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Noble LCD with a Single Supporting Substrate

Jung-jong Wook and Jae-Hoon Kim*

Abstract

A recently developed phase separated composite film method has been employed to fabricate a liquid crystal (LC) based electro-optical device using a single glass substrate. The resulting device is made of adjacent parallel layers of LC and polymer maded by phase separation. The LC layer is confined between the solidified polymer layer on one side and the glass substrate on the other. The electro-optical properties of these devices demonstrate their technological potential in light weight and hand-held electronic products.

Keywords : LCD, phase separation

1. Introduction

The conventional liquid crystal (LC) electro-optical (EO) devices, such as flat panel displays, were prepared by sandwiching the LC between two glass substrates with transparent indium-tin-oxide (ITO) electrode pattern and rubbed polymer alignment layers to facilitate alignment of the LC's optical axis in a predetermined configuration. It is not possible to avoid the use of two substrates because of the fluid nature of LCs. In recent years considerable effort have been put in to replace glass substrates by plastic films for thin profile, light weight, and flexible devices which are essential requirements for hand-held electronic products [1].

In the past 20 years, many techniques to prepare dispersions of microscopic LC droplets in polymer matrix have been developed [2-4]. These polymer dispersed liquid crystal (PDLC) devices operate in a scattering mode, in which an applied electric field is used to control the degree of the light scattered by the LC droplets caused by the mismatch of refractive indices at the droplet boundary. PDLC structures are the result of isotropic and relatively fast phase separation. Recently, a method using anisotropic phase separation 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 into regions of nearly pure LC and solid polymer. This PSCOF method can, be generally used to prepare multi-layer or other complex geometrical structures. In the simplest case, it yields adjacent, uniform, and parallel layers of the LC and the polymer. The configuration of the optic axis in the LC layer is controlled with an alignment layer on the substrate that is in touch with the LC. The operation of such PSCOF devices exploits the birefringence of the LC and relies on the changes in the direction of the LC's optic axis according to an applied electric field, as in conventional displays. Since the LC is naturally confined between one of the glass substrates and the phase separated polymer layer, the PSCOF method lends itself to building devices with a single glass or plastic substrate.

Here, we report of the fabrication of an EO device with the PSCOF method using the nematic liquid crystal and that which require only one supporting substrate imprinted with in-plane electrodes in appling the electric field.

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*Member, KIDS

Corresponding Author : Jae Hoon Kim

Department of Physics, Hallym University, Chunchon, Kangwon-Do, 200-702, Korea.

E-mail : jhkim@hallym.ac.kr **Tel** : +33 240-1415 **Fax** : +33 256-3421

2. Experiments

The materials used are commercially available E48 (Merck) nematic LC and UV curable optical adhesive NOA-72 (Norland) for prepolymer. A solution of E48 and NOA-72 was prepared at a 1:1 ratio. The in-plane electrodes were prepared by etching 100 μm wide interdigitated ITO strips on the glass substrate with a gap of 100 μm. In order to get a wide viewing angle, we patterned the ITO in to a chevron shape. The substrate was spin-coated with a 1 wt.% Nylon 6 in trichloroethanol. The Nylon 6 film was unidirectionally rubbed after drying to obtain a homogeneous LC alignment. Also we used a two-step process to obtain an optically uniform film of the LC + prepolymer mixture, First, the mixture was spread on to the substrate by using a steel blade as shown in Fig. 1. The coating direction was kept parallel (or antiparallel) to the rubbing direction to avoid LC misalignment caused by shear stress. The thickness of the film was about 10 μm. Then, we spun the glass substrate for 30 seconds at 1500 rpm to increase its uniformity. A phase separation was initiated by exposing the film directly to a collimated beam of UV light for approximately 60 minutes to fully cure the prepolymer. The source of UV light was a high pressure mercury vapor lamp operated at electrical power of 400W.

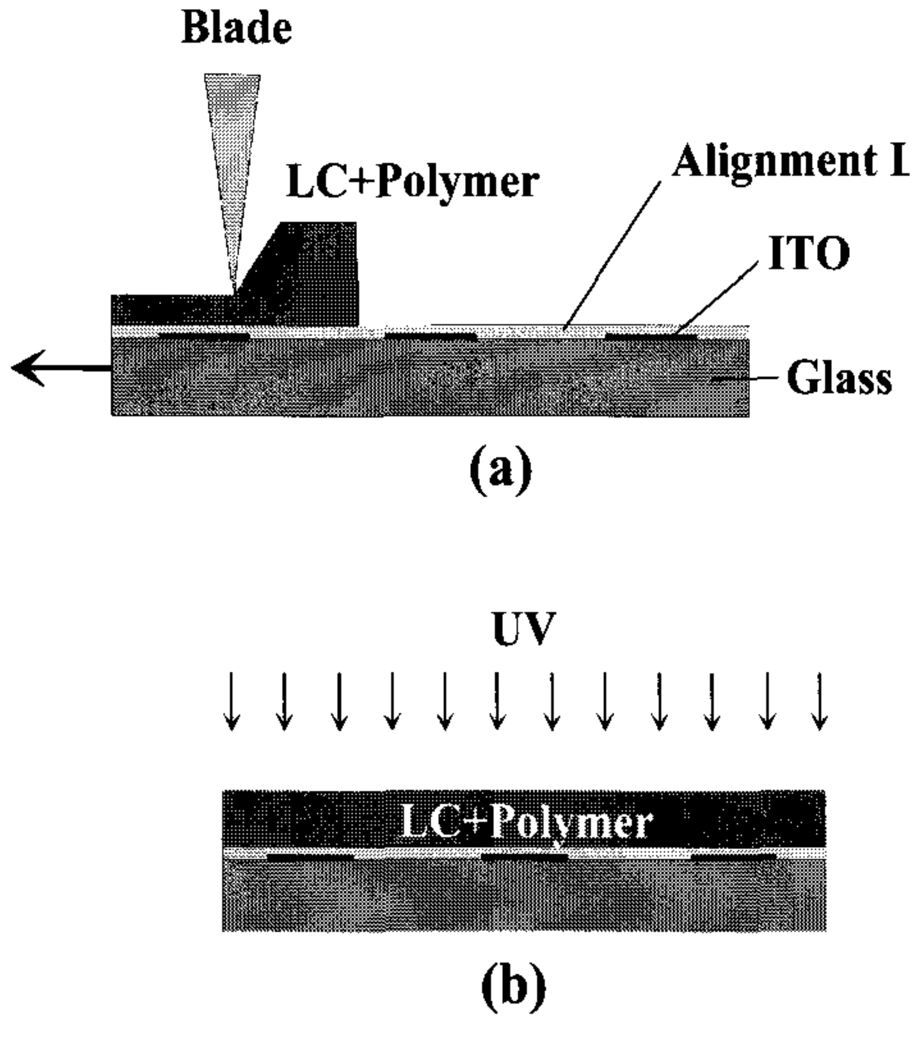

Fig. 1. Schematic illustration of the fabrication process: (a) the mixture was spread on the substrate using a steel blade; and (b) A collimated beam of UV light was exposed to the sample for approximately 60 minutes.

3. Results and Discussion

The mechanism behind the formation of PSCOF is similar to the anisotropic polymerization reported previously [6]. Due of the absorption of the UV light by the LC and prepolymer molecules in the solution, an intensity gradient was produced in the direction perpendicular to the sample. Consequently, NOA-72 molecules first underwent polymerization near the UV source at the air-film interface and the LC was expelled from the polymerised volume, forcing them to move away from the source. Droplet formation was inhibited because of the relatively slow rate of phase separation and fast diffusion of the relatively small LC moleculesd. As a result, the phase separated liquid crystal moved closer to the glass substrate. The LC's tendency to wet the alignment layer on the substrate enhanced the formation of a uniform film. LC molecules near the alignment layer responded to its anchoring potential and aligned parallel to the rubbing direction. The volume of aligned LC grew during phase separation. Oriented LC molecules determine the microscopic structure of the polymer-LC interface which became compatible with the LC alignment.

Measurements on PSCOF cells prepared with different concentrations of nematic liquid crystal show that the thickness of the LC layer depends on the amount of LC in the mixture and that < 2 % of LC is retained in the polymer film. The light scattered by the trapped LC was found to be negligible.

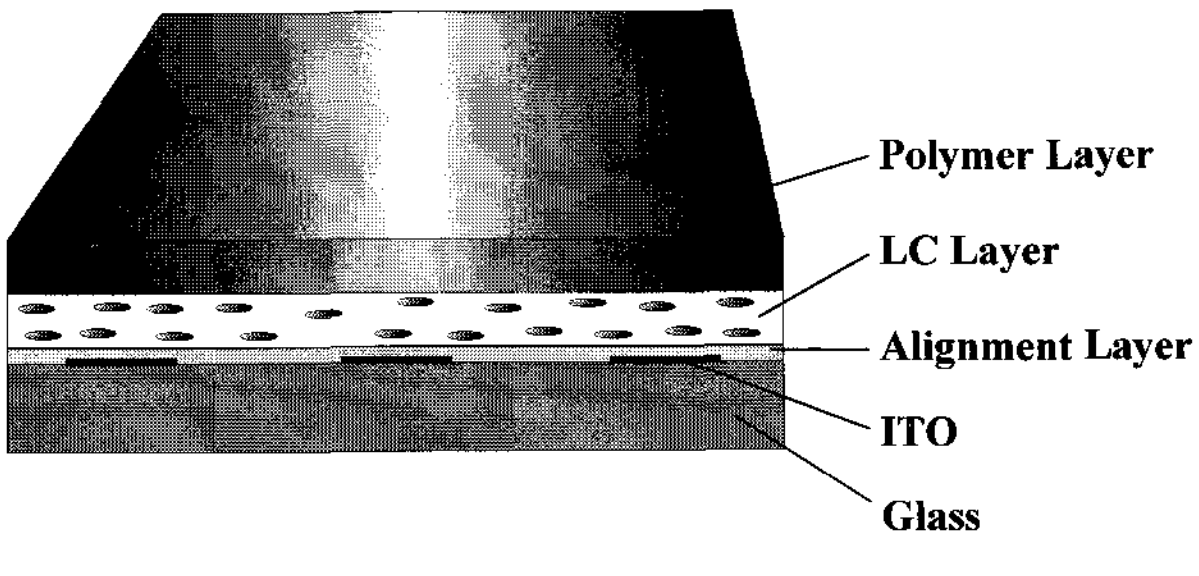

Fig. 2. Schematic diagram of fabricated LC device with a single glass substrate.

As shown schematically in Fig. 2, the LC layer is confined between the glass substrate and the solidified polymer layer which replaces the second glass substrate in conventional cells. The LC acquires a homogeneous alignment under the influence of the rubbed alignment

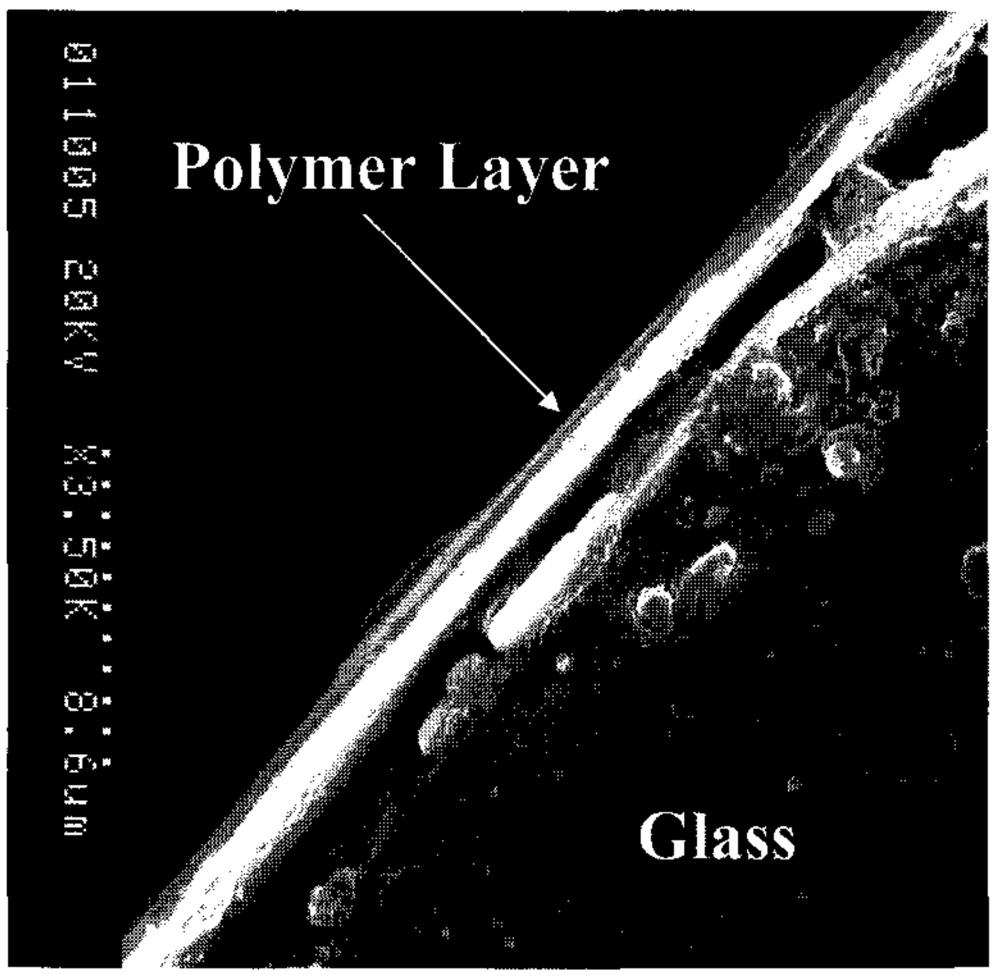

Fig. 3. SEM image showing substrate and polymer film.

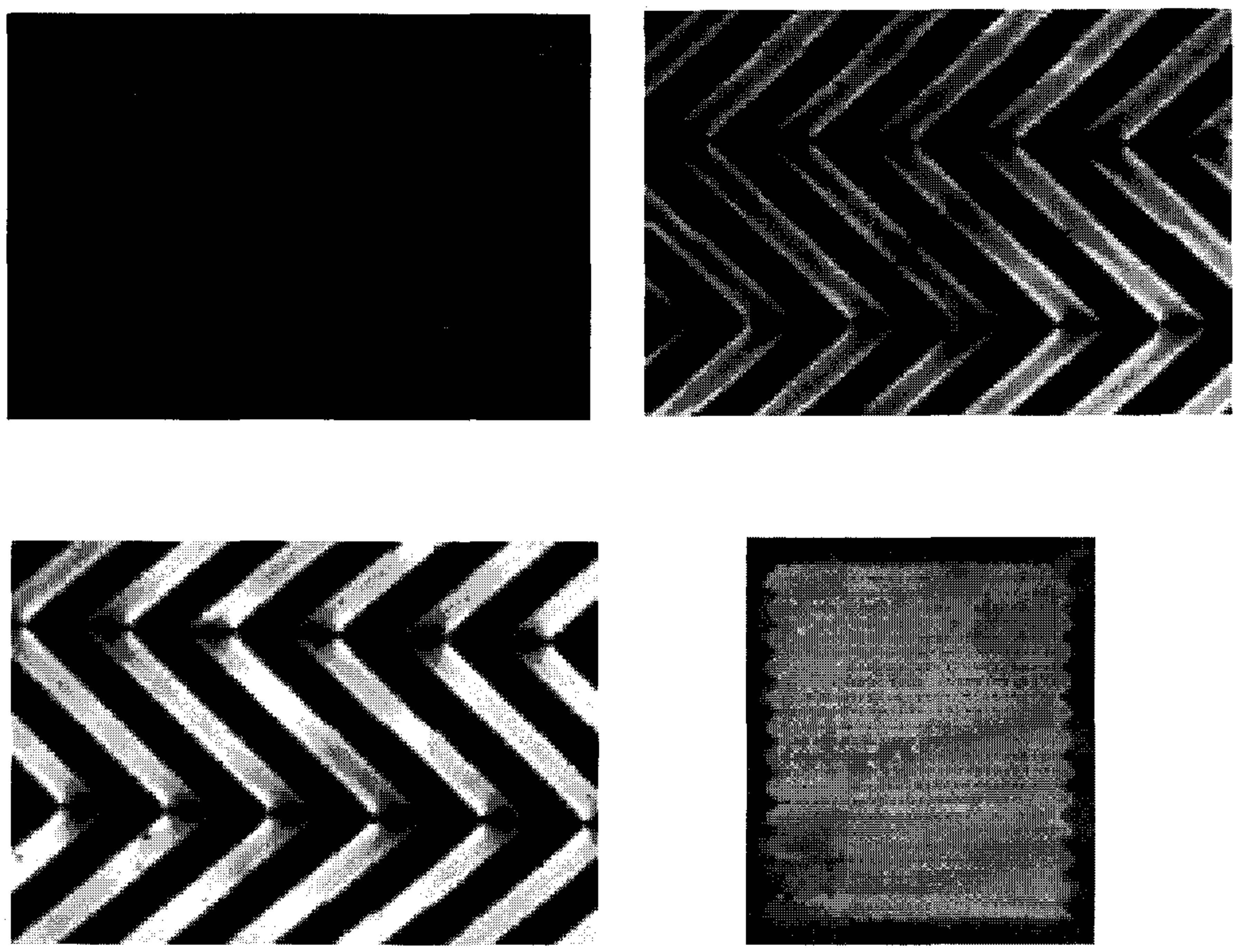

Fig. 4. Microscopic textures under polarizing microscope with/without applied field: (a) 0 V/µm, (b) 0.7 V/µm, (c) 1.5 V/µm; and (d) 1.5 cm x 2 cm cell between crossed polarizers with an applied field of 1.5 V/µm.

layer. The thickness of the LC layer mainly depends on the concentration and the speed of spin coating. The LC and polymer films are uniform except in microscopic regions where the polymer-LC interface bonds to the substrate. These bonding sites are usually influenced by the concentration, chemical nature of the LC, defects and singularities in the alignment layer, temperature, and the rate of phase separation. The process can be optimized to reduce the lateral cross section of these bounding sites to ~ 1 µm and to control their density, resulting in an almost perfectly uniform LC film. It is important to note that such PSCOF devices can also be made using flexible plastic substrates.

To determine the internal structure of the devices obtained, one of the cells was viewed under a scanning electron microscope (SEM). As it is evident from Fig. 3, a 3 μm thick solidified film of polymer is seen to have been formed. For this device, since the prepolymer and the LC were mixed at a 1:1 ratio, we estimate the thickness of LC layer also to be ~ 3 μm.

Fig. 4 shows the microscopic and macroscopic textures under polarizing microscope with/without applied voltages. Without applying any voltage, the uniform dark state was achieved as a result of good LC alignment [Fig. 4(a)]. The small number of visible defects as faint spots in the photograph were due to nonuniform mixing of the LC and prepolymer [Fig. 4(b)]. Beyond certain field strength (0.2 V/μm), the LC molecules start to reorient and align along the electric field due to their positive dielectric anisotropy. At higher field strengths (> 1.5 V/μm), one can obtain the white state in which the LC molecules have turned 45° in the the rubbing direction [Fig. 4(c)]. The results demonstrate that devices so fabricated using single glass substrate are uniform and possess gray scale capability. Fig. 4 (d) shows a 1.5 cm x 2 cm cell between crossed polarizers with an applied field of 1.5 V/μm. Except for a small area enclosed by the circle, the whole sample is found to be in the uniform white state. The dark area is caused by non-uniformity of the LC and prepolymer coat.

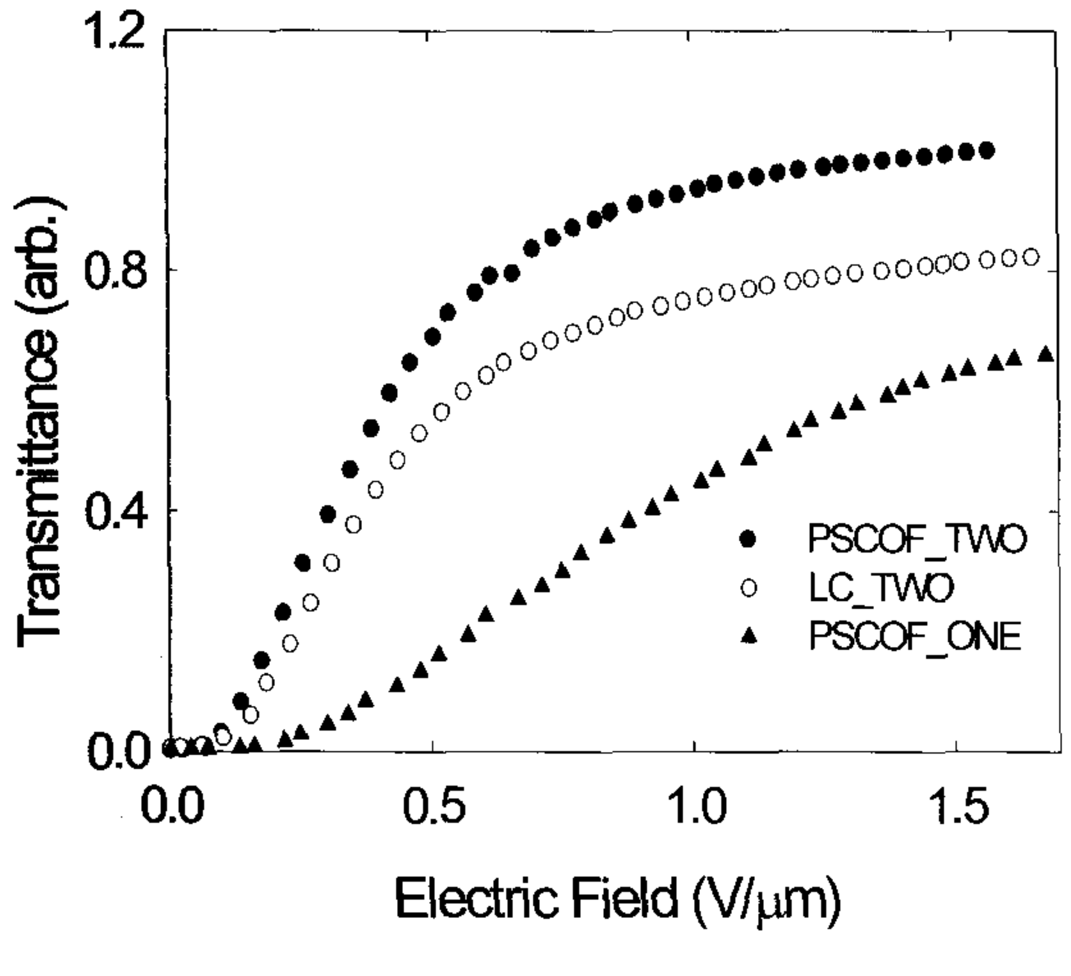

Fig. 5. Transmission vs. Applied field for the one substrate (PSCOF_ONE), two-substrate (PSCOF_TWO), and normal IPS cell (LC_TWO).

Fig. 5 compares the field dependence of optical transmission of a one substrate device (PSCOF_ONE) with a conventional two substrate (LC_TWO) and a two substrate PSCOF (PSCOF_TWO) cell. All devices were operated in the in-plane switching (IPS) mode. The two-substrate cells are seen to show almost the same behavior. Their transmittance begins to increase at a field of 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, overall cell gap, and the electrode pattern. The maximum contrast of the one-glass sample is about 200:1 which is comparable to a normal IPS sample. The field driven and relaxation times are 7.8 ms and 20 ms at 1.5 V/μm, respectively. The cell exhibits good switching characteristics at all gray levels.

4. Conclusions

We have successfully fabricated a LC device using anisotropic phase separation and a single glass substrate. The resuling structures were made of adjacent parallel layers of liquid crystal and solidified polymer. The electro-optical properties of these displays were comparable to the normal displays using two glass substrates. The method demonstrated here is expected to open doors to new class of devices.

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