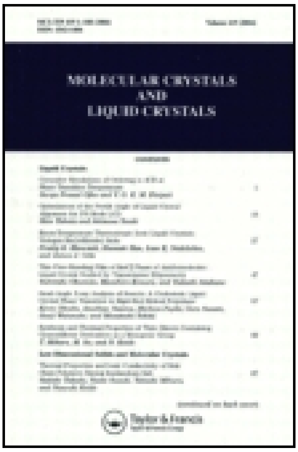

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Multi-domain Liquid Crystal Display with Self-Aligned 4-Domains on Surface Relief Gratings of Photopolymer

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We propose a new method of fabricating a vertically aligned multi-domain liquid crystal display (LCD) using surface relief gratings. A linear array of surface relief gratings is produced in the photosensitive polymer coated on glass substrates by the illumination of the UV light through a photomask. The LCD cell is assembled with two grating surfaces in such way that their grating vectors are orthogonal to each other. In this configuration, the nematic molecules are reoriented by a distorted electric field at the grating surfaces to make four different domains. The cell shows good extinction in the off-state and the wide-viewing property in the on-state.

Keywords: liquid crystal display; photopolymer; surface relief grating; wide-viewing

INTRODUCTION

Currently, LCD is one of the most competitive flat panel information displays because of its lightness and low power consumption. Although active matrix addressed LCDs based on twisted nematic (TN) mode have been greatly improved in their overall quality, there remain some serious problems to replace the cathode ray tube by the LCD in a variety of applications. One of them is the viewing property. The conventional TN mode shows asymmetric viewing properties due to the asymmetric alignment structure. To overcome this shortcoming, various techniques have been devised such as the birefringence compensation method using retardation films [1,2], the multi-domain TN method [3,4,5], the multi-domain vertically aligned (VA) method [6,7], and the in-plane switching [8]. Among the above methods to obtain symmetric viewing property, the multi-domain alignment method is most efficient one because the transmitted light through each pixel should be spatially averaged over sub-domains where the LC molecules are aligned along different directions in domain by domain, providing wide viewing property. However, the realization of some technologies involves complex processes such as multiple rubbing, elaborate evaporation of aligning materials or formation of delicate electrode patterns. Recently, a simple method of making microlens arrays has been extensively studied [9]. This technique is based on the diffusion effect of the ultra-violet (UV) curable photopolymer, by which the surface morphology can be easily controlled.

In this paper, by utilizing such concept, we propose a wide-viewing LCD structure with two arrays of photo-polymer gratings arranged orthogonal to each other. In this configuration, in the-off state, the nematic molecules align perpendicular to cell surface, and under an applied voltage, they are reoriented by the distorted electric field at the grating surfaces to make four different domains. The cell shows good extinction in the off-state and wide-viewing property in the on-state.

EXPERIMENTAL

The UV curable photopolymer (NOA65, Norland Products Inc.) was spin-coated on the indium-tin-oxide coated glasses under the condition of 3000 r.p.m. for 300 seconds. As shown in Fig. 1, the photopolymer layer was irradiated by UV light from a Xe-Hg lamp with 125 mJ/cm^2 through a chromium photomask with 200 μm striped apertures which were arranged in a period of 400 μm. The photopolymer was subsequently illuminated with the same power of UV light with no photomask. The homeotropic polyimide, JALS 2021-R1 (Japan Synthetic Rubber Co.), was spin-coated onto the photopolymer surface. The cell was assembled with two grating surfaces whose grating vectors were orthogonal to each other. The cell thickness was maintained using glass spacers of 5 μm thick and filled with a nematic liquid crystal, EN37 (Chisso Petrochemical Co.) which has negative dielectric anisotropy ($\varepsilon_\perp = 6.3$, $\varepsilon_\parallel = 3.3$).

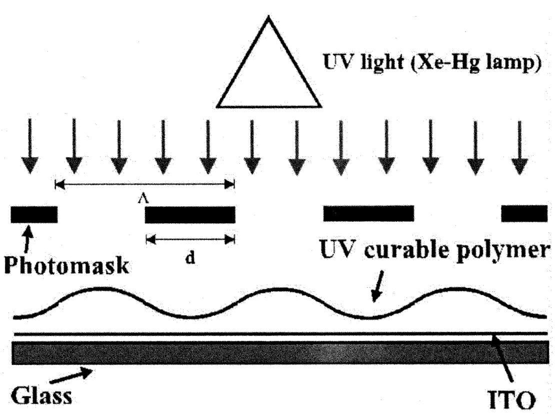

FIGURE 1 Fabrication process of surface relief grating (d=200 μm, Λ=400 μm).

We observed the cell textures as a function of the applied voltage of a bipolar square waveform at the frequency of 1 kHz (for AC driving) under an optical microscope (Optiphotpol2, Nikon). For measuring the electro-optic (EO) properties of the cell, LCD characterizing system (DMS, Autronics Co.) with a white light source was used. All measurements were carried out at room temperature.

RESULTS AND DISCUSSION

When the photopolymer was illuminated with UV light through the photomask, the photopolymerization process began at positions corresponding to the apertures. Then, the difference in monomer density between the illuminated areas and unilluminated ones caused the diffusion effect to move unpolymerized monomer into the illuminated region during the polymerization process so that the surface relief grating was formed. Fig. 2 shows the relative amplitude variation of the surface relief grating formed by the above process. This is measured by amplitude measuring system (α-stepper). The periodicity of the grating is well consistent with that of the photomask.

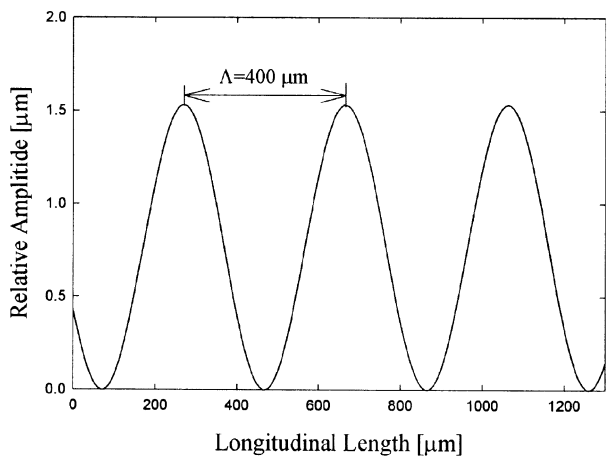

FIGURE 2 The relative amplitude variation of surface relief grating

The dielectric coefficient of the polymer is larger than that of LC ($\varepsilon_{polymer}$= 10 at 1 kHz) under an applied voltage. Therefore, the existence of the polymer gratings induces the distribution of the distorted electric field due to the non-uniform dielectric constant in space.

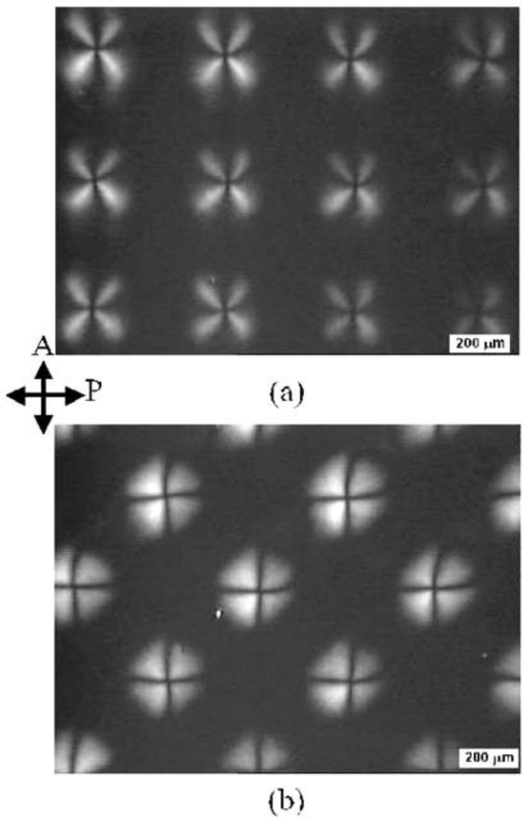

FIGURE 3 Microscopic texture under crossed polarizers in the on-state; (a) the grating vectors coincide with the polarizer directions and (b) the grating vectors make an angle of 45° to the polarizer directions.

When the voltage is applied, in our case, the distorted electric field may be very large throughout the cell because the amplitude of the grating is comparable to the cell gap. Under no applied voltage, the LC molecules are homeotropically aligned so that a dark state similar to a normal VA mode is obtained. As mentioned above, two surface grating vectors of the cell are orthogonal to each other. Therefore, in the on-state, the distribution of the distorted electric field has two-fold symmetry axes in the center of each unit domain. As shown in Fig. 3, when the voltage is applied, the four-domain structure are naturally formed due to the distorted electric field.

Fig. 4 illustrates the normalized EO transmittance when a bipolar square waveform at the frequency of 1kHz is applied to the cell. The driving voltage is somewhat higher than that of a conventional LC cell. Therefore, it is needed to optimize the cell parameters such as the cell gap, the dielectric coefficients of both LC and the polymer.

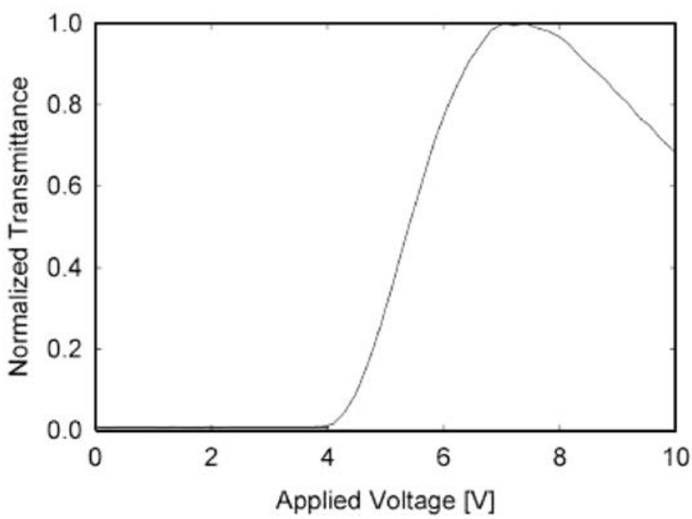

FIGURE 4 The normalized transmittance as a function of the applied voltage.

Fig. 5 shows the viewing angle dependence of luminance. The luminance has a high symmetry property, meaning that the directional dependence of the viewing property is very low. This is due to the natural formation of the multi-domain structure in the cell.

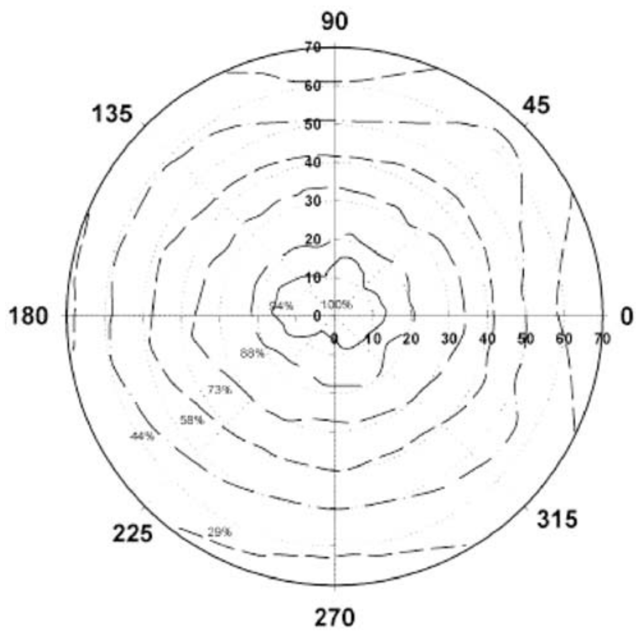

FIGURE 5 Viewing angle dependence of luminance at 6.23 V (the luminance at normal direction is 100%).

In summary, we have demonstrated a new wide-viewing LCD mode in a self-aligned configuration. We have fabricated a rubbing free, homeotropic cell by using two grating surfaces whose grating vectors are orthogonal to each other. The new mode shows excellent extinction in the off-state and the symmetric wide-viewing property in the on-state.

Acknowledgments

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