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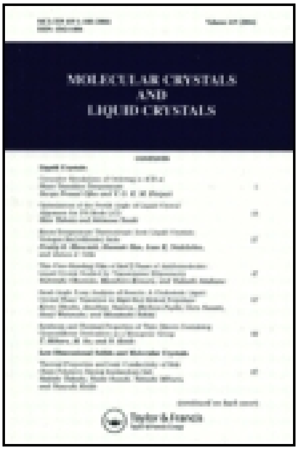

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Molecular Reorientation of a Liquid Crystal on a Periodic Array of Surface Relief Gratings

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MOLECULAR REORIENTATION OF A LIQUID CRYSTAL ON A PERIODIC ARRAY OF SURFACE RELIEF GRATINGS

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We introduce a surface relief layer with periodic undulation into a liquid crystal (LC) cell for designing a wide-viewing LC display. The 2-dimensional surface gratings were produced using a photosensitive polymer by the illumination of UV light through a photomask. A symmetrical LC molecular configuration was obtained on the surface gratings in the whole LC cell without any rubbing process. The electro-optic characteristics of LC cells were determined as a function of the applied voltage.

Keywords: liquid crystal display; photopolymer; surface relief grating; symmetrical molecular configuration

INTRODUCTION

The wide viewing and fast response characteristics are needed for high performance liquid crystal displays (LCDs). Especially, for improving the viewing property of LCD, various techniques have been reported such as a birefringence compensation method [1], a multi-domain method [2–5], an in-plane switching method, and so on. Among them, the multi-domain method is commonly used for commercial products because of high efficiency and reliability. In the previous work [6], we reported the 4-domain display with no rubbing process using surface relief gratings.

In this paper, we present the molecular distribution and electro-optic characteristics of a new type of the 4-domain structure which results from two arrays of photopolymer gratings arranged orthogonal to each other. In this configuration, the nematic molecules align perpendicular to cell

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surface in the off-state. Under an applied voltage, the molecules are reoriented by the distorted electric field at the grating surfaces to produce four different domains.

BASIC CONCEPT OF A DEVICE WITH SURFACE GRATINGS

It is well known that the LC molecules with negative dielectric anisotropy are reoriented along the direction perpendicular to an electric field. If there exists a distorted electric field in space, variations of LC alignment can be produced without any multiple surface treatment. For this purpose, we introduced a dielectric media with periodic undulation into a LC cell. Moreover, it is possible to obtain two-fold symmetrical molecular distribution using 1-dimensional dielectric grating surfaces. Using this concept, the 4-domain structure can be produced by arranging two arrays of photopolymer gratings that are orthogonal to each other. The schematic diagram of a device with surface gratings is shown in Figure 1. Under no applied voltage, the device is in the off-state where the LC molecules are aligned perpendicular to the surfaces.

EXPERIMENTAL

For fabricating the surface relief layer, the UV curable photopolymer (NOA65, Norland Products Inc.) was used. It was spin-coated on the

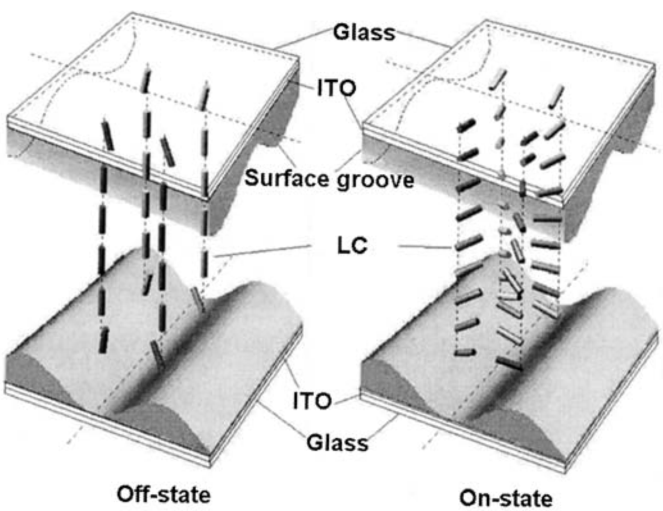

FIGURE 1 Schematic diagram of a device with surface gratings.

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indium-tin-oxide coated glasses under the condition of 3000 r.p.m. for 5 minutes. The photopolymer layer was irradiated by UV light from a Hg lamp with $125\,\text{mJ/cm}^2$ through a chromium photomask with 200 μm striped apertures having a period of 400 μm. The photopolymer was subsequently illuminated with the same power of UV light with no photomask. After it was fully solidified, the dielectric constant was 4.6 (at 1 kHz). 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 such that the grating vectors were orthogonal to each other. The cell thickness was maintained using glass spacers of 5 μm thick. The cell was filled with a nematic liquid crystal, EN37 (Chisso Petrochemical Co.). The dielectric constants of LC are ($\epsilon_{\perp} = 6.3$ and $\epsilon_{\|} = 3.3$). The microscopic textures were observed as a function of the applied voltage of a bipolar square waveform at the frequency of 1 kHz (for AC driving) under an optical polarizing microscope (Optiphotpol2, Nikon). For measuring the electro-optic (EO) properties of the cell, an LCD characterizing system (DMS, Autronics Co.) with a white light source was used. All the 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. The difference in the monomer density between the illuminated areas and unilluminated ones then caused the diffusion effect to move unpolymerized monomers into the illuminated region during the polymerization process so that the surface relief grating was formed. Note that 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 four-fold symmetry in the center of each unit domain. Figure 2 shows the microscopic textures of the sample cell under crossed polarizers at several applied voltages, clearly, the four-domain structure was naturally formed due to the distorted electric field.

As shown in Figure 2, the different operating domains were clearly developed with increasing the applied voltage. This is due to the existence of surface relief layers which cause the variations of the effective voltage in the LC cell. The expression for the effective voltage can be written as

$$V_{effective} = V_{applied}(1 + \varepsilon_{LC} d_{polymer}/\varepsilon_{polymer} d_{LC})^{-1}.$$

In above expression, V_{applied} is the applied voltage, d is the thickness of the relevant material at the local region, $\varepsilon_{\text{polymer}}$ is the dielectric constant of polymer, and ε_{LC} is the dielectric constant of LC. Note that ε_{LC} is a function

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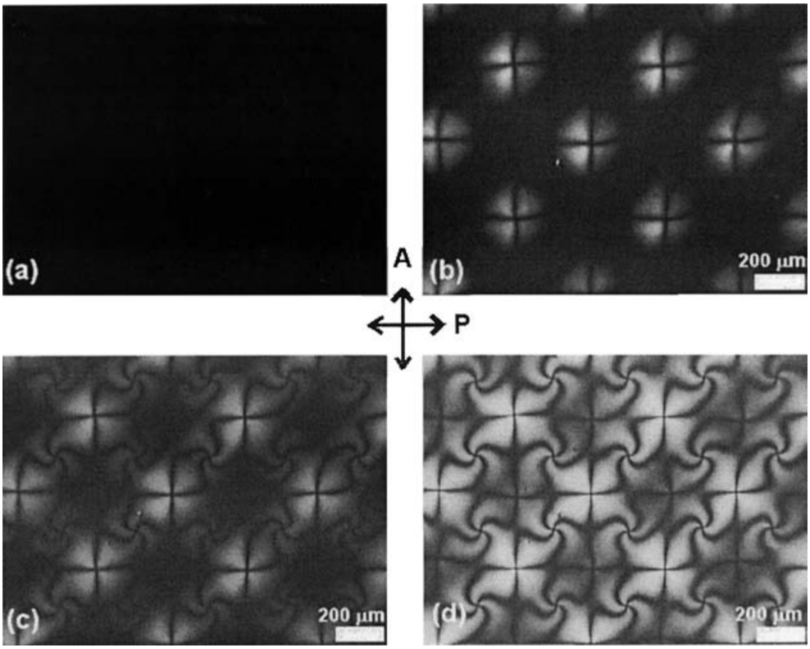

FIGURE 2 The microscopic texture of the sample cell at various applied voltages: (a) 0 V, (b) 3.59 V, (c) 3.79 V, and (d) 4.09 V.

of the applied voltage. The field dependence of ε_{LC} causes the equi-potential lines to be distorted inside the LC cell so that the LC molecules are periodically reoriented according to the presence of surface gratings. In other words, the LC molecules are reoriented along the direction of the grating vector by the distorted field, orthogonal to the equi-potential line, near the grating surface. The field distortion is nearly proportional to the curvature of the surface grating. In our case, two gratings are aligned orthogonal to each other so that the field distortions are generated not only in the plane which is perpendicular to the cell surface plane but also in the plane which is parallel to the cell surface. Therefore, we can guess the net molecular distribution over the cell when the field is applied. Figure 2(b) corresponds to the reorientation of molecules on the upheaval area of each grating at relative low voltage. When the voltage is increased, the operation region becomes wider. The guessed molecular distribution corresponds the Figure 2(b) are showed in Figure 3.

In order to see details of the molecular distribution, microscopic textures were observed during the rotating of the sample cell under fixed polarizers. Figure 4(a)–(c) are experimentally observed textures while

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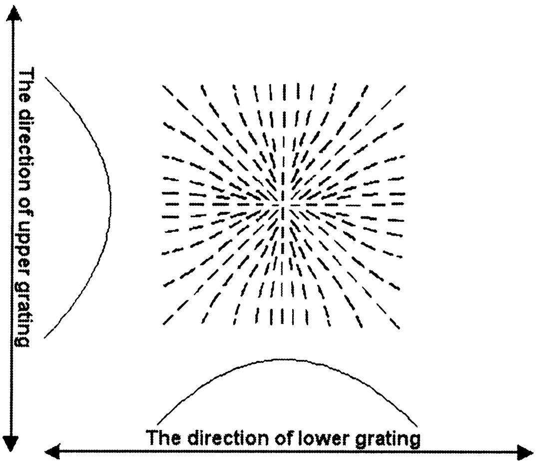

FIGURE 3 The molecular distribution corresponding to Figure 2 (b).

(a′)–(c′) are calculated results using the molecular distribution shown in Figure 3. It is clear that the experimental results agree well with the guessed molecular distribution. It is noted that the actual applied voltage is somewhat higher than the net voltage across the LC layer because the presence of the dielectric surface gratings. Figure 5 shows the normalized

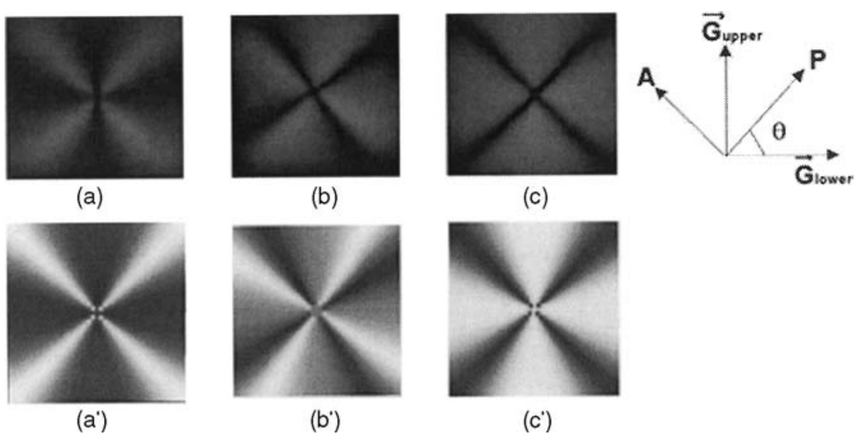

FIGURE 4 The microscopic textures of the cell under fixed polarizers: (a)–(c) are experimentally observed textures and (a′)–(c′) are simulated results. The rotation angles are $\theta = 0°$ for (a) and (a′), $\theta = 22.5°$ for (b) and (b′), and $\theta = 45°$ for (c) and (c′), respectively. ($\overrightarrow{G}_{upper}$ and $\overrightarrow{G}_{lower}$ represent the grating directions on two surfaces.)

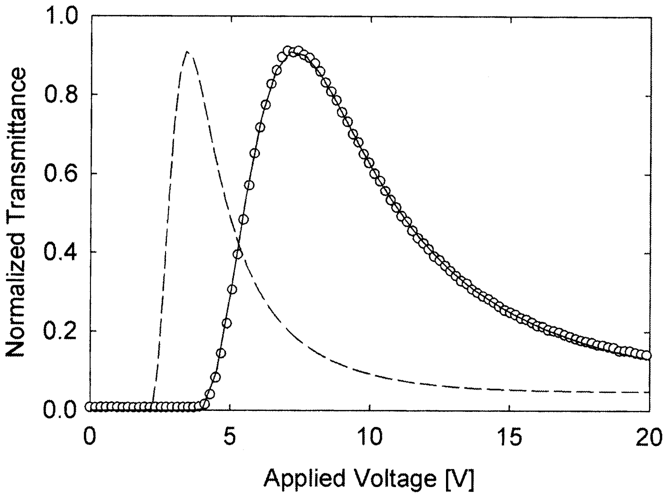

FIGURE 5 The normalized transmittance as a function of the applied voltage (The solid line represents the least-square fit to the experimental data.).

transmittance as a function of the applied voltage. The open circles represent the experimental results and the dashed line represents the numerical results for the LC cell with no dielectric layer. For fitting, the surface grating was assumed to be a flat dielectric layer over the whole region, $d_{LC} = 6.25\,\mu m$, and $d_{polymer} = 3.15$.

CONCLUSION

We have represented 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 the cell surface. Under an applied voltage, the molecules are reoriented by the distorted electric field at the grating surfaces to produce four different domains. The multi-domain structure presented here would be useful for understanding the physical mechanism for the geometrical alignment of LCs as well as for designing new LCDs. Further studies on the dynamics of the domain formation remain to be carried out.

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