New Developments in Flexible Cholesteric Liquid Crystal Displays

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ABSTRACT

Flexible Cholesteric liquid crystal displays have been rapidly maturing into a strong contender in the flexible display market. Encapsulation of the Cholesteric liquid crystal permits the use of flexible plastic substrates and roll-to-roll production. Recent advances include ultra-thin displays, laser-cut segmented displays of variable geometry, and smart card applications. Exciting technologies such as simultaneous laser-edge sealing and singulation enable high volume production, excellent quality control and non-traditional display geometries and formats.

Keywords: Flexible Displays, Roll-to-Roll, Plastic Substrates, Cholesteric Liquid Crystals, Bistable, Passive Matrix

1. INTRODUCTION

Most liquid crystal displays (LCDs) are made from a sandwich of liquid crystal (LC) between two spaced glass substrates coated with a transparent conductor. The glass substrates are generally held together to a predetermined gap using an epoxy-based gasket at the edge. For glass LCDs, two big challenges remain; namely, flexibility and durability. These problems can be addressed by using plastic substrates; however, the need remains for an effective edge seal to prevent the two plastic substrates from delaminating.

One advantage in using plastic to make LCDs is to make the display in a roll-to-roll process. For roll-to-roll processing to be effective, the liquid crystal material should be filled between two spaced substrates and prevented from flowing by an encapsulation process. Liquid crystal can be encapsulated using Polymerization Induced Phase Separation (PIPS) [1]. With PIPS, the droplets of liquid crystal are excluded from the bulk via phase separation as polymeric chains grow in molecular weight -the liquid crystal becomes encapsulated into micron-sized droplets by solid polymer walls [1]. Once encapsulated, the liquid crystal cannot flow between the substrates or leak out if the substrates are cut. Oftentimes the polymer walls created during the encapsulation process are not very strong since they can have a width on the scale of micron to sub-micron. Due to the thin polymer walls and the fact that there is very little solid material to hold the substrates together, the two bounding substrates are susceptible to delamination at the edges of the LCD. Therefore, an edge seal mechanism is required to prevent delamination.

An LCD can be edge sealed in a number of ways. As mentioned above, one may use an internal gasket (e.g., composed of epoxy or photo-resin), an adhesive tape, or an external gasket such as silicone. The internal gasket is very effective for edge sealing and is the dominant technology used in the LCD industry because of a strong bond between the substrates and low moisture permeability. This technique of, creating an internal gasket and then filling the cell with liquid crystal is quite challenging in a roll-to-roll process. Alternatively, one may edge seal using an external adhesive tape but it forms a weaker bond, is less mechanically robust and is generally quite permeable and susceptible to water-damage. An external gasket such as silicone is an effective moisture barrier as it has low gas permeability; however, it is not very mechanically robust, as it tears easily. Another drawback to external edge seals such as adhesive tape or external gaskets is that one must first make the display on a roll, singulate (or cut) the display, and then apply the edge seal.

It is well known that infrared lasers can cut and weld plastic materials [2,3]. Laser welding two thermoplastic substrates together requires that the two plastic pieces absorb infra-red light, heat-up, and flow together to create a strong bond [4]. A limitation of conventional laser welding is that only pure thermoplastic materials in contact with one another can be laser welded because impurities in the area to be bonded can contaminate the bond and cause its failure.

In our approach, the LCDs are simultaneously singulated from a roll or sheet and edge-sealed via laser welding in one step.

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2. METHOD

Stacked layers of polymer substrate, liquid crystal material and electrically conductive material are cut along a line around the perimeter of the liquid crystal display. Consistent with the conventional understanding that only pure thermoplastic materials in contact with one another can be laser welded together due to contamination of the bond by impurities, we found that attempting to laser edge seal a PIPS-encapsulated plastic LCD using Polyethylene Terephthalate (PET) substrates with a straight-line weld, results in intermittent segments (e.g., on the order of 100 micrometers long) being welded or melted together, while large segments (e.g., on the order of millimeters) are not welded together. In the non-welded segments, the liquid crystal was not sufficiently heated to be ablated out of the weld area and remained as a residual that inhibited flow of the PET for melting the two substrates. We observed in the straight-line weld that the intermittent weld was quite strong perpendicular to the cut/weld-line direction but easily failed when sufficient force was applied at an oblique angle to the linear cut/weld-line.

To dramatically improve the strength of the laser weld, the laser is moved along the cut/weld-line and transverse (e.g., perpendicular) to the cut/weld-line along the perimeter. Even in the presence of liquid crystal material, the laser is able to both cut and weld the layers of the display together in a continuous manner. By propagating the laser on and transverse to the cut/weld-line (e.g., in a sinusoidal motion), the path length is increased thereby increasing the strength of the weld.

All laser edge seals were made using a M-300 laser marking system built by Universal Laser Systems, Inc (Scottsdale, AZ). This unit consists of an air-cooled CO_2 laser head integrated with an X-Y beam positioning system which can scan the beam over a 12”x24” work area. A 1.5” focusing lens is used to produce a laser spot size of 0.075” in the work plane. The substrate sits on a honeycomb work table. The desired graphics image is created in a drawing program such as AutoCad or Corel Draw. The laser system functions as a printer that accepts this data file then raster and/or vector scans the graphics image on the substrate using operator selected laser power settings.

3. LASER SINGULATING PATTERNED CONDUCTOR

With ITO-based substrates, one patterns the conductor on the substrate (in either sheet or roll form), laminates the PIPS mixture, UV cures the system, and then laser singulates the display. The laser-edge seal should not cut into the ITO, as the ITO prevents proper flow of the polymer to form a good bond between the top and bottom substrates. Therefore, with ITO-based substrates, the laser-edge seal should be no closer than 100μm away from the patterned conductor. Figure 1 shows a laser singulated “KENT” display where each letter is a single pixel. Note that in Fig. 1, only portions of the display that did not contain active ITO were laser edge sealed and removed. Even if a conductor is shorted at the edge after being laser cut, it is possible to repair the display using a laser to burn out the short (e.g., a Nd:YAG laser in the case of ITO electrodes) or to burn out the short by driving the display with a sufficient current.

Fig. 1 Laser edge sealed ITO-based display. Inactive portions of the display were laser edge sealed and removed.

4. DISPLAYS OF UNUSUAL SHAPE

An advantage to the laser edge seal is that the display may be cut to any polygon or shape that is determined by a simple graphic image drawn in Auto CAD or Corel Draw. In this way, the singulation and simultaneous edge seal lead to rapid prototyping with little to no retooling. In general, as long as the actively switching conductor is not cut with the laser, no shorting from the top substrate to the bottom substrate will occur. Figure 4 shows a "spiral" display made from 2mil thick ITO patterned on PET. The individual words of this display are single pixels. This non-conventional format display enables a helical spiral when hanging (inset, Fig. 2).

Fig. 2 A "spiral" display made from patterned ITO on 2mil PET. Inset: the display takes a helical shape when hanging.

5. FULL COLOR PIXELATED MULTI-LAYER DISPLAYS

Cholesteric liquid crystal displays achieve color by stacking selectively reflective layers, e.g., red, green, and blue layers can be stacked for full color. Laser edge sealing can also work on multilayer-multiple substrate displays by a careful selection of power and resolution. Figure 3 shows an ultra-thin (~70µm) 24x20 pixel 3-layer (RGB) display using conductive polymer for the electrodes that has been laser edge sealed.

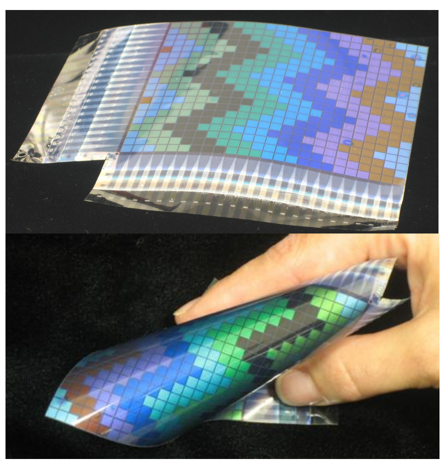

Fig. 3 Above: A laser edge sealed 24x20 pixel 3 layer ultra-thin (~70µm) display. The laser edge seal at the left corner is within 200µm of the active area. Below: the display being flexed.

The display was made with ½ mil thick PET substrates that were inkjet printed conductive polymer electrodes [5]. In figure 4, we can see a 3 layer (RGB) display that was laser edge sealed diagonally across the active portion of the display. To demonstrate the display, it was passively addressed to show a United States flag pattern after the laser-edge seal, Fig. 4.

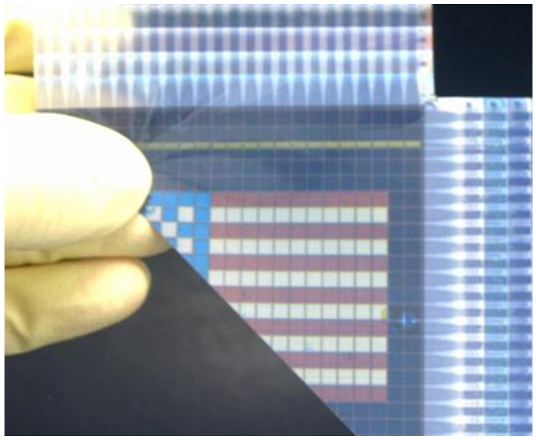

Fig. 4 A multi-layer 24 x 20 pixilated display that was laser-edge sealed diagonally through the active area demonstrating multiplexing.

6. UTILITY AND MANUFACTURING

Not only can laser welding be used to singulate and seal a single/multilayer display at the edges, but it can also be used to reinforce the bonding ledges by welding multiple substrate layers, to add stress and strain relief points to the display, to reinforce exterior corners by rounding them, to add strain relief to an interior corner, to bond multiple substrate layers for reinforcement to the inter-pixel area of the display, to define an area where the single/multi-layer display should bend, and to cut out through-holes in the display.

In addition, laser edge sealing is ideally suited to both batch processing and roll-to-roll processing. Using laser-edge sealing, displays can be simultaneously laser edge-sealed and singulated in an array format from a sheet or roll. Figure 8 shows an array of smartcard displays (each about 0.75" diagonal) just before laser singulation and after singulation (inset).

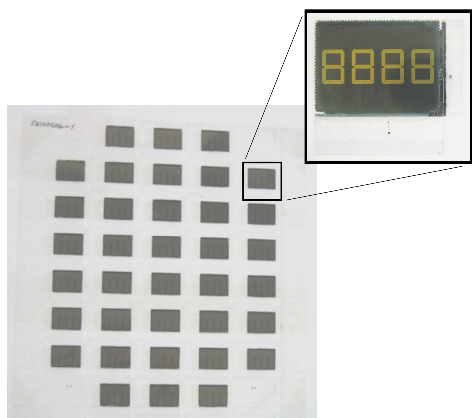

Figure 5 Smart card displays in an array format awaiting laser singulation (inset).

7. CONCLUSION

Flexible Cholesteric liquid crystal displays have been rapidly maturing into a strong contender in the future flexible display market. Encapsulation of the Cholesteric liquid crystal permits the use of flexible plastic substrates and roll-to-roll production. Simultaneous laser-edge sealing and singulation enable low cost batch and roll-to-roll production. The synergy of ultra-thin, variable geometry displays that can be retooled for different formats on the same manufacturing line hints towards a disruptive display technology.

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