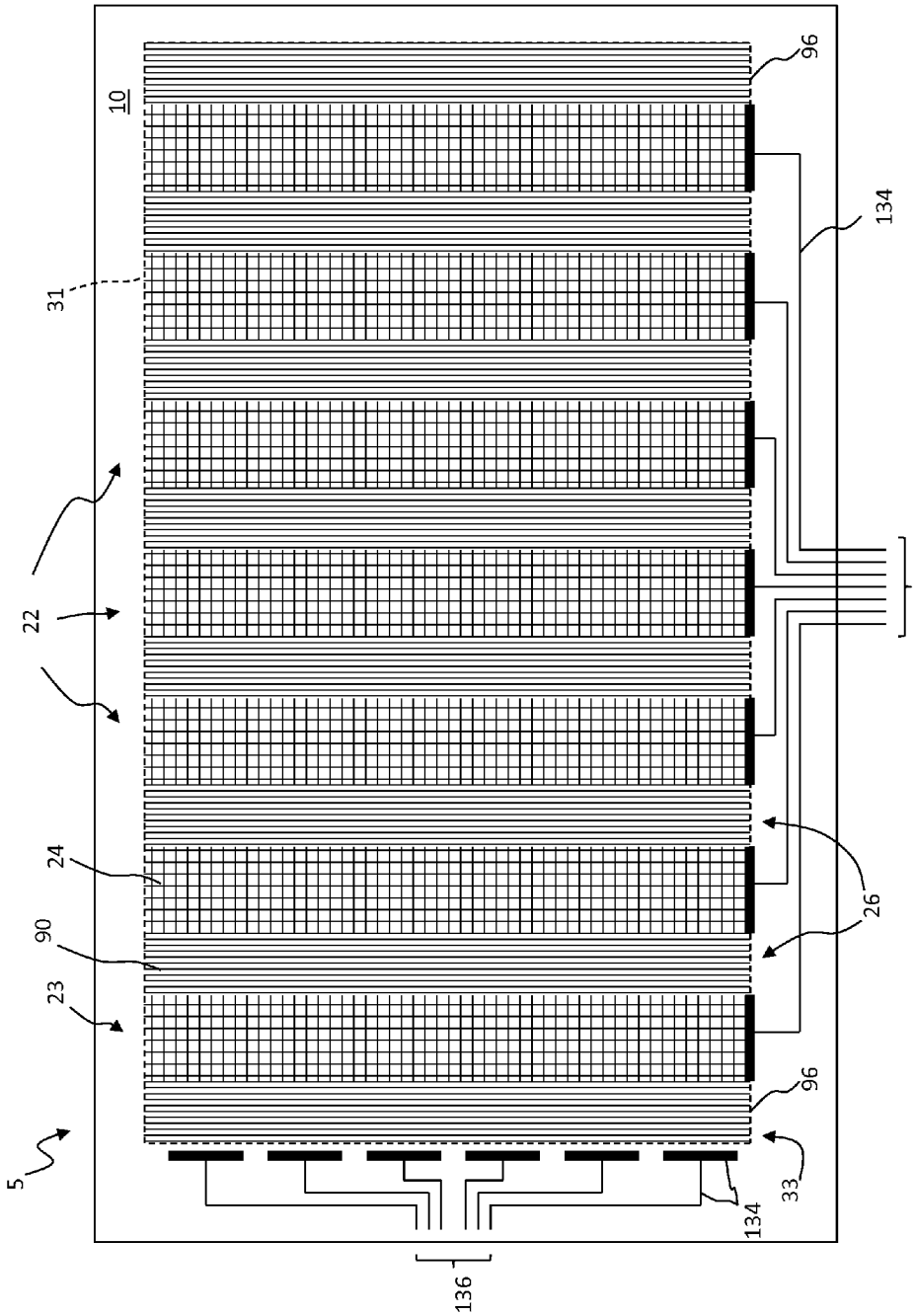

FIG. 5

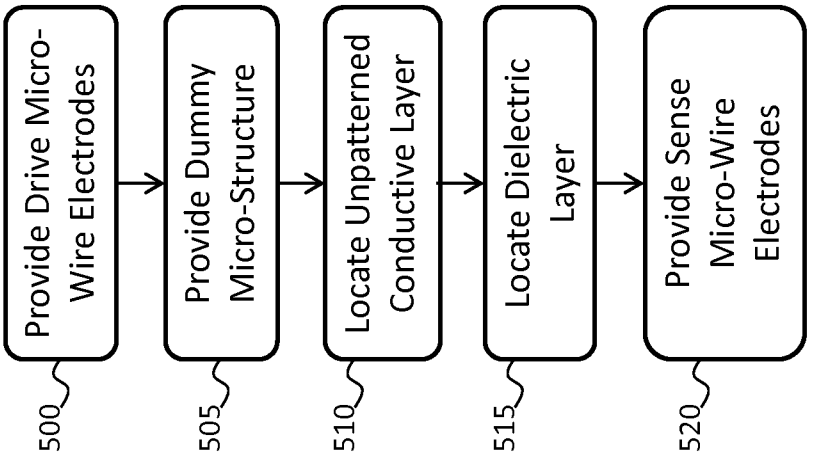
Provide Drive Micro-Wire Electrodes
Provide Dummy Micro-Structure
Locate Unpatterned Conductive Layer
Locate Dielectric Layer
Provide Sense Micro-Wire Electrodes
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FIG. 6

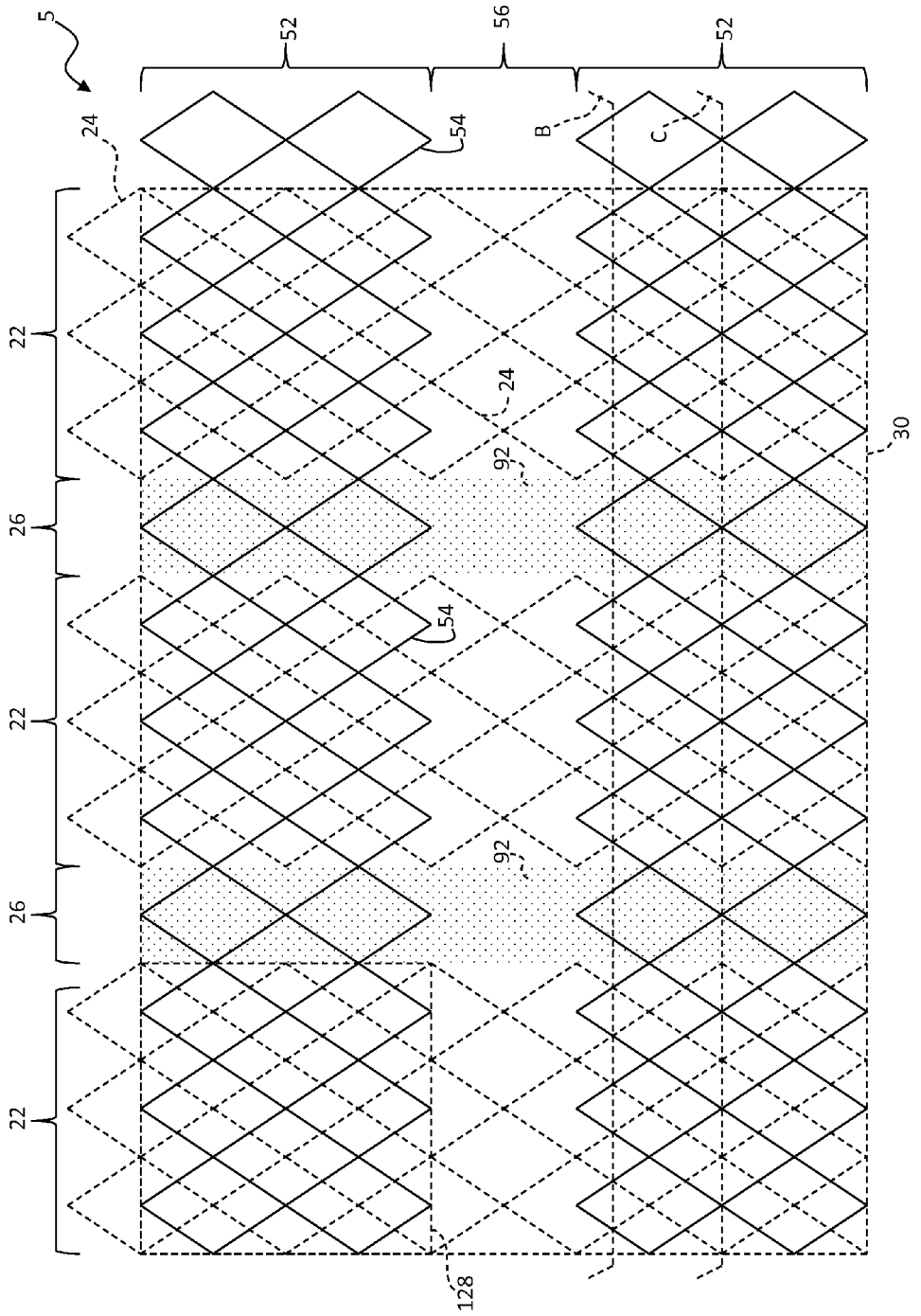

FIG. 7A

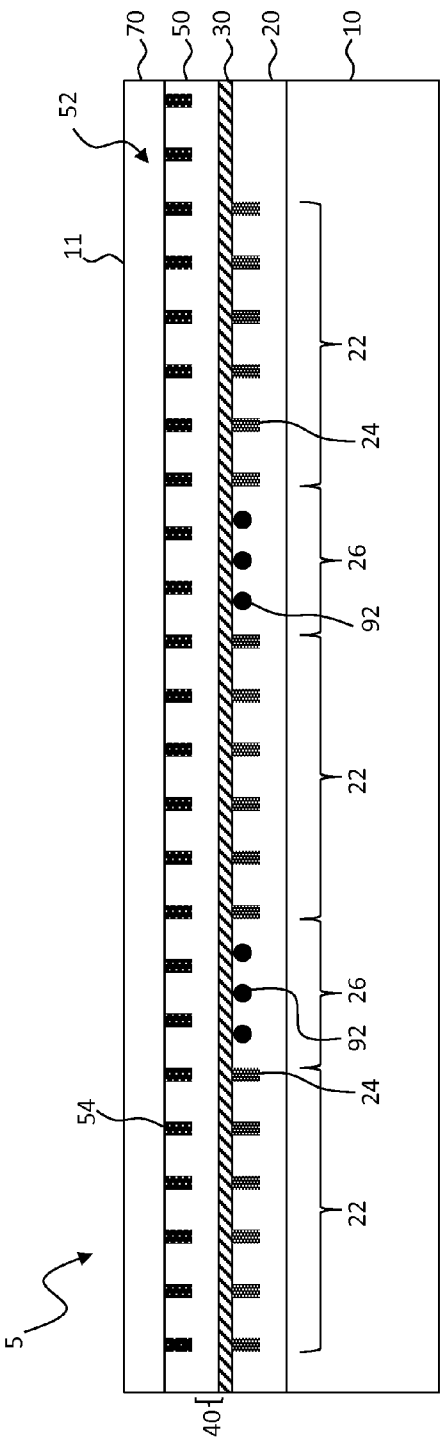
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FIG. 7B

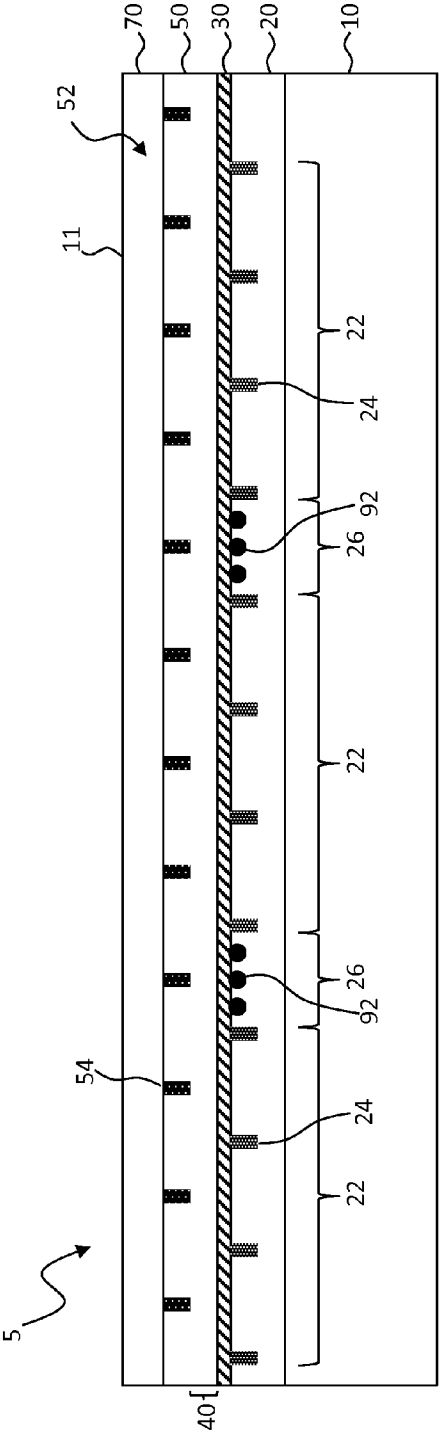
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FIG. 7C

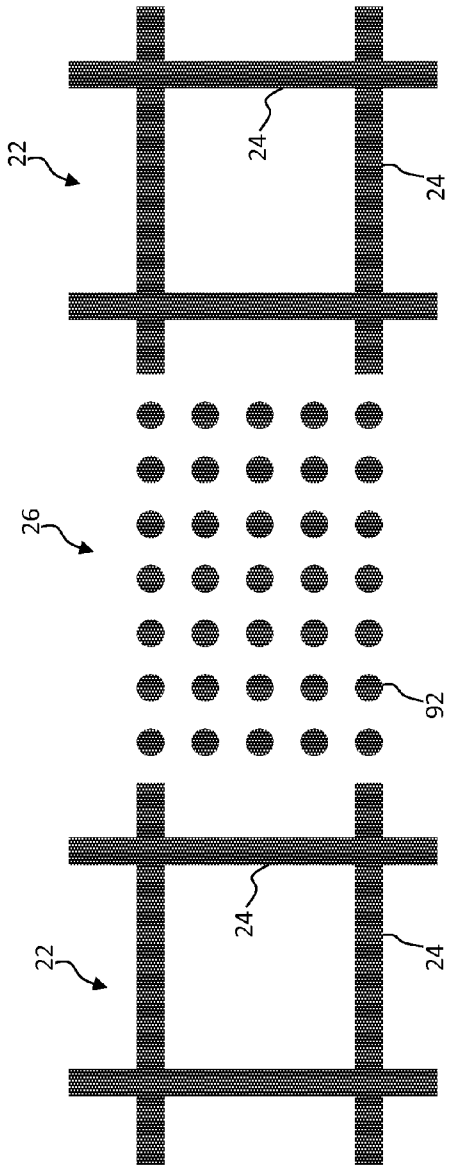


FIG. 8

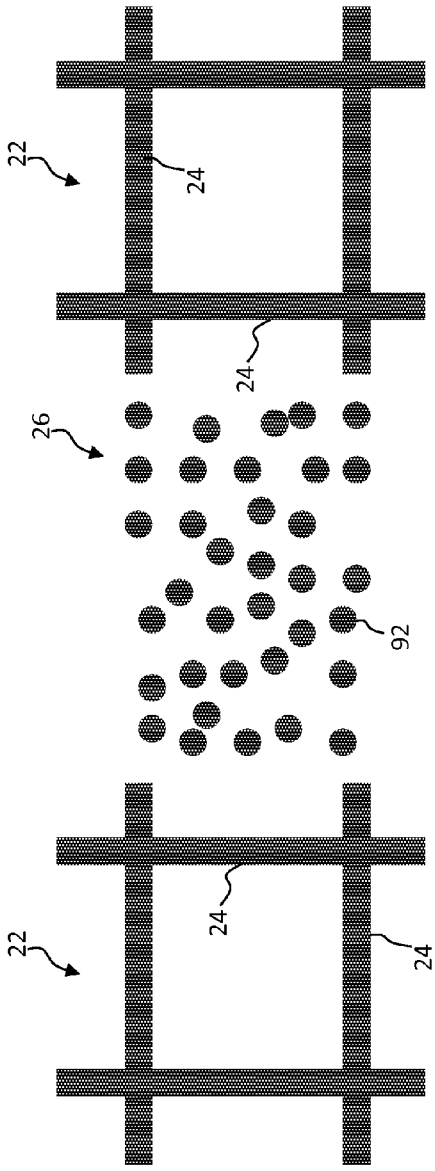


FIG. 9

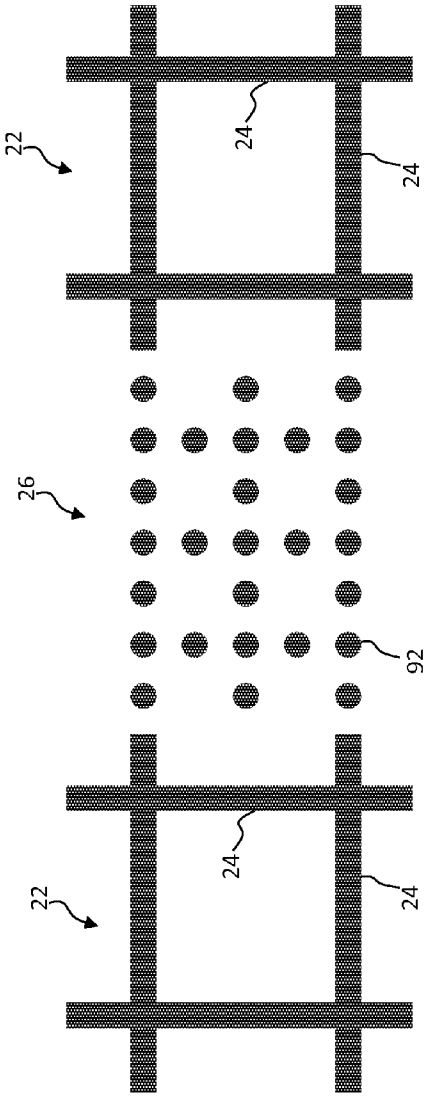


FIG. 10

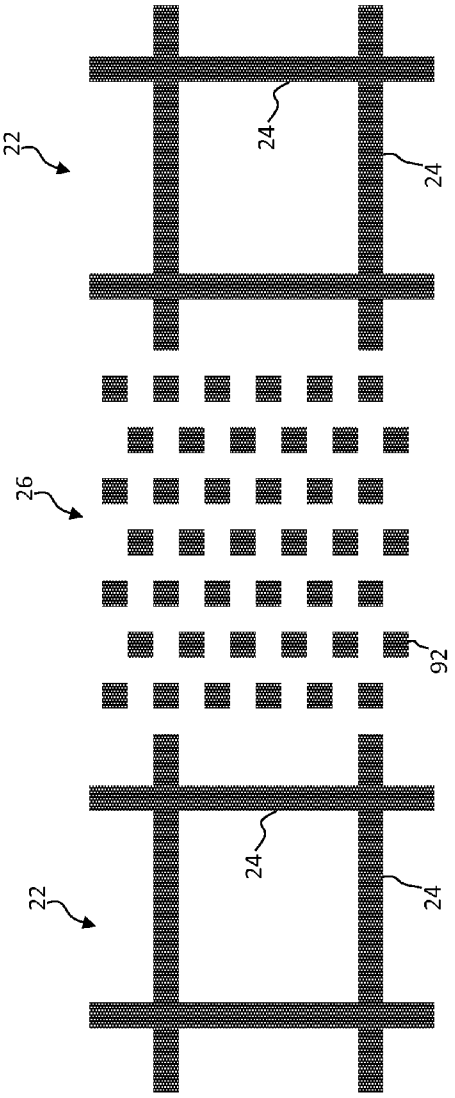


FIG. 11

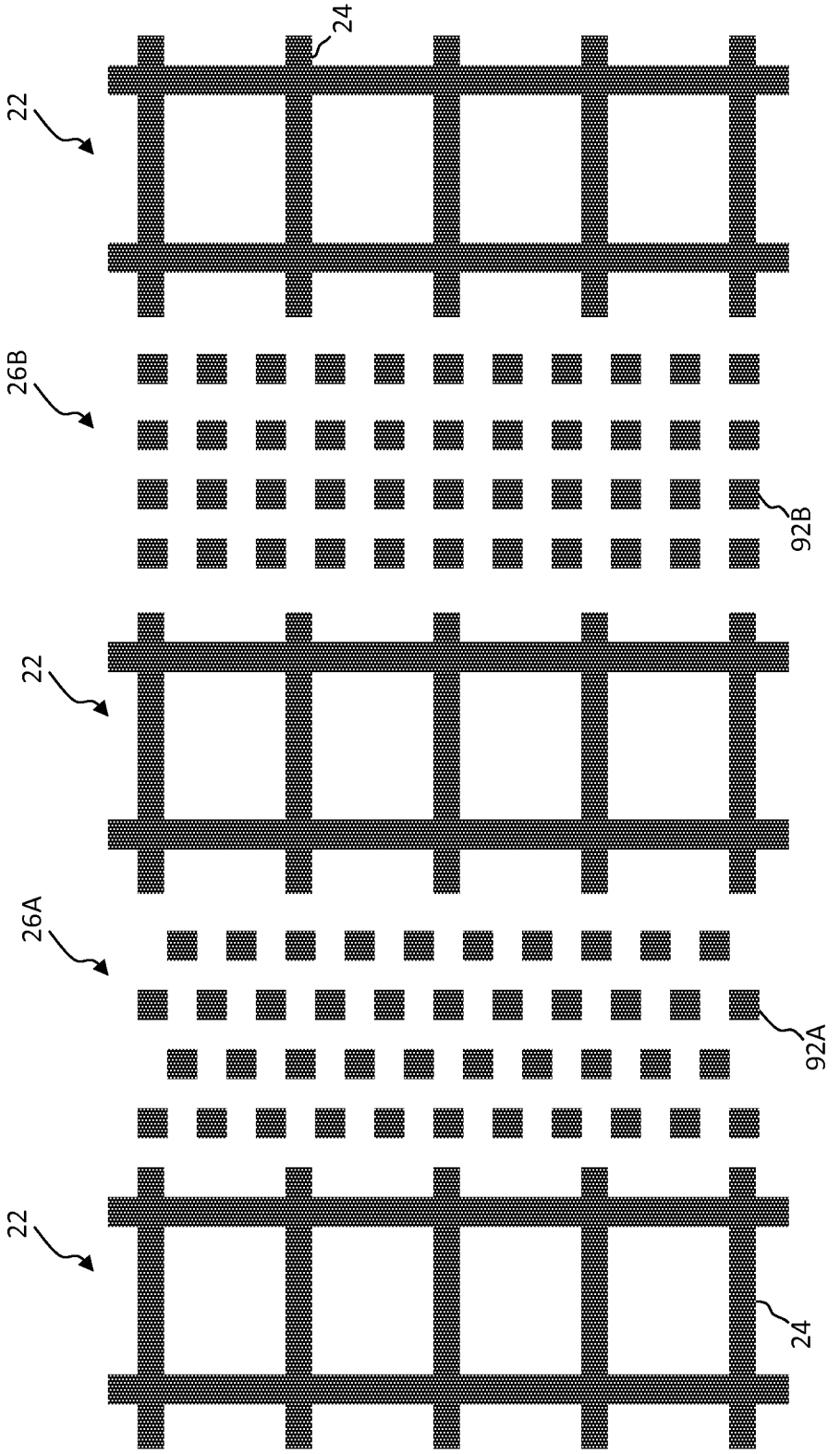


FIG. 12

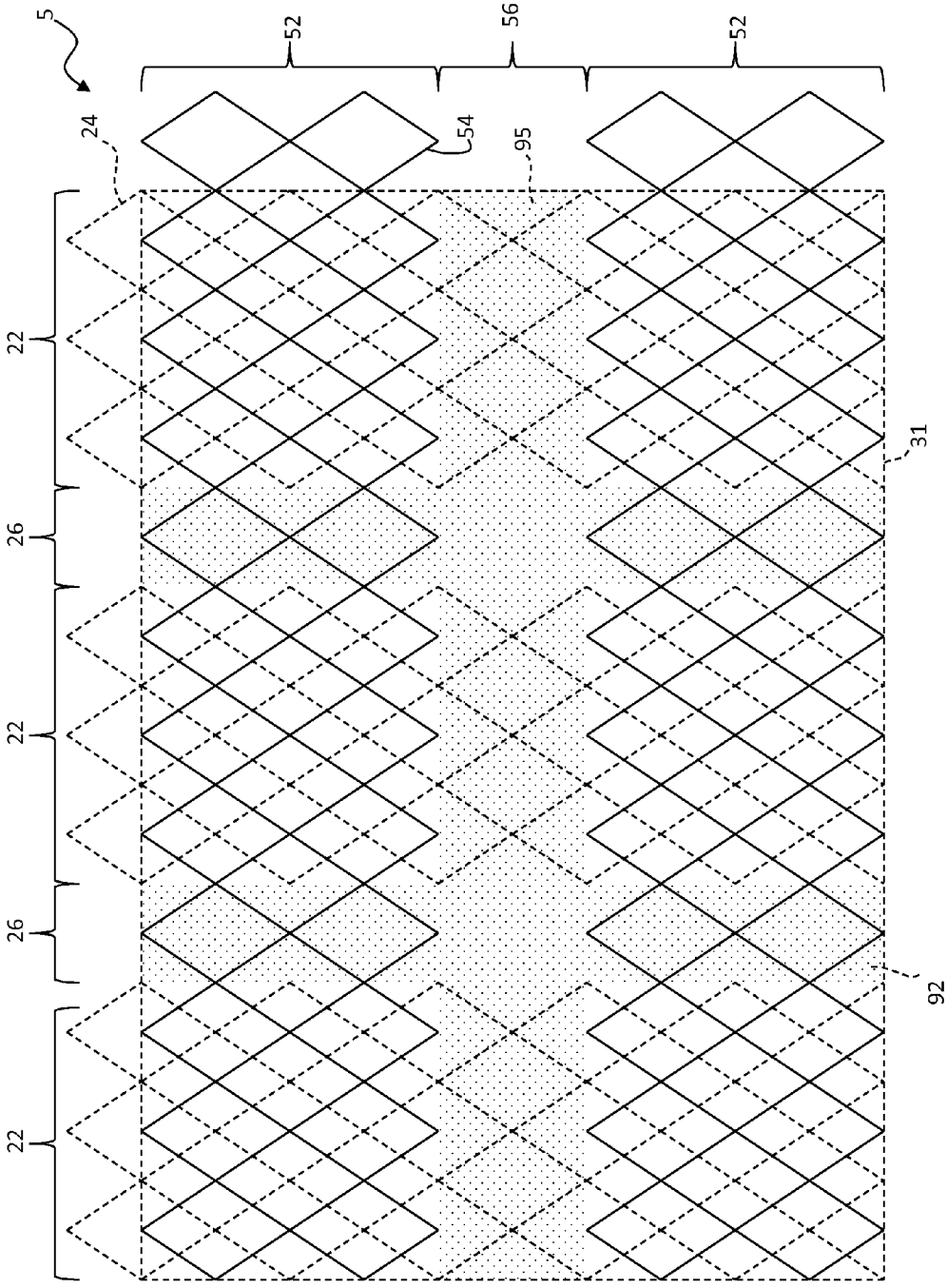


FIG. 13

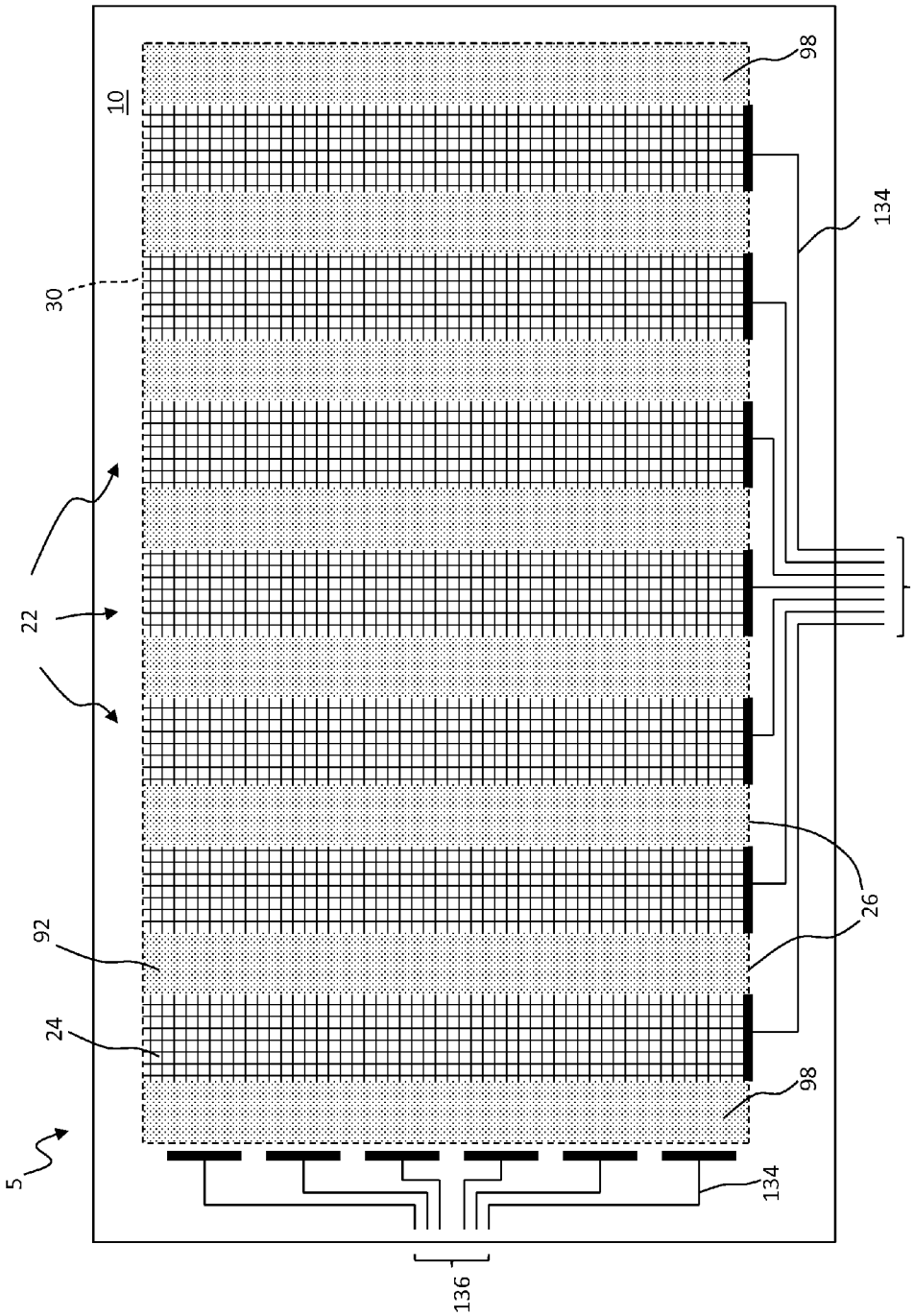


FIG. 14

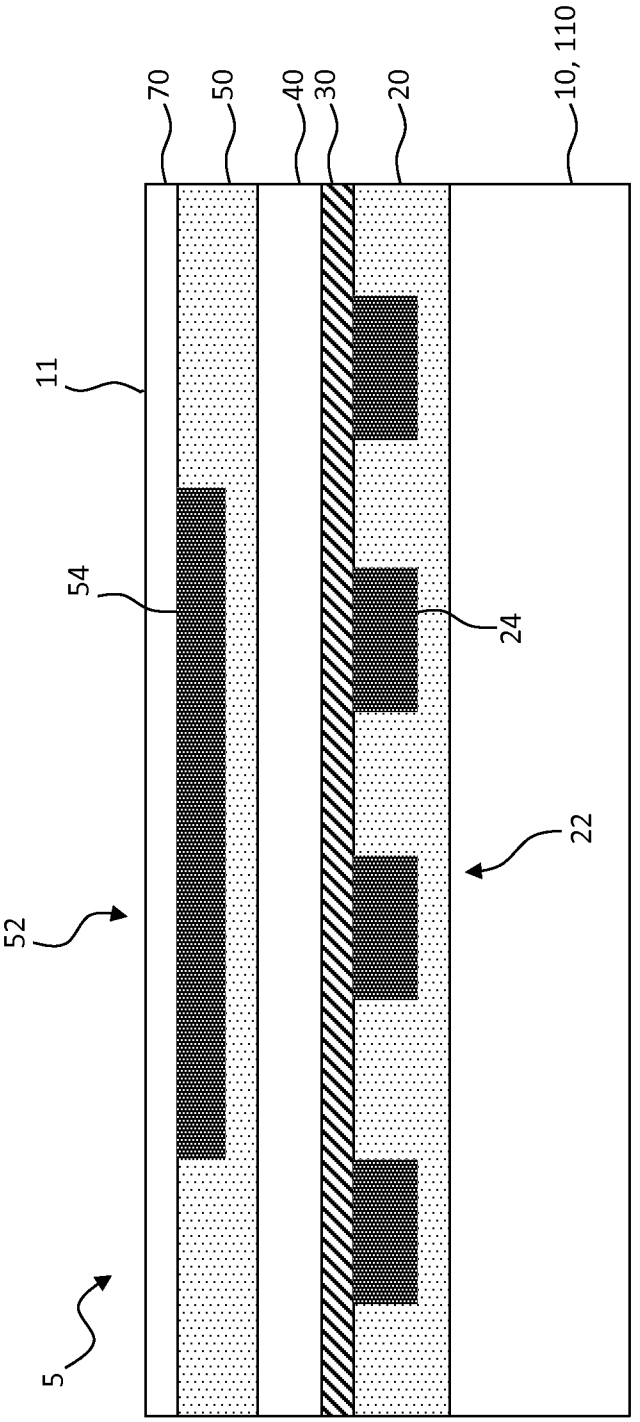


FIG. 15

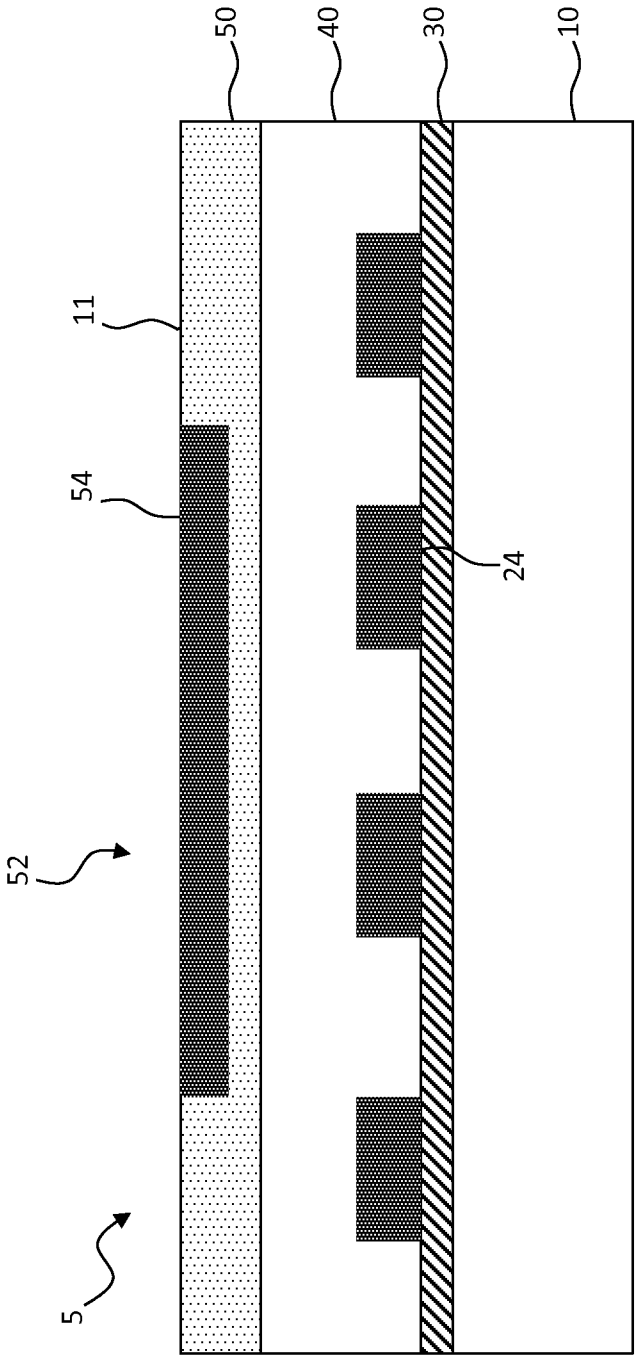


FIG. 16

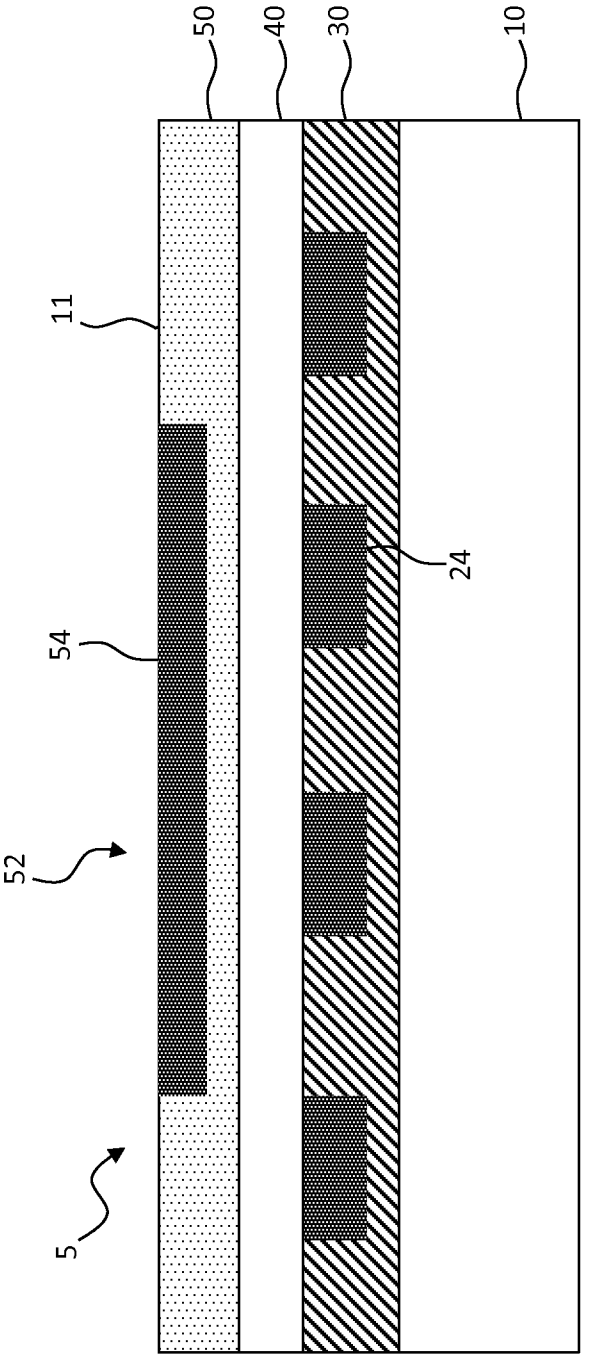


FIG. 17

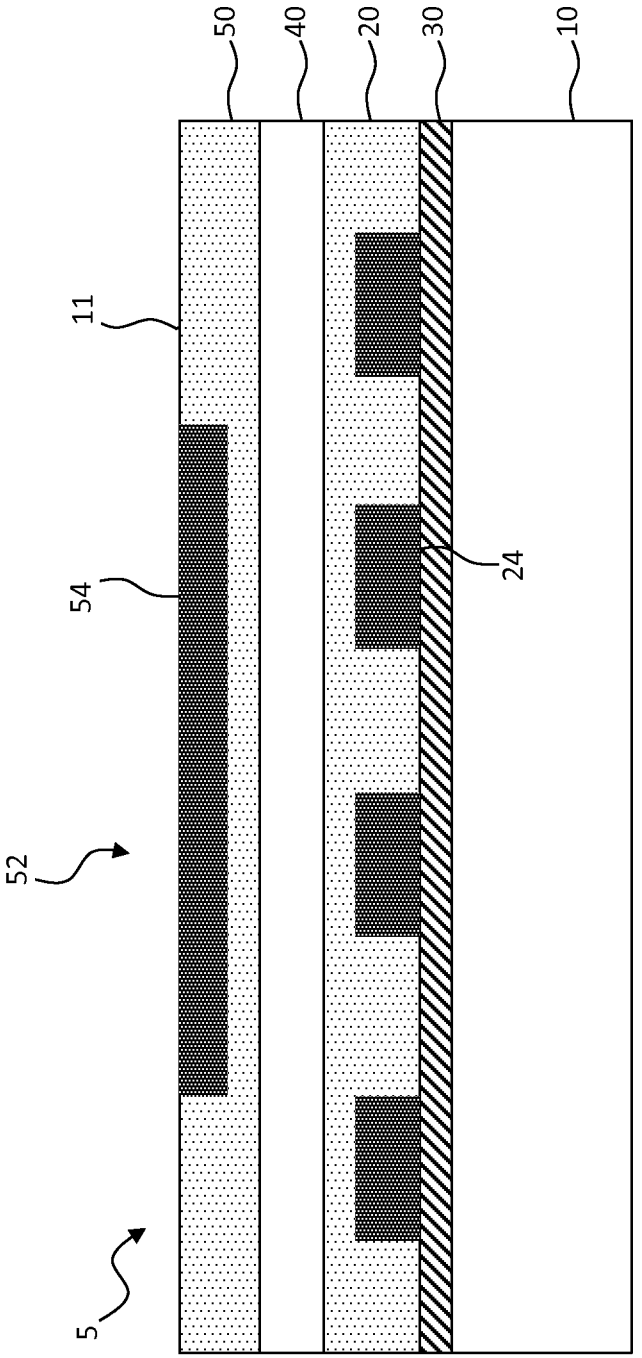


FIG. 18

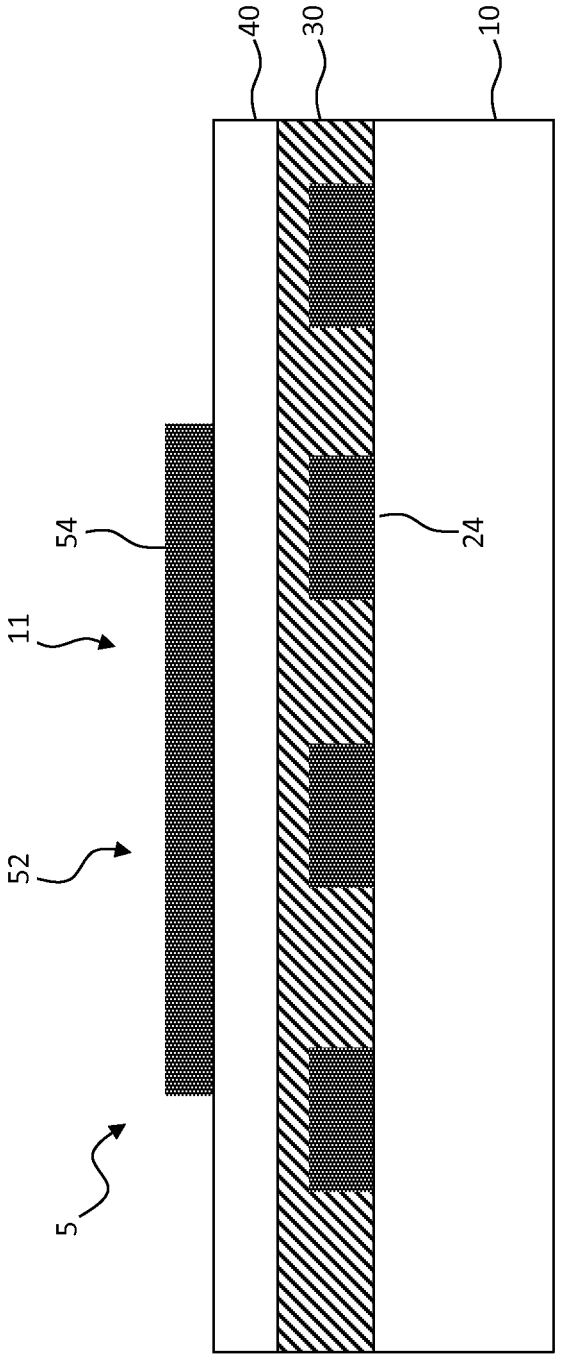


FIG. 19

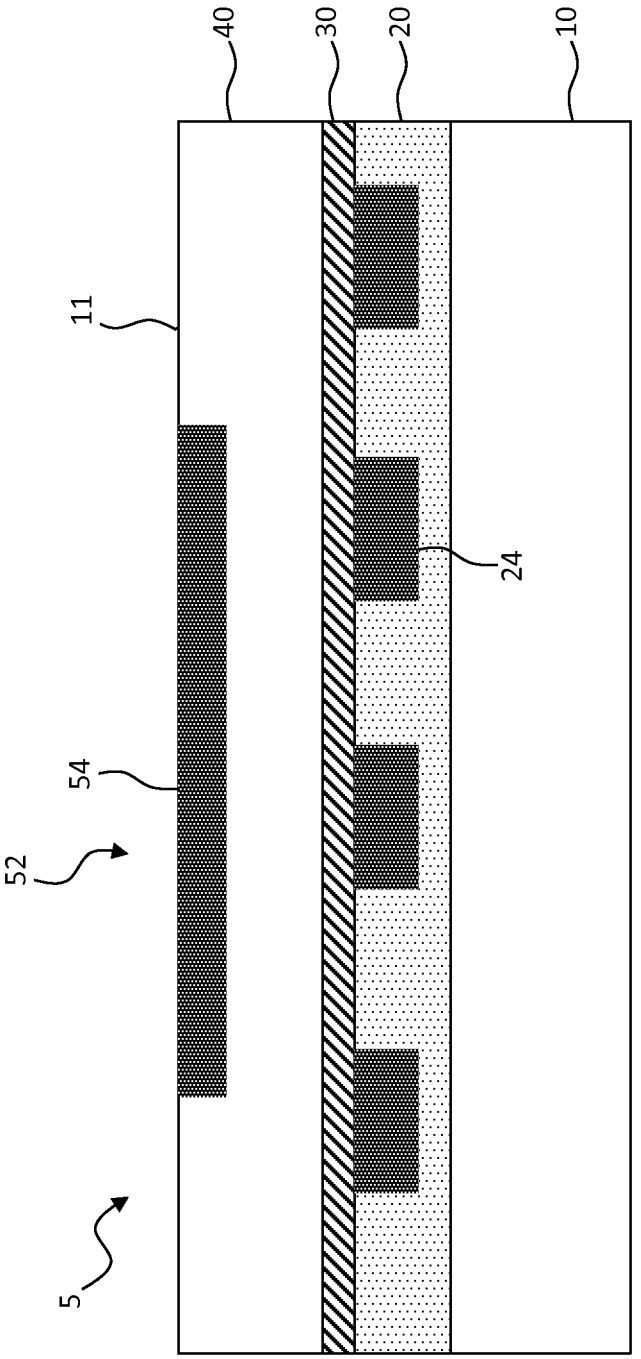


FIG. 20

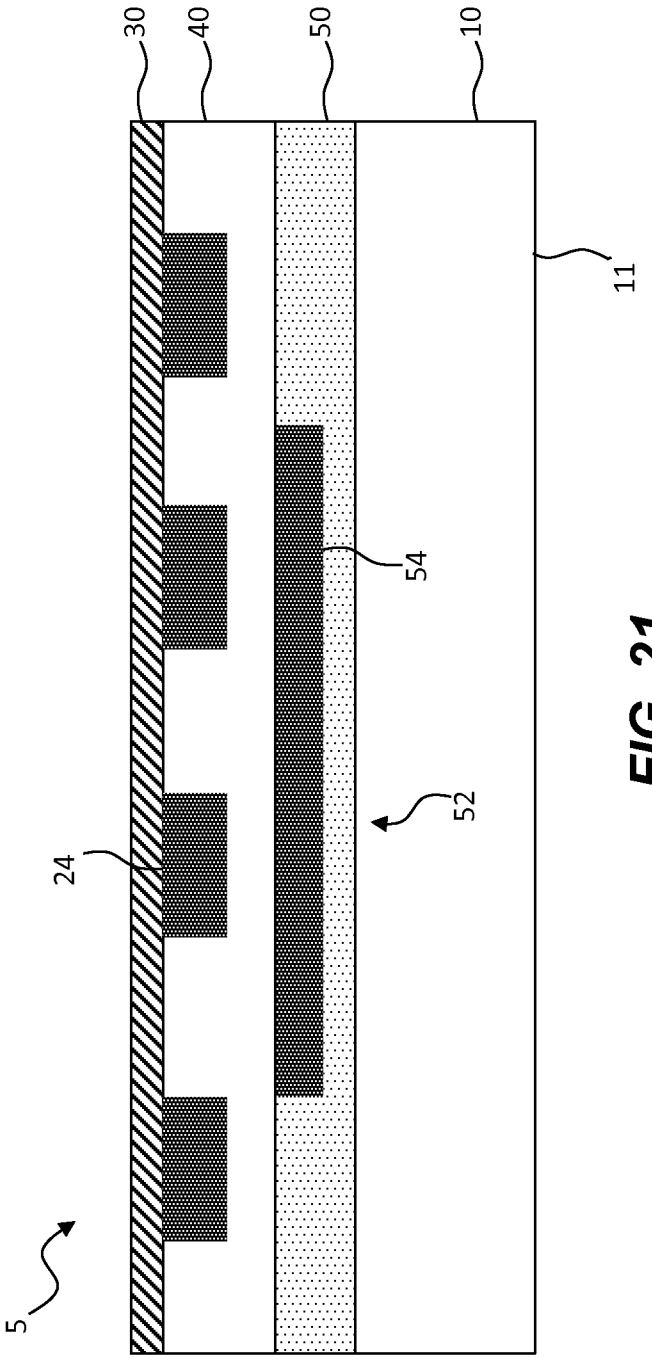


FIG. 21

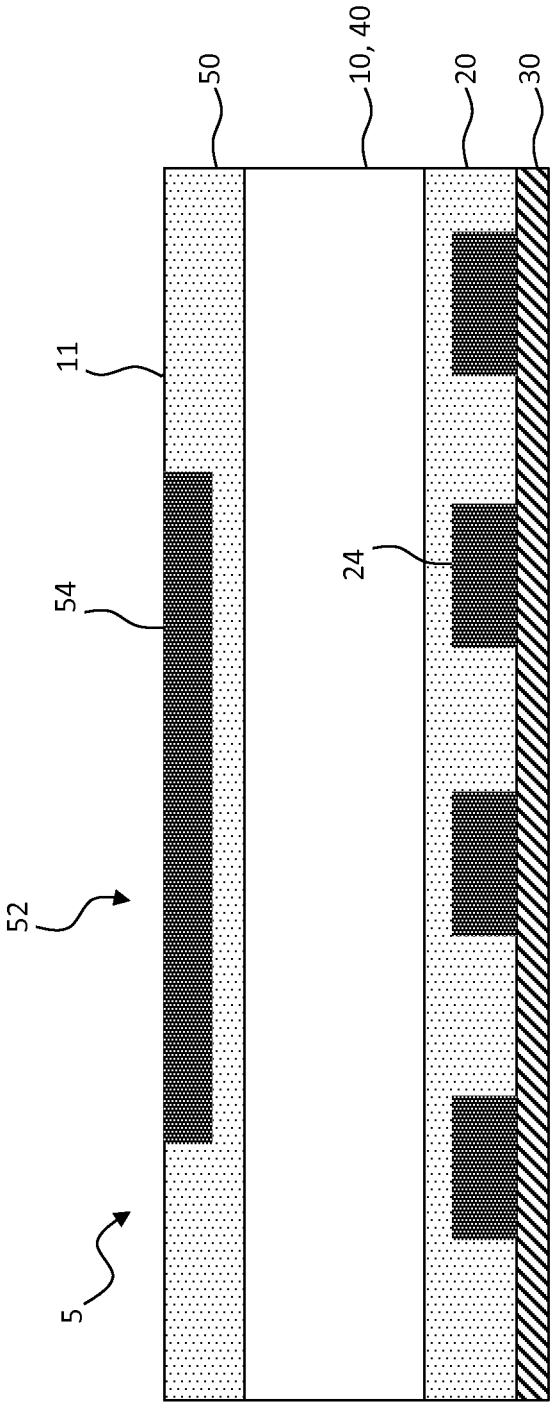


FIG. 22

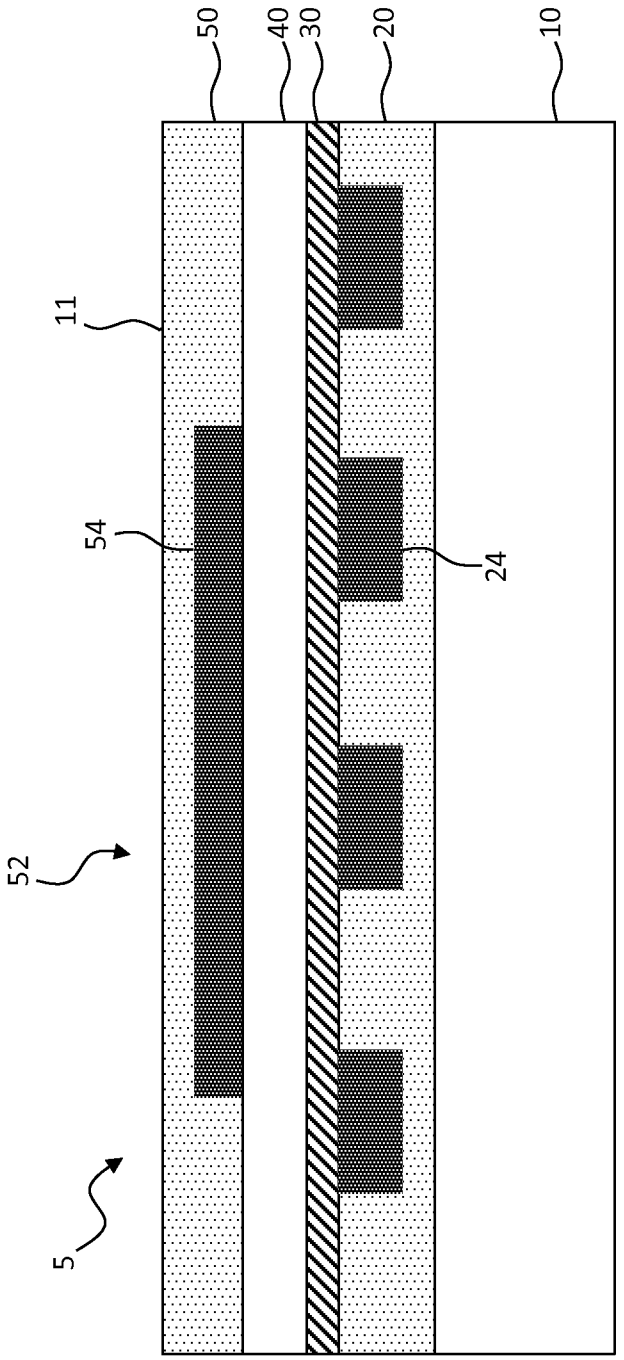


FIG. 23

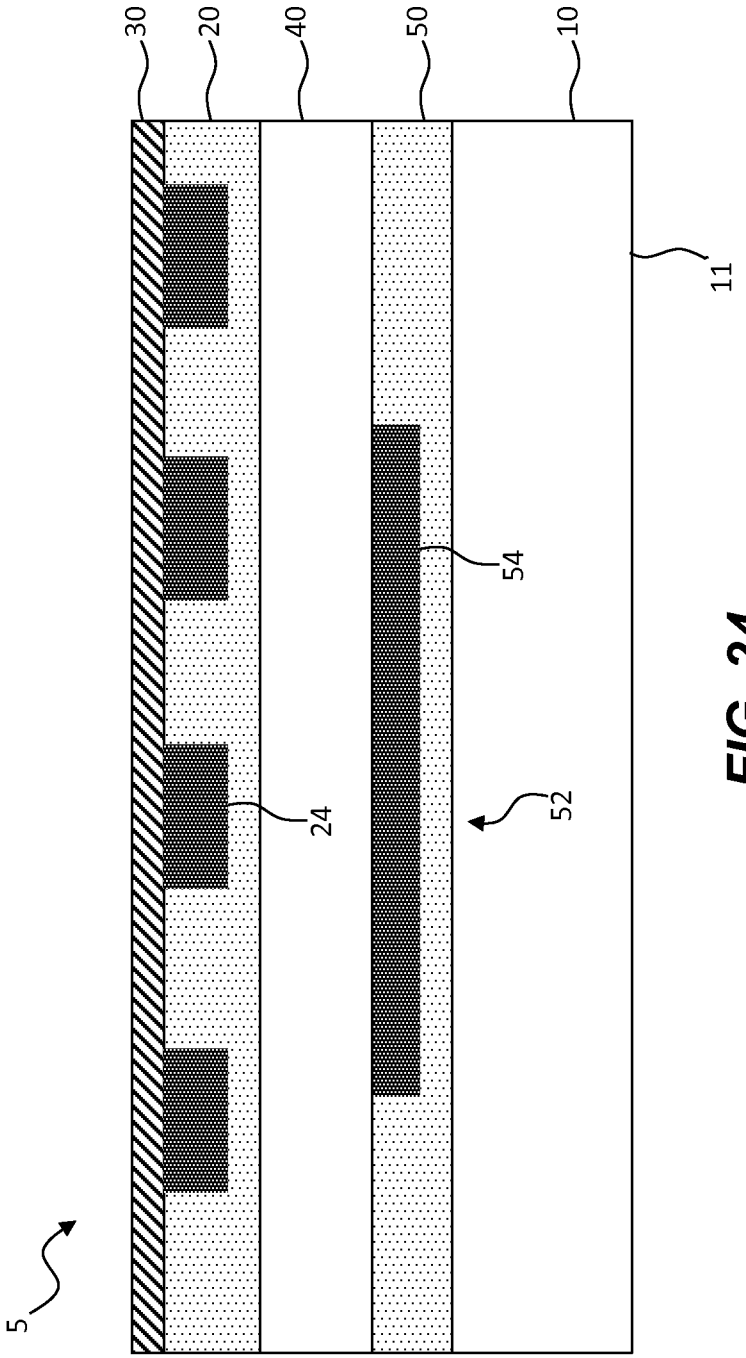


FIG. 24

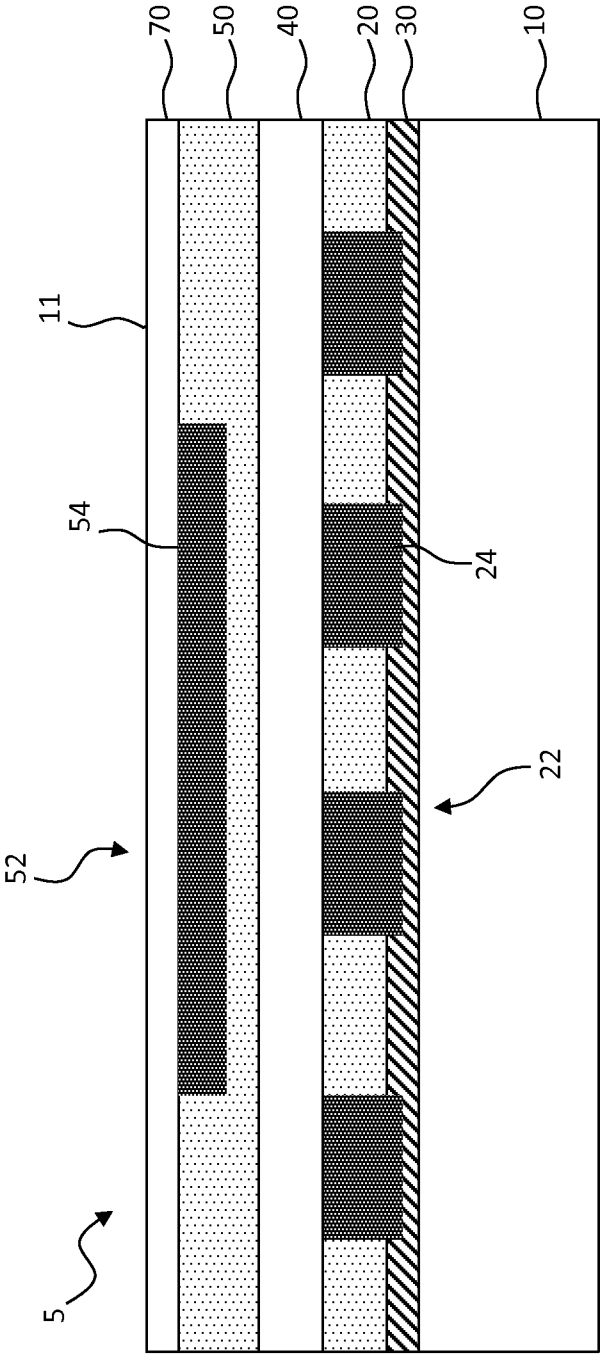


FIG. 25

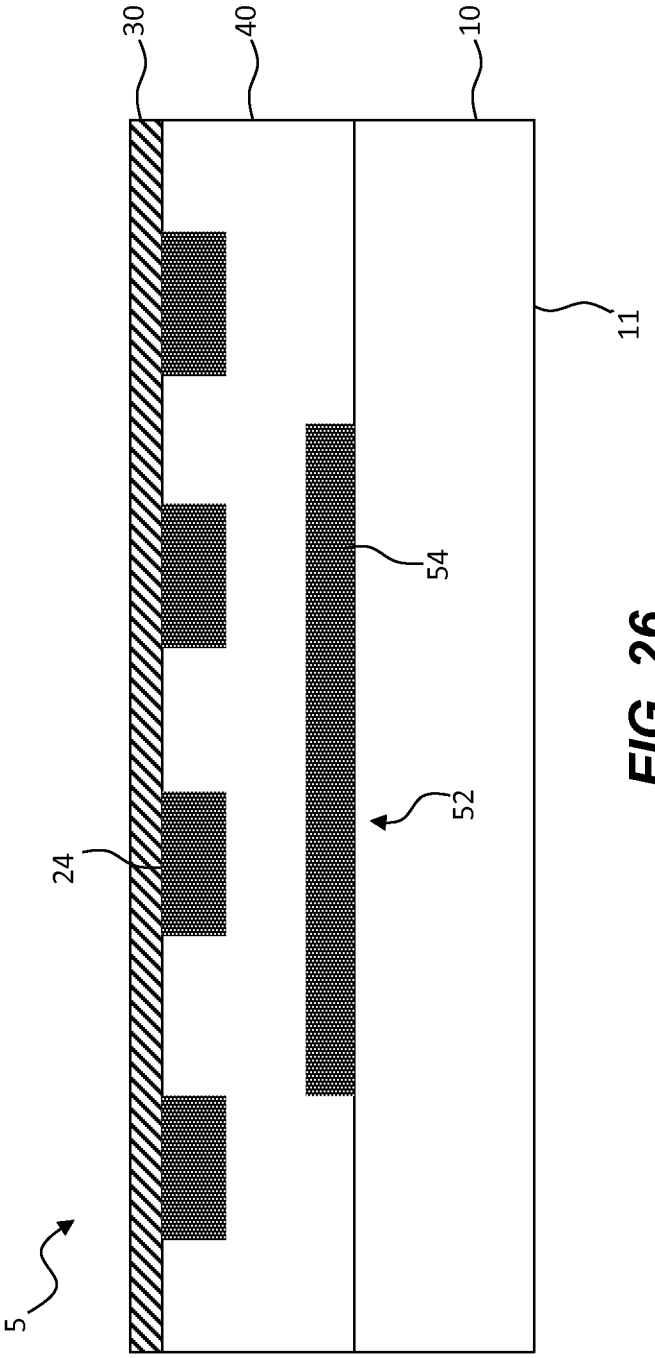


FIG. 26

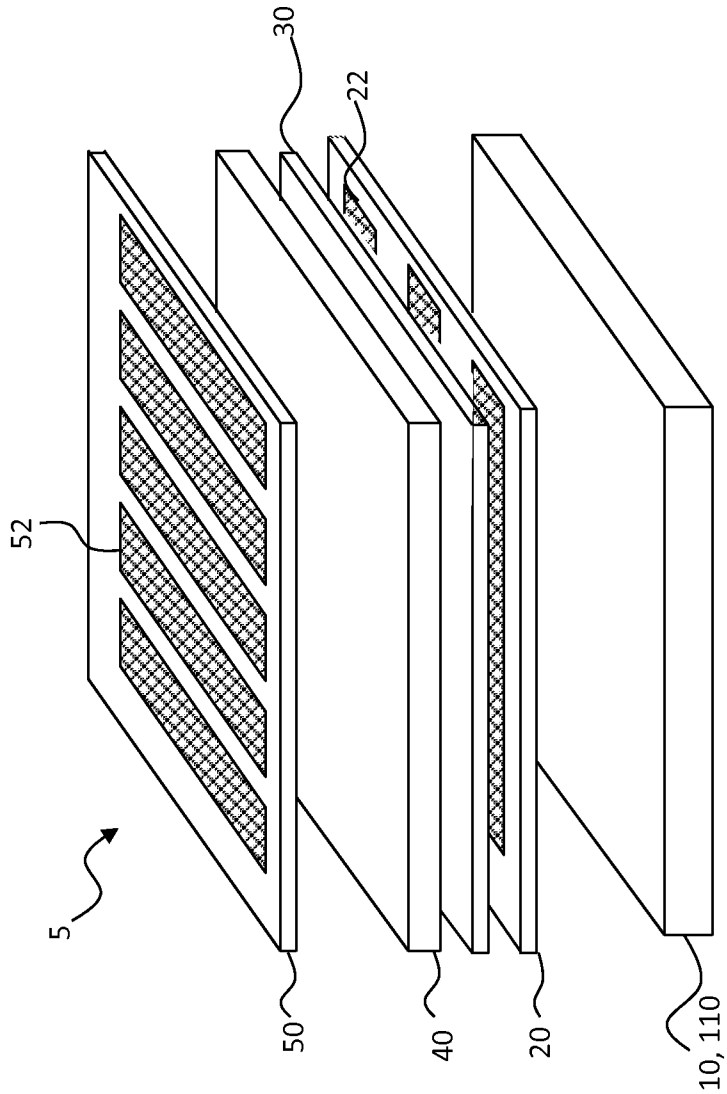
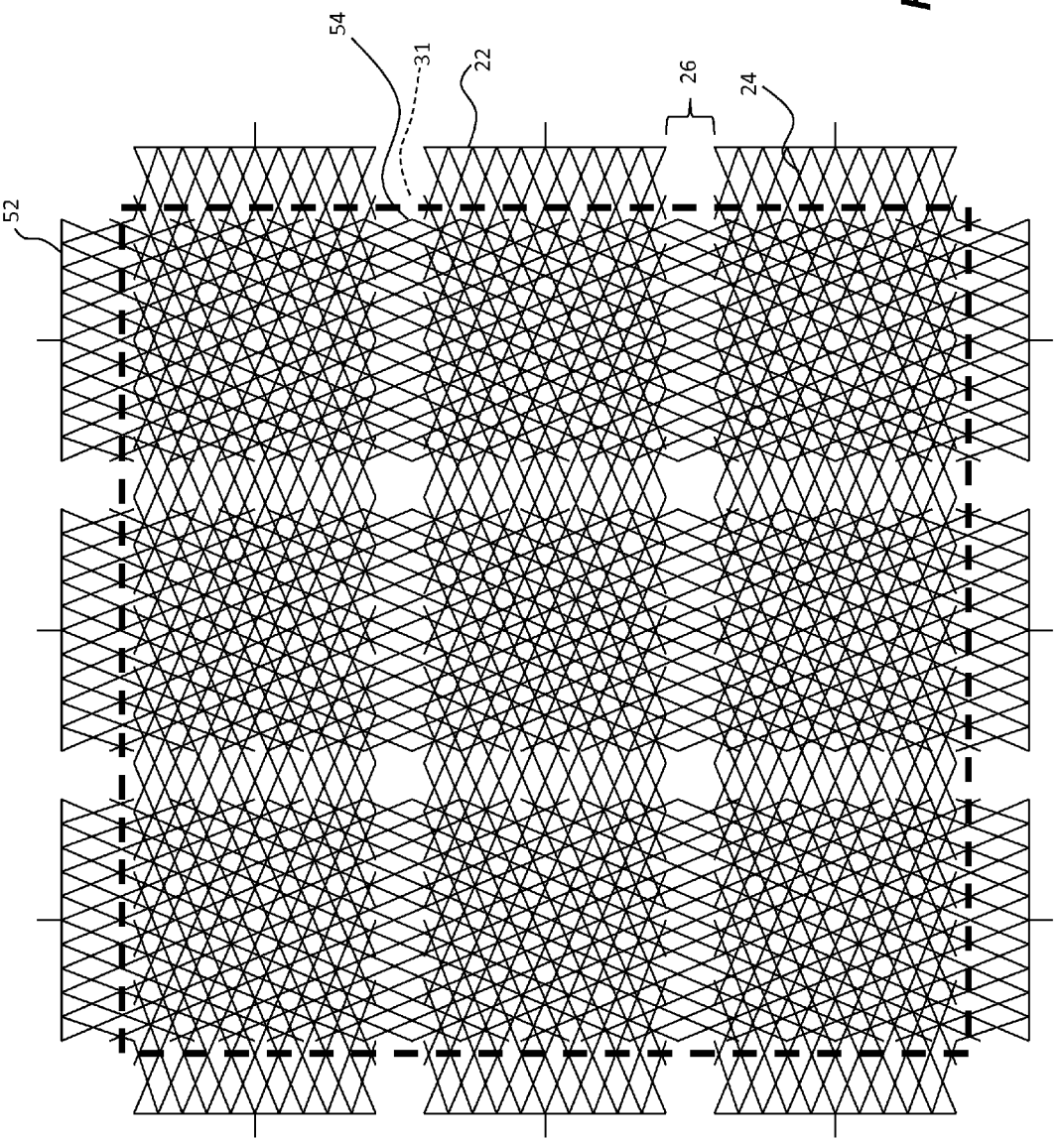


FIG. 27

FIG. 28



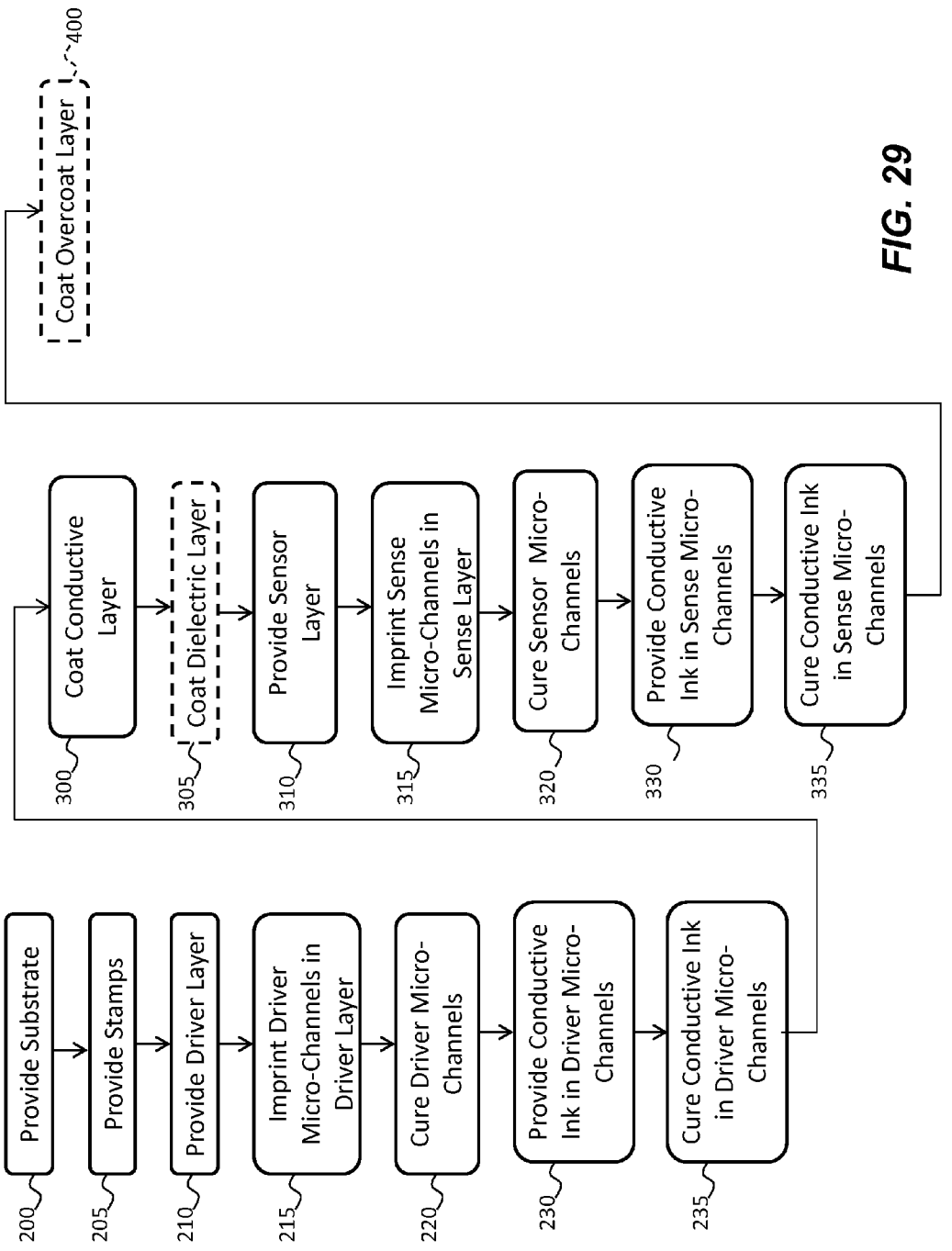

Provide Substrate
200
Provide Stamps
205
Provide Driver Layer
210
Imprint Driver Micro-Channels in Driver Layer
215
Cure Driver Micro-Channels
220
Provide Conductive Ink in Driver Micro-Channels
230
Cure Conductive Ink in Driver Micro-Channels
235
Coat Conductive Layer
300
Coat Dielectric Layer
305
Provide Sensor Layer
310
Imprint Sense Micro-Channels in Sense Layer
315
Cure Sensor Micro-Channels
320
Provide Conductive Ink in Sense Micro-Channels
330
Cure Conductive Ink in Sense Micro-Channels
335
Coat Overcoat Layer
400

FIG. 29

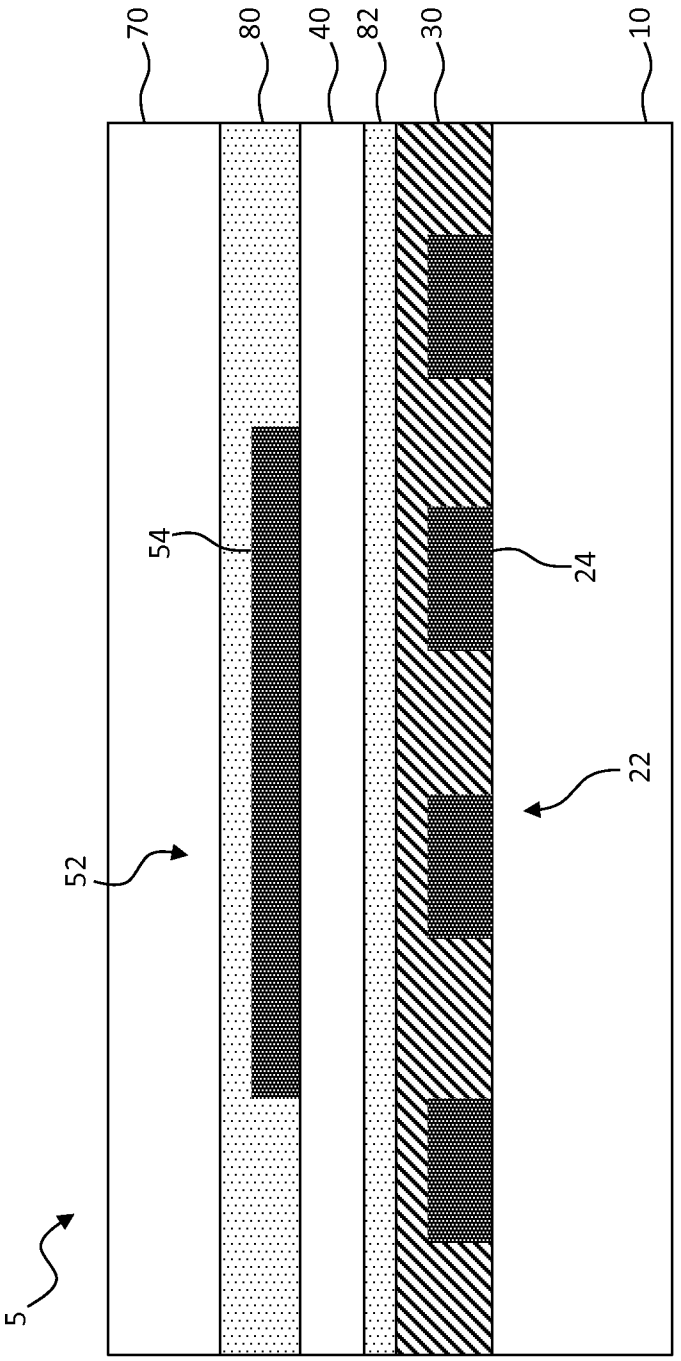


FIG. 30

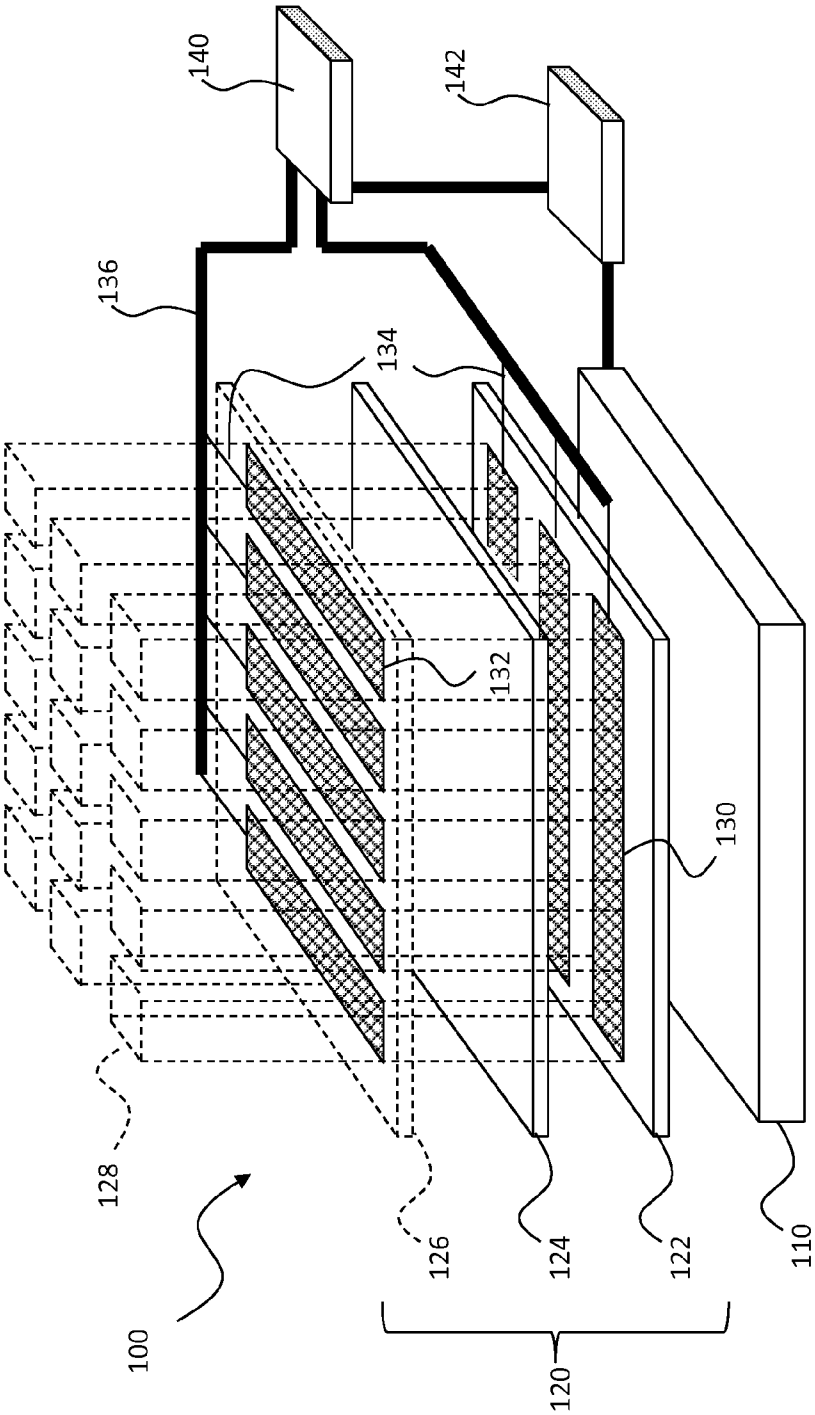


FIG. 31
Prior Art

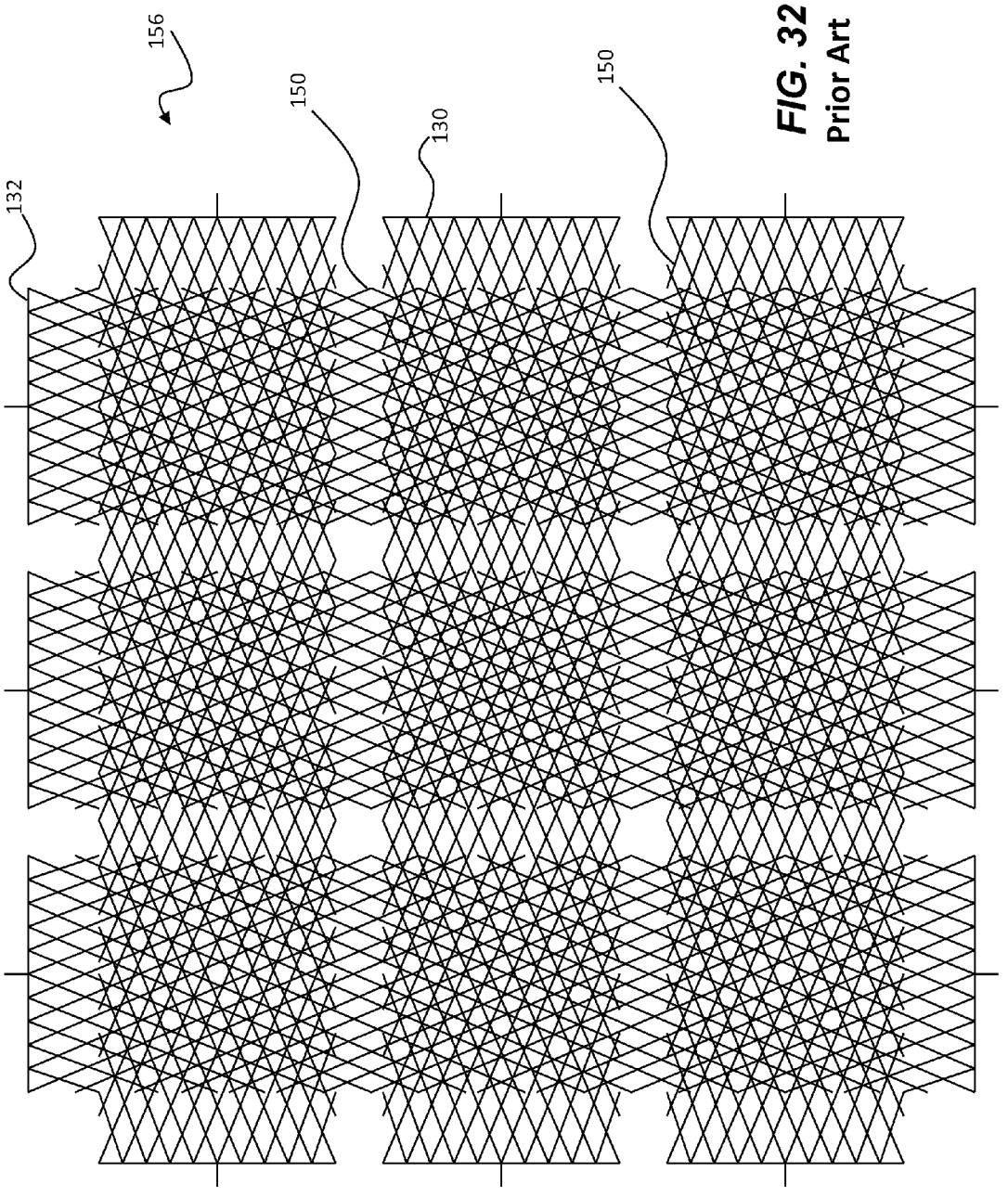


FIG. 32
Prior Art

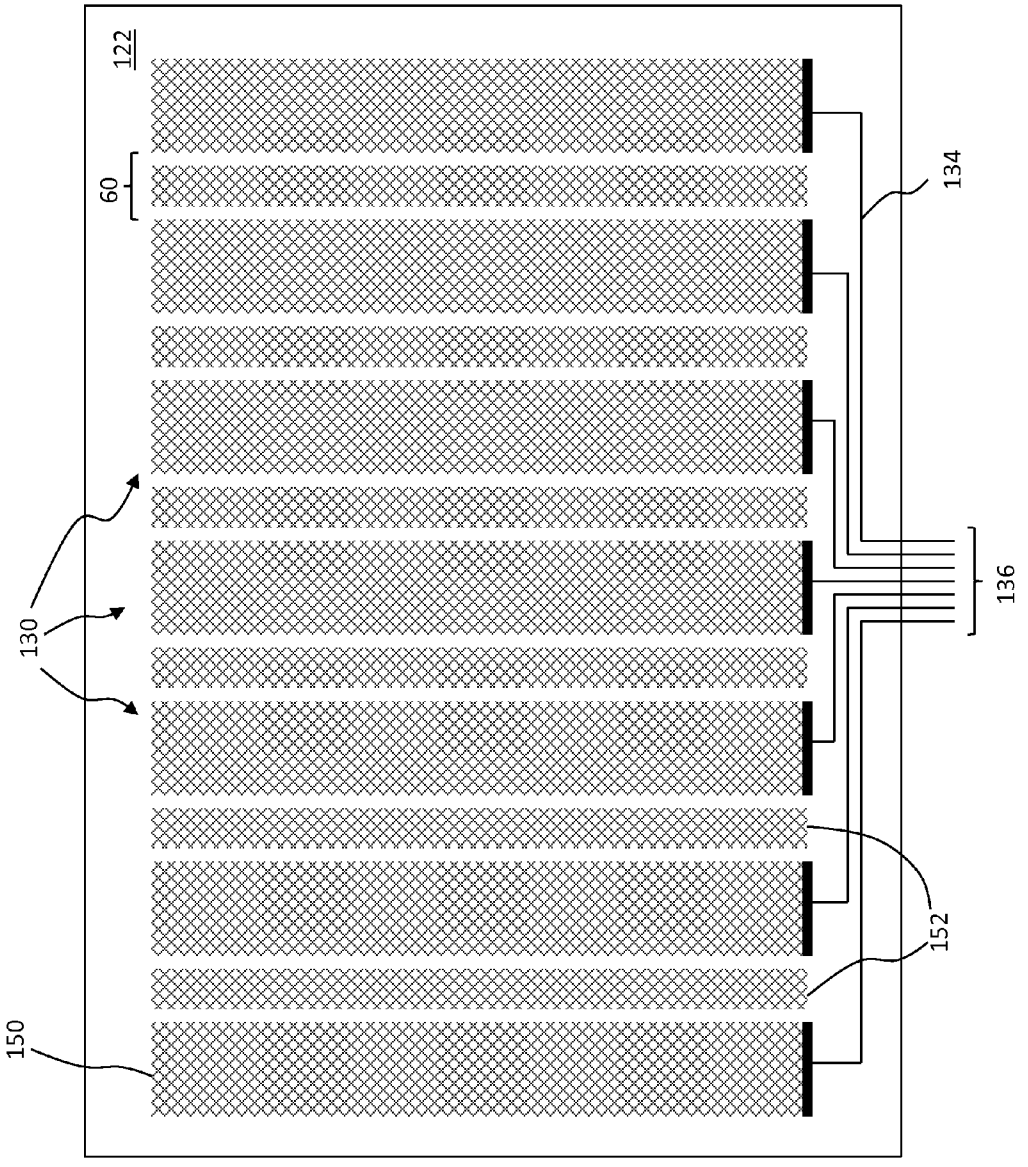


FIG. 33 - Prior Art

MICRO-WIRE ELECTRODES WITH EQUI-POTENTIAL DUMMY MICRO-WIRES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] Reference is made to commonly-assigned, co-pending U.S. patent application Ser. No. _____ filed concurrently herewith, entitled "Micro-Wire Electrodes with Dummy Micro-Dots" by Fowlkes et al and to commonly-assigned, co-pending U.S. patent application Ser. No. 14/032,213 filed Sep. 20, 2013 entitled "Micro-Wire Touch-Screen with Unpatterned Conductive Layer" by Burberry et al, the disclosures of which are incorporated herein.

FIELD OF THE INVENTION

[0002] The present invention relates to touch screens having micro-wire electrodes, an unpatterned transparent conductor layer, and electrically isolated dummy structures.

BACKGROUND OF THE INVENTION

[0003] Transparent conductors are widely used in the flat-panel display industry to form electrodes that are used to electrically switch light-emitting or light-transmitting properties of a display pixel, for example in liquid crystal or organic light-emitting diode displays. Transparent conductive electrodes are also used in touch screens in conjunction with displays. In such applications, the transparency and conductivity of the transparent electrodes are important attributes. In general, it is desired that transparent conductors have a high transparency (for example, greater than 90% in the visible spectrum) and a low electrical resistivity (for example, less than 10 ohms/square).

[0004] Transparent conductive metal oxides are well known in the display and touch-screen industries and have a number of disadvantages, including limited transparency and conductivity and a tendency to crack under mechanical or environmental stress. Typical prior-art conductive electrode materials include conductive metal oxides such as indium tin oxide (ITO) or very thin layers of metal, for example silver or aluminum or metal alloys including silver or aluminum. These materials are coated, for example, by sputtering or vapor deposition, and are patterned on display or touch-screen substrates, such as glass. For example, the use of transparent conductive oxides to form arrays of touch senses on one side of a substrate is taught in U.S. Patent Application Publication No. 2011/0099805 entitled "Method of Fabricating Capacitive Touch-Screen Panel".

[0005] Transparent conductive metal oxides are increasingly expensive and relatively costly to deposit and pattern. Moreover, the substrate materials are limited by the electrode material deposition process (such as sputtering) and the current-carrying capacity of such electrodes is limited, thereby limiting the amount of power that is supplied to the pixel elements and the size of touch screens that employ such electrodes. Although thicker layers of metal oxides or metals increase conductivity, they also reduce the transparency of the electrodes.

[0006] Apparently transparent electrodes including very fine patterns of conductive elements, such as metal wires or conductive traces are known. For example, U.S. Patent Application Publication No. 2011/0007011 teaches a capacitive touch screen with a mesh electrode, as do U.S. Patent Application Publication No. 2010/0026664, U.S. Patent Application Publication No. 2010/0328248, and U.S. Pat. No. 8,179,381, which are hereby incorporated in their entirety by reference. As disclosed in U.S. Pat. No. 8,179,381, fine conductor patterns are made by one of several processes, including laser-cured masking, inkjet printing, gravure printing, micro-replication, and micro-contact printing. In particular, micro-replication is used to form micro-conductors formed in micro-replicated channels. The apparently transparent micro-wire electrodes include micro-wires between 0.5μ and 4μ wide and a transparency of between approximately 86% and 96%.

[0007] Conductive micro-wires are formed in micro-channels embossed in a substrate, for example as taught in CN102063951, which is hereby incorporated by reference in its entirety. As discussed in CN102063951, a pattern of micro-channels are formed in a substrate using an embossing technique. Embossing methods are generally known in the prior art and typically include coating a curable liquid, such as a polymer, onto a rigid substrate. A pattern of micro-channels is embossed (impressed or imprinted) onto the polymer layer by a master having an inverted pattern of structures formed on its surface. The polymer is then cured. A conductive ink is coated over the substrate and into the micro-channels, the excess conductive ink between micro-channels is removed, for example by mechanical buffing, patterned chemical electrolysis, or patterned chemical corrosion. The conductive ink in the micro-channels is cured, for example by heating. In an alternative method described in CN102063951, a photosensitive layer, chemical plating, or sputtering is used to pattern conductors, for example using patterned radiation exposure or physical masks. Unwanted material (such as photosensitive resist) is removed, followed by electro-deposition of metallic ions in a bath.

[0008] Capacitive touch screen devices are constructed by locating drive electrodes near sense electrodes to form an electric field. In one prior-art design, the drive and sense electrodes are located on a common substrate with bridge electrical connections to prevent electrical shorts between the drive and sense electrodes where the drive electrodes cross over or under the sense electrodes. In another prior-art design, the drive and sense electrodes are located on either side of a dielectric layer. Referring to FIG. **31**, a prior-art display and touch-screen apparatus **100** includes a display **110** with a corresponding touch screen **120** mounted with the display **110** so that information displayed on the display **110** can be viewed through the touch screen **120**. Graphic elements displayed on the display **110** are selected, indicated, or manipulated by touching a corresponding location on the touch screen **120**. The touch screen **120** includes a first transparent substrate **122** with first transparent electrodes **130** extending in the x dimension on the first transparent substrate **122** and a second transparent substrate **126** with second transparent electrodes **132** extending in the y dimension facing the x-dimension first transparent electrodes **130** on the second transparent substrate **126**. A dielectric layer **124** is located between the first and second transparent substrates **122**, **126** and first and second transparent electrodes **130**, **132**. Touch pad areas **128** are formed by the overlap of the first transparent electrodes **130** and the second transparent electrodes **132**. When a voltage is applied across the first and second transparent electrodes **130**, **132**, electric fields are formed between them that are measurable to detect changes in capacitance due to the presence of a touch element, such as a finger or stylus.

[0009] A display controller **142** connected through electrical buss connections **136** controls the display **110** in cooperation with a touch-screen controller **140**. The touch-screen controller **140** is connected through electrical buss connections **136** and wires **134** and controls the touch screen **120**. The touch-screen controller **140** detects touches on the touch screen **120** by sequentially electrically energizing and testing the x-dimension first and y-dimension second transparent electrodes **130**, **132**.

[0010] Referring to FIG. **32** as well as FIG. **31**, in another prior-art embodiment, the rectangular first and second transparent electrodes **130**, **132** that include micro-wires **150** are arranged orthogonally in a micro-pattern **156** on first and second transparent substrates **122**, **126** with intervening dielectric layer **124**, forming touch screen **120** which, in combination with the display **110** forms the touch screen **120** and display apparatus **100**.

[0011] As is known in the prior art, electromagnetic interference from the display **110** can interfere with the operation of the touch-screen **120**. This problem can be ameliorated by providing a ground plane between the touch screen **120** and display **110**. However, such a structure undesirably increases the thickness and decreases the transparency of the display and touch screen apparatus **100**.

[0012] Alternatively, it has been recognized that shielding can be achieved by controlling the relative width of the drive and sense electrodes. For example U.S. Pat. No. 7,920,129 discloses a multi-touch capacitive touch-sense panel created using a substrate with column and row traces formed on either side of the substrate. To shield the column (sense) traces from the effects of capacitive coupling from a modulated V_{com} layer in an adjacent liquid crystal display (LCD) or any source of capacitive coupling, the row traces were widened to shield the column traces, and the row (drive) traces were placed closer to the LCD. In particular, the rows can be widened so that there is spacing of about 30 microns between adjacent row traces. In this manner, the row traces can serve the dual functions of driving the touch sense panel, and also the function of shielding the more sensitive column (sense) traces from the effects of capacitive coupling.

[0013] Shielding has also been achieved by using metal micro-wire sense electrodes in combination with transparent conductive drive electrodes. For example U.S. Pat. No. 8,279,187 discloses a multi-layer touch panel having an upper electrode layer having a plurality of composite electrodes including a plurality of metal or metal alloy micro-wire conductors with a cross-sectional dimension of less than 10 microns, a lower electrode layer having a plurality of (patterned) indium oxide-based electrodes, the upper electrodes and lower electrodes defining an electrode matrix having nodes where the upper and lower electrodes cross over. The upper electrode layer is disposed between the first layer and the lower electrode layer and a dielectric layer is disposed between the upper electrode layer and the lower electrode layer. As noted above, it is difficult, expensive, or impossible to meet conductivity requirements for larger touch-screens using patterned indium tin oxide electrodes.

[0014] In general, touch screens are intended to be invisible to a user. It is important, therefore, that any conductive structures in a touch screen be visually imperceptible. In prior-art designs, relatively transparent conductive electrodes made of transparent conductive oxides reduce electrode visibility. Nonetheless, such electrodes do absorb some light, having a transparency for example of 88% in the visible range and a slightly yellow appearance. Thus, electrode structures in a touch screen having transparent conductive oxides are visible to perceptive users. In particular, regular gaps between electrodes are visible as areas with increased transparency.

[0015] To reduce the visibility of gaps between electrodes in a touch screen, dummy structures are provided in the gaps. These dummy structures typically include conductive materials and structures similar to those found in the electrodes but are not electrically connected to the electrodes. Thus, the dummy structures provide optical uniformity in the touch screen by providing structures with an appearance similar to the electrodes but without any electrical function. Gaps between the dummy structures and the electrodes are typically so small (for example, a few microns) that the gaps are imperceptible to viewers. Referring to FIG. **33**, a plurality of rectangular, spatially separated first transparent electrodes **130** are arranged in an array on a first transparent substrate **122**. Each first transparent electrode **130** includes a plurality of electrically connected micro-wires **150**. Dummy micro-wires **152** located in gaps **60** between the first transparent electrodes **150** are arranged in a similar way so that the dummy micro-wires **152** located in the gaps **60** between the first transparent electrodes **130** appear similar to the micro-wire electrodes **130**.

[0016] U.S. Patent Application Publication No. 2011/0248953 entitled "Touch Screen Panel" describes conductive dummy patterns between adjacent sensing cells in a touch screen panel. U.S. Patent Application Publication No. 2011/0289771 entitled "Method for Producing Conductive Sheet and Method for Producing Touch Panel" describes unconnected dummy patterns formed near each side of a sensing region. U.S. Pat. No. 7,663,607 entitled "Multi-Point Touch Screen" describes dummy features disposed between driving lines and sensing lines to optically improve the visual appearance of the touch screen. The dummy features provide the touch screen with a more uniform appearance and are electrically isolated and positioned in the gaps between each of the lines. Although they can be patterned separately, the dummy features are typically patterned along with the lines and formed with the same conductive materials. The dummy features still produce some gaps but the gaps are much smaller than the gaps found between the lines.

SUMMARY OF THE INVENTION

[0017] There remains a need for further improvements in the structure of a multi-electrode structure that reduces susceptibility to electromagnetic interference, reduces thickness and cost, improves sensitivity and efficiency, and provides optical uniformity.

[0018] In accordance with the present invention, a micro-wire multi-electrode structure having an area of substantially uniform optical density comprises:

[0019] a plurality of spatially separated patterned electrodes located in an electrode layer in the area, each electrode including a plurality of patterned conductive electrically connected electrode micro-wires;

[0020] one or more patterned equi-potential electrically conductive dummy micro-wires in the area located substantially along equi-potential lines between adjacent electrodes and electrically isolated from the electrode micro-wires, whereby the area has a substantially uniform optical density; and

[0021] an unpatterned conductive layer in the area, the unpatterned conductive layer in electrical contact with the electrode micro-wires and the dummy micro-wires.

[0022] The present invention provides a micro-wire multi-electrode structure useful in capacitive touch screens having improved sensitivity, efficiency, consistency, optical uniformity, and reduced susceptibility to electromagnetic interference and reduced thickness and cost. The presence of an unpatterned conductive layer electrically connected to drive electrodes and drive micro-wires provides electromagnetic shielding to sense electrodes, thereby reducing electromagnetic interference. The integrated unpatterned conductive layer reduces device thickness by reducing the number of insulating layers, reducing conductive layer thickness, and improving transparency in comparison to a conventional shielding system. The presence of dummy structures improves optical uniformity without compromising the function of the unpatterned conductive layer.

[0023] The presence of the unpatterned conductive layer also increases capacitance between drive and sense electrodes, thereby reducing the voltage needed to sense changes in the capacitive field, for example due to touches, and improving efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The above and other features and advantages of the present invention will become more apparent when taken in conjunction with the following description and drawings wherein identical reference numerals have been used to designate identical features that are common to the figures, and wherein:

[0025] FIG. **1**A is a plan view of an embodiment of the present invention;

[0026] FIG. **1**B is a cross section of the embodiment of FIG. **1**A taken along cross section line B of FIG. **1**A;

[0027] FIG. **1**C is a cross section of the embodiment of FIG. **1**A taken along cross section line C of FIG. **1**A;

[0028] FIG. **2**A is a plan view of a micro-structure useful in understanding the present invention;

[0029] FIG. **2**B is a plan view of an alternative micro-structure useful in understanding the present invention;

[0030] FIG. **3** is a plan view of another micro-structure useful in understanding the present invention;

[0031] FIG. **4** is a plan view of another embodiment of the present invention;

[0032] FIG. **5** is a plan view of yet another embodiment of the present invention;

[0033] FIG. **6** is a flow chart illustrating a method of the present invention;

[0034] FIG. **7**A is a plan view of an embodiment of the present invention;

[0035] FIG. **7**B is a cross section of the embodiment of FIG. **7**A taken along cross section line B of FIG. **7**A;

[0036] FIG. **7**C is a cross section of the embodiment of FIG. **7**A taken along cross section line C of FIG. **7**A;

[0037] FIGS. **8-12** are plan views of various micro-structures useful in understanding the present invention;

[0038] FIG. **13** is a plan view of an embodiment of the present invention;

[0039] FIG. **14** is a plan view of another embodiment of the present invention;

[0040] FIGS. **15-26** are cross sections of various embodiments of the present invention;

[0041] FIG. **27** is a perspective of another embodiment of the present invention;

[0042] FIG. **28** is a plan view of a micro-wire structure useful in an embodiment of the present invention;

[0043] FIG. **29** is a flow diagram illustrating the construction of an embodiment of the present invention;

[0044] FIG. **30** is a cross section of an experimental sample of an embodiment of the present invention;

[0045] FIG. **31** is a perspective of a touch screen and display apparatus according to the prior art;

[0046] FIG. **32** is a plan view of micro-wire electrodes according to the prior art; and

[0047] FIG. **33** is a plan view of micro-wire electrodes and dummy micro-wires according to the prior art.

[0048] The Figures are not drawn to scale since the variation in size of various elements in the Figures is too great to permit depiction to scale.

DETAILED DESCRIPTION OF THE INVENTION

[0049] The present invention provides a micro-wire multi-electrode structure useful, for example, in touch-screen devices in combination with a display. The micro-wire multi-electrode structure reduces the effects of electromagnetic interference and improves touch-response sensitivity, efficiency, consistency, and optical uniformity over the extent of the touch screen.

[0050] Referring to FIG. **1**A in a plan view and to FIGS. **1**B and **1**C in cross sections taken along cross section lines B and C, respectively, of FIG. **1**A, an embodiment of a micro-wire multi-electrode structure **5** of the present invention has an area **31** of substantially uniform optical density that includes a plurality of spatially separated patterned electrodes **22** located in an electrode layer **20** in the area **31**. Each electrode **22** includes a plurality of patterned conductive and electrically connected electrode micro-wires **24**. The electrodes **22** are spatially separated by gaps **26**. One or more patterned electrically conductive equi-potential dummy micro-wires **90** are located in the area **31** substantially along equi-potential lines between adjacent electrodes **22**, for example in the gaps **26**. Adjacent electrodes **22** are pairs of electrodes **22** between which there is no other electrode **22**. The dummy micro-wires **90** are electrically isolated from the electrode micro-wires **24**. An unpatterned conductive layer **30** in the area **31** is in electrical contact with the electrode micro-wires **24** and the dummy micro-wires **90**. The percent of incident light transmitted through the gap **26** and the dummy micro-wires **90** is similar to the percent of incident light transmitted through the electrodes **22** and the electrode micro-wires **24**, so that the area **31** has a substantially uniform optical density.

[0051] The area of the unpatterned conductive layer **30** is equal to or greater than the area **31** of uniform optical density and the unpatterned conductive layer **30** is not necessarily distinguished from the area **31** in the Figures. Generally, the unpatterned conductive layer **30** is illustrated in cross sections and the area **31** is indicated in the plan views.

[0052] The unpatterned conductive layer **30** in the area **31** can refer to the touch-sensitive portion of a layer of conductive material located over a substrate **10**. The unpatterned conductive layer **30** is a layer of electrically conductive material that can extend beyond the area **31** and can be patterned outside of the area **31**, for example around the periphery of a touch screen (such as in the bezel or buss areas of a touch

screen), but is unpatterned within the area **31**. The electrodes **22** can extend beyond the area **31** or the unpatterned conductive layer **30**.

[0053] In an embodiment, the electrode micro-wires **24** form a mesh and typically have a width less than 10 microns and a pitch of hundreds or even more than a thousand microns. Since such relative sizes and spacing are difficult to illustrate in the Figures, the micro-structures (such as the electrode micro-wires **24**) are typically shown much larger and closer together than is the case in a practical implementation. In an embodiment of the present invention, the micro-structures of the present invention, including the electrode micro-wires **24** and dummy micro-wires **90** are too small to be resolved by, or visible to, the unaided human visual system.

[0054] Optical uniformity, as used herein refers to optical uniformity as easily perceived by the unaided human visual system without special effort under typical display viewing conditions and is averaged over areas much larger than the individual micro-structures in the optically uniform area **31**, for example areas of several square millimeters. Substantially uniform means that the area **31** appears uniform to the unaided human visual system. The area **31** can have less than 20%, 10%, 5%, 2%, or 1% variation over the area **31**. The spatial distribution of the electrode micro-wires **22** and dummy micro-wires **90** in the area **31** can affect the optical uniformity of the area **31** so that, in an embodiment of the present invention, the area **31** has a substantially uniform spatial distribution of electrode micro-wires **22** and dummy micro-wires **90** in the area **31**.

[0055] Although the present invention discloses an optically uniform area **31**, such uniformity is not readily illustrated in the Figures and the optically uniform area **31** in the Figures is not necessarily illustrated as optically uniform. Furthermore, optical uniformity is taken over a two-dimensional area. Cross-sectional Figures represent only one dimension of the area **31** and are not, therefore, illustrative of optical uniformity.

[0056] The electrode micro-wires **24** are electrically connected within each electrode **22** but are not electrically connected to electrode micro-wires **24** of other electrodes **22**. Thus, each electrode **22** is electrically isolated from any other electrode **22**. Furthermore, the dummy micro-wires **90** are not electrically connected to any electrode micro-wires **24**. In an embodiment, the dummy micro-wires **90** are formed in a common layer with the electrode micro-wires **24** or include one or more common materials with the electrode micro-wires **24**. In another embodiment, the dummy micro-wires **90** and the electrode micro-wires **24** are formed from the same materials. In an embodiment, the dummy micro-wires **90** and the electrode micro-wires **24** are formed in a common step with common materials in a common layer and have a common thickness. In another embodiment, the dummy micro-wires **90** have a thickness that is less than the thickness of the electrode micro-wires **24**.

[0057] Each dummy micro-wire **90** extends along an equi-potential line. When adjacent electrodes **22** are energized at different voltages, an electrical field exists between the electrodes **22**. For example, two opposing, parallel conductors will create an electrical field having field lines that extend orthogonally from one conductor to the other (ignoring edge effects). Each point along each field line has an electrical potential. The dummy micro-wires **90** extend from field line to field line at positions of equal electrical potential. In the case of two opposing, parallel conductors and orthogonal field lines, the equi-potential lines will be lines parallel to the conductors. Thus, an equi-potential line is a set of connected points forming at least a portion of a line, curved or straight, that have a common potential when the micro-wires **24** of adjacent electrodes **22** are controlled to have different voltage potentials. Each dummy micro-wire **90** extends along an equi-potential line. Different dummy micro-wires **90** can extend along different equi-potential lines so that the different dummy micro-wires **90** can have different electrical potentials. Moreover, the dummy micro-wires **90** can extend over only a portion of an equi-potential line. Multiple, electrically isolated dummy micro-wires **90** can extend along a common, same equi-potential line (for example as a sequence of dashed lines). Electrically isolated dummy micro-wires **90** are micro-wires that are not electrically connected to any electrode micro-wires **24**.

[0058] By substantially equi-potential is meant that the conductivity of the unpatterned conductive layer **30** is not changed so much that the electrodes **22** cannot effectively maintain different voltages when driven by a drive circuit or that the conductivity of the unpatterned conductive layer **30** is not changed so much that electrical fields generated by the electrodes **22** cannot be distinguished with a sense circuit (e.g. drive and sense circuits in touch-screen controller **140**). Thus, the dummy micro-wires **90** provide optical density in the gap **26** without compromising the conductivity of the unpatterned conductive layer **30** by increasing the conductivity to an unacceptable level.

[0059] In a further embodiment of a micro-wire multi-electrode structure **5**, the electrodes **22** are drive electrodes **22**, the electrode layer **20** is a drive layer **20**, the electrode micro-wires **24** are drive micro-wires **24**, gaps **26** separating the drive electrodes **22** are drive gaps **26**, and the area **31** is a touch-sensitive area **31**.

[0060] In this embodiment, a plurality of spatially separated patterned sense electrodes **52** is located in a sense layer **50** in the touch-sensitive area **31**. Each sense electrode **52** includes a plurality of patterned conductive electrically connected sense micro-wires **54**. The sense electrodes **52** are separated by sense gaps **56** and a dielectric layer **40** is located between the drive electrodes **22** and the sense electrodes **52**. Areas in which the drive electrodes **22** and the sense electrodes **52** overlap form touch-pad areas **128**. The touch-pad areas **128** form capacitors whose capacitance changes can be measured to detect a touch.

[0061] In one embodiment, the dielectric layer **40** is a separate layer (e.g. as shown in FIG. **31** with dielectric layer **124**), in another embodiment the dielectric layer **40** is a portion of another layer, for example a portion of the sense layer **50** as shown in FIGS. **1**B and **1**C. In an embodiment, a protective overcoat layer **70** is provided over the sense layer **50**. A surface of the protective overcoat layer **70** provides a touch surface **11**.

[0062] FIG. **1**B is taken along the cross section line B of FIG. **1**A where the drive micro-wires **24** overlap the sense micro-wires **54**. To aid understanding, FIG. **1**C is also provided to clarify an embodiment of the present invention. FIG. **1**C is taken along the cross section line C of FIG. **1**A where the drive micro-wires **24** overlap the drive micro-wires **24** and the sense micro-wires **54** overlap the drive micro-wires **54**.

[0063] Although illustrated in FIGS. **1**B and **1**C with the drive layer **20** between the sense layer **50** and the substrate **10**, in another embodiment, as discussed below, the sense layer

50 is located between the drive layer **20** and the substrate **10**, or the sense layer **50** and the drive layer **20** are located on opposite sides of the substrate **10**. In an embodiment of the present invention, and as illustrated in FIGS. **1**B and **1**C, the dummy micro-wires **90** are located in the drive layer **20**.

[0064] Referring to FIG. **2**A, in an embodiment a first dummy micro-wire **90**A is located along a first equi-potential line and a second dummy micro-wire **90**B is located along a second equi-potential line different from the first equi-potential line between electrodes **22** with electrode micro-wires **24**. Referring to FIG. **2**B, in other embodiments, separate multiple dummy micro-wires **90**A are located along portions of a common equi-potential line or have a different pattern from other dummy micro-wires **90**B. The dummy micro-wires **90** can form straight lines or straight line segments. The straight line segments can be connected at an angle (not shown).

[0065] Referring to FIG. **3**, adjacent electrodes **22** having electrode micro-wires **24** are separated by the dummy micro-wires **90**A in gap **26**A. The dummy micro-wires **90**A are curved and dummy micro-wires **90**A at different equi-potentials have different shapes. The dummy micro-wires **90**B in gap **26**B between adjacent electrodes **22** have a different shape or pattern from the dummy micro-wires in gap **26**A. Thus, in various embodiments of the present invention, the dummy micro-wires have different shapes or patterns within a gap or in different gaps so that first dummy micro-wires **90**A are located between first adjacent electrodes **22** in a first pattern and second dummy micro-wires **90**B are located between second adjacent electrodes **22** in a second pattern different from the first pattern. Alternatively, as shown in FIG. **1**A, first dummy micro-wires **90** are located between first adjacent electrodes **22** in a first pattern and second dummy micro-wires **90** are located between second adjacent electrodes **22** in a second pattern that is the same as the first pattern.

[0066] Furthermore, the patterns of electrode micro-wires **24** can vary. Referring to FIG. **3**, the plurality of spatially separated patterned electrodes **22** in the area **31** can include a first electrode **22** having electrically connected electrode micro-wires **24** forming a first pattern and a second electrode **22** having electrically connected electrode micro-wires **24** forming a second pattern different from the first pattern. As shown in FIG. **3**, the center and left electrodes **22** are mirror images and the center and right electrodes **22** are different mirror images. Alternatively, the first and second electrode micro-wire patterns are the same pattern (e.g. as in FIG. **1**A). In some embodiments, the plurality of spatially separated patterned electrodes **22** in the area **31** forms a regular array of electrodes **22**.

[0067] Referring to FIG. **4** and also to FIGS. **1**A and **1**B, in a further embodiment of a micro-wire multi-electrode structure **5**, additional dummy micro-wires **94** are provided. The additional dummy micro-wires **94** provide optical uniformity in the sense gaps **56** between sense electrodes **52** having sense micro-wires **54**. The additional dummy micro-wires **94** complement the dummy micro-wires **90** in the drive gaps **26** between drive electrodes **22** having drive micro-wires **24**. The additional dummy micro-wires **94** are not necessarily electrically connected to the unpatterned conductive layer **30** in the area **31**, are therefore not necessarily located along equi-potential lines between the sense electrodes **52** and, in an embodiment, are located in the sense layer **50**.

[0068] Referring next to FIG. **5**, an embodiment of a micro-wire multi-electrode structure **5** includes a plurality of electrodes **22** having electrode micro-wires **24** formed in or on the substrate **10** in the area **31**. The electrodes **22** are separated by gaps **26** having dummy micro-wires **90** arranged along equi-potential lines. The area **31** has an area edge **33** and includes an edge electrode **23** adjacent to the area edge **33**. By adjacent is meant that no other electrode **22** is between the area edge **33** and the edge electrode **23**. Edge dummy micro-wires **96** are located along equi-potential lines between the edge electrode **23** and the area edge **33** and are electrically disconnected from the edge electrode **23**. Thus optical uniformity is preserved within the area **31** even if the edge electrode **23** is not at the area edge **33**. In a further embodiment, an electrical wire **134** is located outside the area **31** and adjacent to the area edge **33**. Edge dummy micro-wires **96** are located between the edge electrode **23** and the electrical wire **134**. Electrical wires **134** are combined to form electrical busses **136**. FIG. **5** only illustrates the drive electrodes **22** in the drive layer **20** and not the sense electrodes **52** in the sense layer **50**. In an embodiment, the electrical wire **134** located outside the area **31** and adjacent to the area edge **33** is electrically connected to a sense electrode **52**. In an embodiment, the electrical wire **134** is in the drive layer **20** (not shown in FIG. **5**); in another embodiment the electrical wire **134** is in the sense layer **50** (not shown in FIG. **5**).

[0069] In an embodiment of the present invention, a touch-screen device having a substantially uniform optical density in a touch-sensitive area **31** includes a plurality of spatially separated patterned drive electrodes **22** located in a drive layer **20** in the touch-sensitive area **31**. Each drive electrode **22** includes a plurality of patterned conductive electrically connected drive micro-wires **24**. A plurality of spatially separated patterned sense electrodes **52** in the sense layer **50** is located in the touch-sensitive area **31**. Each sense electrode **52** includes a plurality of patterned conductive electrically connected sense micro-wires **54**. A dielectric layer **40** is located between the drive electrodes **22** and the sense electrodes **52**. One or more patterned electrically isolated equi-potential dummy micro-wires **90** are located in the touch-sensitive area **31** substantially along equi-potential lines between adjacent drive electrodes **22** and electrically disconnected from the adjacent drive electrodes **22**, so that the touch-sensitive area **31** has a substantially uniform optical density. An unpatterned conductive layer **30** that is unpatterned in the touch-sensitive area **31** is in electrical contact with the drive micro-wires **24** and the dummy micro-wires **90**. A controller is electrically connected to the drive and sense electrodes **22**, **52** to control the drive and sense electrodes **22**, **52**.

[0070] Referring to the flow-diagram of FIG. **6**, a method of making a micro-wire multi-electrode structure **5** having an area **31** of substantially uniform optical density includes providing in step **500** a plurality of spatially separated patterned electrodes **22** in an electrode layer **20** in the area **31**. Each electrode **22** includes a plurality of patterned conductive electrically connected electrode micro-wires **24**. One or more patterned electrically isolated dummy micro-structures are located in step **505** in the area **31**. In this embodiment, the micro-structures include electrode micro-wires **24** and dummy micro-wires **90** located substantially along equi-potential lines between adjacent electrodes **22**, so that the area **31** has a substantially uniform optical density. In step **510**, an unpatterned conductive layer **30** is located in step **515** in the area **31**. The unpatterned conductive layer **30** is in electrical contact with the electrode micro-wires **24** and dummy micro-wires **90**.

[0071] Referring to FIG. **7**A, in an alternative embodiment of the present invention, dummy micro-dots **92** are used in place of dummy micro-wires **90**. The dummy micro-dots **92** are micro-structures that have negligible conductivity in any given direction, for example having a cross section in the plane of the electrode layer **20** that is a circle, a square, or other polygonal shape that has an effective aspect ratio of one. The dummy micro-dots **92** can have a thickness (depth) that is similar to a thickness (depth) of the electrode micro-wires **24**. Alternatively, the dummy micro-dots **92** can have a thickness that is less than the thickness of the electrode micro-wires **22**. In either case, for example, dummy micro-dots **92** that have a circular cross section are cylindrical.

[0072] Although the dummy micro-dots **92** have a negligible conductivity in any given direction, they do absorb or reflect light and can therefore provide a substantially uniform optical density in the area **31**. A negligible conductivity in any given direction is a conductivity that is small enough that conductivity of the unpatterned conductive layer **30** is not changed so much that the electrodes **22** cannot effectively maintain different voltages when driven by a drive circuit or that the conductivity of the unpatterned conductive layer **30** is not changed so much that electrical fields generated by the electrodes **22** cannot be distinguished with a sense circuit (e.g. drive and sense circuits in touch-screen controller **140**). Thus, the dummy micro-dots **92** provide optical density in the gap **26** without compromising the conductivity of the unpatterned conductive layer **30** by increasing the conductivity to an unacceptable level.

[0073] As shown in FIG. **7**A in a plan view and in FIGS. **7**B and **7**C in cross sections taken along cross section lines B and C, respectively, of FIG. **7**A, an embodiment of a micro-wire multi-electrode structure **5** of the present invention has an area **31** of substantially uniform optical density that includes a plurality of spatially separated patterned electrodes **22** located in an electrode layer **20** in the area **31**. Each electrode **22** includes a plurality of patterned conductive and electrically connected electrode micro-wires **24**. The electrodes **22** are spatially separated by gaps **26** and are arranged in a regular array. One or more patterned dummy micro-dots **92** are located in the area **31**, for example in the gaps **26**. Adjacent electrodes **22** are pairs of electrodes **22** between which there is no other electrode **22**. The dummy micro-dots **92** are electrically isolated from the electrode micro-wires **24**. An unpatterned conductive layer **30** in the area **31** is in electrical contact with the electrode micro-wires **24** and the dummy micro-dots **92**. Light incident on the dummy micro-dots **92** is absorbed or reflected in an amount similar to the amount of light incident on the electrode micro-wires **24** that is absorbed or reflected, so that the area **31** has a substantially uniform optical density.

[0074] In various embodiments, the dummy micro-dots **92** are in a common layer with the electrode **22** or electrode micro-wires **24**, are formed in a common step with the electrode micro-wires **24**, include similar materials or are made of the same materials as the electrode micro-wires **24**, or have a similar depth as the electrode micro-wires **24**.

[0075] In a further embodiment of a micro-wire multi-electrode structure **5**, the electrodes **22** are drive electrodes **22**, the electrode layer **20** is a drive layer **20**, the electrode micro-wires **24** are drive micro-wires **24**, gaps **26** separating the drive electrodes **22** are drive gaps **26**, and the area **31** is a touch-sensitive area **31**. In an embodiment, the dummy micro-dots **92** are in the same drive layer **20** as the drive micro-wires **24**.

[0076] In this embodiment, a plurality of spatially separated patterned sense electrodes **52** is located in the sense layer **50** in the touch-sensitive area **31**. Each sense electrode **52** includes a plurality of patterned conductive electrically connected sense micro-wires **54**. The sense electrodes **52** are separated by sense gaps **56** and a dielectric layer **40** is located between the drive electrodes **22** and the sense electrodes **52**. Areas in which the drive electrodes **22** and the sense electrodes **52** overlap form touch-pad areas **128**. The touch-pad areas **128** form capacitors whose capacitance changes can be measured to detect a touch.

[0077] In one embodiment, the dielectric layer **40** is a separate layer (e.g. as shown in FIG. **31** with dielectric layer **124**), in another embodiment the dielectric layer **40** is a portion of another layer, for example a portion of the sense layer **50**. In an embodiment, the protective overcoat layer **70** is provided over the sense layer **50**. A surface of the protective overcoat layer **70** provides a touch surface **11**.

[0078] FIG. **7**B is taken along the cross section line B of FIG. **7**A where the sense micro-wires **54** overlap the drive micro-wires **24**. To aid understanding, FIG. **7**C is also provided to clarify an embodiment of the present invention. FIG. **7**C is taken along the cross section line C of FIG. **7**A where the sense micro-wires **54** do not overlap the drive micro-wires **24** but are offset from them along the cross section.

[0079] Although illustrated in FIGS. **7**B and **7**C with the drive layer **20** between the sense layer **50** and the substrate **10**, in another embodiment, as discussed below, the sense layer **50** is located between the drive layer **20** and the substrate **10**, or the sense layer **50** and the drive layer **20** are located on opposite sides of the substrate **10**. In an embodiment of the present invention, and as illustrated in FIGS. **7**B and **7**C, the dummy micro-dots **92** are located in the drive layer **20**.

[0080] In an embodiment, the dummy micro-dots **92** are arranged in lines, arrays, or other regular arrangements. As shown in FIG. **7**A, the dummy micro-dots **92** are located in lines that extend in a direction that is the same as the direction in which electrodes **22** extend. Referring to FIG. **8**, the dummy micro-dots **92** located in the gaps **26** are arranged in lines that extend in a direction that is the same as the direction in which electrode micro-wires **24** in electrodes **22** extend. In an embodiment, the dummy micro-dots **92** are arranged in a regular array. Referring to FIG. **9**, the dummy micro-dots **92** are located randomly or pseudo-randomly in the gaps **26** between the electrode micro-wires **24** in electrodes **22**.

[0081] Referring to FIG. **10**, the electrode micro-wires **24** form a pattern and the dummy micro-dots **92** form a similar pattern in the gap **26** between adjacent electrodes **22**, in this case a grid pattern. As shown in FIG. **11**, dummy micro-dots **92** in gap **26** between electrodes **22** having electrode micro-wires **24** are arranged in lines that extend in a direction of some of the electrode micro-wires **24** but not others.

[0082] Referring to FIG. **12**, the arrangement of dummy micro-dots **92** in gaps **26** between electrodes **22** having electrode micro-wires **24** can be different between different pairs of adjacent electrodes in different gaps **26**. As shown in FIG. **12**, the dummy micro-dots **92**A in gap **26**A are arranged differently from the dummy micro-dots **92**B in gap **26**B. Thus, in an embodiment, first dummy micro-dots **92**A are located between first adjacent electrodes in a first pattern and second dummy micro-dots are located between second adja-

cent electrodes in a second pattern different from the first pattern or that is the same as the first pattern.

[0083] Drive or sense electrodes **22**, **52** can be formed in a variety of patterns. Electrodes can be rectangular and arranged in regular arrays. Drive electrodes **22** and sense electrodes **52** can be arranged orthogonally to each other. Alternatively, electrodes can be arranged using polar coordinates, in circles, or in other curvilinear patterns. Electrodes can have uniform spacing or widths. Alternatively, electrodes can have non-uniform spacing and variable widths.

[0084] Referring to FIG. **13** and also to FIGS. **7**B and **7**C, a micro-wire multi-electrode structure **5** further includes additional dummy micro-dots **95** located in the sense layer **50**. As shown in FIG. **13**, dummy micro-dots **92** in gaps **26** between drive electrodes **22** having electrode micro-wires **24** provide optical uniformity in the drive layer **20**. Additional dummy micro-dots **95** in gaps **56** between sense electrodes **52** having sense micro-wires **54** provide optical uniformity in the sense layer **50** and over the area **31**. In an embodiment, additional dummy micro-wires **94** are provided in the gaps **56** as shown in FIG. **4**.

[0085] Referring next to FIG. **14**, an embodiment of a micro-wire multi-electrode structure **5** includes a plurality of electrodes **22** having electrode micro-wires **24** formed in or on the substrate **10** in an area **31**. The electrodes **22** are separated by gaps **26** having dummy micro-dots **92** in the gaps **26**. The area **31** has an area edge **33** and includes an edge electrode **23** adjacent to the area edge **33**. By adjacent is meant that no other electrode is between the area edge **33** and the edge electrode **23**. Edge dummy micro-dots **98** are located between the area edge **33** and the edge electrode **23** and are electrically disconnected from the edge electrode **23**. Thus optical uniformity is preserved within the area **31** even if the edge electrode **23** is not at the area edge **33**. In a further embodiment, an electrical wire **134** is located outside the area **31** and adjacent to the area edge **33**. Edge dummy micro-dots **98** are located between the edge electrode **23** and the electrical wire **134**. Electrical wires **134** are combined to form electrical busses **136**. FIG. **14** only illustrates the drive electrodes **22** in the drive layer **20** and not the sense electrodes **52** in the sense layer **50**. In an embodiment, the electrical wire **134** located outside the area **31** and adjacent to the area edge **33** is electrically connected to the sense electrode **52**. In an embodiment, the electrical wire **134** is in the drive layer **20** (not shown in FIG. **14**); in another embodiment the electrical wire **134** is in the sense layer **50** (not shown in FIG. **14**).

[0086] In an embodiment of the present invention, a touch-screen device having a substantially uniform optical density in a touch-sensitive area **31** includes a plurality of spatially separated patterned drive electrodes **22** located in a drive layer **20** in the touch-sensitive area **31**. Each drive electrode **22** includes a plurality of patterned conductive electrically connected drive micro-wires **24**. A plurality of spatially separated patterned sense electrodes **52** in the sense layer **50** is located in the touch-sensitive area **31**. Each sense electrode **52** includes a plurality of patterned conductive electrically connected sense micro-wires **54**. The dielectric layer **40** is located between the drive electrodes **22** and the sense electrodes **52**. One or more patterned electrically isolated dummy micro-dots **92** are located in the touch-sensitive area **31** and electrically disconnected from the adjacent drive electrodes **22**, so that the touch-sensitive area **31** has a substantially uniform optical density. The unpatterned conductive layer **30** that is unpatterned in the touch-sensitive area **31** is in electrical contact with the drive micro-wires **24** and the dummy micro-wires **90**. The touch screen controller **140** is electrically connected to the drive and sense electrodes **22**, **52** to control the drive and sense electrodes **22**, **52**.

[0087] In a method of the present invention, referring again to FIG. **6**, a plurality of spatially separated patterned drive electrodes **22** are provided in step **500** in a drive layer **20** in the area **31**, each drive electrode **22** including a plurality of patterned conductive electrically connected drive micro-wires **24**. One or more patterned electrically isolated dummy micro-structures, in this case micro-dots **92**, are located in the area **31** in step **505**, so that the area **31** has a substantially uniform optical density. The unpatterned conductive layer **30** is located in the area **31** in step **510** in electrical contact with the drive micro-wires **24** and dummy micro-dots **92**. In step **515**, the dielectric layer **40** is located adjacent to the drive electrodes **22** and in step **520**, a plurality of spatially separated patterned sense electrodes **52** are provided in the sense layer **50** in the area **31**, each sense electrode **52** including a plurality of patterned conductive electrically connected sense micro-wires **54**.

[0088] In various embodiments, the unpatterned conductive layer **30** is provided in various configurations with respect to the drive layer **20**, the sense layer **50** and the substrate **10**. In these embodiments, the dummy micro-wires **90** or dummy micro-dots **92** are formed in the same layer as the drive micro-wires **24** and are not shown separately.

[0089] Referring to FIG. **15**, in cross section, to FIG. **27** in perspective, and to FIG. **28** in plan view, in an embodiment of the present invention the micro-wire multi-electrode structure **5** includes a plurality of patterned drive electrodes **22** in a touch-sensitive area **31**, each drive electrode **22** including the plurality of patterned conductive electrically connected drive micro-wires **24**. An unpatterned conductive layer **30** that is unpatterned in the touch-sensitive area **31** is in electrical contact with the drive electrodes **22**. A plurality of patterned sense electrodes **52** in the touch-sensitive area **31**, each sense electrode **52** including a plurality of patterned conductive electrically connected sense micro-wires **54** is located on a side of the dielectric layer **40** opposite the drive electrodes **22** so that the dielectric layer **40** is located between the drive electrodes **22** and the sense electrodes **52** and electrically insulates the drive micro-wires **24** from the sense electrodes **52**. An optional protective overcoat layer **70** on the sense electrodes **52** protects the sense electrodes **52** from the environment, and in particular from touches by a finger or a stylus. FIG. **15** illustrates a cross section through a single drive electrode **22** and along a single sense micro-wire **54** of the sense electrode **52**.

[0090] As is illustrated further in the embodiment of FIGS. **15** and **27**, the drive electrodes **22**, the unpatterned conductive layer **30**, the dielectric layer **40**, and the sense electrodes **52** are formed on the substrate **10** that can also serve as an element of the display **110**, for example a display cover or substrate. Drive electrodes **22** are formed in the drive layer **20** and sense electrodes **52** are formed in the sense layer **50**. Such drive and sense layers **20**, **50** can, for example, include polymers such as curable polymers that are cured in various ways, such as by exposure to ultra-violet radiation or heat.

[0091] According to various embodiments of the present invention, FIGS. **16**-**30** illustrate touch-screen devices having various arrangements of the substrate **10**, drive layer **20**, unpatterned conductive layer **30**, dielectric layer **40**, and sense layer **50**. Separate drive layers **20** or sense layers **50** are

included in some embodiments and not in other embodiments. Drive micro-wires **24**, dummy micro-wires **90**, dummy micro-dots **92**, and sense micro-wires **54** are formed in or on the various layers using a variety of construction methods. The protective overcoat layer **70** can optionally be provided on layers formed on either side of the substrate **10**.

[0092] In the embodiment of FIGS. **15**, **20**, and **23**, the unpatterned conductive layer **30** is between the drive electrodes **22** and the dielectric layer **40**. The drive micro-wires **24** are formed in the separate drive layer **20**. Referring to FIGS. **16**, **18**, **21**, **22**, **24**, and **26** in an alternative arrangement according to various embodiments of the present invention, the unpatterned conductive layer **30** is not between the drive electrodes **22** and the dielectric layer **40** but is rather on a side of the drive electrodes **22** opposite the dielectric layer **40** or the sense electrodes **52** so that the drive electrodes **22** are between the unpatterned conductive layer **30** and the dielectric layer **40** or the sense electrodes **52**. The drive micro-wires **24**, dummy micro-wires **90** (not shown), or dummy micro-dots **92** (not shown) are formed in the dielectric layer **40**. In yet another embodiment illustrated in FIGS. **17** and **19**, the drive electrodes **22** are formed in the unpatterned conductive layer **30**, so that the unpatterned conductive layer **30** serves as the drive layer **20** supporting the drive electrodes **22**. In all three sets of arrangements, the sense micro-wires **54** are formed in the separate sense layer **50**.

[0093] In various embodiments of the present invention, the drive electrodes **22** are adjacent to the substrate **10**, as shown in FIGS. **15-20**, **23**, **25**, and **27**. By adjacent is meant that no other electrodes are between the drive electrodes **22** and the substrate **10**. The drive electrodes **22** are therefore located between the substrate **10** and the dielectric layer **40**. As illustrated in FIGS. **21**, **24**, and **26** in another embodiment, the sense electrodes **52** are adjacent to the substrate **10** so that no other electrodes are between the sense electrodes **52** and the substrate **10**. The sense electrodes **52** are therefore located between the substrate **10** and the dielectric layer **40**. In FIG. **24**, the drive micro-wires **24** are formed in the separate drive layer **20** and the sense micro-wires **54** are formed in a separate sense layer **50**. The unpatterned conductive layer **30** is located on a side of the drive electrodes **22** opposite the dielectric layer **40**. In FIG. **21**, the drive micro-wires **24** are formed in the dielectric layer **40** and the sense micro-wires **54** are formed in the separate sense layer **50**. The unpatterned conductive layer **30** is located on the dielectric layer **40** on a side of the dielectric layer **40** opposite the sense electrodes **52**.

[0094] In an embodiment illustrated in FIG. **22**, the drive electrodes **22** and the sense electrodes **52** are on opposite sides of the substrate **10** so that the substrate **10** also serves as the dielectric layer **40**. In this embodiment, as in the embodiment of FIG. **24**, the drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** are formed in the separate drive layer **20** and the sense micro-wires **54** are formed in the separate sense layer **50**. The unpatterned conductive layer **30** is located on a side of the drive electrodes **22** opposite the dielectric layer **40** (substrate **10**).

[0095] In the embodiment of FIG. **26**, the drive micro-wires **24** and dummy micro-wires **90** or dummy micro-dots **92** and the sense micro-wires **54** are embedded in opposite sides of the dielectric layer **40** formed on the substrate **10** adjacent to the sense micro-wires **54**. The unpatterned conductive layer **30** is on a side of the drive micro-wires **24** opposite the dielectric layer **40**.

[0096] Not all possible combinations and arrangements of layers are illustrated herein. Other arrangements that provide patterned micro-wire drive electrodes **22** electrically connected to an unpatterned conductive layer **30** on a side of the dielectric layer **40** opposite patterned micro-wire sense electrodes **52** are included within the present invention. In particular: either the drive electrodes **22** or the sense electrodes **52** can be independently arranged adjacent to the substrate **10**; the unpatterned conductive layer **30** is located between the drive electrodes **22** and the dielectric layer **40**, the drive electrodes **22** are located between the conductive layer and the dielectric layer **40**, or the drive electrodes **22** are located at least partially in the unpatterned conductive layer **30**; the drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** are formed in the separate drive layer **20**, in the dielectric layer **40**, in the unpatterned conductive layer **30**, or in the substrate **10**; or the sense electrodes **52** are located in a separate sense layer **50** or in the dielectric layer **40**. Various arrangements of each of these layers can be combined with other layer arrangements. In general, the touch surface of the touch-screen device is adjacent to the sense electrode **52**. For example, in FIGS. **21**, **24**, and **26** the touch surface **11** is a side of the substrate **10**. In the embodiments of FIGS. **15-20**, the touch surface **11** is opposite the substrate **10** rather than a substrate side.

[0097] There are at least three methods of providing the drive micro-wires **24**, dummy micro-wires **90**, dummy micro-dots **92**, and sense micro-wires **54**. In one method, the drive layer **20** or sense layer **50** is first formed and then the drive or sense micro-wires **24**, **54**, respectively, dummy micro-wires **90**, or dummy micro-dots **92** are formed in micro-channels imprinted in the drive layer **20** or sense layer **50** to embed the drive or sense micro-wires **24**, **54**, dummy micro-wires **90**, or dummy micro-dots **92** in the provided layer. In the Figures, the drive or sense micro-wires **24**, **54**, dummy micro-wires **90**, or dummy micro-dots **92** are formed in micro-channels and are illustrated as filling the micro-channels. Thus, the micro-channels are not distinguished from the micro-wires in the illustrations. In a second method, the drive or sense micro-wires **24**, **54**, dummy micro-wires **90**, or dummy micro-dots **92** are first formed, for example by printing or transfer onto the surface of substrate **10**, and then any subsequent drive layer **20** or sense layer **50** is coated, deposited, or otherwise provided over the drive or sense micro-wires **24**, **54**, dummy micro-wires **90**, or dummy micro-dots **92** to embed the drive or sense micro-wires **24**, **54**, dummy micro-wires **90**, or dummy micro-dots **92** in the provided layer. In a third method, a pre-made layer (for example using either of the first or second method) is laminated onto an underlying layer, for example the surface of substrate **10**. The pre-made layer can be, for example, either of the sense layer **50** with sense micro-wires **54** or the drive layer **20** with drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92**.

[0098] As shown in FIGS. **15**, **20**, and **22-24**, in the first method the drive layer **20** is provided, for example as a curable drive layer **20** that is then imprinted with an imprinting stamp to form drive micro-channels that are then filled with conductive ink and cured to form the drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** in the drive micro-channels in the drive layer **20**. As shown in FIG. **17**, the unpatterned conductive layer **30**, rather than the separate drive layer **20**, is imprinted with drive micro-channels and having cured drive micro-wires **24**. In the embodiment of FIG. **26**, the drive micro-wires **24**, dummy micro-wires **90**, or

dummy micro-dots **92** are formed in imprinted drive micro-channels in the dielectric layer **40**. Similarly, the sense micro-wires **54** are formed in sense micro-channels formed in the sense layer **50**, as shown in the embodiments of FIGS. **15-18**, **21**, **22**, and **25**. In FIG. **20**, sense micro-channels are imprinted in the dielectric layer **40** rather than the separate sense layer **50** and sense micro-wires **54** are formed in the sense micro-channels.

[0099] Referring to FIG. **25**, drive micro-wires **24** can extend through micro-channels formed in the drive layer **20** into the unpatterned conductive layer **30** to electrically connect the drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** to the unpatterned conductive layer **30**. In such an embodiment, the unpatterned conductive layer **30** and the drive layer **20** can be coated together, for example with slot or extrusion coating, imprinted together with a stamp having protrusions as deep as or deeper than the depth of drive layer **20**. The drive and unpatterned conductive layers **20**, **30** are then cured together to form micro-channels that are filled with conductive ink and cured to form drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** in the drive layer **20** in electrical contact with the unpatterned conductive layer **30**. The dielectric layer **40**, sense layer **50** with sense micro-wires **54**, and protective overcoat layer **70** are formed as described with respect to FIG. **15**.

[0100] In the second method of first forming micro-wires and then coating over the micro-wires and as shown in the example of FIG. **16**, the drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** are printed or otherwise transferred on the unpatterned conductive layer **30** and then the dielectric layer **40** is provided, for example by coating or laminating, over the drive micro-wires **24**. In FIG. **18**, the drive micro-wires **24** are printed or otherwise transferred on the unpatterned conductive layer **30** and then the drive layer **20** is provided, for example by coating, on the drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92**. In FIG. **19**, the drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** are printed or otherwise transferred on the substrate **10** and then the unpatterned conductive layer **30** is provided. Also as shown in FIG. **19**, the sense micro-wires **54** are printed or transferred on the dielectric layer **40**; no separate sense layer **50** is formed, although the protective overcoat layer **70** (not shown) can be provided and can serve as the sense layer **50**, if desired.

[0101] In all these various embodiments, the various layers can alternatively be pre-made and laminated together. Optically clear adhesives can be used as can conductive adhesives, if desired, for example to electrically connect the unpatterned conductive layer **30** to the drive micro-wires **24**. In such an embodiment, the conductive adhesive is considered to be part of the unpatterned conductive layer **30**.

[0102] In an embodiment of the present invention, the electrical resistance of the unpatterned conductive layer **30** is greater than the resistance of each of the drive electrodes **22**. The resistance of the unpatterned conductive layer **30** was measured as the sheet resistance of the unpatterned conductive layer **30** independently of the drive micro-wires **24**. The resistance of the drive electrodes **22** is the resistance measured along the length of the drive electrode **22**.

[0103] In an embodiment, the unpatterned conductive layer **30** has a sheet resistance greater than 1 kΩ per square, greater than 10 kΩ per square, greater than 100 kΩ per square, greater than 1 MΩ per square, greater than 10 MΩ per square, greater than 100 MΩ per square, greater than 1 GΩ per square, greater than 10 GΩ per square, or greater than 100 GΩ per square. This lower limit in resistivity of the unpatterned conductive layer **30** is dependent in part on the frequency at which the drive electrodes **22** are driven and on the drive current and voltage characteristics and on the conductivity of the drive electrodes **22**.

[0104] In another embodiment, the resistance of the unpatterned conductive layer **30** between any two drive electrodes **22** is at least five times greater, at least ten times greater, at least twenty times greater, at least fifty times greater, at least 100 times greater, at least 500 times greater, at least 1,000 times greater, at least 10,000, at least 100,000, or at least 1,000,000 times greater than the resistance of either of the two drive electrodes **22**. For example, as illustrated in FIG. **28**, the unpatterned conductive layer **30** is in electrical contact with the drive electrodes **22**. The drive electrodes **22** are made up of drive micro-wires **24**. The sense electrodes **52**, made up of sense micro-wires **54**, are separated from the drive electrodes **22** by the dielectric layer **40** (FIG. **27**, not shown in the plan view of FIG. **28**). The drive electrodes **22** are arranged in an array and separated by a gap **60**. The sense electrodes **52** are arranged in an array orthogonal to the array of drive electrodes **22**. Thus, in this example, the resistance of the unpatterned conductive layer **30** between drive electrodes **22** separated by the gap **60** is at least ten times greater than the resistance of any of the drive electrodes **22**. The conductive material in the unpatterned conductive layer **30** can extend over the substrate **10** beyond the area **31** but outside the area **31** the conductive material can be, but is not necessarily, patterned.

[0105] In various embodiments of the present invention, the resistance of the unpatterned conductive layer **30** can be adjusted to compensate for any unwanted conductivity between adjacent drive electrodes **22**. Although the dummy micro-wires **90** extend along equi-potential lines or the dummy micro-dots have a limited extent and an aspect ratio of approximately one, the dummy micro-wires **90** and dummy micro-dots **92** do have a physical width and therefore they do have some conductivity. If the dummy micro-wires **90** and dummy micro-dots **92** are made with common materials and in a common step with the driver micro-wires **24**, the physical width of the dummy micro-wires **90** and dummy micro-dots **92** will slightly decrease the resistance between adjacent driver electrodes **22**. This slight decrease can be compensated by a corresponding slight reduction in the conductivity of the unpatterned conductive layer **30**, for example by changing the material composition of the unpatterned conductive layer **30** or by reducing the thickness of the unpatterned conductive layer **30**.

[0106] In a further embodiment of the present invention, a driver, for example an integrated circuit, for driving the drive electrodes **22** provides voltage and current to the drive electrodes **22** in a desired drive waveform having a period and frequency. The frequency of the drive waveform limits the rate at which the capacitance between the drive and sense electrodes **22**, **52** can be measured. Because the unpatterned conductive layer **30** is electrically connected to the drive electrode **22** and has a limited conductivity, the rate at which the drive electrode **22** and the unpatterned conductive layer **30** can be charged is likewise limited. A micro-wire electrode, such as the drive electrode **22**, has gaps **26** between the micro-wires in the micro-wire electrode that, according to the present invention, are bridged with conductive material in the unpatterned conductive layer **30**. Thus, the conductivity of the

unpatterned conductive layer **30** will define, in combination with the open area defined by the geometry of the drive micro-wires **24** in the drive electrode **22**, the rate at which the drive electrode **22** and the unpatterned conductive layer **30** can be charged or discharged. Therefore, the conductivity of the unpatterned conductive layer **30** and the open area define the time constant for charging or discharging the drive electrode **22** and the center of the open area in response to a voltage change as provided by the drive waveform. Therefore, according to the further embodiment of the present invention, the sheet resistance of the unpatterned conductive layer **30**, including the dummy micro-wires **90** or dummy micro-dots **92**, is sufficiently low that the time constant for charging the center of the open area between drive micro-wires **24** in the drive electrode **22** is less than the period of a drive waveform. In another embodiment, the time constant is substantially less than the period. By substantially less is meant at least 5% less, at least 10% less, at least 20% less, or at least 50% less.

[0107] In operation, a touch-screen controller (for example touch-screen controller **140** of FIG. **27**) energizes one of the drive electrodes **22** and senses one of the sense electrode **52** to detect the capacitance, charge, or current or changes in capacitance, charge, or current of the area overlapped by the one drive electrode **22** and one sense electrode **52**. Since the unpatterned conductive layer **30** electrically connects the drive electrodes **22**, some current leaks from the driven drive electrode **22** to other drive electrodes **22**. However, because the resistance of the unpatterned conductive layer **30** is high relative to the resistance of the drive electrodes **22**, capacitance is still detected in the overlapped electrode area. Moreover, the presence of the unpatterned conductive layer **30** inhibits electromagnetic interference from affecting the capacitance measure by the sense electrode **52**, especially if the electromagnetic interference originates from a side of the unpatterned conductive layer **30** opposite the sense electrodes **52**. Furthermore, the unpatterned conductive layer **30** assists in extending the electrical field produced by driving the drive micro-wires **24** in the one drive electrode **22** into the spaces between the drive micro-wires **24**, thereby providing a more uniform field between the drive electrode **22** and the sense electrode **52**. A more uniform field enables a more consistent and sensitive detection of capacitance changes due to the presence of perturbing elements such as a finger or a stylus at varying spatial locations. Furthermore, the presence of the unpatterned conductive layer **30** reduces the sensitivity of the touch-screen device to differences in alignment between the drive micro-wires **24** of the drive electrodes **22** and the sense micro-wires **54** of the sense electrodes **52**.

[0108] In comparison to other prior-art solutions using a separate ground plane beneath drive electrodes to reduce the effect of electro-magnetic radiation, for example from a display located beneath the touch screen, the present invention provides a thinner touch-screen and display structure. Moreover, the use of dummy micro-wires **90** or dummy micro-dots **92** provides optical uniformity over the touch-screen area **31**.

[0109] If prior-art dummy micro-wires **152**, for example those illustrated in FIG. **33** having a typical arrangement corresponding to the arrangement of the electrode micro-wires **150**, are used in combination with the unpatterned conductive layer **30** of the present invention, the unpatterned conductive layer **30** and the prior-art dummy micro-wires **152** will electrically short the separate drive electrodes **22** together so that they cannot function. Furthermore, the pitch of the electrode micro-wires **24** anticipated in practical applications is so large that electromagnetic interference can readily pass through the electrode micro-wires **24** or prior-art dummy micro-wires **152** in the absence of the unpatterned conductive layer **30**. Hence, prior-art dummy micro-wire arrangements cannot be used with the unpatterned conductive layer **30** of the present invention without destroying the functionality of the unpatterned conductive layer **30** and the electrodes **22**.

[0110] Referring again to FIG. **6**, a method of the present invention includes providing a plurality of patterned drive electrodes **22**, for example on the substrate **10**, each drive electrode **22** including a plurality of patterned conductive electrically connected micro-wires **24** and any dummy micro-wires **90** or dummy micro-dots **92** at the same time in simultaneous steps **500** and **505**. The unpatterned conductive layer **30** is located in electrical contact with the drive electrodes **22** in step **510**. The dielectric layer **40** is located adjacent to the unpatterned conductive layer **30** in step **515**. A plurality of patterned sense electrodes **52**, each sense electrode **52** including a plurality of patterned conductive electrically connected micro-wires **54** is located over the dielectric layer **40** so that the dielectric layer **40** is located between the drive electrodes **22** and the sense electrodes **52** in step **520**.

[0111] A variety of techniques are usable to construct a touch screen device of the present invention. In various embodiments, the patterned drive electrodes **22** are formed in a layer, such as drive layer **20**, unpatterned conductive layer **30**, or dielectric layer **40**, printed or transferred onto a layer, such as the substrate **10**, unpatterned conductive layer **30**, or dielectric layer **40**, or laminated on the substrate **10** or other layer on the substrate **10**. In other embodiments, the unpatterned conductive layer **30** is laminated, coated, formed by evaporation, sputtering, or chemical vapor deposition, or formed by atomic layer deposition on the drive electrodes **22** or drive layer **20**. The dielectric layer **40** is laminated, coated, formed by evaporation, sputtering, or chemical vapor deposition, or formed by atomic layer deposition on the unpatterned conductive layer **30**. The patterned sense electrodes **52** are formed in a layer, such as sense layer **50** or dielectric layer **40**, printed or transferred onto a layer, such as the substrate **10** or dielectric layer **40**, or laminated on the substrate **10** or other layer on the substrate **10**.

[0112] In an embodiment, unpatterned conductive layer **30** or dielectric layer **40** is deposited by sputtering or deposition and patterned outside the touch-sensitive area **31** either with masks or by photolithographic processes. In an embodiment, conductive material is only deposited in the touch-sensitive area **31**. Alternatively, conductive material is deposited over the entire substrate **10** and removed as needed, for example in peripheral regions of the touch screen outside the touch-sensitive area **31**. In another embodiment, atomic layer deposition methods are used to form a transparent conductive layer, for example a patterned aluminum zinc oxide layer using methods known in the art. Patterning outside the touch-sensitive area **31** is accomplished, for example, by masking the deposition, using patterned deposition inhibitors, or by photolithographic processes.

[0113] Alternatively or in addition, referring to FIG. **29**, the substrate **10** is provided in step **200**, together with imprinting stamps in step **205**. The drive layer **20** is provided on the substrate **10**, for example by coating in step **210**. The patterned drive electrodes **22** are formed by imprinting the drive layer **20** with an imprinting stamp to form micro-channels in step **215**, curing the drive layer **20** to form drive micro-

channels in step **220** that are filled with conductive ink in step **230**. The conductive ink is cured in step **235** to form drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92**. The unpatterned conductive layer **30** is coated over the drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** in step **300** and the dielectric layer **40** is coated over the unpatterned conductive layer **30** in step **305**. The unpatterned conductive layer **30** is provided on the drive layer **20**, for example by coating in step **300**. The dielectric layer **40** is coated over the unpatterned conductive layer **30** in step **305** and the sense layer **50** in step **310**. Alternatively, the separate dielectric layer **40** is not coated and the sensor layer **50** also serves as the dielectric layer (as shown for example in FIG. **1**A). The patterned sense electrodes **52** are formed by imprinting the sense layer **50** with an imprinting stamp to form micro-channels in step **315**, the sense layer **50** is cured to form sense micro-channels in step **320**, and the sense micro-channels are filled with conductive ink in step **330**. The conductive ink is cured in step **335** to form sense micro-wires **54**. The protective overcoat layer **70** is optionally coated in step **400**.

[0114] In other embodiments, imprinting methods are used to imprint drive micro-channels in the dielectric layer **40** (as shown in FIG. **21**) or in the unpatterned conductive layer **30** (as shown in FIG. **18**). Similarly, in other embodiments imprinting methods are used to imprint sense micro-channels in the dielectric layer **40** (as shown in FIG. **20**). Likewise, the order of construction of the drive layer **20** and the sense layer **50** can be reversed.

[0115] Printing methods are usable in other embodiments of the present invention. A conductive ink is printable, for example with a flexographic plate, on a substrate **10** or other layer and cured to form micro-wires. Alternatively, a pattern of micro-wires is transferrable to the substrate **10** or other layer. For example, in FIGS. **16** and **18**, drive micro-wires are printed or transferred onto the unpatterned conductive layer **30**. Referring to FIG. **17**, drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** are printed on or transferred to the substrate **10** and then coated with unpatterned conductive layer **30**. Likewise, as shown in FIG. **23**, the sense electrodes **52** are printed on or transferred to the dielectric layer **40** and then coated with the sense layer **50**.

[0116] In an alternative embodiment, micro-wires are formed by coating a flexographic substrate having a raised pattern corresponding to a desired micro-wire pattern with a conductive ink. The flexographic substrate is brought into contact with a layer surface to print the conductive ink onto the layer surface. In an optional step, the conductive ink is dried. Flexographic substrates are known in the flexographic printing arts.

[0117] In yet another embodiment, layer structures are laminated to another layer. Referring to FIG. **15**, for example, the drive layer **20** is made as a separate construction (for example as a layer of PET) including drive micro-wires **24**, dummy micro-wires **90**, or dummy micro-dots **92** and then laminated with an adhesive to substrate **10**. Sense layer **50** is made and similarly laminated. The unpatterned conductive layer **30** or dielectric layer **40** can be laminated onto their respective layers, together or separately. In another embodiment, a layer structure is formed on a temporary substrate with a temporary adhesive on a first side, the layer structure is permanently adhered to the substrate **10** or layer formed on the substrate **10** on a second side, and then the temporary substrate is removed from the first side, for example by peeling.

[0118] In various embodiments, the unpatterned conductive layer **30** is laminated, coated, or deposited on the drive electrodes **22**. In an embodiment, atomic layer deposition is used to form the unpatterned conductive layer **30**. In other embodiments, the dielectric layer **40** is laminated, coated, or deposited on the drive electrodes **22** or sense electrodes **52**.

[0119] Dielectric layer **40** can be any of many known dielectric materials included polymers or oxides and are deposited or formed in any of a variety of known ways, including pattern-wise inkjet deposition, sputter or coating through a mask or blanket coated and patterned using known photo-lithographic methods. Such known photo-lithographic technology can include a photo-sensitive material that is optically patterned through a mask to cure the photo-sensitive material and removal of uncured material.

[0120] In an embodiment, unpatterned conductive layer **30** is transparent and includes one or more of a variety of transparent conductive materials, for example organic conductive polymers such as Poly(3,4-ethylenedioxythiophene) (PEDOT), Poly(3,4-ethylenedioxythiophene) PEDOT: poly(styrene sulfonate) PSS, Poly(4,4-dioctylcyclopentadithiophene), and Polypyrrole (PPy), long-chain aliphatic amines (optionally ethoxylated) and amides, quaternary ammonium salts (such as, behentrimonium chloride or cocamidopropyl betaine), esters of phosphoric acid, polyethylene glycol esters, or polyols, polyaniline nanofibers, carbon nanotubes, graphene, metals such as silver nanowires, and inorganic conductive oxides such as ITO, SnO_2, In_2O_3, ZnO, Aluminum-doped zinc oxide (AZO), CdO, Ga_2O_3, V_2O_5. Deposition methods for conductive materials can include solvent or aqueous coating, printing by for example inkjet, gravure, offset litho, flexographic, or electro-photographic, lamination, evaporation, chemical vapor deposition (CVD), sputtering, atomic-layer deposition (ALD) or spatial-atomic-layer deposition (SALD).

[0121] In another embodiment, unpatterned conductive layer **30** is an ionic conductor, a solid ionic conductor, an electrolyte, a solid electrolyte, or a conductive gel, as are known in the art.

[0122] In an embodiment, the unpatterned conductive layer **30** has a thickness less than or equal to 50 nm, 100 nm, 200 nm, 500 nm, or 1 micron. In other embodiments, the unpatterned conductive layer **30** has a thickness less than or equal to 10 microns, 100 microns, 200 microns, 500 microns, or 1 mm.

[0123] According to various embodiments of the present invention, the substrate **10** is any material on which a layer is formed. The substrate **10** is a rigid or a flexible substrate made of, for example, a glass, metal, plastic, or polymer material, can be transparent, and can have opposing substantially parallel and extensive surfaces. Substrates **10** can include a dielectric material useful for capacitive touch screens and can have a wide variety of thicknesses, for example 10 microns, 50 microns, 100 microns, 1 mm, or more. In various embodiments of the present invention, substrates **10** are provided as a separate structure or are coated on another underlying substrate, for example by coating a polymer substrate layer on an underlying glass substrate.

[0124] In various embodiments substrate **10** is an element of other devices, for example the cover or substrate of a display or a substrate, cover, or dielectric layer of a touch

screen. In an embodiment, the substrate **10** of the present invention is large enough for a user to directly interact therewith, for example using an implement such as a stylus or using a finger or hand. Methods are known in the art for providing suitable surfaces on which to coat or otherwise form layers. In a useful embodiment, the substrate **10** is substantially transparent, for example having a transparency of greater than 90%, 80% 70% or 50% in the visible range of electromagnetic radiation.

[0125] Electrically conductive micro-wires and methods of the present invention are useful for making electrical conductors and busses for transparent micro-wire electrodes, dummy micro-wires **90**, or dummy micro-dots **92** and electrical conductors in general, for example as used in electrical busses. A variety of micro-wire patterns are used and the present invention is not limited to any one pattern. Micro-wires can be spaced apart, form separate electrical conductors, or intersect to form a mesh electrical conductor on, in, or above the substrate **10**. Micro-channels can be identical or have different sizes, aspect ratios, or shapes. Similarly, micro-wires can be identical or have different sizes, aspect ratios, or shapes. Micro-wires can be straight or curved.

[0126] A micro-channel is a groove, trench, or channel formed on or in a layer extending from the surface of the layer and having a cross-sectional width for example less than 20 microns, 10 microns, 5 microns, 4 microns, 3 microns, 2 microns, 1 micron, or 0.5 microns, or less. In an embodiment, the cross-sectional depth of a micro-channel is comparable to its width. Micro-channels can have a rectangular cross section. Other cross-sectional shapes, for example trapezoids, are known and are included in the present invention. The width or depth of a layer is measured in cross section. Micro-channels are not distinguished in the Figures from the micro-wires.

[0127] Imprinted layers useful in the present invention can include a cured polymer material with cross-linking agents that are sensitive to heat or radiation, for example infra-red, visible light, or ultra-violet radiation. The polymer material is a curable material applied in a liquid form that hardens when the cross-linking agents are activated. When a molding device, such as an imprinting stamp having an inverse micro-channel structure is applied to liquid curable material and the cross-linking agents in the curable material are activated, the liquid curable material in the curable layer is hardened into a cured layer. The liquid curable materials can include a surfactant to assist in controlling coating. Materials, tools, and methods are known for embossing coated liquid curable materials to form cured layers.

[0128] A cured layer is a layer of curable material that has been cured. For example, a cured layer is formed of a curable material coated or otherwise deposited on a layer surface to form a curable layer and then cured to form the cured layer. The coated curable material is considered herein to be a curable layer before it is cured and cured layer after it is cured. Similarly, a cured electrical conductor is an electrical conductor formed by locating a curable material in micro-channel and curing the curable material to form a micro-wire in a micro-channel. As used herein, curing refers to changing the properties of a material by processing the material in some fashion, for example by heating, drying, irradiating the material, or exposing the material to a chemical, energetic particles, gases, or liquids.

[0129] The curable layer is deposited as a single layer in a single step using coating methods known in the art, such as curtain coating. In an alternative embodiment, the curable layer is deposited as multiple sub-layers using multi-layer deposition methods known in the art, such as multi-layer slot coating, repeated curtain coatings, or multi-layer extrusion coating. In yet another embodiment, the curable layer includes multiple sub-layers formed in different, separate steps, for example with a multi-layer extrusion, curtain coating, or slot coating machine as is known in the coating arts.

[0130] Curable inks useful in the present invention are known and can include conductive inks having electrically conductive nano-particles, such as silver nano-particles. In an embodiment, the electrically conductive nano-particles are metallic or have an electrically conductive shell. The electrically conductive nano-particles can be silver, can be a silver alloy, or can include silver. In various embodiments, cured inks can include metal particles, for example nano-particles. The metal particles are sintered to form a metallic electrical conductor. The metal nano-particles are silver or a silver alloy or other metals, such as tin, tantalum, titanium, gold, copper, or aluminum, or alloys thereof. Cured inks can include light-absorbing materials such as carbon black, a dye, or a pigment.

[0131] Curable inks provided in a liquid form are deposited or located in drive or sense micro-channels and cured, for example by heating or exposure to radiation such as infra-red light, visible light, or ultra-violet radiation. The curable ink hardens to form the cured ink that makes up drive or sense micro-wires **24**, **54**, dummy micro-wires **90**, or dummy micro-dots **92**. For example, a curable conductive ink with conductive nano-particles are located within drive or sense micro-channels and cured by heating or sintering to agglomerate or weld the nano-particles together, thereby forming an electrically conductive drive or sense micro-wire **24**, **54**. Materials, tools, and methods are known for coating liquid curable inks to form micro-wires.

[0132] In an embodiment, a curable ink can include conductive nano-particles in a liquid carrier (for example an aqueous solution including surfactants that reduce flocculation of metal particles, humectants, thickeners, adhesives or other active chemicals). The liquid carrier is located in micro-channels and heated or dried to remove liquid carrier or treated with hydrochloric acid, leaving a porous assemblage of conductive particles that are agglomerated or sintered to form a porous electrical conductor in a layer. Thus, in an embodiment, curable inks are processed to change their material compositions, for example conductive particles in a liquid carrier are not electrically conductive but after processing form an assemblage that is electrically conductive.

[0133] Once deposited, the conductive inks are cured, for example by heating. The curing process drives out the liquid carrier and sinters the metal particles to form a metallic electrical conductor. Conductive inks are known in the art and are commercially available. In any of these cases, conductive inks or other conducting materials are conductive after they are cured and any needed processing completed. Deposited materials are not necessarily electrically conductive before patterning or before curing. As used herein, a conductive ink is a material that is electrically conductive after any final processing is completed and the conductive ink is not necessarily conductive at any other point in the micro-wire formation process.

[0134] In various embodiments of the present invention, micro-channels or micro-wires have a width less than or equal to 10 microns, 5 microns, 4 microns, 3 microns, 2 microns, or 1 micron. In an example and non-limiting embodiment of the

present invention, each micro-wire is from 10 to 15 microns wide, from 5 to 10 microns wide, or from 5 microns to one micron wide. In some embodiments, micro-wires can fill micro-channels; in other embodiments micro-wires do not fill micro-channels. In an embodiment, the micro-wires are solid; in another embodiment, the micro-wires are porous.

[0135] Micro-wires can be metal, for example silver, gold, aluminum, nickel, tungsten, titanium, tin, or copper or various metal alloys including, for example silver, gold, aluminum, nickel, tungsten, titanium, tin, or copper. Micro-wires can include a thin metal layer composed of highly conductive metals such as gold, silver, copper, or aluminum. Other conductive metals or materials are usable. Alternatively, micro-wires can include cured or sintered metal particles such as nickel, tungsten, silver, gold, titanium, or tin or alloys such as nickel, tungsten, silver, gold, titanium, or tin. Conductive inks are used to form micro-wires with pattern-wise deposition or pattern-wise formation followed by curing steps. Other materials or methods for forming micro-wires, such as curable ink powders including metallic nano-particles, are employed and are included in the present invention.

[0136] Electrically conductive micro-wires of the present invention are operable by electrically connecting micro-wires through connection pads and electrical connectors to electrical circuits that provide electrical current to micro-wires and can control the electrical behavior of micro-wires. Electrically conductive micro-wires of the present invention are useful, for example in touch screens such as projected-capacitive touch screens that use transparent micro-wire electrodes and in displays. Electrically conductive micro-wires can be located in areas other than display areas, for example in the perimeter of the display area of a touch screen, where the display area is the area through which a user views a display.

Inventive Example

[0137] Referring to FIG. **30**, sense electrodes **52** including sense micro-wires **54** were prepared using a standard lithographic process. Microposit **1813** photoresist was spin-coated onto a 1000 Å thermally deposited aluminum layer coated on a 2.5 inch by 2.5 inch square 4 mil PET support. The photoresist was exposed to UV light through a chrome-on-quartz mask, developed, rinsed and dried. The film was then etched in PAN etch leaving a positive image having 10 μm wide aluminum micro-wires consisting of connected open right-angle-diamond electrodes, 1600 μm on diagonal. The periodic width of the sense electrodes **52** was 6.42 mm separated by 400 micron breaks in the sense micro-wires **54** at intersections between sense electrodes **52**. The sense electrodes **52** were terminated with conductive rectangular pads to enable simple resistance measurements end-to-end. The pads at one end of the sense electrodes **52** also had conductive buss lines leading to additional pads at the edge of the support (dielectric layer **40**) to enable conventional 1 mm pitch edge connection with electrical test fixtures. The photoresist was removed with acetone and methanol baths and dried with nitrogen. Sense electrode **52** resistance was measured to be on the order of 450Ω from end-to-end and essentially infinite between nearest neighbor electrodes.

[0138] Drive electrodes **22** were prepared as were the sense electrodes **52**, on a separate 4 mil PET support (substrate **10**), and with the final addition of a transparent unpatterned conductive layer **30** formed on the lithographically patterned micro-wires **24** by spin coating a solution of PEDOT/PSS at 3000 rpm and drying on a hotplate for 2 minutes at 110° C. Sheet resistance of the dried PEDOT/PSS coating on a section of bare PET support using a four point probe was 8 MΩ/square. Drive electrode resistance was measured to be on the order of 450Ω from end-to-end with approximately 160 kΩ between nearest neighbor electrodes. Thus the ratio of shorting resistance to drive resistance in this inventive example was 356 to 1.

[0139] A functional touch-screen was fabricated from the prepared sense and drive electrodes **52**, **22** by first, laminating a cover sheet of 4 mil PET (protective overcoat layer **70**) on the exposed side of the sense electrodes **52** on dielectric layer **40** using optically clear adhesive (first optically clear adhesive layer **80**), OCA (Adhesives Research, ARClear 8154 Optically Clear Unsupported Transfer Adhesive) to form a coversheet of the touch-screen example. Sense electrodes **52** were oriented 90 degrees with respect to drive electrodes **22** and offset such that the intersections of the diamonds were directly above the center of the diamonds of the drive electrodes **22**. The uncoated side of the dielectric layer **40** was laminated to the exposed side of the unpatterned conductive layer **30** using the same optically clear adhesive as a second optically clear adhesive layer **82**. The dielectric thus includes both the OCA (second optically clear adhesive layer **82**) and the 4 mil PET dielectric layer **40**.

Comparative Example

[0140] For the purpose of comparison, a control touch-screen representing an example of the prior art was prepared exactly as described above except the coating of PEDOT/PSS forming the unpatterned conductive layer **30** was eliminated in the comparative example.

Results:

[0141] The measurement apparatus consisted of two translation stages which were used to move a mechanical, artificial finger incrementally across the sample. The weight of the finger was used to provide a constant touch force and the tip of the artificial finger consisted of a compliant, conductor loaded polymer foam mounted on the end of a conductive rod. All but one drive electrode **22** were held at ground while a voltage waveform consisting of a controlled burst of sine waves (either 100 kHz or 1 MHz) was applied to one of the drive electrodes **22**. All of the sense electrodes **52** were held at ground and one was connected to a charge sensitive pre-amplifier (operational amplifier with capacitor feedback) which held the sense electrodes **52** at ground and output a voltage proportional to the input charge. The output voltage from the sensing amplifier was sampled periodically at 20 MHz. Digital processing was used to synchronously (with respect to the driven waveform) rectify the sampled signal and compute an average (in phase) voltage. By spatially stepping the artificial finger across the sample in a spatial matrix of locations, the sensed voltages are mapped as a function of the artificial finger location. By inference, the response of a single repetitive unit at a single location is the same as the response at any other location (except for boundaries). By measuring a known conventional capacitor with the same instrument, the voltage reading is converted to effective capacitance readings.

[0142] The mutual no-touch capacitance for the inventive example was 1.8 times higher than the comparative example at either 100 kHz or 1 MHz. This increase illustrates the effective field-spreading characteristic of the unpatterned

conductive layer **30** in the inventive example at practical measurement frequencies and is usable to reduce the relative power consumption of a touch-sense controller resulting in improved system efficiency.

[0143] To test touch sensitivity, the examples were scanned with a 10.4 mm diameter artificial finger in a matrix pattern centered at an intersection of the active sense and drive electrodes **52**, **22**. In each case, far from the intersection, the capacitance was equivalent to the no-touch condition, as expected. Centered on the intersection the capacitance was less than the no-touch condition and the relative difference between the near node touch and no-touch reading was taken as a measure of the touch sensitivity.

$$\text{Touch-Sensitivity}=-(C_{touch}-C_{no_touch})/C_{no_touch}$$

[0144] At 1 MHz the relative touch sensitivity was 42% for the inventive example and 50% for the comparative example. Thus, the touch signal in the inventive example was strong and differences between the inventive and comparative example small, demonstrating that the unpatterned conductive layer **30** has minimal effect on the touch sensitivity while increasing the capacitance. The observed difference in touch sensitivity can be due in part or entirely to imperfections of the alignment of sense and drive electrodes in each example.

[0145] To test the shielding properties, connections to the sense and drive electrodes **52**, **22** were exchanged thus reversing the roles of the drive and sense electrodes **22**, **52** and the artificial finger was scanned over the back-side of the examples. By symmetry this makes no difference for the comparative example but shows a reduction in touch sensitivity due to the shielding effects of the field-spreading unpatterned conductive layer **30** in the inventive example. Indeed, the results showed a factor of 3 reductions in touch sensitivity at 1 MHz and complete elimination of touch signal at 100 kHz for the inventive example. This reduction in frequency response is an illustration of the time constant for charging or discharging the open areas of the unpatterned conductive layer **30** in the drive electrode **22**. Touch sensitivity of the comparative example was unaffected, as expected. Thus the field spreading unpatterned conductive layer **30** in the inventive example exhibited highly effective shielding at practical frequencies with no deleterious effects due to shorting between drive electrodes **22**. Capacitance signal increased and little change in touch sensitivity was observed when driven and sensed in the intended configuration achieving a considerable improvement in overall system efficiency relative to the prior art example was demonstrated.

[0146] The optical uniformity of the dummy micro-wires **90** and dummy micro-dots **92** located between electrodes **20** were tested using image patterns displayed on a high-resolution monitor at standard viewing distances. Dummy micro-wires **90** arranged in lines along different equi-potential lines and dummy micro-wires **90** arranged in dashed lines along different equi-potential lines were both tested with electrode micro-wires arranged as shown in the drive layer **20** of FIG. **1**A. When the length and number of dummy micro-wires **90** were chosen to match the electrode micro-wires **22**, no visible difference in optical uniformity between the drive electrode **22** and the gap **26** was observed. Dummy micro-dots **92** were also tested. The dummy micro-dots were arranged in lines, in a regular two-dimensional array (e.g. as in FIG. **10**), and in a random arrangement. In every case, no visible difference in optical uniformity between the drive electrode **22** and the gap **26** was observed.

[0147] Methods and devices for forming and providing substrates and coating substrates are known in the photolithographic arts. Likewise, tools for laying out electrodes, conductive traces, and connectors are known in the electronics industry as are methods for manufacturing such electronic system elements. Hardware controllers for controlling touch screens and displays and software for managing display and touch screen systems are well known. These tools and methods are usefully employed to design, implement, construct, and operate the present invention. Methods, tools, and devices for operating capacitive touch screens are used with the present invention.

[0148] In addition to the inventive and comparative examples described, a touch-screen structure having a PEDOT/PSS unpatterned conductive layer **30** was constructed using the imprinting techniques described and, in a separate sample, an unpatterned conductive layer **30** of AZO on etched drive micro-wires **24** was formed using atomic-layer deposition methods.

[0149] The present invention is useful in a wide variety of electronic devices. Such devices can include, for example, photovoltaic devices, OLED displays and lighting, LCD displays, plasma displays, inorganic LED displays and lighting, electrophoretic displays, electrowetting displays, dimming mirrors, smart windows, transparent radio antennae, transparent heaters and other touch-screen devices such as capacitive touch screen devices.

[0150] The invention has been described in detail with particular reference to certain embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

[0151] B cross section line
[0152] C cross section line
[0153] **5** micro-wire multi-electrode structure
[0154] **10** substrate
[0155] **11** touch surface
[0156] **20** drive layer/electrode layer
[0157] **22** drive electrode/electrode
[0158] **23** edge electrode
[0159] **24** drive micro-wire/micro-wire
[0160] **26**, **26**A, **26**B drive gap/gap
[0161] **30** unpatterned conductive layer
[0162] **31** area/touch-sensitive area
[0163] **33** area edge **40** dielectric layer
[0164] **50** sense layer
[0165] **52** sense electrode
[0166] **54** sense micro-wire
[0167] **56** sense gap
[0168] **60** gap
[0169] **70** protective overcoat layer
[0170] **80** first optically clear adhesive layer
[0171] **82** second optically clear adhesive layer
[0172] **90**, **90**A, **90**B equi-potential dummy micro-wires
[0173] **92**, **92**A, **92**B dummy micro-dots
[0174] **94** additional dummy micro-wires
[0175] **95** additional dummy micro-dots
[0176] **96** edge dummy micro-wires
[0177] **98** edge dummy micro-dots
[0178] **100** display and touch-screen apparatus
[0179] **110** display

PARTS LIST CONT'D

[0180] **120** touch screen
[0181] **122** first transparent substrate
[0182] **124** dielectric layer
[0183] **126** second transparent substrate
[0184] **128** touch pad area
[0185] **130** first transparent electrode
[0186] **132** second transparent electrode
[0187] **134** wires
[0188] **136** electrical buss connections
[0189] **140** touch-screen controller
[0190] **142** display controller
[0191] **150** micro-wire
[0192] **152** dummy micro-wire
[0193] **156** micro-pattern
[0194] **200** provide substrate step
[0195] **205** provide stamps step
[0196] **210** provide drive layer step
[0197] **215** imprint drive micro-channels step
[0198] **220** cure drive micro-channels step
[0199] **230** provide conductive ink in drive micro-channels step
[0200] **235** cure conductive ink in drive micro-channels step
[0201] **300** coat conductive layer step
[0202] **305** coat dielectric layer step
[0203] **310** provide sense layer step
[0204] **315** imprint sense micro-channels step
[0205] **320** cure sense micro-channels step
[0206] **330** provide conductive ink in sense micro-channels step
[0207] **335** cure conductive ink in sense micro-channels step
[0208] **400** optional coat overcoat step

PARTS LIST CONT'D

[0209] **500** provide drive micro-wire electrode step
[0210] **505** provide dummy micro-wire step
[0211] **510** locate unpatterned conductive layer step
[0212] **515** locate dielectric layer step
[0213] **520** provide sense micro-wire electrode step

1. A micro-wire multi-electrode structure having an area of substantially uniform optical density, comprising:

a plurality of spatially separated patterned electrodes located in an electrode layer in the area, each electrode including a plurality of patterned conductive electrically connected electrode micro-wires;

one or more patterned equi-potential electrically conductive dummy micro-wires in the area located substantially along equi-potential lines between adjacent electrodes and electrically isolated from the electrode micro-wires, whereby the area has a substantially uniform optical density; and

an unpatterned conductive layer in the area, the unpatterned conductive layer in electrical contact with the electrode micro-wires and the dummy micro-wires.

2. The micro-wire multi-electrode structure of claim **1**, wherein the electrodes are drive electrodes, the electrode layer is a drive layer, the electrode micro-wires are drive micro-wires, and the area is a touch-sensitive area and further comprising:

a plurality of spatially separated patterned sense electrodes in a sense layer in the touch-sensitive area, each sense electrode including a plurality of patterned conductive electrically connected sense micro-wires; and

a dielectric layer located between the drive electrodes and the sense electrodes.

3. The micro-wire multi-electrode structure of claim **2**, wherein the dummy micro-wires are located in the drive layer.

4. The micro-wire multi-electrode structure of claim **2**, further including additional dummy micro-wires formed in the sense layer.

5. The micro-wire multi-electrode structure of claim **1**, wherein multiple dummy micro-wires are located along a common equi-potential line.

6. The micro-wire multi-electrode structure of claim **1**, wherein a first dummy micro-wire is located along a first equi-potential line and a second dummy micro-wire is located along a second equi-potential line different from the first equi-potential line.

7. The micro-wire multi-electrode structure of claim **1**, wherein the dummy micro-wires are formed in a common layer with the electrode micro-wires.

8. The micro-wire multi-electrode structure of claim **1**, wherein the dummy micro-wires have a common material with the electrode micro-wires.

9. The micro-wire multi-electrode structure of claim **1**, wherein the area has an area edge and further including an edge electrode adjacent to the area edge and edge dummy micro-wires in the area located along equi-potential lines between the edge electrode and the area edge and electrically disconnected from the edge electrode.

10. The micro-wire multi-electrode structure of claim **9**, further including an electrical wire located outside the area and adjacent to the area edge and the edge dummy micro-wires are located between the electrode and the electrical wire.

11. The micro-wire multi-electrode structure of claim **1**, wherein first dummy micro-wires are located between first adjacent electrodes in a first pattern and second dummy micro-wires are located between second adjacent electrodes in a second pattern different from the first pattern.

12. The micro-wire multi-electrode structure of claim **1**, wherein first dummy micro-wires are located between first adjacent electrodes in a first pattern and second dummy micro-wires are located between second adjacent electrodes in a second pattern that is the same as the first pattern.

13. The micro-wire multi-electrode structure of claim **1**, wherein the plurality of spatially separated patterned electrodes in the area includes a first electrode having electrically connected electrode micro-wires forming a first pattern and a second electrode having electrically connected electrode micro-wires forming a second pattern different from the first pattern.

14. The micro-wire multi-electrode structure of claim **1**, wherein the plurality of spatially separated patterned electrodes in the area includes a first electrode having electrically connected electrode micro-wires forming a first pattern and a second electrode having electrically connected electrode micro-wires forming a second pattern that is the same as the first pattern.

15. The micro-wire multi-electrode structure of claim **1**, wherein the plurality of spatially separated patterned electrodes in the area form a regular array of electrodes.

16. The micro-wire multi-electrode structure of claim **1**, wherein portions of the dummy micro-wires are straight line segments.

17. The micro-wire multi-electrode structure of claim **1**, wherein portions of the dummy micro-wires are curved line segments.

18. The micro-wire multi-electrode structure of claim **1**, wherein at least one dummy micro-wire includes a plurality of line segments connected at an angle.

19. The micro-wire multi-electrode structure of claim **1**, wherein at least one electrode includes electrode micro-wires that are a mirror image of the electrically connected micro-wires in an adjacent electrode.

20. A touch-screen device having a substantially uniform optical density in a touch-sensitive area, comprising:

a plurality of spatially separated patterned drive electrodes located in a drive layer in the touch-sensitive area, each drive electrode including a plurality of patterned conductive electrically connected drive micro-wires;

a plurality of spatially separated patterned sense electrodes in a sense layer in the touch-sensitive area, each sense electrode including a plurality of patterned conductive electrically connected sense micro-wires;

a dielectric layer located between the drive electrodes and the sense electrodes;

one or more patterned electrically isolated equi-potential dummy micro-wires in the touch-sensitive area located substantially along equi-potential lines between adjacent drive electrodes and electrically disconnected from the adjacent drive electrodes, whereby the touch-sensitive area has a substantially uniform optical density;

a conductive layer that is unpatterned in the touch-sensitive area, the conductive layer in electrical contact with the drive micro-wires and the dummy micro-wires; and

a controller electrically connected to the drive and sense electrodes for controlling the drive and sense electrodes.

21. A method of making a micro-wire multi-electrode structure having an area of substantially uniform optical density, comprising:

providing a plurality of spatially separated patterned electrodes in an electrode layer in the area, each electrode including a plurality of patterned conductive electrically connected electrode micro-wires;

providing one or more patterned electrically isolated dummy micro-wires in the area located substantially along equi-potential lines between adjacent electrodes, whereby the area has a substantially uniform optical density; and

locating an unpatterned conductive layer in the area, the unpatterned conductive layer in electrical contact with the electrode micro-wires and dummy micro-wires.

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