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P-19 A New Type of Liquid Crystal Display Using Single Glass Substrate

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A new type of LCD has been developed using recently developed phase separated composite film method with a single glass substrate. The resultant structures are made of adjacent parallel layers of liquid crystal and polymer. The LC layer is confined between the solidified polymer layer and glass substrate. The electro-optical properties of the display have been investigated. This technique has the potential to realize a lightweight display for hand-held portable electronic products.

1. Introduction

Conventional electro-optic (EO) devices using liquid crystals (LCs) such as flat panel displays are prepared by sandwiching LC between two supporting substrates (usually glass) with alignment layers to facilitate alignment of the LC's optical axis in a predetermined configuration. It seems not possible to get rid of those supporting substrates because of fluid properties of LCs. Therefore, there have been considerable efforts to replace glass substrates by plastic for thin profiles, light weight, and flexible displays which are essential requirements for hand-held portable electronic products [1]

In the past 20 years, techniques to prepare dispersions of microscopic liquid crystal droplets in polymer matrix have been developed [2-4]. These *polymer dispersed liquid crystal* (PDLC) devices operate in the scattering mode, where the electric field is used not to change the birefringence but the extent of light scattered by LC droplets due to a mismatch of refractive indices at the droplet boundary. PDLC structures are a result of isotropic and relatively fast phase separation. Recently, anisotropic phase separation method has been developed to fabricate *phase separated composite films* (PSCOFs) of LC and polymer [5]. The rate of phase separation is controlled and deliberately kept low to allow the system to undergo a complete phase separation in to regions of nearly pure LC and solid polymer. This PSCOF method can, in general, be used to prepare multi-layer structures either parallel or perpendicular to substrates. In the simplest case, it yields adjacent uniform and parallel layers of the LC and polymer. The configuration of the optic axis in the LC layer can be controlled with an alignment layer on the substrate closest to the LC layer. The operation of such PSCOF devices relies on changes in the direction of optic axis in response to an applied electric field, as in conventional displays. Since the LC layer is confined between one of the glass substrates and the phase separated polymer layer, the PSCOF method has potential use in building new type of EO devices with a single glass or plastic substrate. Here, we report a unique EO device fabricated with the PSCOF method using nematic liquid crystal, which requires only one supporting substrate imprinted with in-plane electrodes to apply electric field.

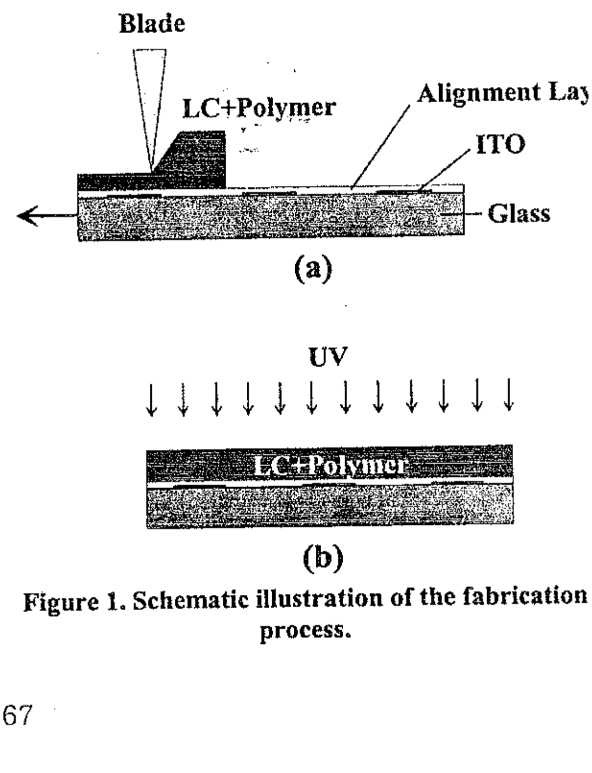


Figure 1. Schematic illustration of the fabrication process.

2. Experimental

The materials used are E48 (Merck) for nematic LC and UV curable epoxy NOA-72 (Norland) for prepolymer. To build a PSCOF device, solution was prepared with 1:1 ratio of the prepolymer and the liquid crystal. The in-plane electrode is prepared by etching 100 μm wide interdigitated electrodes onto indium-tin-oxide (ITO) coated glass, with a separation of 100 μm. In order to achieve wide viewing angle, we patterned ITO in chevron shape. The ITO glass substrate was spin coated with 1 wt. % of a Nylon 6 in trichloroethanol. The Nylon 6 film was unidirectionally rubbed after drying coated to achieve homogeneous LC alignment and induce anisotropic phase separation during UV exposure. To obtain a uniform of the mixture of LC and prepolymer, we used a two step process: first, we spread the mixture on the glass substrate using steel blade as shown in Fig. 1(a). The coating direction was kept parallel or antiparallel to the Nylon film's rubbing direction to avoid LC misalignment by shear stress. The thickness of the composite materials was about 10 μm. Then, we spun the glass substrate for 30 seconds at 1500 rpm to increase its uniformity. Phase separation was initiated by exposing the cell to a collimated beam UV light through the coated side for approximately 60 minutes to fully cure the prepolymer, as shown in Fig. 1(b). The source of UV light was a high pressure mercury vapor lamp operated at 400 W of electrical power.

The mechanism responsible for the formation of PSCOF is similar to the anisotropic polymerization [6]. Because of the absorption of the UV light predominantly by the LC molecules in the solution, an intensity gradient is produced in the sample. Consequently, NOA-72 molecules first undergo polymerization near the UV source and LC molecules are expelled from the polymerized volume, forcing them to move away from the source. Droplet formation is inhibited because of the relatively slow rate of phase separation and fast diffusion of the relatively small LC molecules. Consequently, the phase separated liquid crystal moves closer to the glass substrate, towards the region of lower UV intensity. The LC's tendency to wet the alignment layer on the adjacent substrate enhances the formation of a uniform film. The LC molecules near the alignment layer respond to its anchoring potential and align parallel to the rubbing direction. The volume of aligned LC grows during the phase separation process. Oriented LC molecules determine the microscopic structure of the polymer-LC interface which becomes compatible with the LC alignment. Measurements on PSCOF cells, prepared with different concentrations of nematic liquid crystal and prepolymer, show that the thickness of the LC layer depends on the amount of LC in the mixture and that only a small amount of LC is retained in the polymer film. Light scattered by the trapped LC is found to be negligible.

3 Result and Discussion

Fig. 2 shows the schematic diagram of the resultant structure on the single substrate. The LC layer is confined between glass substrate and solidified polymer layer which acts like a glass substrate in conventional cell with two glass substrates. The LC acquires a homogeneous alignment due to the influence of the rubbed alignment layer on the adjacent substrate. The thickness of the LC layer mainly depends on the concentration of LCs and speed of spin coating. The LC and polymer films are uniform except in regions where the polymer-LC interface bonds to the substrate. These bonding sites are affected by a host of factors such as: the concentration and chemical nature of the LC compound, the alignment layer, the temperature and rate of phase separation, and the cell thickness. The process can be optimized to reduce the cross section to ~ 1 μm and control the number of these bounding sites resulting in an almost perfectly uniform LC film. It is important to note that such PSCOFs devices can also be made flexible with the use of plastic substrates due to the inherent flexibility of the internal polymer film.

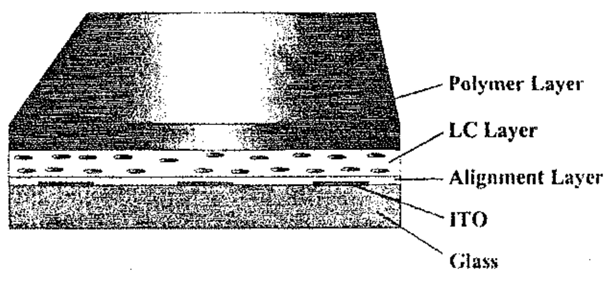


Figure 2. Schematic diagram of fabricated LC device with a single glass substrate.

To determine the internal structure of the device obtained, the cell was viewed under a scanning electron microscope (SEM). As evident from Fig. 3, a solidified film of polymer is formed as a result of anisotropic phase separation. The thickness of the film was about 3 μm. Since the prepolymer and the

LC are mixed with the ratio 1:1, we estimate that the thickness of LC layer to be about 3 μm.

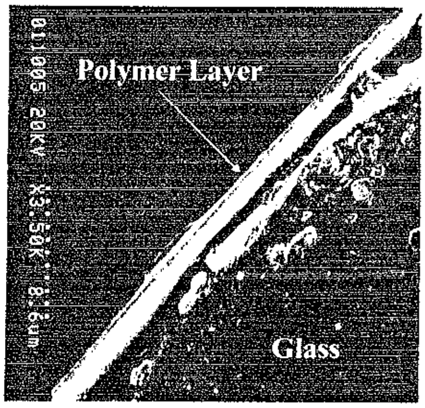


Figure 3. SEM image showing substrate and polymer film.

Fig. 4 shows the microscopic textures under polarizing microscope with/without applied voltages. With zero applied voltage, the uniform dark state is achieved due to good alignment on glass substrate. The small number of defects visible as faint spots in the photograph are due to dust particles and/or nonuniform mixing of LC and prepolymer. Above a certain voltage, the LC molecules start to reorient and align along the electric field due to their positive dielectric anisotropy of LC molecules. With high electric field (>1.5 V/μm), one can obtain the white state which means that the LC molecules have turned by 45° with respect to the rubbing direction. The results demonstrate that devices so fabricated using single glass substrate are uniform and possess gray scale capability.

Fig. 5 shows a 1.5 cm x 2 cm cell between crossed polarizers with 1.5 V/μm. Except for a small area

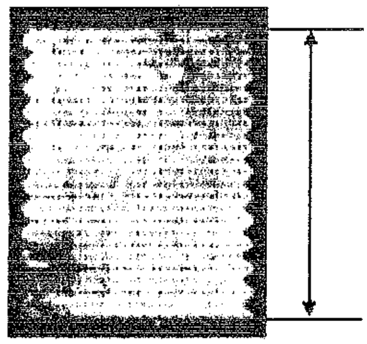
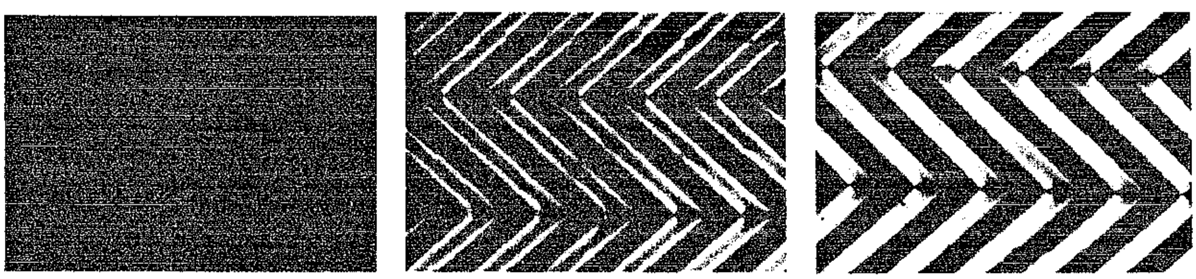


Figure 5. Photograph of 1.5 cm x 2 cm sample between crossed polarizers with 1.5 V/μm.

enclosed by the circle, the whole sample shows a uniform white state. The dark area is caused by non-uniformity of the LC and prepolymer coat.

Fig. 6 presents the field dependent transmission curves for the one glass substrate sample (PSCOF_ONE) prepared in this study and two samples prepared using 2 glass substrates. All devices we prepared to operate in the *in-plane switching* (IPS) mode. One of '' -substrate cells (PSCOF_TWO) was a PS(⁻ --- while the second one (LC_TWO) was conventional. The two-substrate cells show almost similar behavior. Their transmittances begin to increase at about 0.2 V/μm, and reach its maximum value at 0.8 V/μm. In contrast, transmission through the PSCOF_ONE cell reaches saturation at 1.5 V/μm. It is possible to reduce the driving voltage by optimizing the concentration, dielectric anisotropy of LC, dielectric constant of polymer, and overall cell gap. The maximum contrast of the one-glass sample is about 200:1 which is comparable to normal IPS sample.

In Fig. 7, we present the switching behavior of the



(a) (b) (c)

Figure 4. Microscopic textures under polarizing microscope with/without applied field: (a) 0 V/μm, (b) 0.7 V/μm, and (c) 1.5 V/μm

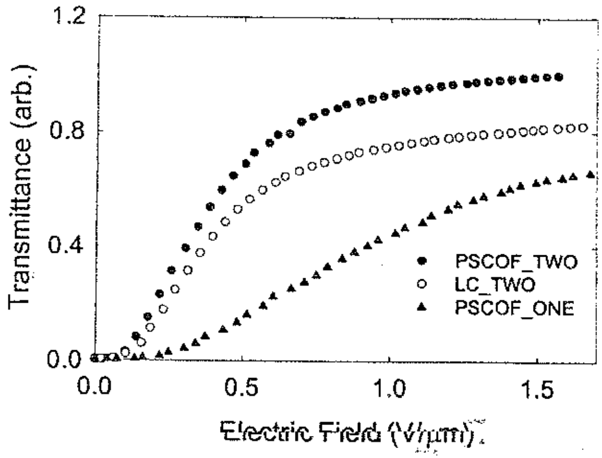


Figure 6. Transmission vs. Applied field for the one substrate (PSCOF_ONE), two-substrate (PSCOF_TWO), and normal IPS cell

sample. The field driven and relaxation times are 7.8 ms and 20 ms at 1.5 V/mm, respectively. The cell exhibits good switching characteristics at all gray levels.

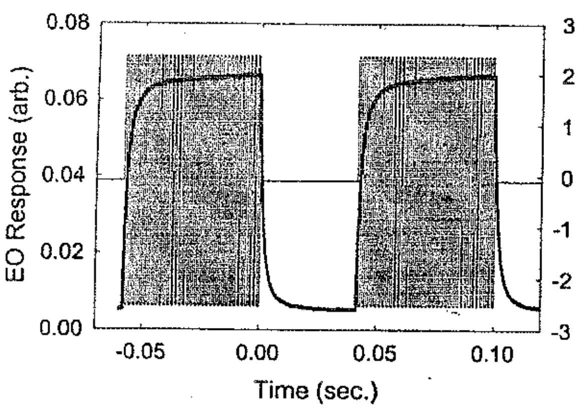


Figure 7. Optical switching behavior

4. Conclusion

We have successfully fabricated a new type of LC device using anisotropic phase separation and a single glass substrate. The resultant structures are made of adjacent parallel layers of liquid crystal and solidified polymer. The electro-optical properties of these displays are comparable to the normal displays using two glass substrates.

Acknowledgement

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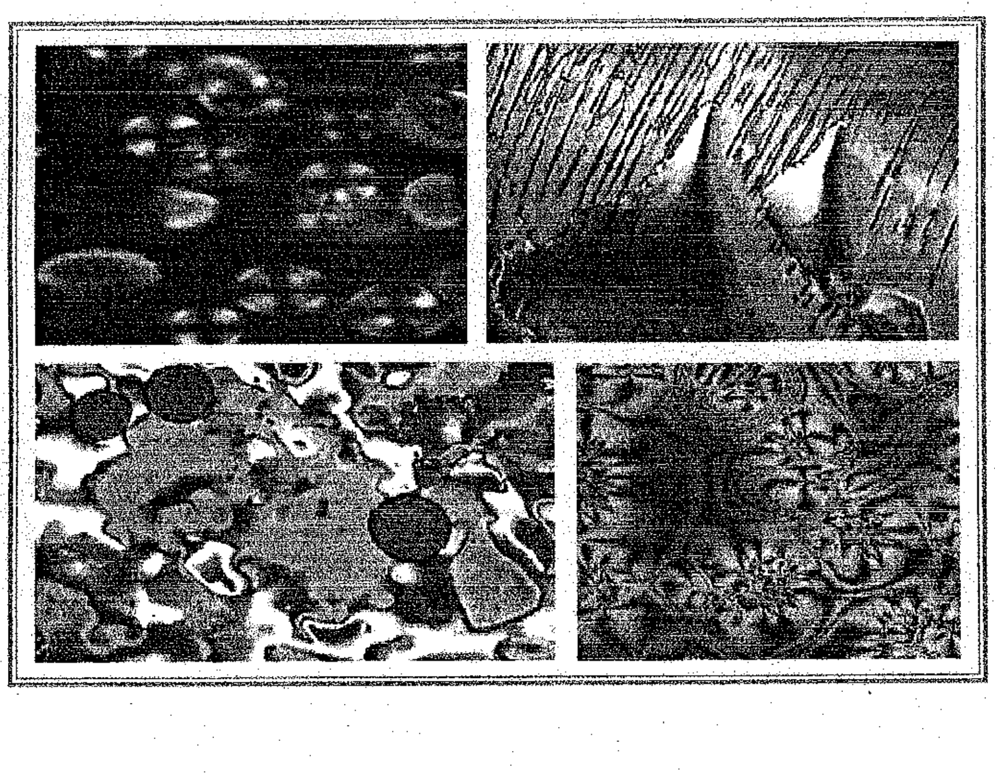

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