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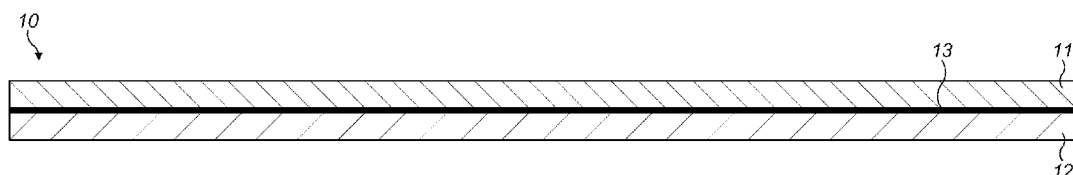


FIG. 1

(57) Abstract: The present disclosure describes an electronic display device comprising a planar flexible electronic display panel and a planar flexible substrate. The planar flexible electronic display panel and the planar flexible substrate are positioned adjacently in a face-to-face relationship. The planar flexible substrate is formed of a material which is auxetic when subjected to an out-of-plane deformation. In certain examples, the planar flexible electronic display panel is a thin film transistor display panel, a liquid crystal display panel or an organic light-emitting diode display panel, suitably in a device selected from mobile telephones, computers and electronic books, including tablet computers, laptop computers and foldable computers. The disclosure further describes a method of supporting a planar flexible electronic display panel in an electronic display system. The method comprises positioning a planar flexible substrate which is auxetic when subjected to an out-of-plane deformation in a face-to-face relationship with a planar flexible electronic display panel.



ELECTRONIC DISPLAY DEVICES

BACKGROUND

[0001] A feature of a foldable electronic device having a flexible or foldable display screen, such as a foldable personal computer, tablet device or mobile telephone, is that a device with a relatively large screen can be made more easily transportable by virtue of its being foldable. Foldability can be achieved by mounting the display screen to a housing for the screen wherein the housing is in two parts joined by a hinge. Similar devices can be made having two or more hinges such that the device folds into three or more portions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Fig 1 is a schematic cross-section of an example electronic display device which may make use of the present disclosure;

[0003] Fig 2 is a schematic perspective view of an example of an electronic device incorporating the example electronic display device of Fig 1 with the device in an opened configuration;

[0004] Fig 3 is a schematic side view of the example electronic device of Fig 2 in a folded configuration;

[0005] Fig 4 is a schematic perspective view of a first example planar flexible substrate which may be incorporated into the example electronic display device of Fig 1;

[0006] Fig 5 is a schematic perspective view of a second example planar flexible substrate which may be incorporated into the example electronic display device of Fig 1;

[0007] Fig 6 is a detail of a portion of the example display device of Figure 1 with the example planar flexible substrate of Figure 4 in a planar configuration;

[0008] Fig 7 is a detail of a portion of the example display device of Figure 1 with the example planar flexible substrate of Figure 4 in a folded configuration;

[0009] Fig 8 is a detail of a portion of the example display device of Figure 1 with the example planar flexible substrate of Figure 5 in a planar configuration; and

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[0010] Fig 9 is a detail of a portion of the example display device of Figure 1 with the example planar flexible substrate of Figure 5 in a folded configuration.

[0011] The figures depict examples of the present disclosure. It should be understood that the present disclosure is not limited to the examples depicted in the figures.

DETAILED DESCRIPTION

[0012] As used in the present disclosure, the term “about” is used to provide flexibility to a value or an endpoint of a numerical range. The degree of flexibility of this term can be dictated by the particular variable and is determined based on the associated description herein.

[0013] Amounts and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not just the numerical values explicitly recited as the limits of the range, but also to include individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited.

[0014] As used in the present disclosure, the term “comprises” has an open meaning, which allows other, unspecified features to be present. This term embraces, but is not limited to, the semi-closed term “consisting essentially of” and the closed term “consisting of”. Unless the context indicates otherwise, the term “comprises” may be replaced with either “consisting essentially of” or “consists of”.

[0015] It is noted that, as used in this specification and the appended claims, the singular forms “a”, “an” and “the” include plural referents unless the context clearly dictates otherwise.

[0016] The present disclosure relates to an electronic display device. The display comprises i) a planar flexible electronic display panel; and ii) a planar flexible substrate. The planar flexible electronic display panel and the planar flexible substrate are positioned in a face-to-face relationship. The planar flexible substrate is auxetic.

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[0017] The present disclosure also relates to an electronic device comprising an electronic display device above. The electronic device is a device selected from the group consisting of mobile telephones, computers and electronic books. In some examples, the electronic device may be a computer selected from the group consisting of tablet computers, laptop computers and foldable computers.

[0018] In some examples, the present disclosure may relate to a method of supporting a planar flexible electronic display panel in an electronic display system. The method comprises positioning a planar flexible substrate in a face-to-face relationship with a planar flexible electronic display panel. The planar flexible substrate is a planar flexible substrate which is auxetic, for example, when subjected to an out-of-plane deformation.

[0019] In a foldable electronic device, a planar flexible electronic display panel may be supported by a housing. The housing may comprise at least two sections that are joined by a hinge. In some instances, it can be difficult to maintain a uniform length to the inner surface of the hinge in both the folded and unfolded configurations. As a consequence, as the hinge is folded and unfolded, tolerances may be applied to the display panel, increasing a risk that the display panel may become damaged during or as a consequence of repeated folding and unfolding of the foldable electronic device in use.

[0020] In the present disclosure, a planar flexible substrate is positioned in a face-to-face relationship with a planar flexible electronic display panel. The planar flexible substrate is auxetic, for example, when subjected to an out-of-plane deformation.

[0021] Auxetic materials are those materials which have a negative Poisson's ratio. The Poisson's ratio of a material is the ratio of the relative contraction strain or transverse strain, normal to an applied load, to the relative extension strain or axial strain in the direction of the applied load. Most materials exhibit a positive Poisson's ratio. For example, when stretched, they become thinner and, when compressed, they become thicker. Other materials exhibit a negative Poisson's ratio in at least one direction. If such materials are stretched, they become thicker and, if compressed, they become thinner in directions perpendicular to the applied force. Such materials are known as auxetic materials. Auxetic materials may be planar auxetic materials, in

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the sense that the auxetic properties are exhibited only in a single plane or they may be three-dimensional auxetic materials, exhibiting auxetic properties in more than one plane.

[0022] By positioning a planar flexible electronic display panel adjacent to an auxetic planar flexible substrate in a face-to-face relationship, it may be possible to at least partially shield the planar flexible electronic display panel from tolerances applied during folding and unfolding, as the tolerances may be “absorbed” by the auxetic planar flexible substrate.

[0023] In some examples, the planar flexible substrate is formed of a material which is auxetic when subjected to a flexing or folding deformation and in which the material expands arcuately in a radial direction.

[0024] In some examples, the auxetic planar flexible substrate may be formed of an auxetic material that is selected from an auxetic cellular solid.

[0025] In some examples, the auxetic planar flexible substrate is formed of a material selected from the group consisting of rubber materials, foamed polymeric materials, fiber materials and resin materials. These materials may be used to form an auxetic cellular solid.

[0026] In some examples, the auxetic planar flexible substrate is formed of an auxetic material. The auxetic planar flexible substrate may have an auxetic cellular structure. The auxetic cellular structure may be formed, for example, by 3D printing; by extrusion, molding or casting; or by assembly from sheet materials.

[0027] In some examples, the cellular structure comprises at least one row of cells, each cell having auxetic properties in at least one direction or orientation. In certain examples, the substrate comprises a plurality of rows of cells.

[0028] In some examples, the auxetic cellular structure comprises a plurality of cells, each cell having a re-entrant polygonal form. In some examples, the re-entrant polygon may be a polygon that has at least one interior angle that is greater than 180°. In some examples, a plurality of rows of cells are provided, wherein each cell is a polygon that has at least one interior angle that is greater than 180°.

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[0029] In some examples, each cell has a re-entrant hexagonal form. In some examples, each cell has a re-entrant triangular form.

[0030] In some examples, the planar flexible substrate has a honeycomb structure. In certain examples, the honeycomb structure comprises an array of elongate cells.

5 [0031] In some examples, the auxetic planar flexible substrate has a skeletal structure.

[0032] In certain examples, the skeletal structure comprises three-dimensional array comprising a plurality of ribs wherein adjacent ribs are flexibly or hingedly adjoined.

[0033] In certain examples, the skeletal structure comprises an array of elongate cells having auxetic properties in at least one direction or orientation.

10 [0034] In some examples, the planar flexible substrate may be formed of an auxetic material. The material may have intrinsic auxetic properties or may be auxetic as a result of its e.g. cellular structure as discussed above. In some examples, the planar flexible substrate is formed of a material selected from the group consisting of rubber materials, solid or foamed polymeric materials, fiber materials and resin materials.

15 [0035] In some examples, the planar flexible substrate is formed of a composite material comprising a material selected from the group consisting of rubber materials, solid or foamed polymeric materials and resin materials and a fiber.

[0036] Suitable polymers include polyurethane, polyethylene, polytetrafluoroethylene and polyester.

20 [0037] Suitable fibers include glass fibers, carbon fibers and nylon fibers.

[0038] In some examples, the auxetic planar flexible substrate has a thickness of about 50 μ m to about 500 μ m.

[0039] In some examples, the auxetic planar flexible substrate is mounted to the planar flexible electronic display panel. The auxetic planar flexible substrate may be adjacent
25 to the planar flexible electronic display panel.

[0040] In some examples, the auxetic planar flexible substrate is mounted to the planar flexible electronic display panel by an adhesive. In certain examples, the adhesive is in the form of an adhesive sheet intermediate the substrate and the display panel.

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[0041] In some examples, the planar flexible electronic display panel is selected from the group consisting of thin film transistor display panels, liquid crystal display panels and organic light-emitting diode display panels.

[0042] As discussed above, the present disclosure also relates to an electronic device comprising an electronic display device described herein. In some examples, the electronic device is a device selected from the group consisting of mobile telephones, computers and electronic books. Such a computer may be selected from the group consisting of tablet computers, laptop computers and foldable computers.

[0043] In some examples, the electronic device comprises a housing that supports the planar flexible substrate and the planar flexible electronic display panel in the face-to-face relationship.

[0044] In some examples, the planar flexible substrate has dimensions substantially corresponding with dimensions of the planar flexible electronic display panel.

[0045] In some examples, the housing includes a hinge. In certain examples, the planar flexible substrate is mounted to the planar flexible electronic display panel at least in an area of the hinge. In some examples, the planar flexible substrate may overlie at least an area of the hinge, and the planar flexible electronic display panel may overlie at least an area of the planar flexible substrate. In some examples, the planar flexible substrate overlies the hinge, and the planar flexible electronic display panel overlies the planar flexible substrate in the region overlying the hinge.

[0046] In one example, the housing includes a first section and a second section. The first section may be coupled to the second section via a hinge. The electronic display device of the present disclosure may be mounted in the housing so that it overlies at least part of the hinge. The electronic display device may overlie at least part of the hinge, such that the planar flexible substrate is adjacent the at least part of the hinge. In some examples, the electronic display device may overlie at least part of the first section, the hinge and at least part of the second section. The electronic display device may overlie at least part of the first section, the hinge and at least part of the second section, such that the planar flexible substrate is adjacent the at least part of the first section, the hinge and the at least part of the second section.

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[0047] The hinge may allow the angle between the first section and the second section to be varied. Thus, by varying the angle between the first section and the second section, it is possible to move the electronic display device from an “unfolded” to a “folded” configuration. In some examples, the hinge may allow the angle between the first section and second section to be varied from a reflex or obtuse angle to an acute angle.

[0048] In some examples, the hinge may allow the angle between the first section and second section to vary from an “unfolded” angle of about 100 to about 210° to a “folded” angle of less than about 80°. Suitable “unfolded” angles may range from about 150 to about 200°, for example, about 160 to about 190° or about 170 to about 185°. In one example, the “unfolded” angle may be about 178 to about 182°, for example, about 180°. In some examples, the first section and second section may present a substantially horizontal surface when the hinge is in the “unfolded” configuration.

[0049] Suitable “folded” angles may be less than about 40°, for example, less than about 30°, less than about 20°, less than about 10°, less than about 5° or less than about 1°. In some examples, the first section and second section may overlies on another when the hinge is in the “folded” configuration.

[0050] Any suitable hinge may be used. In some examples, the hinge may comprise a number of sequentially interconnected sliding links. A sliding link may be coupled or formed integrally with a first section of the housing of the electronic device and another sliding link may be coupled or formed integrally with a second section of the housing of the electronic device. The sliding links may each be interconnected by means of respective curved prongs for sliding engagement with a corresponding curved rail formed in an adjacent sliding link.

[0051] While some examples are described below in relation to an X axis, Y axis, and Z axis, these axes are shown and used herein for convenience of description and may not reflect an orientation of the device or its components. The description of each axis in relation to various components of a device is used to provide relative orientation information for each of the components. In one example, the X axis and Y axis are in the plane of the electronic display device or base of an electronic

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device, while a Z axis is perpendicular to the electronic display device or base of the electronic device. As will be observed in the figures, when the electronic device is held flat and viewed on edge in front of the viewer in a portrait orientation, the X axis, in the following description, is in the direction of left-right, and the Y axis is top to bottom and the Z axis is front-back.

[0052] Figure 1 is a schematic cross-section of an example electronic display device 10 making use of the present disclosure in which a planar flexible electronic display panel 11 is mounted to a planar flexible substrate 12. The flexible display panel 11 may be a flexible or rollable organic light emitting diode (OLED) type display. However, examples of the present disclosure may equally be suitable for application with other constructions of display panels.

[0053] In accordance with examples of the present disclosure, the planar flexible substrate 12 is formed of a material which is auxetic, for example, when subjected to an out-of-plane deformation, as will be described in further detail below.

[0054] In the example shown in Figure 1, a rear face of the planar flexible electronic display panel 11 is mounted to a proximal face of the planar flexible substrate 12 in a face-to-face relationship by means of an intermediate adhesive layer 13. Adhesive layer 13 may be a sheet material having a compatible adhesive applied to each face thereof. In alternative examples, the adhesive layer 13 may be an adhesive applied directly to one or both faces of the panel 11 and substrate 12 prior to the two components being brought together.

[0055] In an alternative example (not shown), the planar flexible electronic display panel 11 and the planar flexible substrate 12 are positioned and retained adjacently in a face-to-face relationship by means of a frame within which the two components are mounted. The frame suitably forms a part of the device in which the display panel is intended to be used. An intermediate adhesive layer 13 may additionally be used in this arrangement.

[0056] An example of an electronic device in which the electronic display device 10 may be used is shown schematically in Figure 2, showing an example form of a foldable computer 14 or a foldable hand-held device such as a tablet or smartphone.

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The foldable computer 14 may have an electronic display device 10 mounted within a housing or case having a first section 15 and a second section 16 joined with a transverse foldable hinge 17. The construction of the case may be as described in further detail in our earlier application, WO 2018/194604, to which further reference should be made and which is hereby incorporated herein by reference in its entirety. In this example, the hinge 17 may be formed of a number of sequentially interconnected sliding links 17a, 17b, 17c, 17d and 17e. First sliding link 17a may be connected or attached to, or formed integrally with, first section 15 of the case of the electronic device and the final sliding link 17e may be connected or attached to, or formed integrally with, the second section 16 of the case of the electronic device. For this purpose, first and final sliding links may be of similar or same design as the intermediate sliding links or may be different. The first and second sections 15, 16 of the case may be adapted accordingly. The sliding links 17a, 17b, 17c, 17d, 17e may each be interconnected by means of respective curved prongs 18a, 18b, 18c, 18d slidably interfitting or engaging a corresponding curved rail 19a, 19b, 19c, 19d formed in an adjacent sliding link. Further, as illustrated in the example shown, each curved prong 18 and curved rail 19 may be formed with a respective detent 20a, 20b which inter-cooperate to maintain interconnection between the sliding links.

[0057] Figure 2 shows the foldable computer 14 in an opened or substantially flat configuration, in which the computer may be operated by a user in the same manner as a tablet computer. Figure 3 schematically shows the foldable computer in a fully-folded configuration. The skilled reader will appreciate that, for clarity, the figures exaggerate the relative dimensions of the components of a foldable computer. The foldable computer 14 may also be operated by the user in configurations intermediate the configurations shown in Figures 2 and 3.

[0058] In the example shown in Figures 1 to 3, the planar flexible substrate 12 has substantially the same dimensions of length and width as the dimensions of the planar flexible electronic display panel 11. In alternative examples, the planar flexible substrate 12 is dimensioned to provide a support for the planar flexible electronic display panel 11 substantially in an area in which the example electronic display device 10 overlays the foldable hinge 17 of the case of the foldable computer 14.

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[0059] The foldable computer 14 may include components additional to those illustrated in the figures, such as a touchscreen sensor, which may overlie the electronic display device 10; power input and rechargeable battery; CPU, graphics and audio processors and wireless networking components, which may be mounted on a motherboard, switches, speakers, microphone and so on. The components may be distributed within the first and second sections 15,16 of the case. These additional components are omitted from the figures for the purposes of clarity.

[0060] As discussed above, an auxetic material is one which exhibits a negative Poisson's ratio. In other words, when stretched, they become thicker perpendicular to the applied force. Examples of the present disclosure take advantage of this property, applying it to a planar sheet material such that, when subjected to an out-of-plane deformation such as a folding or bending action, the face of the auxetic planar sheet to which the deformation force is applied (which, in a folding deformation is the inner face) may substantially maintain its dimensions whereas the opposite face may expand in an arcuate manner, in a radial direction.

[0061] In some examples, the planar flexible substrate 12 may have a width substantially corresponding with the width of the planar flexible electronic display panel 11 and a length substantially corresponding with the lateral width of the hinge such that the substrate may provide support for the electronic display panel 11 in the region in which, in the electronic device, the electronic display panel 11 overlies the hinge.

[0062] In some examples, the planar flexible substrate 12 may have a width and a length substantially corresponding with the width and length of the planar flexible electronic display panel 11 such that the substrate may provide support for the electronic display panel across substantially the whole area of the panel.

[0063] Accordingly, the proximal face of the auxetic planar flexible substrate 12 to which the planar flexible electronic display panel 11 is mounted maintains the same dimensions as the display panel is folded and unfolded and any tensions or stresses generated during folding and unfolding by manufacturing and assembly tolerances in the hinge mechanism of the housing are absorbed by the auxetic substrate 12 and not transferred to the display panel 11.

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[0064] Examples of the substrate of the present disclosure include auxetic materials which may be elastically anisotropic, having a different Poisson's ratio depending upon the direction in which they are stretched, or isotropic, having the same Poisson's ratio in all directions. Examples of anisotropic materials include polymeric or metallic honeycombs which deform by flexure of ribs joining nodes of the auxetic skeleton. Examples of isotropic materials include polymeric and metallic auxetic foams.

[0065] Example polymeric foams for example substrates may include foamed polytetrafluoroethylene, polyurethane, polyethylene and polypropylene.

[0066] Example metallic foams may include copper foams and aluminium foams.

[0067] Auxetic materials may derive their auxetic properties through their molecular or crystal structure or through their microscopic or macroscopic construction. Figures 4 and 5 show example macroscopic structures which may be applied to the planar flexible substrate 12 of examples of the present disclosure. The example substrates 12A (Figure 4) and 12B (Figure 5) are generally planar, having a dimension x in the X axis, corresponding generally with a width of the planar flexible panel 11, and a dimension y in the Y axis corresponding with a length of the planar flexible display panel 11. The substrates have a dimension z in the Z axis, corresponding with the thickness of the panel 11.

[0068] Examples of the substrates of the disclosure are constructed to exhibit planar auxetic properties in the ZY plane for extension or extrusion along the x direction along at least the X axis such that the substrate deforms auxetically when subjected to an out-of-plane (Z-axis) deformation, such as a folding motion or a bending or flexing motion applied across the width x of the substrate. In other examples, the substrate may exhibit three-dimensional auxetic properties with flexing being achieved along both the X and Y axes.

[0069] In some examples, the honeycomb cellular structure may be considered to be formed of interconnected ribs and that the cells open auxetically due to flexing and/or hinging, of the ribs at their interconnection sites, or nodes, when the structure is placed under tension. In other examples, the honeycomb structure may be chiral, in which each node is defined by a cylinder with the cylinders being interconnected by ribs or

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ligaments, wherein the auxetic effects arise due to cylinder rotation-induced bending of the ligaments.

[0070] In Figure 4, the auxetic properties of the planar flexible substrate 12A are provided by forming the substrate as a three-dimensional structure based on a two-dimensional re-entrant hexagonal structure of the type proposed by Masters and Evans (*Masters IG, Evans KE - Models for the elastic deformation of honeycombs. Compos Struct 35(4):403–422*), applied to the X axis of the substrate by extending each honeycomb cell to form an array of tube-like passages or ducts 21 translated transversely across the body of the substrate 12A, in a similar manner to the flutes of a sheet of corrugated fiberboard. The passages 21 of the array may have closed walls (as shown). In alternative examples (not shown), especially substrates also exhibiting three dimensional auxetic properties in both of the x and y dimensions, the passages 21 may have a framework structure with open walls. In some examples, the substrates may form an auxetic foam.

[0071] The example auxetic materials may be formed of any suitable material, including natural or synthetic rubber materials, foamed polymeric materials, microporous polymers, fiber materials and resin materials.

[0072] The substrate 12 may have a thickness of about 50 μ m to about 500 μ m.

[0073] In an example assembled electronic device 14, the display panel 11 to which the planar flexible substrate 12A is mounted is assembled to the frame or case of the device 14 with the array of transverse passages 21 parallel to the transverse hinge 17. With this construction, as the first and second case portions are folded about hinge 17, the transverse passages 21 in the region of the hinge 17 are caused to expand radially in a direction away from the display panel 11.

[0074] An alternative example is shown in Figure 5 in which the re-entrant hexagonal structure is modified to use the re-entrant triangular or arrowhead design described by Larsen & Bouwstra in (*Larsen, U. D., Sigmund, O., & Bouwstra, S. Design and fabrication of compliant micromechanisms and structures with negative Poisson's ratio. IEEE Journal of Microelectromechanical Systems, 6, 99-106. DOI: 10.1109/84.585787*) to form transverse tube-like passages 22. As explained above

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with respect to the example of Figure 4, whereas the passages 22 of the array of Figure 5 have closed walls, alternative examples (not shown), especially substrates also exhibiting three-dimensional auxetic properties along both of the X and Y axes, may have a framework structure with open walls.

5 [0075] Figures 6 to 8 illustrate in more detail the performance of the planar flexible substrate during use. The figures are schematic and, for reasons of clarity, exaggerate the relative thicknesses of the example substrates and the display panel 11. The dimensions of certain examples of the present disclosure is indicated above.

[0076] For additional clarity for the purposes of explanation, the figures also amplify
10 the construction and flexing of the example auxetic substrates. Figure 6 is a detail view of the circled portion of Figure 1 in which the electronic display device 10 is in an unfolded configuration and planar flexible substrate 12 mounted to the display panel 11 is the substrate 12A of Figure 4. Figure 6 shows a dimension L which, in the example corresponding to the substrate 12A of Figure 4, represents the distance
15 between adjacent corresponding features, such as adjacent apexes, of the arrowhead design of auxetic substrate. Figure 7 is the same view with the electronic display device 10 in at least a partially folded configuration such that the device becomes curved and shows the effect of folding the substrate and the panel to which it is attached. As can be seen, in this folded configuration, the separation of adjacent
20 corresponding features at the face remote the display panel 11 is extended by a tolerance distance t such that the total distance between adjacent corresponding features has increased to $L+t$, whilst the separation of adjacent corresponding features at the face of the substrate mounted to the display panel 12 remains at L .

[0077] Figure 8 and 9 correspond with Figures 6 and 7, save that the planar flexible
25 substrate 12 is the substrate 12B of Figure 5. As with the comparison between Figure 6 and 7, it can be seen that the separation of adjacent corresponding features of the auxetic substrate material at the face remote the display panel 11 increases in the folded configuration to a distance $L+t$ whereas that of the face of the substrate 12B mounted to the display panel 12 remains at L .

30 [0078] The geometry of the illustrated example substrates will now be described in further detail.

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[0079] It can be seen from Figure 6 that certain examples of auxetic materials suitable for example substrates may include a repeating pattern or array of cells 23 which, with the substrate in a planar configuration, are substantially identical. One such cell is highlighted in bold in Figure 6. The cell has the form of a re-entrant hexagon formed by six ribs which join or intersect at six respective nodes 24, forming a pair of side ribs defined by nodes 24a,24b and 24c,24d respectively, with upper and lower intermediate nodes 24e,24f which are re-entrant, in the substrate in a planar configuration, with respect to the side ribs. A linking rib 25 depends from lower intermediate node 24f and links lower intermediate node 24f of one cell to upper intermediate node 24e in a cell below. It will also be observed from Figure 6 that the lower intermediate node 24f of one cell also forms node 24a of the cells in the row below such that the cells in adjacent rows are offset. Similarly, upper intermediate node 24e of one cell also forms node 24b in the offset row below.

[0080] In some examples, the array of cells may have a single row of cells. In other examples, the array of cells include a series of rows of cells. The uppermost row of which (as viewed in the figures) defines the proximal face of the substrate 21 to which, at correspondingly upper nodes 24a,24c, the flexible electronic display panel 11 is attached.

[0081] Since upper nodes 24a,24c are fixedly mounted with respect to the flexible electronic display panel 11, the separation between corresponding nodes in adjacent cells remains fixed at the point at which the nodes are attached to the flexible electronic display panel 11. In contrast, as can be seen by comparison with Figure 7, as the flexible electronic display panel 11 is flexed, those cells distal from the proximal face of the substrate 21 expand in a radial direction in a generally arcuate manner such that side ribs move to become radially aligned with a centre of curvature (not shown) of the flexible electronic display panel 11. Consequently, the distal face of the substrate is able to expand and lengthen to an arc length of $L+t$ as the substrate is folded whilst the proximal face to which the flexible electronic display panel 11 is attached retains a constant length L .

[0082] In the alternative example substrate of Figure 8, the cells may be formed by a repeating pattern of two re-entrant triangles arranged adjacently in oppositely-directed

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orientations, forming rows of alternating upwardly (as viewed in the figures) and downwardly pointing re-entrant triangular cells 30. As with the example of Figures 6 and 7, the arrangement is defined by a series of six nodes 31a,31b,31c,31d,31e,31f in which, in the unit cell, upper nodes 31a,31c are both joined to re-entrant upper intermediate node 31e and lower intermediate node 31f which, in contrast to the re-entrantly positioned node 24f of the example substrate of Figure 6, is positioned saliently with respect to side nodes 31a,31b,31c,31d. Lower intermediate node 31f is also attached to upper side nodes 31a,31d of adjacent cells in the row below.

[0083] In this example, nodes 31a,31c form, in the substrate, the proximal face of substrate 22 to which the flexible electronic display panel 11 is mounted. As can be seen by comparing Figure 8 with Figure 9, as the flexible electronic display panel 11 is folded or flexed, the proximal face of substrate 22 is constrained by its attachment to the flexible electronic display panel to maintain the same separation L between upper nodes 31a,31c whereas distal rows are able to expand arcuately, such that the separation or arc length between adjacent corresponding nodes is able to increase to $L+t$.

[0084] In the examples shown in Figures 4 to 9, the ribs may be substantially rigid, inflexible or inextensible such that cell expansion in the radial direction is achieved by a flexing or hinging motion at the nodes only. Alternatively, the ribs may be elastically flexible and/or extensible such that expansion of the cells in the radial direction is by flexing and/or extension of the ribs, optionally in addition to flexing or hinging at the nodes.

[0085] Although described above with respect to Figures 4 to 9 in respect of anisotropic auxetic substrates, other auxetic materials capable of being formed into a generally planar substrate are equally suitable. For example, foamed materials such as expanded microporous polytetrafluoroethylene, polymers based on a reflexyne-type molecular skeleton and auxetic ultra-high molecular weight polyethylene are suitable.

[0086] Accordingly, by the mounting of the display panel 11 to a substrate 12 formed of an auxetic material, tolerances in the case construction of a foldable computer are absorbed by the auxetic material rather than being transferred to the display panel 11.

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[0087] Although described above with respect to a foldable computer, the present disclosure is equally applicable to other electronic products incorporating one or more display panels, especially flexible display panels. For example, the present disclosure is equally applicable to foldable mobile telephony devices, such as smartphones, 5 tablet devices, electronic books and media players for viewing images and video media.

[0088] Equally, although described above with respect to flexible display panels, such as OLED devices, the present disclosure is equally applicable to providing support for non-flexible or partially flexible display panels which may be subjected to out-of-plane 10 deformations or other forces, such as impact forces.

CLAIMS

1. An electronic display device comprising:
 - i) a planar flexible electronic display panel; and
 - ii) a planar flexible substrate;

5 wherein the planar flexible electronic display panel and the planar flexible substrate are positioned in a face-to-face relationship; and

 wherein the planar flexible substrate is auxetic.
2. The electronic display device as claimed in claim 1, wherein the auxetic planar flexible substrate is formed of a material selected from the group consisting of
10 rubber materials, foamed polymeric materials, fiber materials and resin materials.
3. The electronic display device as claimed in claim 1, wherein the auxetic planar flexible substrate comprises an auxetic cellular structure.
15
4. The electronic display device as claimed in claim 3, wherein the auxetic cellular structure comprises a plurality of cells, each cell having a re-entrant polygonal form.
20
5. The electronic display device as claimed in claim 3, wherein the auxetic cellular structure comprises cells having a re-entrant hexagonal form or cells having a re-entrant triangular form.
6. The electronic display device as claimed in claim 1, wherein the auxetic planar flexible substrate has a thickness of about 50 μ m to about 500 μ m.
25
7. The electronic display device as claimed in claim 1, wherein the auxetic planar flexible substrate is mounted to the planar flexible electronic display panel.
30

- 8 The electronic display device as claimed in claim 1, wherein the auxetic planar flexible substrate is mounted to the planar flexible electronic display panel by an adhesive.
- 5 9 The electronic display device as claimed in claim 1, wherein the planar flexible electronic display panel is selected from the group consisting of thin film transistor display panels, liquid crystal display panels and organic light-emitting diode display panels.
- 10 10. An electronic device comprising an electronic display device as claimed in claim 1 wherein the electronic device is a device selected from the group consisting of mobile telephones, computers and electronic books.
- 15 11. The electronic device as claimed in claim 10 comprising housing wherein the housing supports the auxetic planar flexible substrate and the planar flexible electronic display panel in the face-to-face relationship.
12. The electronic device as claimed in claim 12, wherein the housing includes a hinge.
- 20 13. The electronic device as claimed in claim 12, wherein the planar flexible substrate is mounted to the planar flexible electronic display panel at least in an area of the hinge.
- 25 14. The electronic device as claimed in claim 12, wherein the planar flexible substrate overlies the hinge, and the planar flexible electronic display panel overlies the planar flexible substrate in the region overlying the hinge.

15. The electronic device as claimed in claim 12, wherein the hinge comprises a number of sequentially interconnected sliding links.

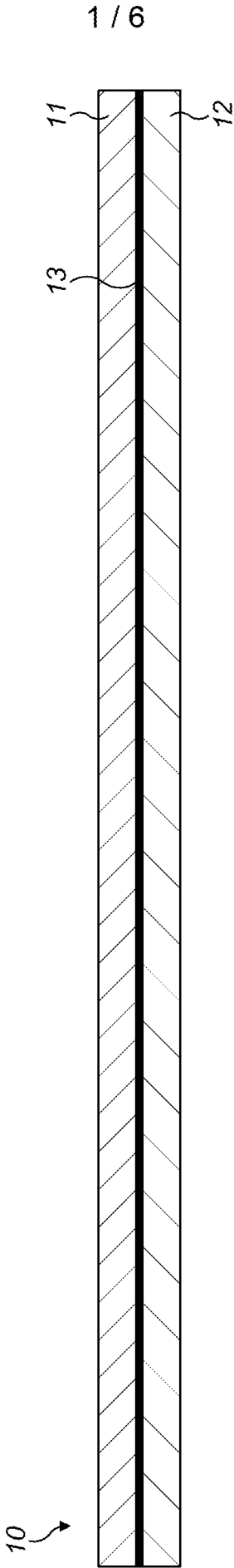


FIG. 1

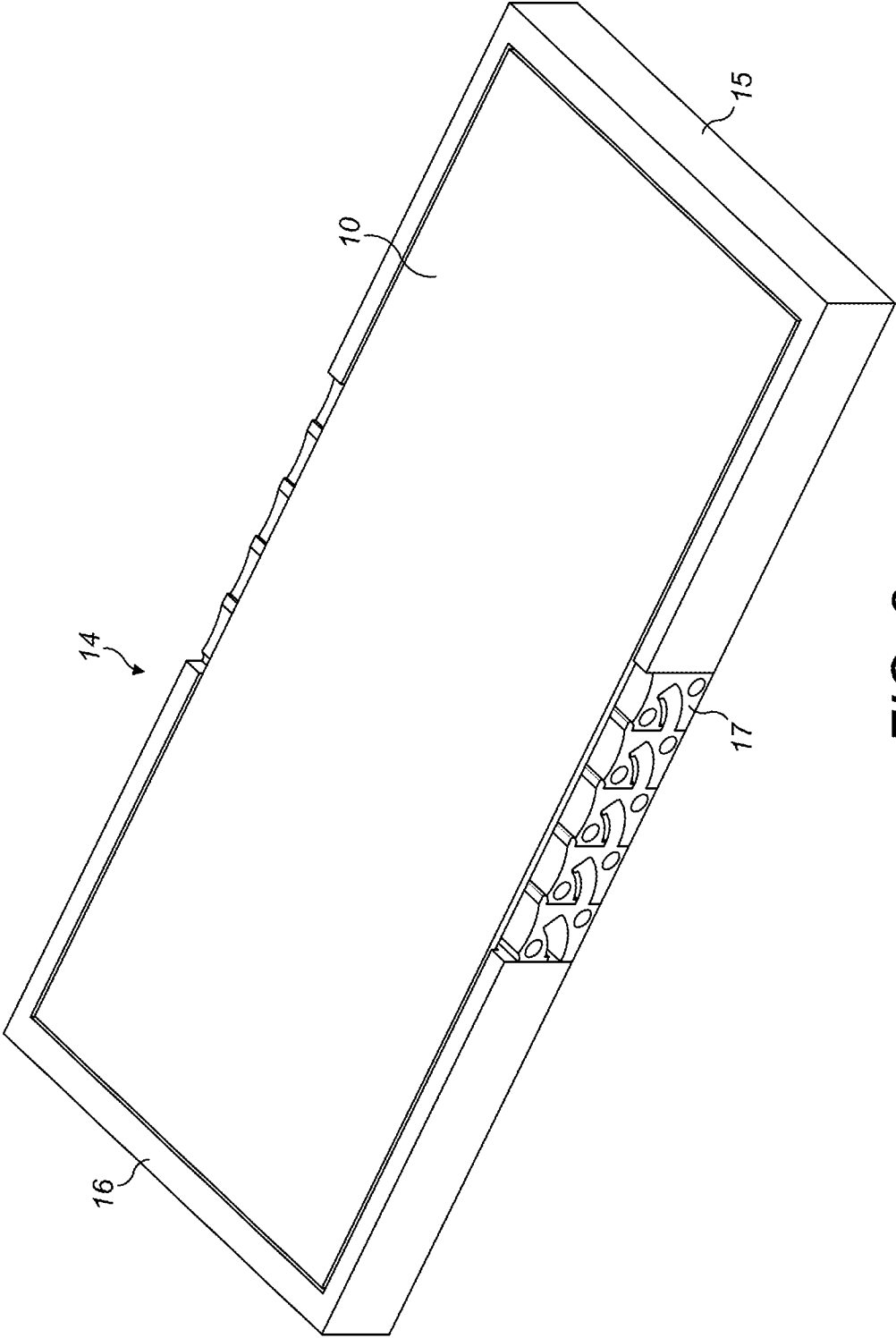


FIG. 2

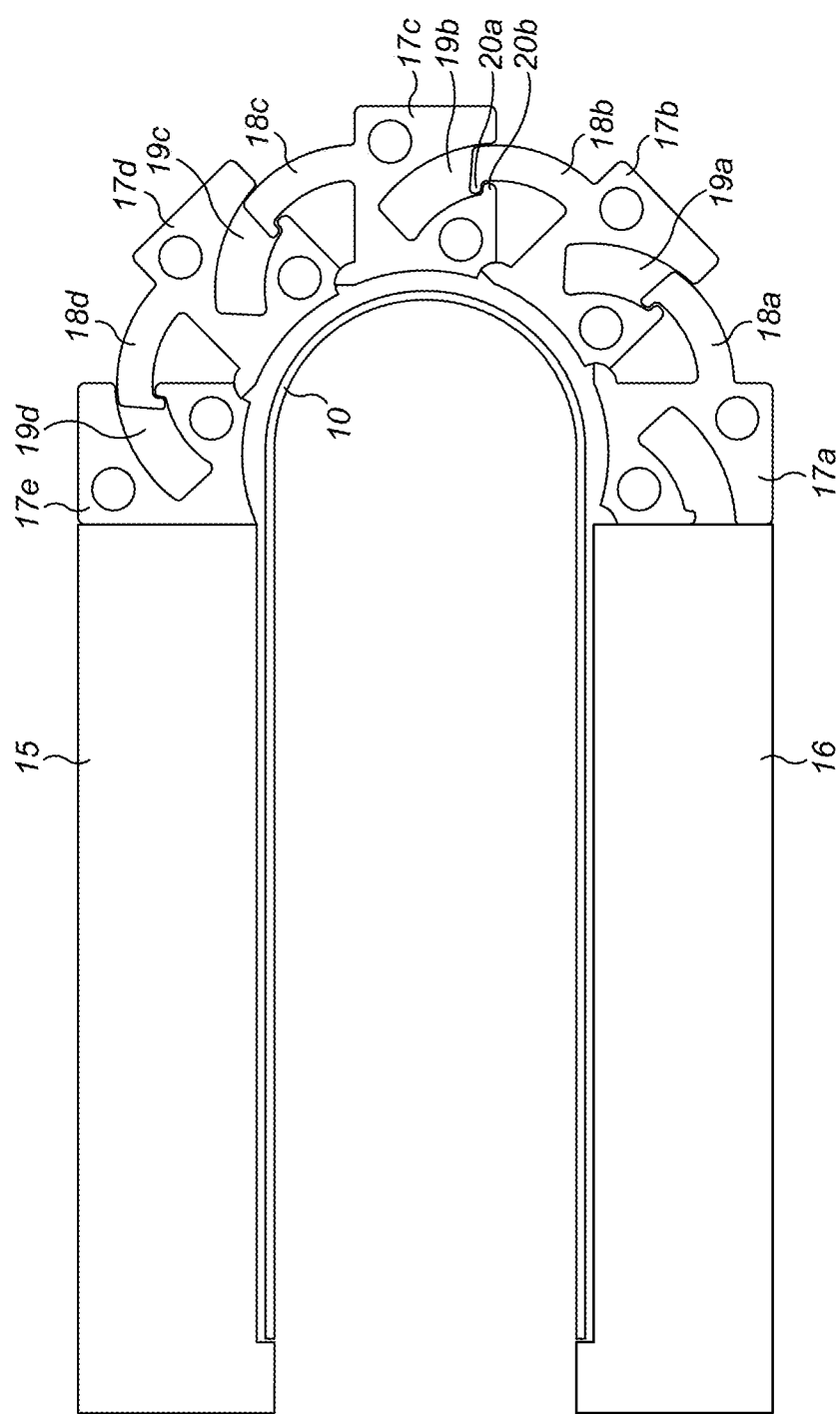


FIG. 3

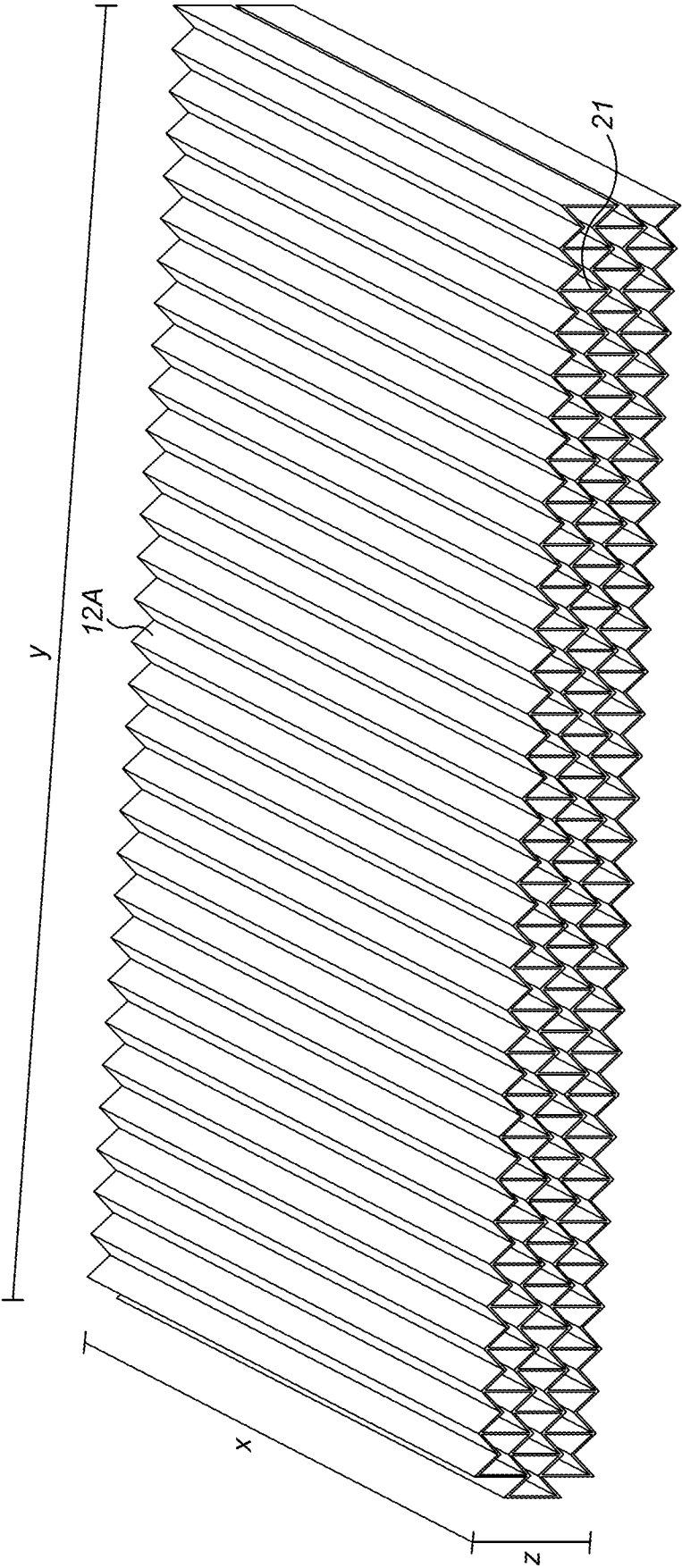


FIG. 4

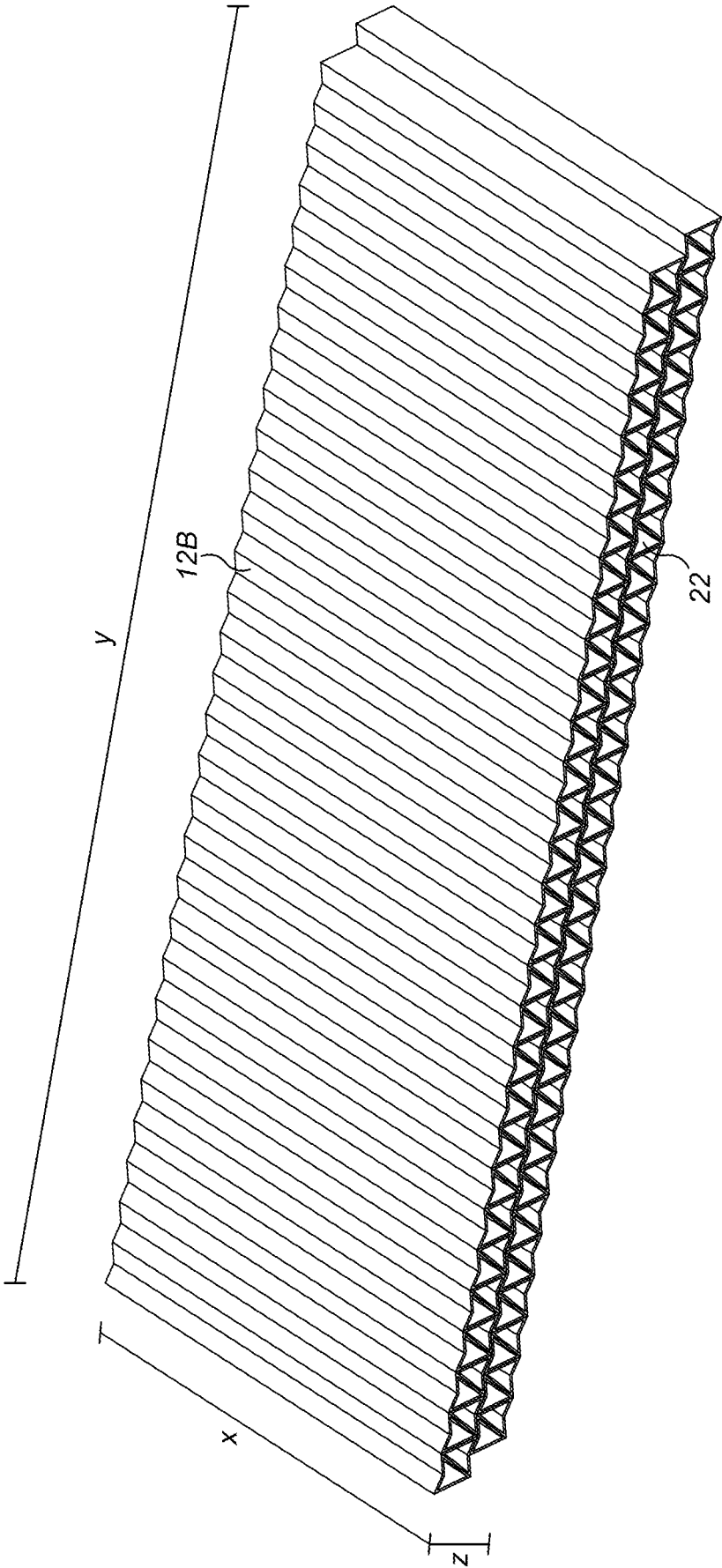


FIG. 5

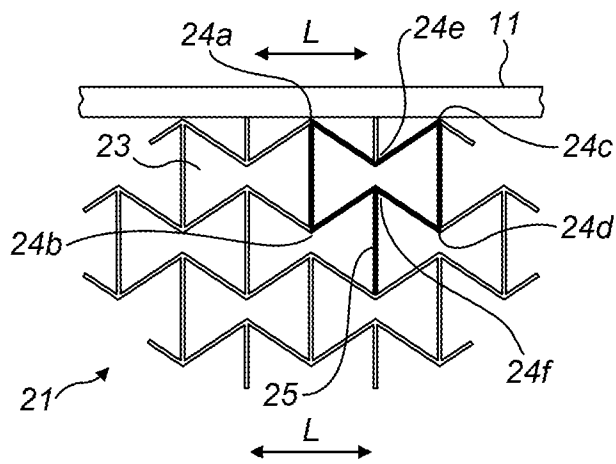


FIG. 6

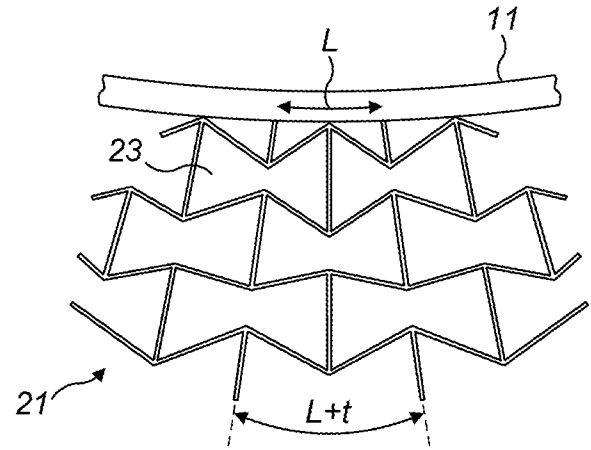


FIG. 7

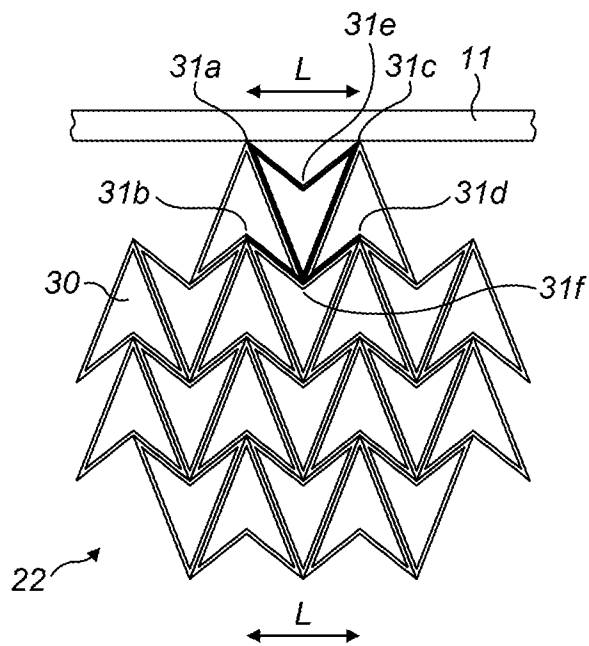


FIG. 8

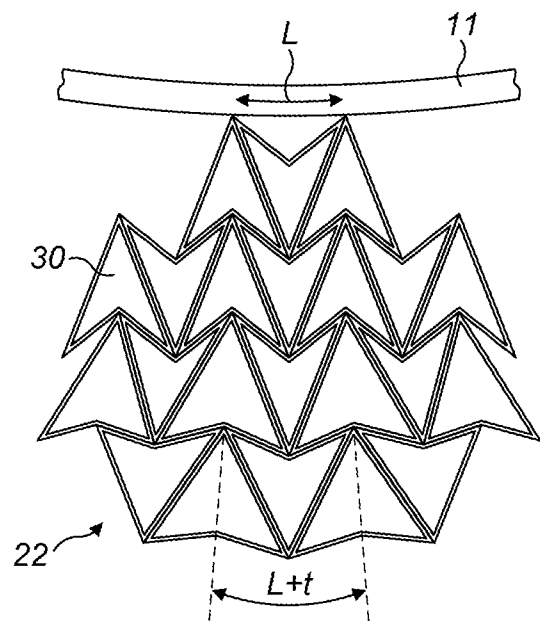


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2019/016455

A. CLASSIFICATION OF SUBJECT MATTER

G09G 3/00 (2006.01)
G02F 1/1333 (2006.01)

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 1/00-1/39, G09F 9/00-9/46, G09G 3/00-3/38

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

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

PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 103177656 B (HARBIN INST OF TECHNOLOGY) 01.07.2015, abstract, [0002], [0008], [0011], [0012], [0013], [0027], fig.2,3	1-7, 10-11
Y		12-15
Y	JP 2008182289 A (TOYO SANGYO KK) 07.08.2008, abstract, claim 1, fig.12	12-15
X	US 2016/104850 A1 (SAMSUNG DISPLAY CO LTD) 14.04.2016, [0003], [0011], [0012], [0034], [0035], [0098]	1, 8-9, 11



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
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"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search

24 October 2019 (24.10.2019)

Date of mailing of the international search report

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