

New Techniques for Fabrication of Flexible Plastic LCD's

John. L. West, Grea R. Novotny, Michael R. Fisch, and David Heinman

Abstract

We report simple techniques to manufacture low-powered, high-resolution, reflective cholesteric displays using flexible plastic substrates. We use wax transfer printing to replace photo-lithography and incorporate polymer walls to increase the mechanical strength and lifetime of the displays. These printing methods can easily be adapted to roll-to-roll production.

Keywords : flexible plastic displays, polymer walls, roll-to-roll production.

1. Introduction

Flexible plastic displays offer several advantages compared to displays using glass substrates. They are lighter, are not as easily broken and have the potential of being made using roll-to-roll processing techniques.

We utilize reflective cholesterics materials that switch between two stable state; a colored planar state and a transparent focal conic state [1,2]. The planar state is produced by application of a high voltage pulse while the focal conic state is produced by application of a lower voltage pulse. Gray scale can be achieved by application of pulses of voltages between those required to produce the colored and transparent states.

These bistable cholesteric materials can be used to produce displays that switch between a stable, colored, reflective state and a stable transmissive state. By incorporating a black background these displays switch between black and colored states. Because these displays do not require polarizers relatively bright displays can be made. Because they operate using reflected light they are particularly good when viewed in high ambient light conditions. These displays do not use polarizers allowing use of birefringent substrates such as ITO coated polyester films. The material bistability allows high-resolution displays to be made using simple passive matrix addressing schemes.

Fig. 1. A four inch square, 320 by 320 pixel bistable cholesteric display made using flexible polyester substrates.

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Corresponding Author : John. L, West
a. Liquid Crystal Institute Kent State University, Kent, Ohio 44242, USA.
E-mail : johnwest@lci.kent.edu
Tel : +1 330-672-2654 **Fax** : +1 330-672-2796

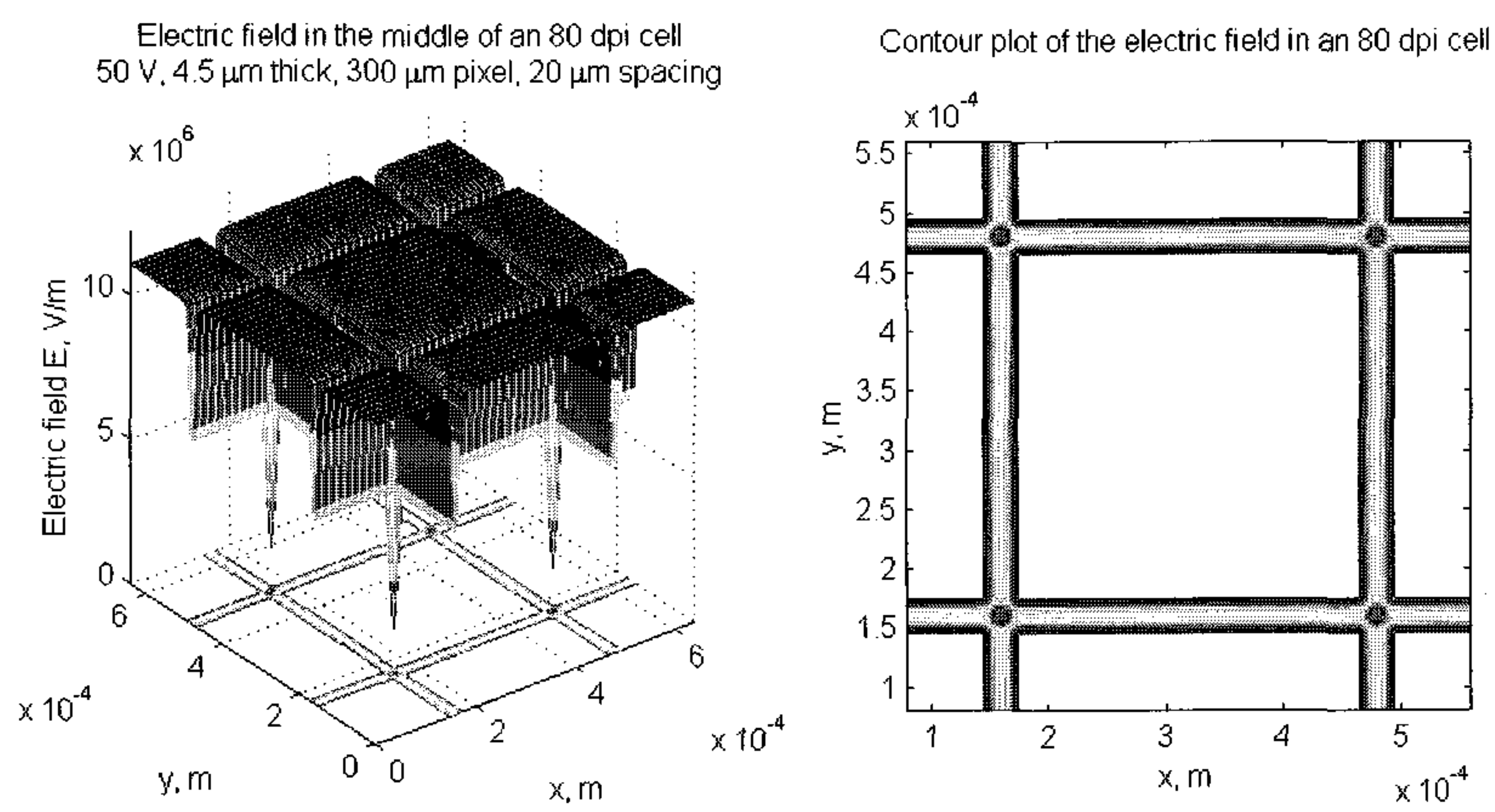

Fig. 2. Calculated electric field produced by the patterned electrodes in a passive matrix addressed liquid crystal.

The combination of characteristics of the bistable cholesteric materials makes them particularly well suited for the fabrication of flexible plastic displays. We previously reported using these materials to produce flexible plastic displays using ITO coated polyester substrates, Fig. 1.[i] We included polymers in these formulations to form self-adhering, self-sustaining films that increase the mechanical stability of the display. The polymer forms a network structure throughout the liquid crystal. Unfortunately the polymer network introduces light scattering in the displays, reducing the brightness and contrast.

We have shown that the light scattering of the polymer liquid crystal dispersions can be minimized and the brightness and contrast maximized by segregating the polymer into the inter-pixel region of these displays.[ii] We have also shown that the polymer walls can be formed using the patterned electric field produced by the row and column electrodes used to address the display.[iii] The applied patterned electric field results in the liquid crystal segregating in the high field pixel region and the polymer segregating in the low field interpixel region. It appears that the segregation is driven by the difference in the dielectric constants of the liquid crystal and the polymer.

The row and column electrodes used to address the display produce the patterned electric field used to form the walls. Fig. 2 shows the calculated electric field produced by typical row and column electrodes.

Fig. 3 shows the structure of these polymer walls. Segregating the polymer into walls in the inter-pixel region provides mechanical strength without reducing the brightness of the display.

The walls are self aligning and do not require the additional cost aligning a mask prior to UV exposure. Forming polymer walls using the patterned electric field produced by the drive electrodes of a liquid crystal display is therefore compatible with roll-to-roll processing.

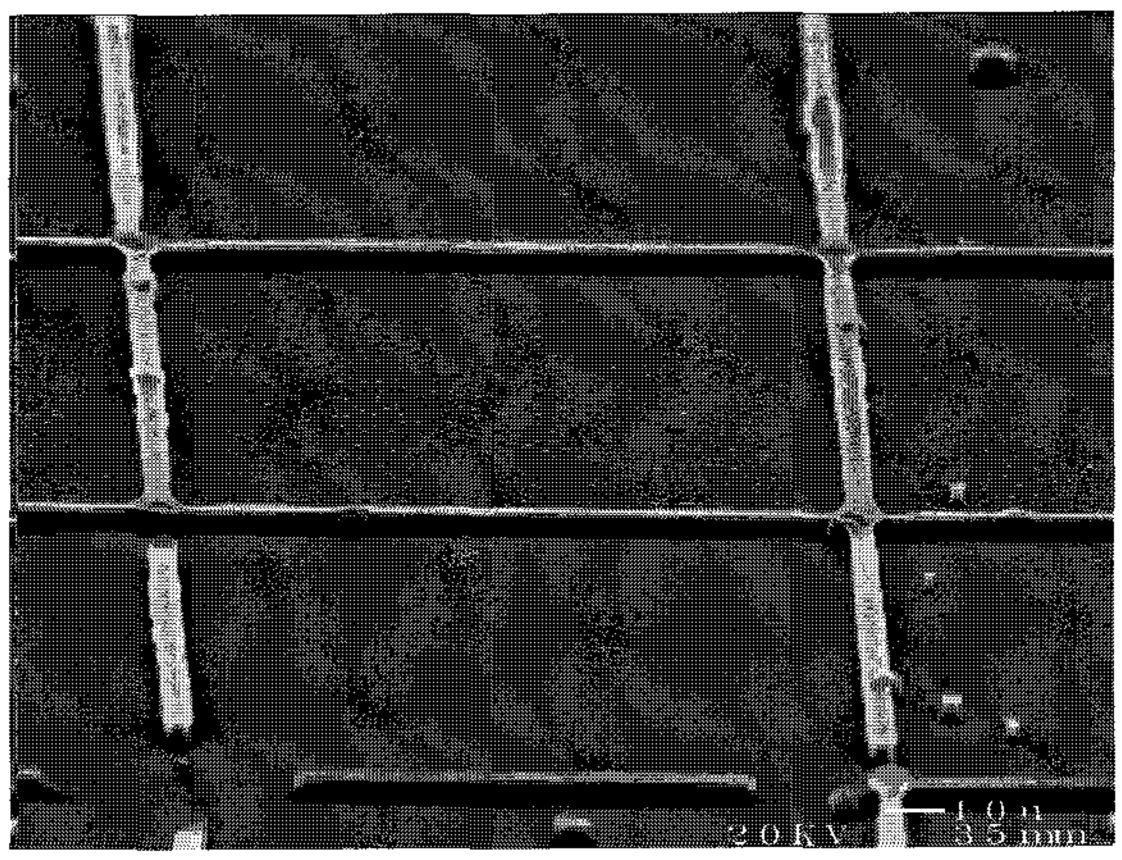

Fig. 3. SEM image of the polymer walls produced by the patterned electric fields in a passive addressed LCD.

2. Results

We developed techniques that can be used to fabricate flexible plastic displays using roll-to-roll fabrication processes. These techniques can be used to produce lightweight rugged displays at substantially reduced costs. Here we report using printing techniques to replace much more costly photolithography currently used to produce passive matrix displays. We also report on the kinetics of formation of polymer walls in the inter-pixel region of the display. The walls can be formed in times fast enough to be compatible with continuous roll-to-roll processing..

2.1 Pringting Resist

We used a Tektronix Phaser 240 Wax Transfer Printer to print a wax resist pattern onto an ITO coated polyester substrate. The pattern was printed in solid red color with a resolution of 40 lines per inch. The exposed ITO of the substrate was removed in a standard nitric-sulfuric acid etch bath. The wax resist was stripped using either THF or toluene.

The etched substrates were used to fabricate a cholesteric display. The cholesteric mixture consisted of 60 % by weight E7, 10 % CE2 and 30 % CB15 (Merck). This liquid crystal was then mixed with the UV curable monomer NOA 65 (Norland) in the ratio of 85:15 respectively.

The plastic substrates were sprayed with 15-micron spacers to control thickness. The liquid crystal mixture was then squeezed between the substrate using a roller. The electrodes of the display were charged to induce segregation of the polymer precursor into the interpixel region. The cell was then exposed to UV light to cure the polymer.

Fig. 4. Picture of bistable cholesteric display using flexible polyester substrates and polymer walls. The background is the screen of a laptop computer.

Fig. 4 shows the resulting display. The active area produces a bright, high contrast image. The high brightness results from the polymer being segregated as walls in the inter-pixel regions. The polymer walls also add mechanical stability allowing the display to be bent without affecting appearance or performance, Fig. 5.

Efficient production will require that the polymer walls rapidly form upon application of an electric field. We therefore have also examined the rate of the walls formation process.

2.2 Kinetics of Wall Formation

We examined the rate of the wall formation process using UV spectroscopy. To do this we used passivated aluminum electrodes on one of the substrates. The aluminum blocks light transmission throught the pixels. Using this arrangement. we monitored the absorbs. we could therefore monitor changes in the concentration of the liquid crystal, and by extrapolation the monomer, as a function of time and as a function of the applied voltage and temperature.

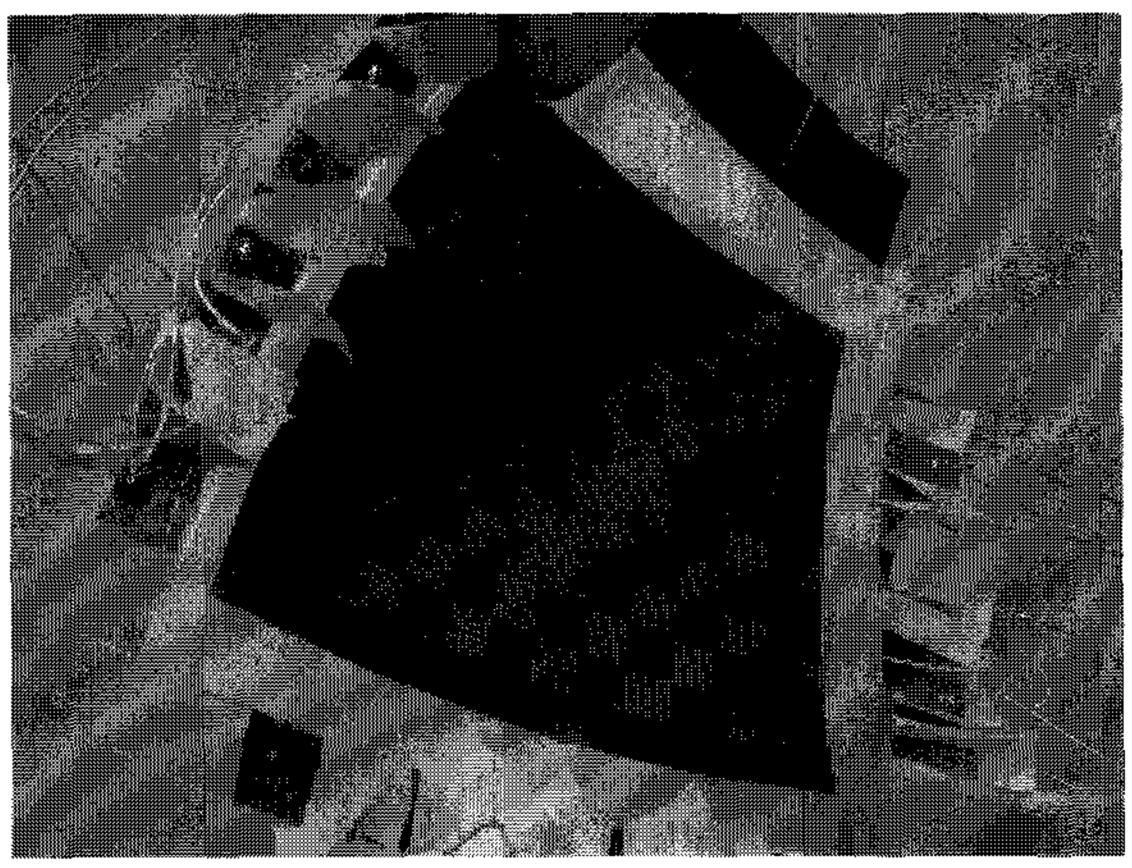

Fig. 5. Picture of bent bistable cholesteric display using flexible polyester substrates and polymer walls.

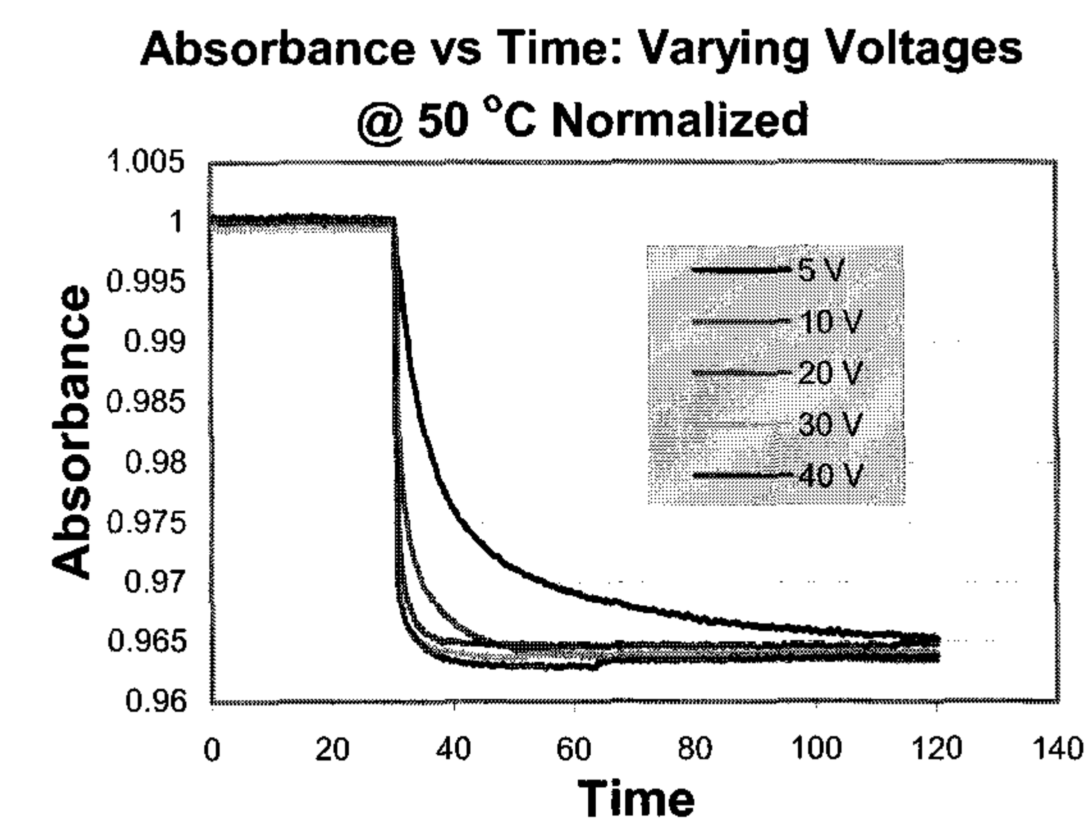

Fig. 6. graph of the absorbance of the liquid crystal as a function of time after application of electric fields of varying magnitude.

Fig. 6 shows the change in absorption of the liquid crystal as a function of time and applied electric field while Fig. 7 shows the effect of varying temperature.

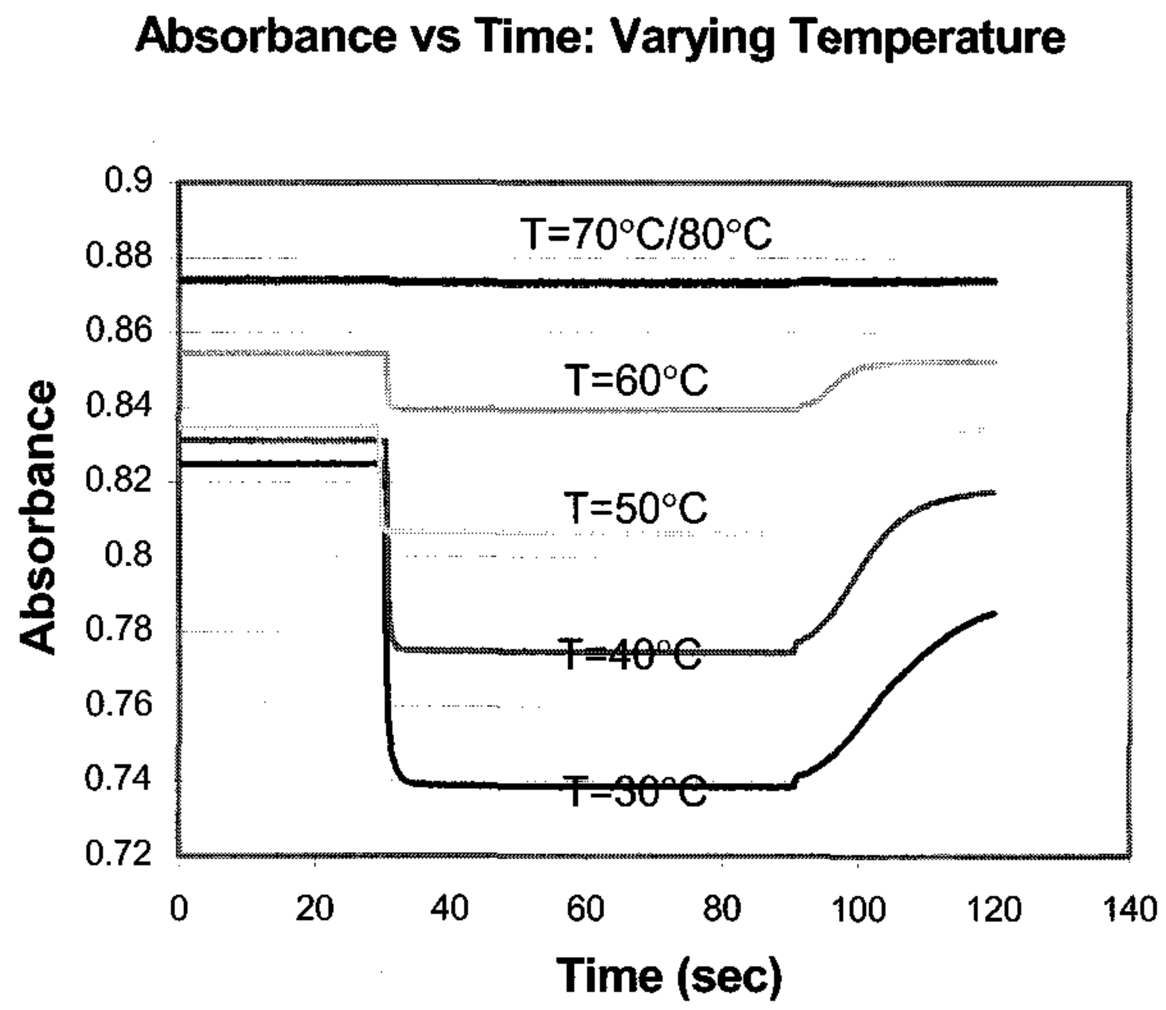

Fig. 7. The absorbence of the liquid crystal as a function of time for several temperatures. The field is applied at 30 seconds and removed at 90 seconds.

The phase separation occurs in several seconds. Increasing the temperature has little affect on the rate of phase separation but decreases the magnitude of the effect. Increasing the applied voltage increases the rate and the extent of phase separation. These results indicate that higher fields and lower temperatures will produce more complete phase separation in a shorter period of time.

The phase separation occurs in times compatible with continuous roll-to-roll processing. The field is applied while the liquid crystal polymer formulation is maintained above the phase separation temperature. The film is then be rapidly cooled with the field applied and then cured with a blanket UV exposure.

3. Impact

Utilizing bistable cholesteric formulations has allowed us to fabricate flexible plastic displays using relatively inexpensive, commercially available ITO coated polyester substrates. We demonstrated etching electrodes using simple wax transfer printing techniques. This simple technique replaces the several complex steps required for photolithography.

We also measured the kinetics of wall formation using patterned electric fields. We demonstrated that the walls could be formed in several seconds. The resulting walls provide mechanical stability to flexible plastic displays.

These techniques can be used to produce flexible plastic displays using continuous roll-to-roll processing. This offers the potential of greatly reducing the cost of LCDs. Perhaps as important, it is relatively straight-forward to scale roll-to-roll processing, making possible very large area displays.

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