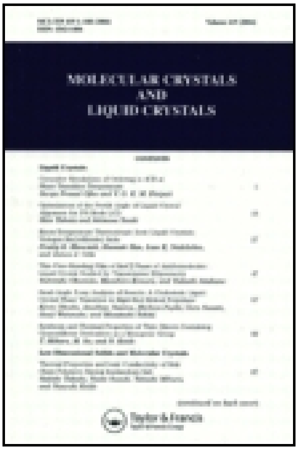

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Analysis of Electro-Optic Properties of a Polymer Network Liquid Crystal Display with Crossed Polarizers

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An active-matrix polymer network liquid crystal display (AMPNLCD) of 1.79″ QCIF(176 × 144) was fabricated. The operating mode of normally black was reversed to normally white by using crossed polarizers. The contrast ratio, as a result, was drastically increased, which was comparable to a conventional liquid crystal display. The response time at a typical driving voltage, 2.8 V, was also fast enough to play still image smooth. The electro-optic properties of AMPNLCD with crossed polarizers were evaluated and discussed.

Keywords: crossed polarizers; image inversion; PDLC; polymer network liquid crystal; wide viewing angle

INTRODUCTION

Polymer/LC composites have been studied for a wide variety of applications such as electrically switchable windows, optical shutters,

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flexible displays, diffractive optics, and photorefractive systems [1,2,3,4] due to their high light efficiency (no polarizer), easy processing (no rubbing process), wide viewing angle and flexibility. The opaque state by light scattering in polymer/LC composites is simply switchable to transparent state by external electric fields, which is caused by matching of refractive indices of LC(no) droplets and polymer(np) [5]. But their display application was somewhat restricted by high driving voltage, slow response time and poor contrast ratio. In recent years, in order to overcome these weakness, various types of polymer/LC composites have been developed, which including polymer dispersed liquid crystal (PDLC), polymer network liquid crystal (PNLC, higher LC contents than PDLC), polymer stabilized ferroelectric liquid crystal and others [6]. We have considered to adapt crossed polarizers in a thin PNLC for display application. In this article, we report on the electro-optic properties of a thin film transistor (TFT)-PNLCD and the effect of crossed polarizers on the contrast ratio variation as well as an image mode control.

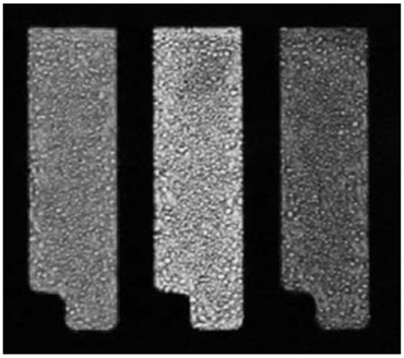
EXPERIMENTAL

The PNLC material used in this experiment is homogeneous solution of 70 wt% TN-LC (TL205 supplied from Merck Co.) and 28 wt% UV-curable acrylate type pre-polymer (mixture of 26 wt% 3,5,5-trimethylhexyl acrylate (TMHA) and 2 wt% 1,6-hexanediol diacrylate (HDDA)) and 2 wt% photoinitiator (2,2-dimethoxy 2-phenyl acetophenone (DMAP)). Homogeneous solution was injected into a conventional TNLCD empty panel of 1.79″ QCIF(176×144) using LC injection equipment and photo-polymerized to separate the LC/polymer phases by UV irradiation of 15 mW/cm^2 (peak wavelength = 365 nm) for 60 seconds. The details on PNLC preparation were described elsewhere [7]. The morphology of PNLC films was investigated by optical microscope (Nikon, LV100D). The voltage-transmittance, viewing angle and contrast ratio were measured by I-V-L system equipped with CS1000 spectroradiometer and Keithley 236 source measure unit.

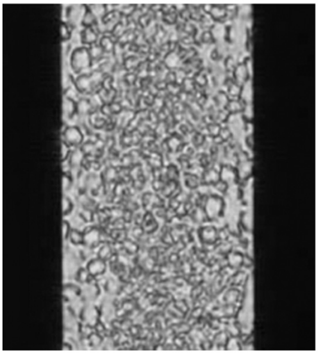
RESULTS AND DISCUSSION

Film Morphology

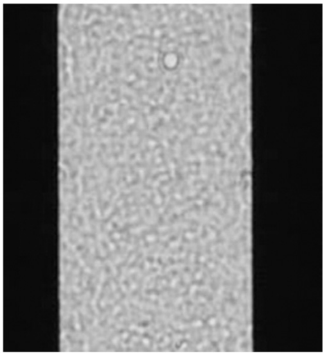
The size and shape of LC domain in polymer/LC composites are important factors affecting the electro-optic performance of the device [8]. Figure 1, optical images, shows the morphology of polymer/LC composites after phase separation. Most of the LC domains (bright area without any contrast) seem to be far from a spherical shape. Considering that LC content was around 70 wt%, the construction of PNLC would be more preferable to PDLC so that the cell gap is filled by continuous LC phase in polymer network. PDLC, in general, reveals a rather high driving voltage and slow response characteristics because LC molecules are tightly bound on the interface of polymer and LC droplets. LCs in PNLC system become continuous phase, and three-dimensional polymer networks are dispersed in liquid crystals to form bicontinuous polymer/liquid crystal networks which has less tight binding between LC molecule and polymer interface. Therefore PNLC is known to exhibit low driving voltage, fast response time, and low contrast ratio compared to PDLC [9,10]. The driving voltage and contrast ratio of PNLC, in this work, were about 0.63 V/μm and 1.07(without



(a)



(b)



(c)

FIGURE 1 Optical micrographs of PNLCD pixel (a) and PNLC morphology (b) (c) without crossed polarizers. (b) at V = off (0 V), light scattering state (c) at V = on (2.8 V), light transmission state.

polarizers), respectively. They were much lower than those of conventional PDLC [11].

Voltage-Transmittance Property

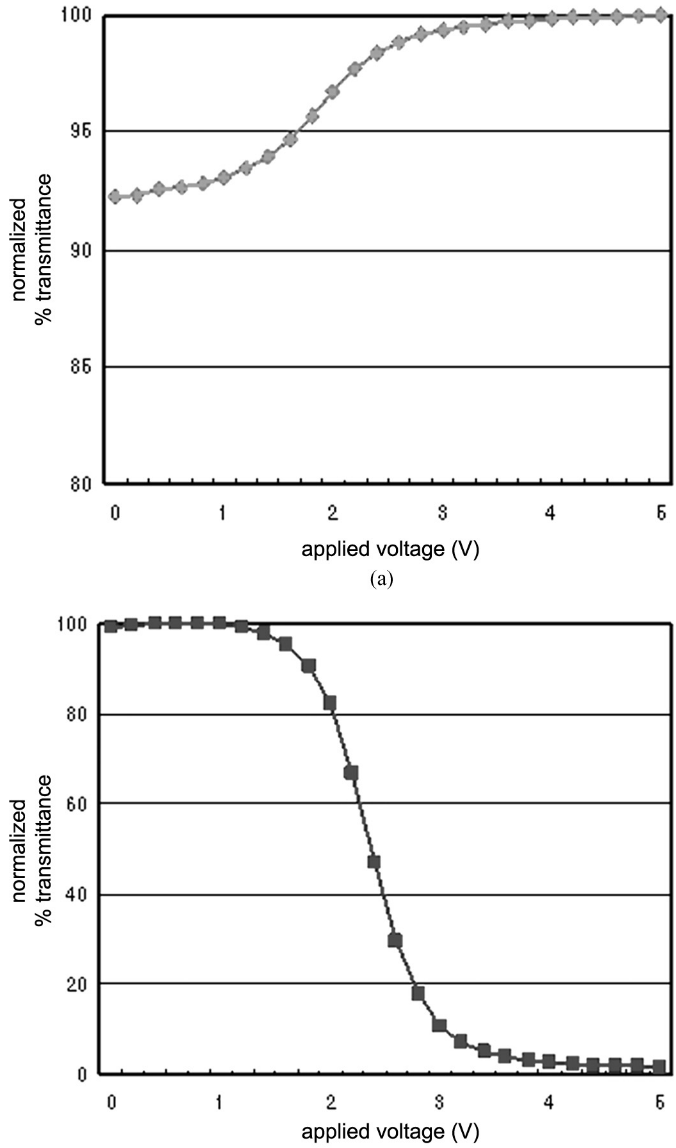
The transmittance of PNLCD with crossed polarizers was measured as a function of the applied voltage, as shown in Figure 2(b). We used a conventional LED backlight unit (BLU) as a diffusive light source right behind the panel. The curve shape is similar to conventional normally white mode LC displays. Driving voltage and threshold voltage of normally white mode LC display are usually defined as the voltages corresponding to the transmittance 10% (V10) and 90% (V90), respectively. Our PNLC panels with crossed polarizers were operated at a driving voltage range of $2.8 \sim 3.0\,\mathrm{V}$ which is comparable to that of the conventional TFT-LCD. However, the panels without crossed polarizers as given in Figure 2(a) were operated at normally black mode with unclear on/off property and revealed low contrast ratio.

Image Inversion Effect

Figure 3 shows the TFT-PNLCD for same input image (the inset) with and without crossed polarizers. When polarizers were not used, the color was inverted because PNLC operates at normally black mode. The images, however, were hard to be recognized due to the poor contrast ratio. While the display equipped with crossed polarizers produced the input image and the contrast ratio was greatly improved. (Fig. 3(b)) This was illustrated at the schematics shown in Figure 4. For the case of without polarizers, it shows normally black mode. On-pixels are transparent white state ($n_p = n_o$), Off-pixels are opaque black state ($n_p \neq n_o$). However, for the case of with polarizer, it shows normally white mode. A linearly polarized light transmitted through the on pixels is blocked by the top polarizer (analyzer), and then it became the real black state. While a certain degree of linearly polarized light scattered by off-pixels passes through the top polarizer (analyzer) to be observed over a wide viewing angle, then it became the dark white state.

Viewing Angle Property

Figure 5 shows the images at various viewing angles. At any angle, the images look the same quality without severe color inversion and brightness degradation, which comes from the inherent scattering characteristic of PNLC materials [3,12].



(b)

FIGURE 2 Voltage-transmittance graph of PNLCD panel (a) without crossed polarizer (b) with crossed polarizer.

(a)

(b)

FIGURE 3 TFT-PNLCD module image without(a) and with(b) polarizer at 2.8 V. (The inset is the original input image.)

Contrast Ratio Property

Contrast ratio is a very important property of display devices, but it cannot be easily compared in the literature. Indeed, several definitions of contrast ratio are being used, although the most widespread is: contrast ratio = Tmax/Tmin. The measurement was carried out both with and without crossed polarizers at the front direction of panel. Contrast ratio of the panels has greatly improved by using crossed polarizers. (Table 1) It should be caused by realization of real black state by crossed polarizers.

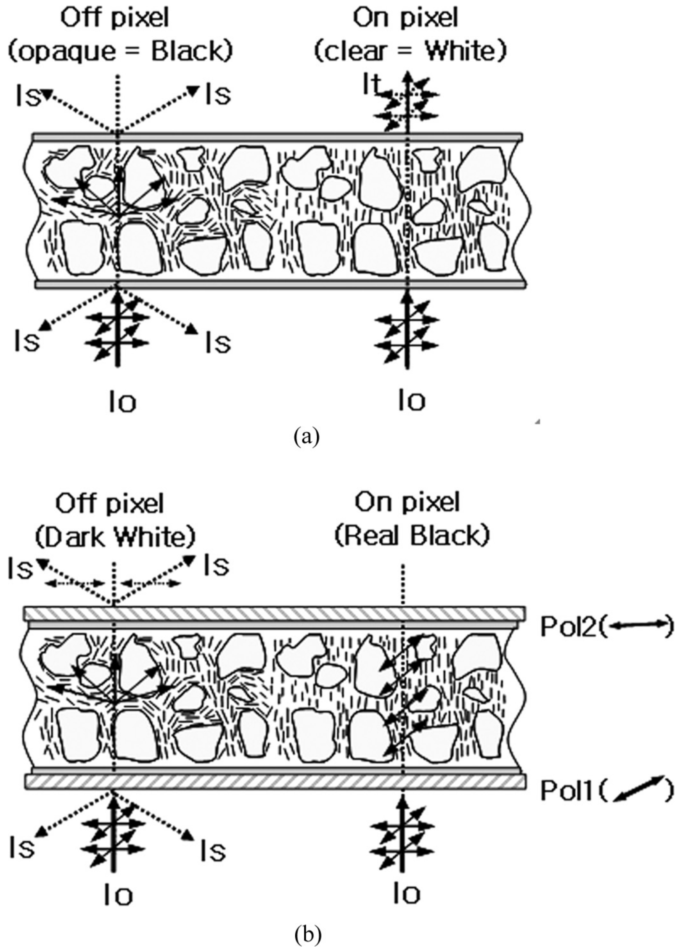


FIGURE 4 The simplified schematic diagram of image inversion effect. (a) without crossed polarizer (b) with crossed polarizer where, Io = input light, Is = scattered light, It = transmitted light.

CONCLUSIONS

We fabricated a full color TFT-PNLCD operating at a driving voltage of 2.8 V by increasing LC content in polymer/LC composites. The contrast ratio of the device was improved from 1.07 to 54.7 by adapting crossed polarizers, which is comparable to a conventional TFT-LCD. The viewing property was rather superior to TFT-LCD because of the light diffusing property of polymer/LC

FIGURE 5 PNLCD panel images with crossed polarizer taken at various viewing angle.

TABLE 1 Contrast Ratio Property of PNLCD Panel

	Without polarizers	With polarizers
Contrast ratio	1.07	54.7

composites. The proposed device has great potential for both small size mobile displays and flexible large size moving image displays.

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