# 40.3: Flexible Displays Prepared Using Phase-Separated Composite Organic Films of Liquid Crystals

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## ABSTRACT

**Very flexible nematic LCDs have been built with plastic substrates using phase separated composite organic method. A study of electro-optical properties of these displays shows a low voltage operation, high contrast, and a high degree of mechanical flexibility.**

## INTRODUCTION

In recent years, plastic LCDs have drawn much attention for use in applications such as smart cards, PDA, head mounted displays because of their lighter weight, thinner packaging, flexibility, and reduced manufacturing cost through web processing[1-3]. Different electro-optical modes have been proposed for use in plastic LCDs including TN/STN, cholesteric, polymer dispersed LC (PDLC), and bistable ferroelectric LC modes. However, currently available plastic TN/STN displays are designed neither to be bent strongly nor to be pressure resistance. They are primarily designed for and used PDAs or mobile phones, where they are mounted on relatively rigid surfaces and protected by rigid enclosures. They offer good drive voltages (<5V) and multiplexibility. On the other hand, plastic substrate PDLCs possesses good mechanical resistance but poor multiplexibility and a high drive voltage. Evidently, the search for a technology with good flexibility, high multiplexibility, and low operating voltage continues.

In this paper, we report successful fabrication of flexible plastic LCDs with good mechanical stability and low operating voltages. The fabrication technique uses the separate composite organic film (PSCOF) method[4]. Although our discussion will focus only on nematic displays, the PSCOF method can be used with to prepare devices based on other LCs.

## EXPERIMENTAL

A PSCOF device is prepared by means of anisotropic phase separation of a liquid crystal from its solution in a prepolymer[4]. As a result of phase separation, two parallel layers, one of the LC and the other of polymer, are obtained between two substrates. The direction of LC's optic axis is controlled with the help of an alignment layer on the adjacent substrate. The LC responds to an applied field in a manner that depends on the

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actual director configuration and modulates a beam of light in a birefringence mode. The materials used in this study are nematic LCs (NLC) E48 and a photocurable prepolymer NOA-65.

To build a PSCOF device, solutions are prepared with different ratio of NOA 65 and the liquid crystal. The substrate used is a polyethersulphone film with a conductive ITO layer and an inorganic gas-barrier coating. These plastic sheets are non-birefringent and stable at temperatures as high as 150 °C for 3 hours. An alignment layer of polyvinyl alcohol is coated on one substrate and rubbed to obtain homogeneous LC alignment. Glass bead spacers of 3 μm diameter are used to fix the cell spacing. Cells thus prepared are filled by capillary action with the LC + prepolymer

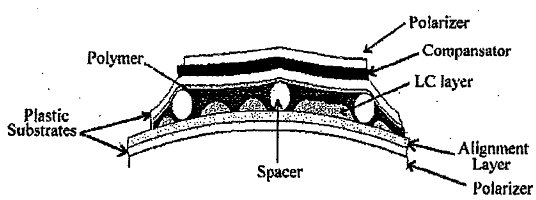


Fig. 1: Schematic diagram of plastic PSCOF LCD.

solution at a temperature corresponding to the isotropic phase of LC, i.e. ~100°C. Phase separation of is induced by 5 min exposure to ultraviolet (UV) light from a high pressure mercury lamp reflected from a UV mirror. During the exposure, the substrate with the alignment layer is kept farther from the UV source. Fig. 1 schematically shows main features of the PSCOF structure between two plastic substrates. In general, parameters such as the phase separation temperature, NLC concentration, cell thickness, UV power, and exposure time affect the formation of PSCOF.

## RESULTS AND DISCUSSION

The transmittance of glass cells, between crossed polarizers, prepared with different concentration of LC but same overall thickness is shown in Fig. 2. With decreasing

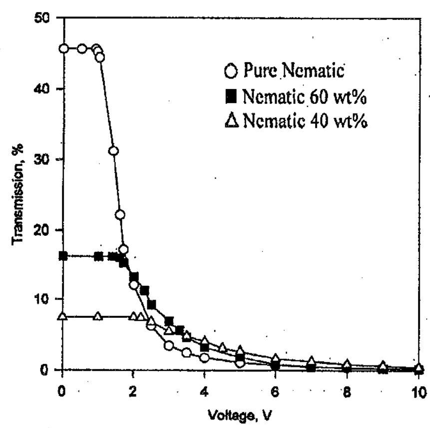


Fig. 2: Transmittance for 60, 40, and 20 wt% of NLC in response to a 1 kHz square wave.

concentration of the LC, the maximum transmittance decreases while the threshold voltages increases. Clearly, this is due to decreasing thickness of the LC layer which is 1.8, 1.2, and 0.8 μm for 60, 40, and 20 wt% samples, respectively. Our ability of making

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uniform NLC film of ~8000 A with the PSCOF method is clearly demonstrated. The switching time is almost the same for all samples. In plastic LCDs, we used 60 wt% of NLCs.

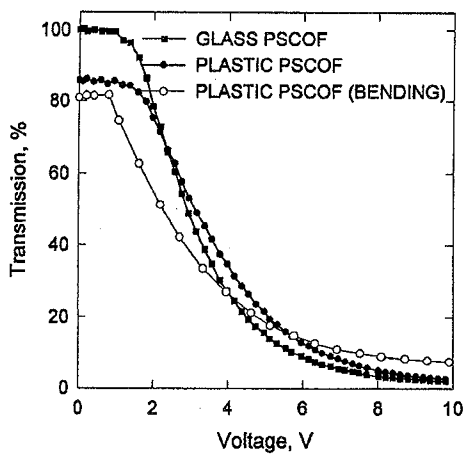



Fig. 3: Transmittance curves for cells with glass substrate, plastic substrate, and plastic substrate with bending. Square wave of 1 kHz is applied.

Fig. 3 shows the normalized transmittance for a glass and a plastic cell between crossed polarizers. The plastic cell was bent as shown in Fig. 4 and its transmittance measured in its natural (flat) and bent states, which are shown in Fig. 3. In all cases, the transmittance begins to decrease at about 1.5 V and reaches its minimum at ~6-7V. Since the applied voltage mainly depends on overall cell thickness, it is possible to reduce the driving voltage by optimizing the concentration; dielectric anisotropy of LC; dielectric constants of polymer and LC; and the overall cell gap.

The maximum contrast of the plastic PSCOF NLC we use to test the effect of bending, is 32:1 in its natural state. When it is highly bent such that the bending ratio a/b is as high as 0.4 [Fig. 4], the contrast decreases to 11:1. This decrease is not because of any changes inside the cell but because of changing orientation of the director along the surface of the cell. For these measurements, crossed (flat) polarizers are not attached to the cell. The contrast recovers when the bending stress is removed and the cell becomes flat.

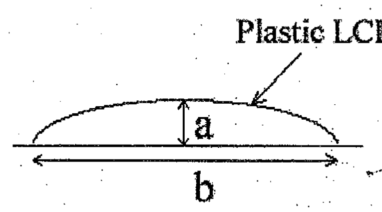
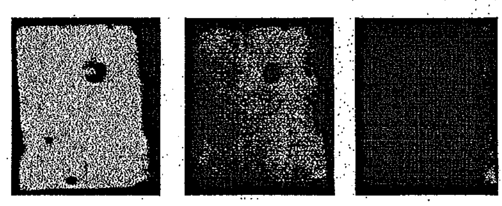



Fig. 4 : Schematic diagram of bending

The remarkable stability of PSCOF devices against mechanical deformation is illustrated in Fig. 5. It shows the appearance of the cell with bend ratio, a/b=0.4. Apparently, except for a reduction in maximum contrast, which is mostly due to



(a) (b) (c)

Fig. 5: Visual appearance of bent plastic LCDs at (a) 0 V, (b) 3 V, and (c) 6 V.

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reorientation of the LC optic axis, there are no adverse effects of bending. The cell exhibits good switching characteristics at all gray levels.

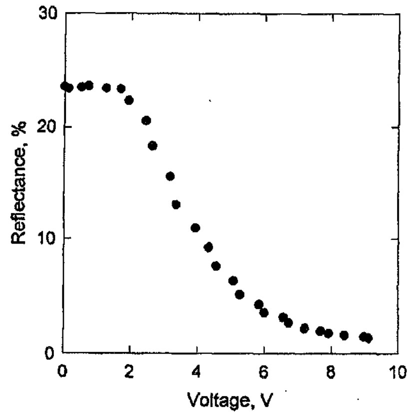
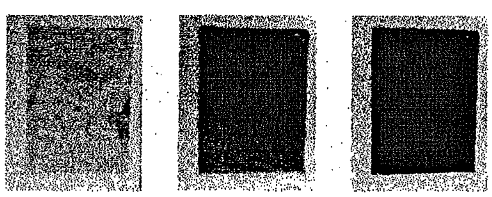



Fig. 6: Reflectance curves for cell with plastic substrate. Square wave of 1 kHz is applied.

Fig. 6 shows the field dependence of reflectance for a plastic LCD between crossed polarizers at a wavelength of 632.8 nm. The reflectance begins to decrease at about 1.7V, and reaches its minimum at 6-7V. The contrast ratio and the reflectance were 20:1 and 25 %, respectively.



(a) (b) (c)

Fig. 7: Visual appearance of reflective mode plastic LCDs at (a) 0 V, (b) 3 V, and (c) 6 V.

Fig. 7 shows a cell in reflective mode with various voltages without bending. Just like the cell in transmission mode, the contrast decreases when the cell is highly bent but recovers upon removal of the stress and, as the cell becomes flat again.

## CONCLUSIONS

Flexible displays fabricated with the PSCOF method possessing, both, mechanical robustness and low power consumption should fill a void in LC display technology and open new areas for their use such as head-mounted and curved displays. PSCOF should also help to enhance the performance of flexible displays for use in smart cards, mobile phone, PDA systems, etc.

## ACKNOWLEDGMENT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