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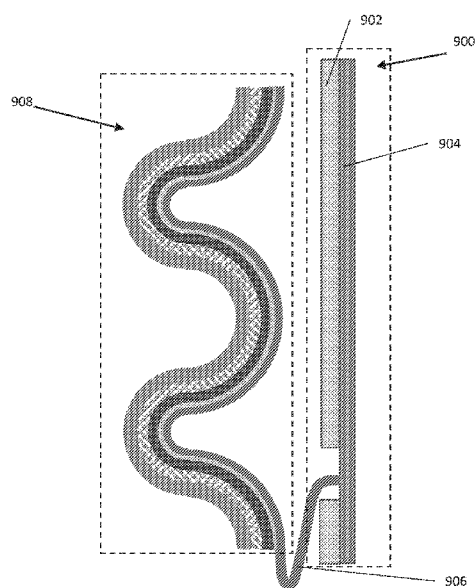


Figure 9

(57) Abstract: A display apparatus having a plurality of display surfaces controlled by a controller, the display apparatus having a mounting substrate for mounting the plurality of display surfaces. The mounting structure having a conductor layer for providing electrical connections to the plurality of display surfaces. The display apparatus may further have at least one display surface sufficiently flexible to have a curvature, wherein the curvature produces a space between the at least one display surface and the mounting structure to house the controller.



## **ELECTRO-OPTIC DISPLAY APPARATUS**

### **REFERENCE TO RELATED APPLICATIONS**

**[Para 1]** This application claims priority to U.S. Provisional Application 62/348,801 filed on June 10, 2016. The entire content of the above mentioned application is herein incorporated by reference.

### **SUBJECT OF THE INVENTION**

**[Para 2]** This invention relates to electro-optic display apparatus. More specifically, this invention provides means for assembling multiple electro-optic displays into a larger display apparatus in a convenient fashion.

### **BACKGROUND OF INVENTION**

**[Para 3]** For some display applications it may be desirable to assemble a plurality of electro-optic together to form a larger display screen. To connect the plurality of displays, normally a set of connecting cables are required for connecting each display to an electrical driver unit. Furthermore, one or more alignment frame structures will be required to properly position the displays. The overall assembly of the displays typically will require careful measurements and precise placements of the individual displays. In operation, the connecting cables are either highly customized for individual display apparatus designs, and in addition, customized connection cables can be time-consuming to assemble and be error prone when installing, making this approach suitably only for low volume applications and prototypes. Alternatively, the display connections can include modular subcomponents that are inter-connectable to span the distance between each display and the driver unit. In this fashion, such approach is feasible only for large volume applications where production cost may be averaged down by a large number of displays apparatus produced.

**[Para 4]** The subject matter presented herein provides means to assemble a plurality of displays into display apparatus of various configurations conveniently and at a low cost.

## SUMMARY OF INVENTION

**[Para 5]** The subject matter presented herein provides for a display apparatus having a plurality of display surfaces controlled by a controller, the display apparatus having a mounting substrate for mounting the plurality of display surfaces, the mounting structure having a conductor layer for providing electrical connections to the plurality of display surfaces. The display apparatus further including at least one display surface sufficiently flexible to have a curvature, wherein the curvature produces a space between the at least one display surface and the mounting structure to house the controller.

## BRIEF DESCRIPTION OF DRAWINGS

**[Para 6]** Figure. 1 illustrates an electrophoretic image display in accordance with the subject matter presented herein;

**[Para 7]** Figure. 2 illustrates an exemplary mounting structure for assembling a plurality of displays in accordance with the subject matter presented herein;

**[Para 8]** Figure. 3 illustrates a set of conductive interconnects in accordance with the subject matter presented herein; and

**[Para 9]** Figure. 4 illustrates a printed graphics layer in accordance with the subject matter presented herein.

**[Para 10]** Figure 5 illustrates an exemplary pixel conductor layer for a display tile with a plurality of irregularly shaped pixel driving electrodes in accordance with the subject matter presented herein;

**[Para 11]** Figure 6 illustrates an exemplary substrate for a display tile in accordance with the subject matter presented herein;

**[Para 12]** Figure 7 illustrates a reverse side conductor layer with conductive traces in accordance with the subject matter presented herein.

**[Para 13]** Figures 8A and 8B illustrate flexible display tiles with various curvatures; and

**[Para 14]** Figure 9 illustrates a flexible display tile mounted onto a mounting structure.

## DETAILED DESCRIPTION

**[Para 15]** The subject matter presented herein relates to an apparatus for assemble a plurality of electro-optic displays. Such apparatus may include a conductive interconnect layer having a set of printed conductive interconnects for connecting the plurality of

displays, and a printed graphics overlay layer for aligning the displays. The electro-optic displays of the present subject matter are especially, but not exclusively, intended for use with particle-based electrophoretic displays in which one or more types of electrically charged particles are suspended in a liquid and are moved through the liquid under the influence of an electric field to change the appearance of the display.

**[Para 16]** The term "electro-optic" as applied to a material or a display, is used herein in its conventional meaning in the imaging art to refer to a material having first and second display states differing in at least one optical property, the material being changed from its first to its second display state by application of an electric field to the material. Although the optical property is typically color perceptible to the human eye, it may be another optical property, such as optical transmission, reflectance, luminescence or, in the case of displays intended for machine reading, pseudo-color in the sense of a change in reflectance of electromagnetic wavelengths outside the visible range.

**[Para 17]** The term "gray state" is used herein in its conventional meaning in the imaging art to refer to a state intermediate two extreme optical states of a pixel, and does not necessarily imply a black-white transition between these two extreme states. For example, several of the E Ink patents and published applications referred to below describe electrophoretic displays in which the extreme states are white and deep blue, so that an intermediate "gray state" would actually be pale blue. Indeed, as already mentioned, the change in optical state may not be a color change at all. The terms "black" and "white" may be used hereinafter to refer to the two extreme optical states of a display, and should be understood as normally including extreme optical states which are not strictly black and white, for example, the aforementioned white and dark blue states. The term "monochrome" may be used hereinafter to denote a drive scheme which only drives pixels to their two extreme optical states with no intervening gray states.

**[Para 18]** Some electro-optic materials are solid in the sense that the materials have solid external surfaces, although the materials may, and often do, have internal liquid- or gas-filled spaces. Such displays using solid electro-optic materials may hereinafter for convenience be referred to as "solid electro-optic displays". Thus, the term "solid electro-optic displays" includes rotating bichromal member displays, encapsulated electrophoretic displays, microcell electrophoretic displays and encapsulated liquid crystal displays.

**[Para 19]** The terms "bistable" and "bistability" are used herein in their conventional meaning in the art to refer to displays comprising display elements having first and second display states differing in at least one optical property, and such that after any given element has been driven, by means of an addressing pulse of finite duration, to assume either its first or second display state, after the addressing pulse has terminated, that state will persist for at least several times, for example at least four times, the minimum duration of the addressing pulse required to change the state of the display element. It is shown in published US Patent Application No. 2002/0180687 (see also the corresponding International Application Publication No. WO 02/079869) that some particle-based electrophoretic displays capable of gray scale are stable not only in their extreme black and white states but also in their intermediate gray states, and the same is true of some other types of electro-optic displays. This type of display is properly called "multi-stable" rather than bistable, although for convenience the term "bistable" may be used herein to cover both bistable and multi-stable displays.

**[Para 20]** Several types of electro-optic displays are known. One type of electro-optic display is a rotating bichromal member type as described, for example, in U.S. Patents Nos. 5,808,783; 5,777,782; 5,760,761; 6,054,071 6,055,091; 6,097,531; 6,128,124; 6,137,467; and 6,147,791 (although this type of display is often referred to as a "rotating bichromal ball" display, the term "rotating bichromal member" is preferred as more accurate since in some of the patents mentioned above the rotating members are not spherical). Such a display uses a large number of small bodies (typically spherical or cylindrical) which have two or more sections with differing optical characteristics and an internal dipole. These bodies are suspended within liquid-filled vacuoles within a matrix, the vacuoles being filled with liquid so that the bodies are free to rotate. The appearance of the display is changed by applying an electric field thereto, thus rotating the bodies to various positions and varying which of the sections of the bodies is seen through a viewing surface. This type of electro-optic medium is typically bistable.

**[Para 21]** Another type of electro-optic display uses an electrochromic medium, for example, an electrochromic medium in the form of a nanochromic film comprising an electrode formed at least in part from a semi-conducting metal oxide and a plurality of dye molecules capable of reversible color change attached to the electrode; see, for example O'Regan, B., et al., *Nature* 1991, 353, 737; and Wood, D., *Information Display*, 18(3), 24

(March 2002). See also Bach, U., et al., *Adv. Mater.*, 2002, *14(11)*, 845. Nanochromic films of this type are also described, for example, in U.S. Patents Nos. 6,301,038; 6,870,657; and 6,950,220. This type of medium is also typically bistable.

**[Para 22]** Another type of electro-optic display is an electro-wetting display developed by Philips and described in Hayes, R.A., et al., "Video-Speed Electronic Paper Based on Electrowetting", *Nature*, 425, 383-385 (2003). It is shown in U.S. Patent No. 7,420,549 that such electro-wetting displays can be made bistable.

**[Para 23]** One type of electro-optic display, which has been the subject of intense research and development for a number of years, is the particle-based electrophoretic display, in which a plurality of charged particles move through a fluid under the influence of an electric field. Electrophoretic displays can have attributes of good brightness and contrast, wide viewing angles, state bistability, and low power consumption when compared with liquid crystal displays. Nevertheless, problems with the long-term image quality of these displays have prevented their widespread usage. For example, particles that make up electrophoretic displays tend to settle, resulting in inadequate service-life for these displays.

**[Para 24]** As noted above, electrophoretic media require the presence of a fluid. In most prior art electrophoretic media, this fluid is a liquid, but electrophoretic media can be produced using gaseous fluids; see, for example, Kitamura, T., et al., "Electrical toner movement for electronic paper-like display", IDW Japan, 2001, Paper HCS1-1, and Yamaguchi, Y., et al., "Toner display using insulative particles charged triboelectrically", IDW Japan, 2001, Paper AMD4-4). See also U.S. Patents Nos. 7,321,459 and 7,236,291. Such gas-based electrophoretic media appear to be susceptible to the same types of problems due to particle settling as liquid-based electrophoretic media, when the media are used in an orientation which permits such settling, for example in a sign where the medium is disposed in a vertical plane. Indeed, particle settling appears to be a more serious problem in gas-based electrophoretic media than in liquid-based ones, since the lower viscosity of gaseous suspending fluids as compared with liquid ones allows more rapid settling of the electrophoretic particles.

**[Para 25]** Numerous patents and applications assigned to or in the names of the Massachusetts Institute of Technology (MIT) and E Ink Corporation have recently been published describing encapsulated electrophoretic media. Such encapsulated media

comprise numerous small capsules, each of which itself comprises an internal phase containing electrophoretically-mobile particles suspended in a liquid suspension medium, and a capsule wall surrounding the internal phase. Typically, the capsules are themselves held within a polymeric binder to form a coherent layer positioned between two electrodes. The technologies described in these patents and applications include:

(a) Electrophoretic particles, fluids and fluid additives; see for example U.S. Patents Nos. 7,002,728 and 7,679,814;

(b) Capsules, binders and encapsulation processes; see for example U.S. Patents Nos. 6,922,276 and 7,411,719;

(c) Microcell structures, wall materials, and methods of forming microcells; see for example United States Patents Nos. 7,072,095 and 9,279,906;

(d) Methods for filling and sealing microcells; see for example United States Patents Nos. 7,144,942 and 7,715,088;

(e) Films and sub-assemblies containing electro-optic materials; see for example U.S. Patents Nos. 6,982,178 and 7,839,564;

(f) Backplanes, adhesive layers and other auxiliary layers and methods used in displays; see for example U.S. Patents Nos. D485,294; 6,124,851; 6,130,773; 6,177,921; 6,232,950; 6,252,564; 6,312,304; 6,312,971; 6,376,828; 6,392,786; 6,413,790; 6,422,687; 6,445,374; 6,480,182; 6,498,114; 6,506,438; 6,518,949; 6,521,489; 6,535,197; 6,545,291; 6,639,578; 6,657,772; 6,664,944; 6,680,725; 6,683,333; 6,724,519; 6,750,473; 6,816,147; 6,819,471; 6,825,068; 6,831,769; 6,842,167; 6,842,279; 6,842,657; 6,865,010; 6,873,452; 6,909,532; 6,967,640; 6,980,196; 7,012,735; 7,030,412; 7,075,703; 7,106,296; 7,110,163; 7,116,318; 7,148,128; 7,167,155; 7,173,752; 7,176,880; 7,190,008; 7,206,119; 7,223,672; 7,230,751; 7,256,766; 7,259,744; 7,280,094; 7,301,693; 7,304,780; 7,327,511; 7,347,957; 7,349,148; 7,352,353; 7,365,394; 7,365,733; 7,382,363; 7,388,572; 7,401,758; 7,442,587; 7,492,497; 7,535,624; 7,551,346; 7,554,712; 7,583,427; 7,598,173; 7,605,799; 7,636,191; 7,649,674; 7,667,886; 7,672,040; 7,688,497; 7,733,335; 7,785,988; 7,830,592; 7,843,626; 7,859,637; 7,880,958; 7,893,435; 7,898,717; 7,905,977; 7,957,053; 7,986,450; 8,009,344; 8,027,081; 8,049,947; 8,072,675; 8,077,141; 8,089,453; 8,120,836; 8,159,636; 8,208,193; 8,237,892; 8,238,021; 8,362,488; 8,373,211; 8,389,381; 8,395,836; 8,437,069; 8,441,414; 8,456,589; 8,498,042; 8,514,168; 8,547,628; 8,576,162; 8,610,988; 8,714,780; 8,728,266;

8,743,077; 8,754,859; 8,797,258; 8,797,633; 8,797,636; 8,830,560; 8,891,155; 8,969,886; 9,147,364; 9,025,234; 9,025,238; 9,030,374; 9,140,952; 9,152,003; 9,152,004; 9,201,279; 9,223,164; 9,285,648; and 9,310,661; and U.S. Patent Applications Publication Nos. 2002/0060321; 2004/0008179; 2004/0085619; 2004/0105036; 2004/0112525; 2005/0122306; 2005/0122563; 2006/0215106; 2006/0255322; 2007/0052757; 2007/0097489; 2007/0109219; 2008/0061300; 2008/0149271; 2009/0122389; 2009/0315044; 2010/0177396; 2011/0140744; 2011/0187683; 2011/0187689; 2011/0292319; 2013/0250397; 2013/0278900; 2014/0078024; 2014/0139501; 2014/0192000; 2014/0210701; 2014/0300837; 2014/0368753; 2014/0376164; 2015/0171112; 2015/0205178; 2015/0226986; 2015/0227018; 2015/0228666; 2015/0261057; 2015/0356927; 2015/0378235; 2016/077375; 2016/0103380; and 2016/0187759; and International Application Publication No. WO 00/38000; European Patents Nos. 1,099,207 B1 and 1,145,072 B1;

(g) Color formation and color adjustment; see for example U.S. Patents Nos. 7,075,502 and 7,839,564;

(h) Methods for driving displays; see for example U.S. Patents Nos. 7,012,600 and 7,453,445;

(i) Applications of displays; see for example U.S. Patents Nos. 7,312,784 and 8,009,348; and

(j) Non-electrophoretic displays, as described in U.S. Patents Nos. 6,241,921 and U.S. Patent Applications Publication Nos. 2015/0277160, and applications of encapsulation and microcell technology other than displays; see for example U.S. Patent Application Publications Nos. 2015/0005720 and 2016/0012710.

**[Para 26]** Many of the aforementioned patents and applications recognize that the walls surrounding the discrete microcapsules in an encapsulated electrophoretic medium could be replaced by a continuous phase, thus producing a so-called polymer-dispersed electrophoretic display, in which the electrophoretic medium comprises a plurality of discrete droplets of an electrophoretic fluid and a continuous phase of a polymeric material, and that the discrete droplets of electrophoretic fluid within such a polymer dispersed electrophoretic display may be regarded as capsules or microcapsules even though no discrete capsule membrane is associated with each individual droplet; see for example, the aforementioned U.S. Patent No. 6,866,760. Accordingly, for purposes of the present

application, such polymer-dispersed electrophoretic media are regarded as subspecies of encapsulated electrophoretic media.

**[Para 27]** A related type of electrophoretic display is a so-called "microcell electrophoretic display". In a microcell electrophoretic display, the charged particles and the fluid are not encapsulated within microcapsules but instead are retained within a plurality of cavities formed within a carrier medium, typically a polymeric film. See, for example, U.S. Patents Nos. 6,672,921 and 6,788,449, both assigned to Sipix Imaging.

**[Para 28]** Although electrophoretic media are often opaque (since, for example, in many electrophoretic media, the particles substantially block transmission of visible light through the display) and operate in a reflective mode, many electrophoretic displays can be made to operate in a so-called "shutter mode" in which one display state is substantially opaque and one is light-transmissive. See, for example, U.S. Patents Nos. 5,872,552; 6,130,774; 6,144,361; 6,172,798; 6,271,823; 6,225,971; and 6,184,856. Dielectrophoretic displays, which are similar to electrophoretic displays but rely upon variations in electric field strength, can operate in a similar mode; see U.S. Patent No. 4,418,346. Other types of electro-optic displays may also be capable of operating in shutter mode. Electro-optic media operating in shutter mode may be useful in multi-layer structures for full-color displays; in such structures, at least one layer adjacent the viewing surface of the display operates in shutter mode to expose or conceal a second layer more distant from the viewing surface.

**[Para 29]** The subject matters described herein make it possible to create a display apparatus consisting of a plurality of electro-optic displays or display tiles. In some embodiments, the plurality of electro-optic displays or display tiles may be electrophoretic image displays (EPID). An EPID 100, as illustrated in Figure 1, may include a backplane 102 having a backplane pixel layer 108 having a plurality of pixel driving electrodes, a front electrode layer 104 and a display layer 106. The display layer 106 may include electrophoretic pigment particles enclosed in micro-capsules or micro-cups. Illustrated in Figure 1 are micro-capsules comprising black and white electrophoretic pigment particles. The front electrode 104 may represent the viewing side of the EPID 100, in which case the front electrode 104 may be a transparent conductor, such as Indium Tin Oxide (ITO) (which in some cases may be deposited onto a transparent substrate, such as polyethylene terephthalate (PET)). In the display illustrated in Figure 1, the display layer 106 may be a

particle-based medium between layers 104 and 108 that includes a plurality of micro-capsules 110. Within each capsule 110 is a liquid medium and one or more types of colored pigment particles that include white pigment particles 112 and black pigment particles 114. The pigment particles 112 and/or 114 may be controlled (displaced) with an electric field (e.g., produced by electrodes on layers 108 and 104), thus making the display 100 operate as an electrophoretic display when addressed.

**[Para 30]** As indicated above, the subject matter presented herein provides a mounting structure for mounting electro-optic displays or display tiles. This mounting structure, in some embodiments, may include a substrate for supporting a conductive interconnect layer. This substrate may be sufficiently flexible such that it can be rolled or folded for shipping. In some embodiment, the conductive interconnect layer may be printed. In some other embodiments, the conductive interconnect layer may be laser scribed or physically or mechanically etched, and the substrate will be designed to resist the piercing cutting of the laser and against etching. In yet some other embodiments, the conductive interconnect layer may be produced separately from the mounting substrate and assembled at a later time. The mounting structure may further include an additional substrate for printed graphics overlaying the conductive interconnect layer. This printed graphics substrate may be fabricated from paper or plastic to function as an electrical insulator to protect the underneath conductive interconnect layer.

**[Para 31]** In one embodiment, once the dimensions and geometrical shapes of the displays have been determined, the placements of the displays and the driver unit can be subsequently determined (e.g., drawn onto) on the mounting structure. To connect the displays and the driver unit, marking traces may be drawn using computer-aided-design software such as AUTOCAD (Registered Trade Mark) or Altium. Conductive interconnects can be subsequently fabricated using the drawn traces as a template. To cover up the conductive interconnects, a layer of printed graphics may be placed on top of the conductive interconnects. Holes or vias may be cut through the layer of printed graphics to allow access to the conductive interconnects. It should be appreciated that the conductive interconnects can be fabricated independently, separate from the other layers, on its own. In this fashion, a designer has the luxury to freely design and fabricate the conductive interconnects to any fitting size and configuration. As such, the designer is not bound by the limitations of any conductive traces producing equipment but is able to

freely fabricate interconnects any sizes and shapes that are fitting to the designer's customizations.

**[Para 32]** Figure 2 illustrates a mounting structure 204 where sixteen electro-optic displays or display tiles 202 may be assembled together to form a larger display apparatus 200. In one example, the display tiles 202 can be arranged in a rectangular array (e.g., 4x4) on a mounting structure 204 as shown in Figure 2, similar in fashion to how tiles are positioned on a wall, with even spacing between the tiles. It should be appreciated that the display tiles' 202 rectangular shapes shown here are for illustrative purposes as the tiles 202 can easily adopt other geometrical shapes. Furthermore, the subject matter disclosed herein enables the display tiles 202 to be arranged and assembled in a variety of configurations. Other than the orderly stacking configuration illustrated in Figure 2, the display tiles 202 may be arranged, for example, with uneven spacing in between, and in an un-orderly fashion. In some embodiments, the display tiles 202 can be arranged according to a particular formation to form a pre-determined image. Or, designers may place display tiles at their discretion to form specific patterns (e.g., an abstract image etc.).

**[Para 33]** In addition, each tile may be given a designated code to match a particular position on the mounting structure 204. For example, a display tile (not shown) may be designated 1A to match a predetermined position 1A on the mounting structure 204, and an end user may simply match the tile 1A to the predetermined position 1A when assembling the display apparatus 200.

**[Para 34]** In some embodiment, the mounting structure 204 may include a substrate for supporting a conductive interconnect layer. This support substrate may be fabricated from a plastic such as poly(ethylene terephthalate) (PET) and have a thickness of at least 2mils (51  $\mu\text{m}$  - 5mils (127  $\mu\text{m}$ ) or above preferred) and is sufficiently flexible to be rolled or folded. In some embodiments, the conductive interconnect layer may be scribed using a beam of energy or particles (e.g., laser) and the support substrate is preferably capable of withstanding the cutting of the laser. Sometimes the conductive interconnects (e.g., traces and/or pads) connecting the display tiles can be made by drawing traces and/or pads between the tiles using continuous conductor such as carbon black or metal-filled ink. Alternatively, interconnecting traces or pads can be mechanically or laser scribed from a conductive layer made out of materials such as Indium Tin Oxide (ITO) or sputtered metal (e.g., aluminum). In yet another embodiment, isolated traces may be printed using

techniques such as screen printing, which may be suitable for high volume applications where tolling and other startup expenses may be averaged down.

**[Para 35]** Furthermore, the mounting structure can also include another substrate for printed graphics and this substrate may be placed over the conductive interconnects layer. This printed graphics substrate layer can be made from paper or plastic and function both as an electrical insulator to protect the underlying conductive interconnects layer and also as a printing surface for the printed graphics. The printed graphics may be produced using ink jet or laser jet printing for uniquely customized designs, or gravure printing for high volume (non-customized) designs. The printed graphics can function as alignment marks during installation as well as provide aesthetic appeal to the display apparatus 200.

**[Para 36]** To assemble the display apparatus 200, in a preferred embodiment, a designer can firstly determine the sizes and shapes of the display tiles 202. The designer can then decide the placements for each tile and where the conductive interconnects may be placed on each tile. The placements of the tiles 202 and their conductive interconnects may be outlined on the same layer as the printed graphics to simplify installation. Subsequently, the location of the driver unit for the display apparatus may be determined. It is preferred that the driver unit is placed behind one of the display tiles 202. In some embodiments, the display tiles 202 may be curved outwardly away from the mounting structure 204, leaving spaces behind the tiles for the driver unit. Alternatively, the driver unit may be placed away from the tiles 202, for example, hidden behind an enclosure (e.g., a baseboard molding), folded around behind the mounting structure 204 (e.g., above a ceiling tile) or at a location that may be conveniently accessed by display operators.

**[Para 37]** Once the placements of the display tiles 202 and the driver unit have been determined, marking traces may be drawn connecting the driver unit outputs to the display tiles 202. The marking traces may be drawn using CAD software such as Autocad, Altium, PADS or Adobe Illustrator. In some embodiments, fiducial marks may also be drawn to aid later alignment of the printed graphics to the conductive interconnects (e.g., traces and/or pads). Subsequently, the conductive interconnects may be fabricated using the drawn marking traces as a template. Referring now to Figure 3, illustrated is a layer of conductive interconnects 300 for providing electrical connections to the display tiles. The conductive interconnect layer 300 may be fabricated by printing traces 302 and pads 304 on a dielectric substrate (e.g., PET) or by scribing a conductive film (e.g., carbon, silver,

aluminum, ITO etc.) already deposited on the dielectric substrate. Other methods of fabricating the conductive interconnects 300 may be conveniently adopted here depending on what manufacturing equipment is available to a user. It should be noted that the conductive interconnect layer 300 here may be fabricated separately from all other layers of the display apparatus 100. In this fashion, a designer is free to utilize any method to produce the interconnect layer 300 and not be bound by any interconnect producing equipment. As such, the designer can fabricate interconnects of any shape or sizes as he sees fitting to accommodate his designs. This allows the designer freedom to produce display apparatus of various shapes and configurations and not be bound by the manufacturing limitations of the conductive interconnects.

**[Para 38]** In use, each display tile may have a connector (e.g., a flat flex connector) port pre-assembled and a matching connector may be placed on a pad 304, in this fashion, when assembling a display apparatus, an user may simply connect the connector on each display tile to the matching connector on the pads 304, thereby eliminate the need to produce connecting cables to connect the plurality of display tiles to the mounting structure, which makes the entire apparatus more compact and convenient to assemble.

**[Para 39]** Referring now to Figure 4, illustrated is a printed graphics layer 400 produced on a dielectric substrate which may be later laminated onto the conductive interconnect layer 300 shown in Figure 3. On the printed graphics layer 400, placements of the display tiles and the driver unit have been outlined, together with through holes 402 for the conductive interconnects. In addition, fiducial or alignment marks may also be drawn on this layer for aligning neighboring interconnect mounting structures if multiple structures or surfaces will be required. Other graphic features such as artistic designs may be further included for aesthetic purposes. Once fabricated, through holes or vias may be cut in this layer 400 to allow access to the conductive interconnects where the driver unit and the display tiles may be connected. The through holes may be made using laser cutting, a die cutter, scissors etc., depending on the designer's preference and electrical connections may be made using conductive pressure sensitive adhesive pads, spring pins, or electrical connections such as crimped pin/socket pairs (i.e., Nicomatic).

**[Para 40]** In a preferred embodiment, the printed graphics and the conductive interconnects may be adhered (e.g., laminated) either together or separately to the supporting substrate to produce a single piece of mounting structure or surface.

Subsequently, the display tiles may be positioned onto the mounting structure at their pre-determined positions. Optionally a mounting frame may also be provided where the mounting structure and the display tiles may be attached to the mounting frame.

**[Para 41]** Furthermore, the subject matter presented herein also provides for display tiles to be connected to the mounting structure 200 presented in Figure 2. An exemplary display tile may include a pixel conductor layer, a substrate layer and a reverse side conductor layer, where the substrate layer may be positioned between the pixel conductor layer and the reverse side conductor layer. Driving electrodes for display pixels or pixel segments can be defined and fabricated on the pixel conductor layer. In a preferred embodiment, the driving electrodes are firstly patterned on the pixel conductor layer using a beam of energy or particles (e.g., laser scribing), where laser scribing allows for the fabrication of driving electrodes of various sizes and geometric shapes without using complex machineries. Subsequently, vias can be created through the substrate layer and conductive traces can be drawn on the reverse side conductor layer, where the conductive traces are used for transmitting electrical voltage or driving waveforms to the driving electrodes through the vias. In this fashion, the backplane is assembled without having to use size-limiting techniques such as photolithography or global alignments, techniques usually required by screen printing or PCB manufacturing. As such, large sized backplanes with variable sized driving electrodes can be conveniently and cheaply assembled.

**[Para 42]** In some embodiments, specialized display applications will require a display to use pixel or pixel segments of irregular geometric shapes. The present subject matter enables the assembly of a display tile having a plurality of irregular shaped display pixel segments at a cheap price. Figure 5 illustrates a pixel conductor layer 500 for a display tile having a plurality of irregular shaped pixel segments. As illustrated in Figure 5, the pixel conductor layer 500 may include a plurality of variable sized driving electrodes 511-517 for driving the plurality of irregular shaped pixel segments (not shown), where the shapes and positions of the driving electrodes 511-517 will match the shapes and positions of the corresponding pixel segments. In some embodiments, the pixel conductor layer 500 may be formed by coating a continuous layer of conducting material such as ITO onto a substrate. Other conductive materials may also be sputtered onto a substrate from the continuous layer, materials such as, but not limited to, various types of conductive oxides,

gold, inert metals, nickel boron, carbon, carbon nanotubes, graphene, and poly(3,4-ethylenedioxythiophene) or also known as PEDOT. In some other embodiments, conductive material such as copper, nickel, aluminum, silver nanowires and printed silver may also be used depending on the specific requirements of the display application.

**[Para 43]** According to some embodiments of the present subject matter, a display tile assembling process may include having a continuous layer of conductive material scribed by a laser to pattern the various shaped driving electrodes 511-517. The scribing may cut deep enough into the conductive material layer to electrically isolate each driving electrodes but not so deep as to cut through the underneath substrate or substantially weaken the substrate to make it fragile. Laser scribing allows for the patterning of driving electrodes of various geometrical configurations without having to perform photolithography or global alignments, which can be prohibitively expensive for large sized displays. Figure 5 further illustrates star shaped 520 and circular 522 driving electrodes, but it should be appreciated that other geometrical shapes can be easily patterned using laser scribing or other comparable etching methods commonly adopted in the industry.

**[Para 44]** Once the driving electrodes have been patterned, vias can be created through the substrate to connect the driving electrodes to driver circuits (not shown). Figure 6 illustrates an exemplary substrate layer 600 in accordance with the subject matter presented herein. In some embodiments, the substrate layer 600 may be manufactured using materials such as PET, Polyethylene naphthalate (PEN), cyclic olefins, paper, fabrics, polyimide, or polycarbonate. To provide electrical connections to the driving electrodes 511-517 as shown in Figure 5, one or more vias 621-627 may be created through the substrate layer 600 for each of the driving electrodes 511-517. Vias 621-627 may be created by cutting through the substrate layer 600 using lasers, but it should be appreciated that mechanical drilling or other puncturing methods commonly used in the art can be easily adopted. In some embodiments, a via cut into a driving electrode may be at least 200  $\mu\text{m}$  in diameter and usually no more than 3 mm to minimize the appearance of the hole in the final display. It should be appreciated that in other embodiments, vias may be formed before the driving electrodes have been patterned, for example, a substrate may come pre-fabricated with vias in place configured to backplane assembling.

**[Para 45]** Once the vias 621-627 have been created, conductive material (not shown) may be dispensed into the vias 621-627 with a porous paper behind the substrate and with vacuum pulling on the porous paper. The vacuum force will pull the conductive material through the vias 621-627 and plates the sides of the vias 621-627 or fill the volume of the vias 621-627, connecting the driving electrodes 511-517 to the reverse side of the substrate 600. It is preferred that the finished vias have surfaces co-planar with both the pixel conductor layer and the reverse side conductor layer to avoid bumps resulting from too much filler or lamination void due to insufficient via filling. In some embodiments, the vias 621-627 may be filled with a hot melt adhesive with a melting temperature around the lamination temperature of the electrophoretic ink material (e.g., 250F), provided that the flow viscosity of the hot melt adhesive is low enough to prevent ink capsule rupture.

**[Para 46]** The properly filled vias 621-627 can provide electrical connections between the driving electrodes 511-517 and the conductive traces that are to be formed on the reverse side (i.e., the side opposite to the pixel conductor layer) of the substrate 600. Prior to the formation of the conductive traces, in some embodiments, an ink FPL stack (not shown) may be firstly laminated to the driving electrodes 511-517. This is done in this fashion such that the thickness of the traces would not press through the substrate 600 and make impressions on the FPL layer during lamination.

**[Para 47]** The subsequent formation of the conductive traces may be carried out in various fashions. In some embodiments, conductive traces may be printed onto the reverse side beginning at the vias and extend according to a pre-determined layout for routing all of the lines from the pixel locations, without crossing, to one condensed area that matches the pad pitch for the electronics to be attached to the device. The printing of the conductive traces may be accomplished manually for small numbers of backplane units, or alternatively, an XY plotting machine with controlled dispensing of printable conductive material may be used. Camera vision alignment may be adopted to locate the vias and a XY plotter may be aligned to that location to start drawing the conductive traces. It should be appreciated that other trace producing methods commonly used in the industry can be conveniently adopted, methods such as, but not limited to, inkjet with conductive inks, rollers, tapes, etc. Some examples of suitable trace materials are silver or carbon filled printing inks. In this fashion, no global alignment may be required to create the conductive traces. For example, local alignment may be perfectly sufficient to places

the traces to connect the vias to a driver circuit. By not having to perform global alignments, large sized (e.g., backplanes larger than 24 inches by 48 inches in sizes) backplanes can be conveniently assembled because global alignments can be hard to design for and expensive to perform.

**[Para 48]** In some other embodiment, the conductive traces may be fabricated (e.g., printed) as a conductive interconnect layer. The conductive interconnect layer may be produced separately from the substrate 600 and the pixel conductor layer 500, and to be assembled together when a display tile is being assembled.

**[Para 49]** Alternatively, conductive traces may be etched or scribed onto a continuous conductive layer, similar to the patterning of the driving electrodes 511-517 mentioned above. In some embodiments, a continuous layer of conductive material may be coated on the reverse side of the substrate 600. After the FPL stack has been laminated onto the driving electrodes 511-517, conductive traces may be etched into the continuous conductive layer with a laser such that each conductive trace is electrically isolated but not cutting into the substrate enough to cut through or make it fragile. Figure 7 illustrates an exemplary reverse side conductor layer 700 with conductive traces 701-707. The conductor layer 700 may be produced as a printed layer of conductive circuitry, or by etching onto a continuous layer of conductive material. In the case it is produced by etching, the cutting of each conductive trace can include the via for the driving electrode and a circular structure around the via adding the width of the conductive trace around each via to ensure continuity to that driving electrode. The alignment to each via may be accomplished with a camera vision alignment system to find and align to each via to locate the conductive trace path. The conductive traces 701-707 can extend in a pre-determined layout for routing all of the lines from the pixel locations, without crossing, to one condensed area that matches the pad pitch for the electronics to be attached to the device.

**[Para 50]** For conductive fabric designs, it may be convenient to firstly produce patterns for the driving electrodes and the conductive traces, then paste them onto a substrate which could be a fabric or film depending on the requirements of the display application. Other suitable substrate material include PET, Polyethylene naphthalate (PEN), cyclic olefins, paper, fabrics, polyimide, or polycarbonate, etc.

**[Para 51]** In general, variations can be made to the backplane assembly processes described above while still produce backplanes that are substantially comparable in

performances. For example, roll to roll machines may be used to assemble backplanes that are in accordance with the subject matter presented herein. In some embodiments, continuous rolls of substrate coated with conductive materials can be processed at multiple assembling stations including a laser cutting/etching station and a XY plotting station, both equipped with camera vision alignment systems. These two stations may be distinct units or may be part of a single assembly station (e.g., both the laser cutter and the plotter can be part of an XY gantry system). Furthermore, a roll to roll machine may further include a station for heated lamination of ink FPL or other materials for assembling display units. This arrangement can be advantageous for at least the reason that the conductive traces can now be radiation cured (e.g., UV cured) at the roll to roll machine, which saves production time and cost by not having to use conventional heat drying ovens.

**[Para 52]** In another embodiment, vias can be cut in a substrate roll prior to the deposition of conductive materials, which permits the filling of the vias using the deposited conductive material. In this fashion, a separate assembling step to fill the vias may be eliminated, further reducing production cost.

**[Para 53]** In yet another embodiment, vias may be left unfilled prior to the lamination of the FPL to a display stack. The subsequent dispensing of the conductive traces to the reverse side of the substrate can in effect fulfill the vias to provide connection between the driving electrodes and the conductive traces.

**[Para 54]** It should be appreciated that the pixel conductor layer, a substrate layer and a reverse side conductor layer presented above may be produced using flexible material, resulting in a display tile that is bendable or flexible. In addition, the flexible nature and robustness of the electrophoretic material enables the display tile to be not only flexible, but capable of having multiple curvatures. Figure 8A illustrates one such flexible display tile 800. The display tile 800 shown here may be sufficiently flexible to be curved to a half-circular shape, where the tile's 800 front electrode 804 may be produced using flexible material common adopted in the industry. The pixel conductor layer 808, the substrate layer 810 and the reverse side conductor layer 812 all may be fabricated from materials sufficiently flexible to support a layer of electrophoretic display material 806. The curved shape of display tile 800 produces a space 814 adjacent to the reversed side conductor layer 812 such that when assembled to a mounting structure similar to the one

illustrated in Figure 2 a controller apparatus (e.g., display controller or control circuit) may be positioned or housed in that space 814, hiding from the view and preserves the overall compactness of the overall display apparatus.

**[Para 55]** In another embodiment shown in Figure 8B, a flexible display tile 802 may include multiple curvatures. The multiple layers of the display tile 802 (e.g., the front electrode 816, the electrophoretic material layer 816, the pixel conductor layer 820, the substrate layer 822 and the reverse side conductor layer 824) may be sufficiently flexible to assume various curvatures to suit a designer's needs.

**[Para 56]** Figure 9 illustrates a flexible display tile 908 that is similar to the one presented in Figure 8B being assembled onto a mounting structure 900. The mounting structure 900, as discussed above, may include a conductive interconnect layer 904 with conductive traces for providing electrical connections to the display tile 908. A printed graphic layer 902 may be positioned between the interconnect layer 904 and the display tile 908 for insulation. A connector 906 may be used to connect the display tile 908 to the interconnect layer 904. The connector 906 may have a short wire for flexibility, or may be a snap on type connector, or any connector commonly adopted in the industry, saving a user from having to use cables to connect individual tiles to the mounting structure.

**[Para 57]** From the foregoing, it will be seen that the present invention provides means for inexpensive customization and quick turn-around manufacturing of tiled display systems or apparatus. The present invention eliminates the need for labor-intensive custom cable fabrication and greatly simplifies the installation process. The subject matter described herein also eliminates the need for cable management and improves the aesthetics of the entire installation process. Also reduced is the overall thickness of the display apparatus, as there is no more need for extra spaces for passing cables behind the display tiles. Furthermore, this invention also allows for tiles to be placed non-adjacent to each other, as the electrical connections are hidden behind the printed graphics layer.

**[Para 58]** It will be apparent to those skilled in the art that numerous changes and modifications can be made to the specific embodiments of the invention described above without departing from the scope of the invention. Accordingly, the whole of the foregoing description is to be interpreted in an illustrative and not in a limitative sense.

## CLAIMS

1. A method for producing a display apparatus having a plurality of display surfaces controlled by a controller, the method comprising:
  - providing a mounting surface with predetermined positions for mounting the plurality of display surfaces;
  - producing a conductive interconnect layer having a plurality of traces configured to connected the plurality of display surfaces to the controller;
  - mounting at least one display surface to the mounting surface, the at least one display surface being sufficiently flexible to have a curvature such that the curvature produces a space between the at least one display surface and the mounting surface; and
  - placing the controller in the space between the at least one display surface and the mounting surface.
2. The method of claim 1 further comprising providing an insulator layer to insulate the interconnect layer from the at least one display surface.
3. The method of claim 1, wherein the producing the conductive interconnect layer step further comprising etching the interconnect layer to produce conductive traces.
4. The method of claim 1, wherein the mounting step further comprising connecting mounting surface and the plurality of display surfaces using a connector.
5. The method of claim 4, the producing the conductive interconnect layer step further comprising using a laser to produce conductive traces.
6. A mounting structure for mounting a plurality of display surfaces controlled by a controller, the structure comprising:

an insulator layer with through holes matching the placements of the plurality of display surface; and

a conductive interconnect layer configured to connect the plurality of display surfaces to the controller, the interconnect layer having plurality of traces extending from the controller to the through holes on the insulator layer.

7. The mounting structure of claim 6, wherein the conductive interconnect layer further comprising pads for connecting the conductive traces to the plurality of display surfaces.
8. A display apparatus having a plurality of display surfaces controlled by a controller, the display apparatus comprising:
  - a mounting substrate for mounting the plurality of display surfaces, the mounting structure having a conductor layer for providing electrical connections to the plurality of display surfaces; and
  - at least one display surface sufficiently flexible to have a curvature, wherein the curvature produces a space between the at least one display surface and the mounting structure to house the controller.
9. The display apparatus of claim 8 wherein the mounting structure is flexible.
10. The display apparatus of claim 8, wherein the mounting structure further comprising an insulator layer positioned between the display surfaces and the conductor layer.
11. The display apparatus of claim 8, wherein the at least one display surface comprises a flexible front electrode.

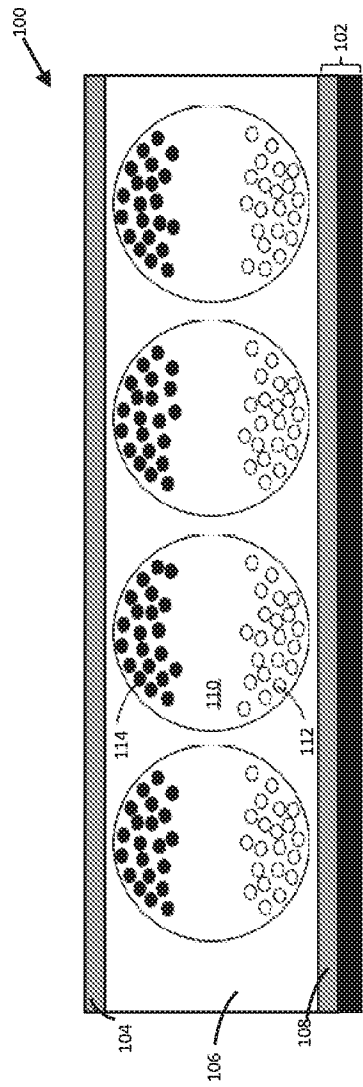


Figure 1

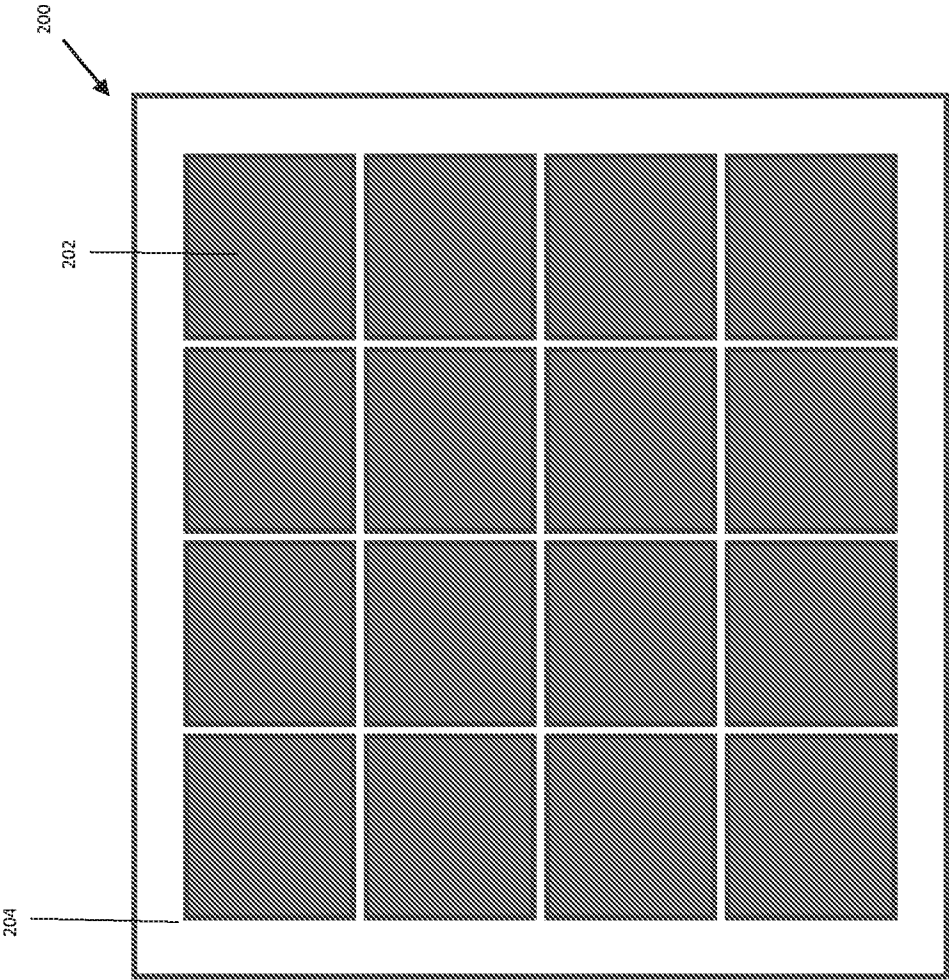


Figure 2

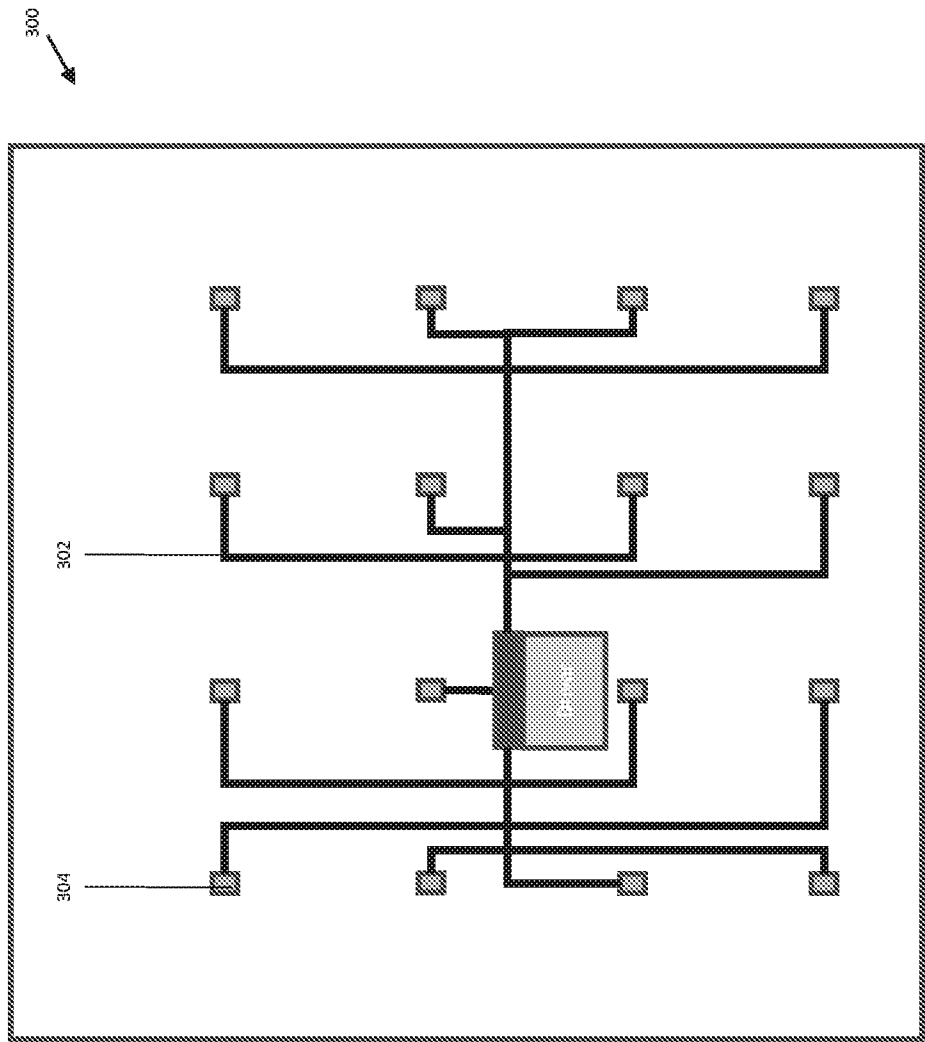


Figure 3

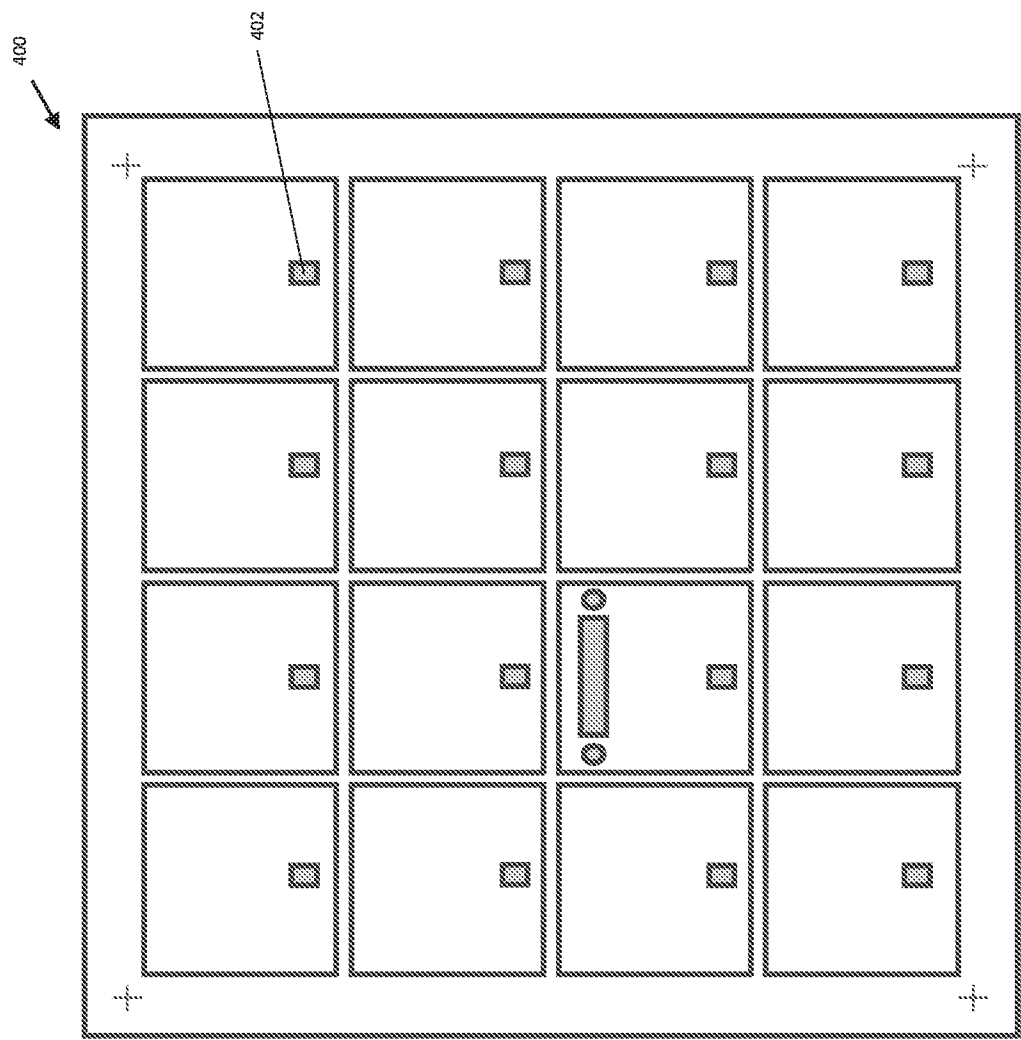


Figure 4

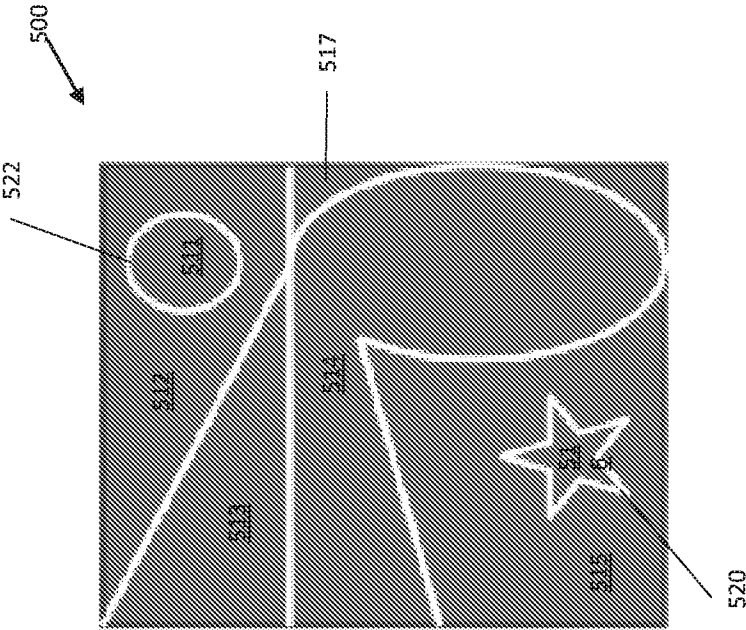


Figure 5

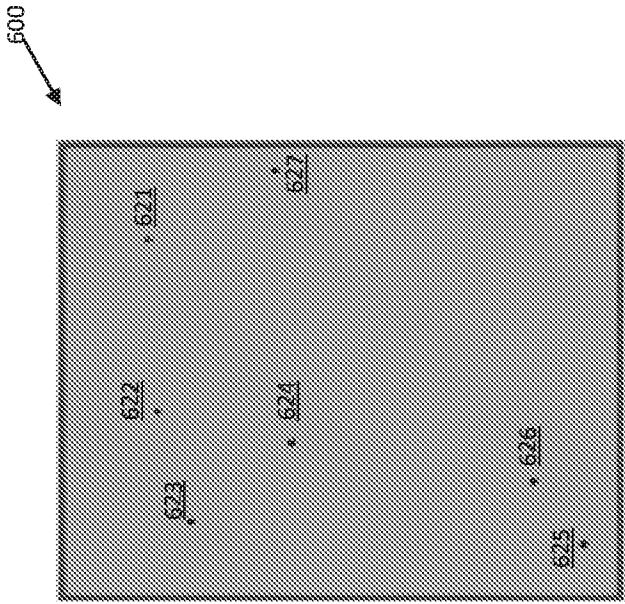


Figure 6

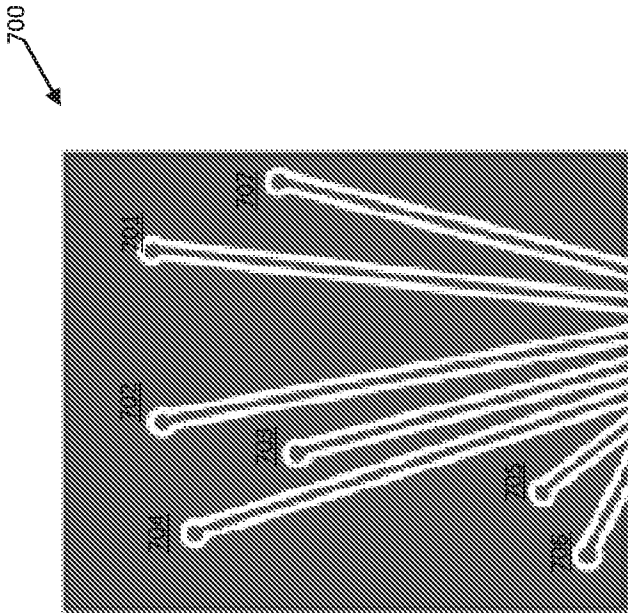


Figure 7

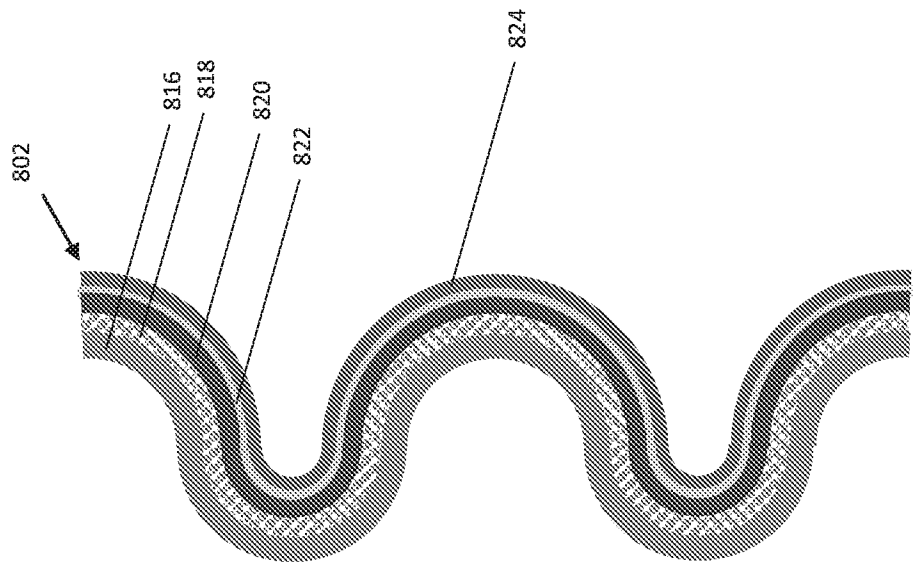


Figure 8B

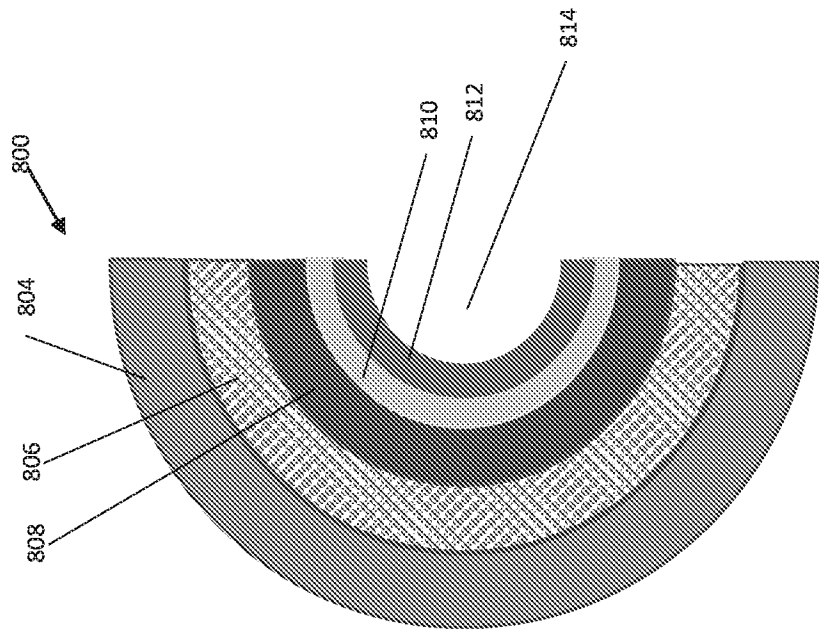


Figure 8A

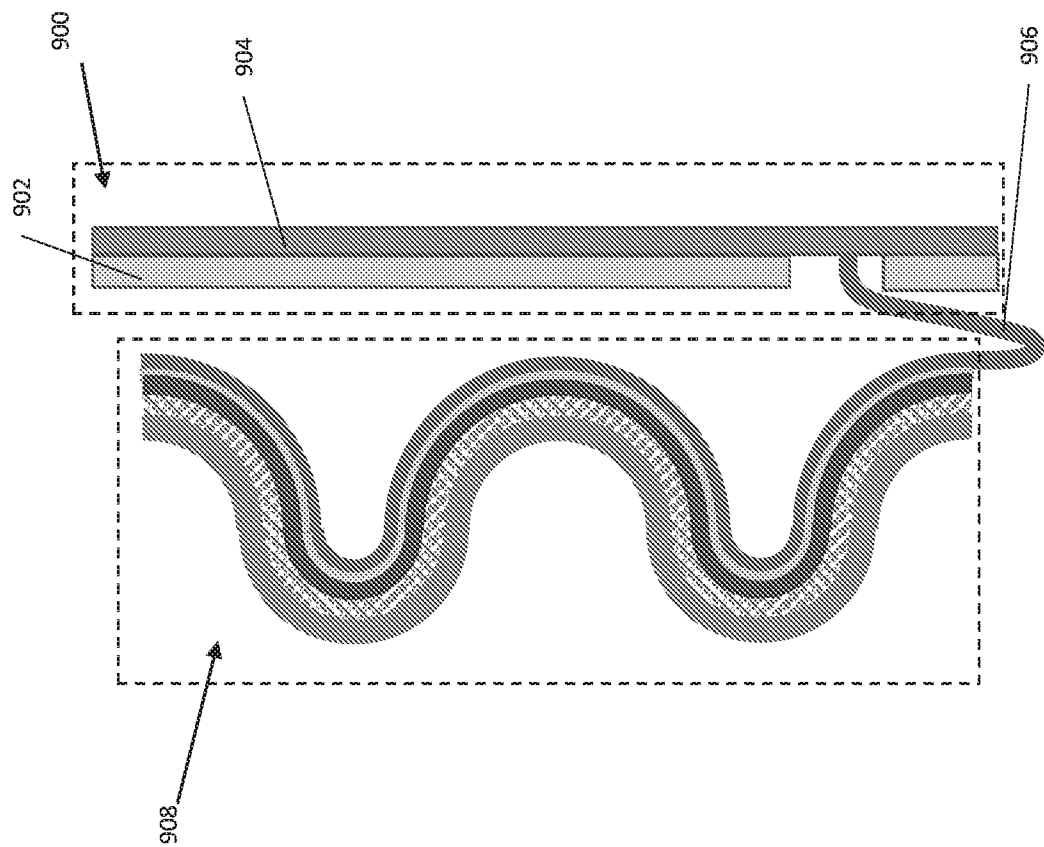


Figure 9

**A. CLASSIFICATION OF SUBJECT MATTER****G02F 1/1333(2006.01)i, G02F 1/167(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

G02F 1/1333; H05K 1/18; H05K 3/30; G09F 9/33; G09F 9/302; G02F 1/1345; G09G 3/30; G09G 5/00; H01R 12/00; G02F 1/167

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &amp; Keywords: mounting, conductive interconnect layer, flexible, curvature, space, controller

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                   | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | US 2013-0082984 A1 (PAUL S. DRZAIC et al.) 04 April 2013<br>See paragraphs [0007], [0020], [0052]-[0064]; claims 1, 3, 8, 17;<br>and figures 3-4, 9. | 1-5,8-11              |
| Y         |                                                                                                                                                      | 6-7                   |
| Y         | US 8007286 B1 (HENRY V. HOLEC et al.) 30 August 2011<br>See column 7, line 30 - column 9, line 2; claim 1; and figures 2a-2b.                        | 6-7                   |
| A         | US 2011-0019370 A1 (WEI-HU KOH) 27 January 2011<br>See paragraphs [0018]-[0026]; and figure 2.                                                       | 1-11                  |
| A         | US 2006-0164586 A1 (KAZUYUKI YAMADA) 27 July 2006<br>See paragraphs [0066]-[0069]; and figures 5-8.                                                  | 1-11                  |
| A         | WO 2015-063115 A1 (BARCO N.V.) 07 May 2015<br>See page 28, line 11 - page 29, line 26; and figures 8a-8e.                                            | 1-11                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

12 September 2017 (12.09.2017)

Date of mailing of the international search report

**12 September 2017 (12.09.2017)**

Name and mailing address of the ISA/KR

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2017/036759**

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)                                                                                                                                                                                                                                                                                                                                                                                                               | Publication<br>date                                                                                                                                                                                                                                                                                              |
|-------------------------------------------|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| US 2013-0082984 A1                        | 04/04/2013          | None                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                  |
| US 8007286 B1                             | 30/08/2011          | EP 2888517 A1<br>US 2009-0226656 A1<br>US 2009-0251068 A1<br>US 2012-0162990 A1<br>US 2013-0128582 A1<br>US 2014-0015414 A1<br>US 2014-0168982 A1<br>US 2014-0197743 A1<br>US 2015-0173183 A1<br>US 2015-0189765 A1<br>US 2017-0055346 A1<br>US 7980863 B1<br>US 8143631 B2<br>US 8410720 B2<br>US 8500456 B1<br>US 8525193 B2<br>US 8710764 B2<br>US 8851356 B1<br>US 8968006 B1<br>US 9341355 B2<br>US 9357639 B2<br>WO 2014-031567 A1 | 01/07/2015<br>10/09/2009<br>08/10/2009<br>28/06/2012<br>23/05/2013<br>16/01/2014<br>19/06/2014<br>17/07/2014<br>18/06/2015<br>02/07/2015<br>23/02/2017<br>19/07/2011<br>27/03/2012<br>02/04/2013<br>06/08/2013<br>03/09/2013<br>29/04/2014<br>07/10/2014<br>03/03/2015<br>17/05/2016<br>31/05/2016<br>27/02/2014 |
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| WO 2015-063115 A1                         | 07/05/2015          | CN 105723444 A<br>CN 105849794 A<br>EP 3063754 A1<br>EP 3063755 A1<br>GB 2519587 A<br>HK 1209891 A1<br>US 2016-0267835 A1<br>US 2016-0267836 A1<br>WO 2015-063116 A1                                                                                                                                                                                                                                                                     | 29/06/2016<br>10/08/2016<br>07/09/2016<br>07/09/2016<br>29/04/2015<br>08/04/2016<br>15/09/2016<br>15/09/2016<br>07/05/2015                                                                                                                                                                                       |