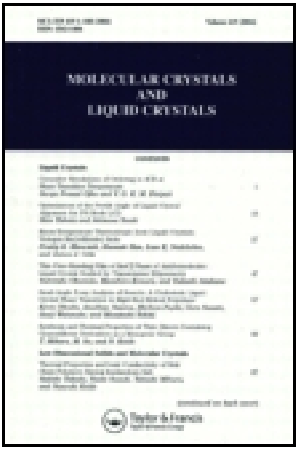


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# Formation of Surface Microstructure Arrays by Selective Wettability for Wide-Viewing Liquid Crystal Displays

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# Formation of Surface Microstructure Arrays by Selective Wettability for Wide-Viewing Liquid Crystal Displays

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*We developed a simple and powerful method of fabricating surface microstructure arrays for wide-viewing liquid crystal (LC) displays on the basis of the selective wettability. The surface microstructures are spontaneously formed on both the top and bottom substrates by selectively patterning the corresponding wettability commanding layers. An axially symmetric director configuration is generated by the electric-field distortions around each surface microstructure in the field-on state. Our LC cell having the surface microstructures shows good electro-optic properties and wide-viewing characteristics.*

**Keywords:** liquid crystal display; photopolymer; selective wettability; surface microstructure; wide-viewing

## INTRODUCTION

Wide-viewing properties of liquid crystal displays (LCDs) are essential ingredients of large-size LCD applications as computer monitors, high-definition televisions, and digital signages. In recent years, a variety of methods of producing wide-viewing (WV) LCDs have been developed, e.g., a birefringence compensation method [1], multi-domain alignment methods [2–5], and an in-plane-switching method [6]. Among them, the multi-domain alignment methods are widely used because of high optical efficiency and reliability. However, such

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methods involve complex processes, for example, multiple rubbing and/or an elaborate chemical etching processes of fabricating protrusion structures. Recently, a simple way of producing self-aligned multi-domains of the LC was proposed using the surface-relief gratings that were formed with ultra-violet (UV) curable photopolymers [7]. In this case, relatively high voltages are needed for driving the LC cell due to the presence of a dielectric layer on the top of the electrode.

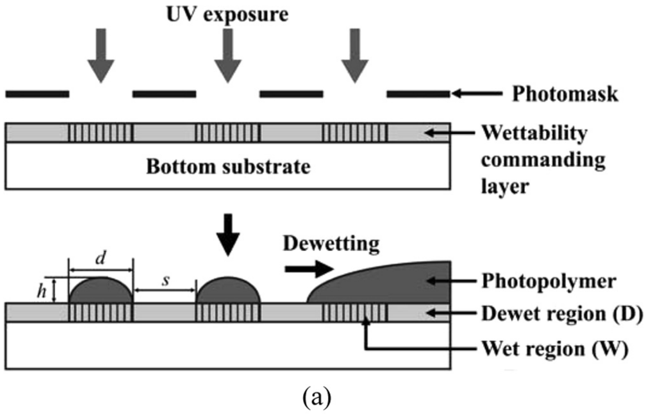
In this work, we develop a simple and powerful method of fabricating surface microstructure arrays for the WV-LCDs. By selectively modifying the surface properties of a wettability commanding layer, the surface microstructures of photopolymers were formed through a simple spin-casting process. Such microstructures produce the electric-field distortions within the LC cell, thereby generating axially symmetric director configurations in the field-on state. Our WV-LCD shows good extinction in the field-off state and the wide-viewing characteristics in the field-on state.

## FORMATION OF SURFACE MICROSTRUCTURES

Figure 1(a) shows the underlying concept of spontaneously forming the surface microstructures. The UV exposure through a photomask produces the wet regions *W* and dewet regions *D* for a photopolymer on a wettability commanding layer prepared on the substrate as shown in Figure 1(a). It is known that both the wetting morphology and the contact angle $\theta$ strongly depend on the droplet volume and the relative fraction of the wet region to the dewet region on the underlying surface [8]. Variations of $\theta$ lie in the range between the contact angle in the *W* region and that in the *D* region. Using the selective wettability, an array of droplets of a photopolymer is spontaneously formed by spin-casting on the wettability commanding layer which consists of *W* regions and *D* regions [9]. The height of each microstructure depends on the diameter of the droplet and the contact angle according to the geometrical equation, $\tan(\theta/2) = 2h/d$, where $h$ and $d$ represent the height and the diameter of the droplet, respectively.

## EXPERIMENTAL

For producing the surface microstructure arrays, a wettability commanding layer (EGC-1700, 3 M) was dip-coated on the top of an indium-tin-oxide deposited glass substrate and subsequently cured at room temperature. The commanding layer was irradiated by a KrF excimer laser ($\lambda = 248\,\text{nm}$) at the intensity of $10\,\text{J/cm}^2$ through



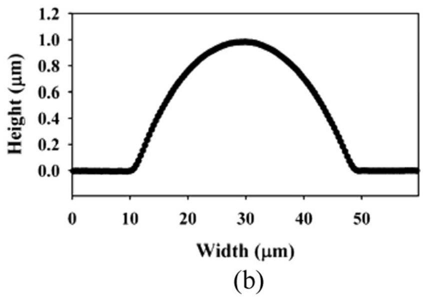




**FIGURE 1** (a) Our concept of fabricating surface microstructures and (b) the surface profile of a single microstructure.

a photomask having an array of circular apertures with the diameter of $d = 40\,\mu m$ and the periodicity of $s = 20\,\mu m$, as shown in Figure 1(a). A photopolymer (NOA65, Norland Ltd.) was then spin-coated onto the substrate at the spinning rate of 3000 rpm for 100 s and cured by the UV light ($\lambda = 365\,nm$) at the intensity of $6\,J/cm^2$ to form the surface microstructure arrays. The measured height of each microstructure using a surface profilometer (Alpha-step 500, KLA Tencor Co.) was about $1\,\mu m$ as shown in Figure 1(b). After removing the wettability commanding layer with a fluorinated solvent (HFE-7100, 3 M), the polyimide of JALS684 (Japan Synthetic Rubber) was spin-coated onto the microstructures to promote the homeotropic LC alignment. The substrates were assembled to produce a WV-LCD with a cell gap of $3\,\mu m$, as shown in Figure 2. A nematic liquid crystal (MLC-6608, Merck) with a negative dielectric anisotropy was filled into the cell by capillary action. A polarizing optical microscope (OptiphotII-pol, Nikon) was used for observing microscopic textures of our WV-LCD.

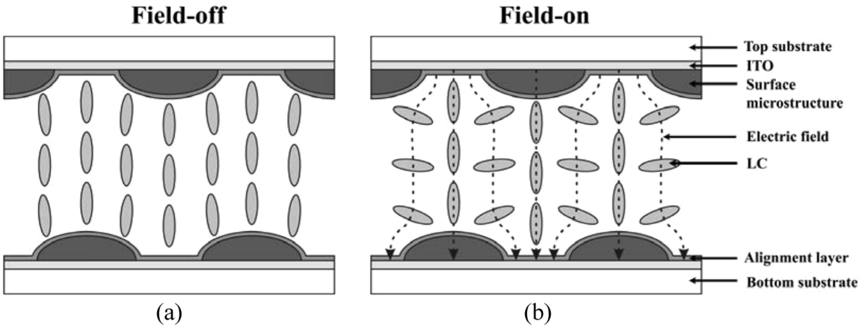



**FIGURE 2** A schematic diagram of our WV-LCD with surface microstructures: (a) the field-off state and (b) the field-on state.

A square wave voltage at the frequency of 1 kHz was applied to our cell to measure the electro-optic (EO) properties using a light source of a He-Ne laser with the wavelength of 632.8 nm. A spatial photometer (EZ-contrast 160 R, ELDIM) was used for measuring the viewing angle properties. All the measurements were carried out at room temperature.

## RESULTS AND DISCUSSION

We first examine how the surface microstructures influence the director distortions in our WV-LCD. Figure 3 shows the microscopic textures of our LC cell observed under crossed polarizers at different applied voltages. In the absence of an applied voltage, the

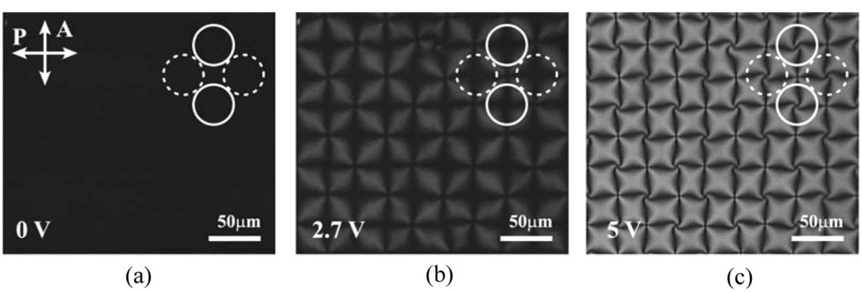



**FIGURE 3** Microscopic textures of our WV-LCD observed under crossed polarizers at different voltages of (a) 0 V, (b) 2.7 V, and (c) 5 V. The solid circles and the dotted circles represent the surface microstructures of the top substrate and the bottom substrate, respectively.

LC molecules are homeotropically aligned so that a dark state is obtained as shown in Figure 3(a). Above a certain threshold voltage, axially symmetric LC domains are generated around two-dimensional surface microstructures as shown Figure 3(b). With increasing the applied voltage to 5 V, self-formed four-domains that are axially symmetric become to appear as shown in Figure 3(c). The size of each domain depends on the diameter and the periodicity of the surface microstructures.

In order to determine the director profiles at different applied voltages, two-dimensional numerical simulations were carried out using a finite difference method [10]. The LC parameters used in the simulations were as follows: the elastic constants are $K_1 = 16.7 \times 10^{-12}\,\mathrm{N}$, $K_3 = 18.1 \times 10^{-12}\,\mathrm{N}$. Two dielectric constants are $\varepsilon_{\Box} = 3.6$ and $\varepsilon_{\perp} = 7.8$. The ordinary and extraordinary refractive indices are

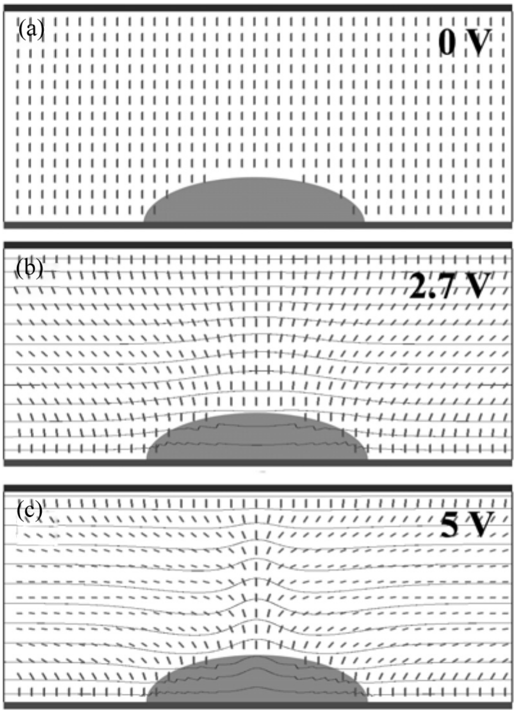



**FIGURE 4** Two-dimensional numerical simulations of the director profiles on a microstructure at different voltages of (a) 0 V, (b) 2.7 V, and (c) 5 V. The thick long-dashes represent the LC molecules and the thin solid lines represent electrical equi-potential lines, respectively.

$n_o = 1.4748$ and $n_e = 1.5578$, respectively. For simplicity, the surface microstructures, having the dielectric constant of 4.2, are assumed to be present only on the bottom substrate. Under no applied voltage, the LC molecules are homeotropically aligned as shown in Figure 4(a). Under the applied voltage of 2.7 V, the LC molecules are symmetrically inclined from the surface normal on the microstructure mainly due to the electric field distortions as shown in Figure 4(b). Since the actual voltage drop across the LC on the surface microstructure is somewhat lower than that on the substrate itself, the LC molecules on the surface microstructure are not reoriented yet. When a relatively high voltage of 5 V is applied, the LC molecules are fully reoriented due to the distorted electric field, thus axially symmetric distributions of the director are generated. Such director distributions are consistent well with the microscopic textures shown in Figure 3.

Figure 5 shows the normalized EO transmission of our WV-LCD as a function of the applied voltage. The experimental and simulation results agree well with each other. The threshold voltage was measured to be 2.4 V which is similar to that of a conventional vertically aligned LCD.

The viewing angle characteristics of our WV-LCD (with no optical compensation film) are shown in Figure 6(a). Wide-viewing characteristics to the angle of $\pm 80^\circ$ were achieved along both the vertical and horizontal directions as expected from the microscopic textures of self-formed four domains in the field-on state shown in Figure 3(c).

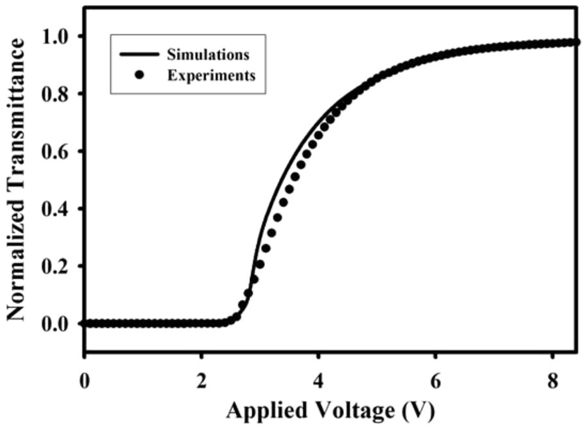



**FIGURE 5** The normalized EO transmittance of our WV-LCD as a function of applied voltage. The filled circles and the solid line represent the experimental data and the simulation results, respectively.

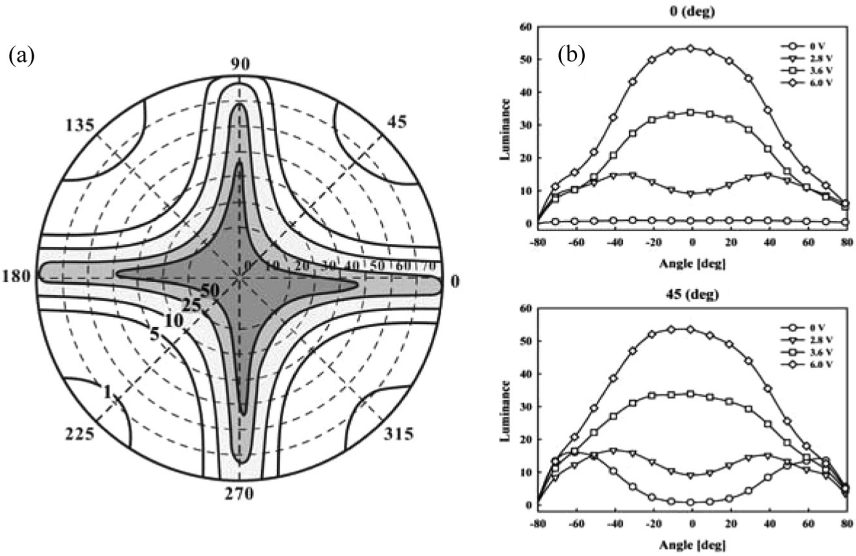



**FIGURE 6** Viewing angle characteristics of our WV-LCD: (a) an iso-contrast plot and (b) variations of four gray levels at two different azimuthal angles of 0° and 45°.

Figure 6(b) shows variations of four gray levels at two different azimuthal angles of 0° and 45°. Symmetrical viewing characteristics without gray scale inversion were observed along the viewing direction up to ±50°.

## CONCLUSION

We developed a new method of directly forming an array of surface microstructures for the WV-LCDs through a selective wettability patterning process. Based on the selective wettability, the surface microstructures for wide-viewing properties are easily obtained without any elaborate chemical etching or multiple rubbing processes. Due to the simplicity and uniformity over large area, our approach has a significant impact on fabricating various display elements on plastic substrates including flexible displays.

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