**Title:** LIQUID CRYSTAL DEVICE

**Abstract**

A method of manufacturing a liquid crystal device is disclosed which comprises assembling together, in a layered structure, a pair of pre-shaped transparent plastic substrates (1, 1'), and a pair of transparent plastic films (5, 5') carrying a pair of conductive coatings (6, 6'). A plurality of spacers (9) are disposed between the plastic films and a partial adhesive seal (8) is provided around and/or between the films to provide a cavity therebetween. The cavity (7) is filled with a fluid liquid crystal mixture (7') or precursor mixture which is polymerisable to polymeric/liquid crystal composite material. The cavity is sealed to retain the liquid crystal mixture or composite material therein. At least one layer (4, 4') of a resilient transparent adhesive is disposed between two of the other layers of the device to enable the cell to be conformed to the required shape.
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LIQUID CRYSTAL DEVICE

The present invention relates to liquid crystal devices (LCDs) and, more particularly, to a method of making such devices.

The construction of liquid crystal devices (LCDs) from sheets of glass is well known and several different types have been described (see eg M G Clark in "Encyclopedia of Physical Science and Technology, 1990 Yearbook" San Diego, Academic Press, 1990 pp401-16, "Liquid Crystal Devices").

"Film" LCDs constructed from polymer substrates have also been described, and are of two types. In those of conventional construction the glass sheets are replaced by thin sheets of plastic onto which a transparent conductive coating has been deposited (see eg Ricoh PF-LCD - brochure issued by Ricoh Ltd, Japan). Alternatively, the liquid crystal and the polymer may be combined into a single composite film. According to the ratio of polymer matrix to liquid crystal these composite materials have different internal structures, and are known, respectively, as polymer-dispersed liquid crystal (PDLC) (see eg PS Drzaic, Proceedings of Eurodisplay '90, September 25-27, 1990, pp128-31. "Liquid Crystal Dispersions for Large Area Light Valves and Displays"), polymer-network liquid crystal (PNLC) (see eg H Ogawa, T Fujisawa, K Maruyama, H Takatsu and K Takeuchi, Proceedings of the 15th Japanese Liquid Crystal Conference (1989), pp204-5. "Structure of Polymer Network and Electro-Optical Properties for Polymer Network Liquid Crystal Display (PN-LCD")", and polymer-gel liquid crystal (PGLC) (see eg JW Doane, D-K Yang and L-C Chein, Conference Record of the 1991 International Display Research Conference, October 15-17, 1991, pp175-8. "Current Trends in Polymer Dispersed Liquid Crystals"), with increasing fraction of liquid crystal.

While for many applications, the above-mentioned devices are completely satisfactory, there are some applications in which the device is desired to be curved.
and/or of non-rectangular outline. Furthermore since the polarizing film in a conventional film LCD, or the polymer surface in a polymer-composite LCD, is vulnerable to scratching, it may be desired to protect the LCD against such scratching.

An application which incorporates all of these required features is that of an electrically switchable sunglass lens see for example, US-A-4 279 474 and H. Seki, Y. Masuda, and Y. Itoh, Proceedings of the Society for Information Display, Vol. 32/3, 1991 pp191-195 "Electro-Optical Liquid-Crystal Light-Control Valve Incorporating a Solar Battery". Furthermore, in this application it may be desired to combine the LCD with a lens having optical power in order to correct defects in the wearer’s vision.

It is an object of this invention to provide a liquid crystal device which satisfies some or all of the above-mentioned desires.

According to the present invention there is provided a method of manufacturing a liquid crystal device comprising assembling together in a layered structure, a pair of pre-shaped transparent plastic substrates, a pair of transparent plastic films, and a pair of conductive coatings; providing a plurality of spacers between the plastic films; providing a partial adhesive seal around and/or between the films to provide a cavity therebetween; filling the cavity with a fluent liquid crystal mixture or precursor mixture which is polymerisable to polymeric/liquid crystal composite material; and, adhesively sealing the cavity to retain the liquid crystal mixture or composite material therein, characterised in that the conductive coatings are applied to said transparent plastics films; and by the application of at least one layer of a compliant transparent adhesive between two of the other layers of the device.
The invention also includes a liquid crystal device comprising a plurality of layers, including a pair of pre-shaped transparent plastic substrates; a pair of transparent plastic films and conductive coatings disposed on the respective films; a plurality of spacers between the respective films; an adhesive seal around and/or between the films and defining therewith a cavity; and a fluent liquid crystal mixture or precursor mixture which is polymerisable to polymeric/liquid crystal composite material filling the cavity, characterised in that the conductive coatings are applied to said transparent plastics films; and by at least one layer of a compliant transparent adhesive disposed between two of the other layers of the device. Preferably, the cell cavity is filled with a low molecular mass liquid mixture or a polymer/liquid crystal composite material.

The invention is applicable to the manufacture of liquid crystal devices of many different types, but will find particular application in curved LCD's such as those used in electrically-controlled sunglass lenses. The LCDs may be cylindrically or spherically curved. Preferably, a pair of polarizer layers are also provided on the substrates or on the plastic films. Preferably, a pair of alignment layers are also provided.

Advantageously, the plastic films and conductive coatings are preformed with the spacers and partial adhesive seal to provide a cavity therebetween; the cavity is filled with a fluent liquid crystal mixture or precursor mixture; the cavity adhesively sealed to retain the liquid crystal mixture or composite material therein; and the preform thereafter assembled with the substrates and sealed thereto.

Additionally, the plastic films are preferably pre-shaped polarizers to which are applied respective transparent conductive layers and alignment layers, and
which are laminated to the respective substrates before being assembled with an adhesive seal and the cell thus formed filled and sealed therein.

A further aspect of the invention comprises a method of manufacturing a liquid crystal device comprising a pair of pre-shaped transparent plastic protective substrates, wherein the substrates are chamfered at the edges of their opposed surfaces and are secured to one another by an adhesive seal disposed in the space between said chamfered edges.

The invention will now be further described with reference to the accompanying drawings, each of which shows a cross-section through a liquid crystal device constructed according to this invention. The sections are drawn not to scale, so that each layer can be identified.

Figure 1 shows a simple construction having two substrates 1,1' which may be of glass or a plastics material, such as "CR 39" which is non-transmissive to UV radiation. The substrates 1,1' are pre-cut and pre-shaped to the desired outline and the surfaces 2,2' which are to face each other within the device are as near as possible parallel to one another. However, it is one purpose of this invention to use a method of construction in which the effects of non-parallelism of these faces are avoided and thus perfect parallelism is not required in the substrates 1,1'.

If the LCD is of twisted nematic or other type requiring polarizers, polarizing films 3,3' are applied to the surfaces 2,2' or to thin plastic films 5,5' bearing transparent conductive coatings 6,6' (pre-etched if necessary) on their matching faces. The plastic films 5,5' are then laminated to the substrates using layers 4,4' of optical adhesive. The coatings 6,6' enable electrical signals to be applied to the LCD in use, to adjust the optical properties of the device. The thickness and kind of adhesive are selected so that the layers 4,4' have sufficient resilience to enable a substantially uniform
pressure to be applied to the films 5,5' after the cell is constructed. A suitable adhesive is, for example, "Glass Bonding Adhesive 350" manufactured by Loctite Inc. The films 5,5' may, for example, be of ITO-coated "Stabar" film manufactured by ICI plc.

An alignment layer (not shown in this example) may then be applied to the conductively-coated surfaces of each of the films 5,5', if required, for example by oblique evaporation of silicon monoxide. A UV curable or low temperature curable adhesive material 8 is then applied, leaving one or more fill holes. In a modification the adhesive is applied in two layers, one to provide a structural join and a second to provide a seal. Suitable adhesives are, respectively, RS's Quick set epoxy resin 503-408 and Loctite's "UV Cure Optical Adhesive 358". Fibre or ball spacers 9 of the appropriately small size are then applied, for example, by being sprinkled uniformly over the surface of one of the films 5,5', so that they are spread uniformly throughout the cell after formation, the cell assembled, and the adhesive seal 8 cured. Pressure, which is applied to the substrates 1,1' during curing of the seal, (by any suitable conventional means such as a mechanical press having means for uniformly spreading the load) is transmitted to the cell walls 5,5' by the resilient layers 4,4' so that the films 5,5' are pressed uniformly down onto the spacers 9 to give a uniform thickness to the cell cavity 7, the adhesive layers 4,4' acting to spread the load to ensure uniformity.

The cell cavity 7 is then filled with the liquid crystal mixture, or if a polymer composite device is being constructed, the precursor mixture; the fill-hole(s) is(are) sealed; and, in the latter case, the precursor polymerised. A suitable low molar mass liquid crystal material is "mixture E7" sold by Merck AG of Darmstadt, DE and suitable precursor mixtures for subsequent polymerisation are available from Merck Ltd. of Poole, GB.
Figure 2 shows a partial cross-section through a second example of LCD constructed according to this invention. The inner layers are initially laid down in a flat state. A pair of plastic films of PET material 5,5', one of which has a thickness of about 37µm and the other a thickness of about 125µm and each of which has an indium-tin oxide (ITO) transparent conductive coating 6,6' (thickness < 1µm) are cut to the desired shape (with a protruding tab for electrical connection in use). These are then coated with a polyimide alignment layer 10,10,' of the order of 500nm thickness, and cured together at low temperature (50°C) for a long time (typically > 1 hour) to avoid degradation of the plastic layer. To produce the desired alignment, the polyimide layer are then brushed, eg by cut velvet, in directions perpendicular to one another.

One or both of the coated faces of the PET/PES layers 5,5' are then dusted with cylindrical or spherical spacers 9 of diameter 5-20µm, blown on to the surface from a dispenser under light air pressure, an epoxy adhesive sealing layer 8 approximately 1mm wide (preferably with a thin outer edge of an optical adhesive) is then applied around the edges of the coated faces of the PET/PES layers, a pair of gaps or fill holes being left uncoated with adhesive, and the layers assembled together (with the protruding tabs of the coated PET films offset from one another) between mould halves of appropriate curvature (80mm in this example) and the adhesive cured to form a cell therebetween by pressure applied in the mould. The mould comprises a convex aluminium block as one surface and a second mould surface previously cast, in solid epoxy resin with a compliant surface layer of eg silicone rubber, as a negative from the aluminium block, to provide a concave surface. The rubber cast is mounted on a metal backing plate and the layers sealed by heat eg from the aluminium block (which has been pre-heated). The empty cell is then removed and the cell cavity 7 is filled (eg by vacuum filling) through the fill holes with a suitable
liquid crystal mixture 7’, the cell is re-compressed in order to remove excess liquid crystal material and all air in the cell, and the pressure released to allow an inflow of adhesive through the fill holes to seal the holes. The adhesive may be UV cured.

The cell is then laminated to the polarizer layers 3,3’ by means of thin (thickness > 1μm, preferably around 10μm) contact adhesive layers 4,4’ provided on the polarizer layers and revealed by removal of a peel off cover sheet.

The cell is then laminated by means of further contact adhesive layers 11,11’ (also of the peel off type) of thickness > 1μm, preferably around 10μm, to pre-shaped transparent plastics substrates 1,1’ (eg of CR 39) which are then sealed at their edges by an epoxy adhesive seal 12.

In a third example (see Figure 3), the positions of the polarizer layers 3,3’ and the substrates 1,1’ may be reversed. Preferably, in this case, the polarizers are coated with an anti-scratch coating. The adhesive layers are substantially as in the second example.

A simplified structure is provided by a fourth example shown in Figure 4, in which the thin plastic films 5,5’ are dispensed with. Spherical lenses may be formed by a structure comprising a pair of spherically curved substrates 1,1’ of CR 39, to which respective spherically curved polarizers 3,3’ (pre- or post-coated with ITO conductive layers 6,6’) are laminated. The polarizers are preferably cut so that their directions of polarization are mutually perpendicular and each lies at 45° to the intended horizontal, when the LCD is considered to be vertically disposed. Polymide alignment layers 10,10’ are formed on the inside of the conductive layers 6,6’ with their direction of alignment disposed preferably parallel to the adjacent polarizer direction and directed so as to locate the quadrant of greatest contrast upwards (the manner of doing this is well known to those skilled in the art), in
order to produce, in a twisted nematic liquid crystal construction, a gradation of darkening, so that, when used as a spectacle lens, such a LCD may be darker at the top than at the bottom.

The assembled layers are again put together using a sealing adhesive strip 8, with spacers 9 therebetween and pressure and heat applied to cure the adhesive to form an empty cell. A liquid crystal composition is then injected into the cell and sealed as with the other examples.

Again, the positions of the polarizers and substrates may be reversed, but a thin polymer layer may be needed to support the conductive ITO coating.

Other examples of devices constructed in accordance with the invention may include liquid crystal mixtures with one or more dichroic dyes.

One or both of the polarizers 3, 3' may be dispensed with if the cell is not desired to be of the twisted nematic type.

When birefringent materials are used for plastics film layers 5, 5', the directionality of the birefringent effect is also preferably aligned with the adjacent polarizing layer 3, 3' in order to suppress birefringence effects.

To enable electrical connection to the conductive coatings 6, 6', the supporting layer may, in all examples, be greater in planar extent than other layers, to protrude from the structure.

It may be advantageous to allow the substrates 1, 1' a degree of deformability to ease creation of the desired cell spacing across the entire liquid crystal cell area. With cylindrical lenses, this may be achieved by having the inner convex face of the one substrate of a higher curvature than the inner concave face of the other substrate, so that the cell spacing in the centre of the face can first be established and then the spacing at the edges accurately adjusted by deformation of the layers towards one another at their edges.
A fifth example is illustrated in Figure 5. This example is substantially the same as that of Figure 2, but the outer adhesive seal 12 is provided between a pair of chamfered edges 13,13' of the transparent substrates 1,1'. The edge chamfers are preferably inclined at 45°. This provides an improved seal and greater strength because of the greater area of contact of the seal with the substrates 1,1' and allows a smoother and narrower finish to the edge of the LCD which may be important when the LCD is for use as a spectacle lens. Chamfers 14,14' are also provided on the outside of the substrates 1,1' to narrow the edge of the LCD, which may be particularly important when the LCD is for use as a spectacle lens.

The ability to UV cure the adhesive 12 is also enhanced by the chamfering, as it helps to overcome the inhibiting effect of the CR 39 substrates which are UV filtering.
CLAIMS

1. A method of manufacturing a liquid crystal device comprising assembling together, in a layered structure, a pair of pre-shaped transparent plastic substrates, a pair of transparent plastic films, and a pair of conductive coatings; providing a plurality of spacers between the plastic films; providing a partial adhesive seal around and/or between the films to provide a cavity therebetween; filling the cavity with a fluent liquid crystal mixture or precursor mixture which is polymerisable to polymeric/liquid crystal composite material; and, adhesively sealing the cavity to retain the liquid crystal mixture or composite material therein, characterised in that the conductive coatings are applied to said transparent plastics films; and by the application of at least one layer of a compliant transparent adhesive between two of the other layers of the device.

2. A method according to claim 1, wherein a pair of polarizer layers are also provided on the substrates or on the plastic films.

3. A method according to claim 1 or claim 2, wherein a pair of alignment layers are also provided.

4. A method according to claim 1, wherein the plastic films and conductive coatings are preformed with the spacers and partial adhesive seal to provide a cavity therebetween; the cavity is filled with a fluent liquid crystal mixture or precursor mixture; the cavity adhesively sealed to retain the liquid crystal mixture or composite material therein; and the preform thereafter assembled with the substrates and sealed thereto.
5. A method according to claim 1, wherein the plastic films are pre-shaped polarizers to which are applied respective transparent conductive layers and alignment layers, and which are laminated to the respective substrates before being assembled with an adhesive seal and the cell thus formed filled and sealed therein.

6. A liquid crystal device comprising a plurality of layers, including a pair of pre-shaped transparent plastic substrates; a pair of transparent plastic films and conductive coatings disposed on the respective films; a plurality of spacers between the respective films; an adhesive seal around and/or between the films and defining therewith a cavity; and a fluent liquid crystal mixture or precursor mixture which is polymerisable to polymeric/liquid crystal composite material filling the cavity, characterised in that the conductive coatings are applied to said transparent plastics films; and by at least one layer of a resilient transparent adhesive disposed between two of the other layers of the device.

7. A liquid crystal device according to claim 6, including a pair of polarizer layers on the substrates or on the plastic films.

8. A liquid crystal device according to claim 6 or claim 7, further including a pair of alignment layers.

9. A liquid crystal device according to claim 6, wherein the plastic films, conductive coatings, spacers and liquid crystal mixture comprise a preform assembled with the substrates and sealed thereto.

10. A liquid crystal device according to claim 6, wherein the plastic films are pre-shaped polarizers, having respective transparent conductive layers and alignment
layers, and laminated to the respective substrates with an adhesive seal.

11. A method according to any of claims 1 to 5, wherein the transparent plastic substrates are chamfered at the edges of their opposed surfaces and are secured to one another by an adhesive seal disposed in the space between said chamfered edges.

12. A method of manufacturing a liquid crystal device comprising a pair of pre-shaped transparent protective substrates, wherein the substrates are chamfered at the edges of their opposed surfaces and are secured to one another by an adhesive seal disposed in the space between said chamfered edges.

13. A liquid crystal device according to any of claims 6 to 10, wherein the transparent plastic substrates are chamfered at the edges of their opposed surfaces, and including an adhesive seal disposed in the space between said chamfered edges.

14. A liquid crystal device comprising a pair of pre-shaped transparent protective substrates, wherein the transparent plastic substrates are chamfered at the edges of their opposed surfaces, and including an adhesive seal disposed in the space between said chamfered edges.