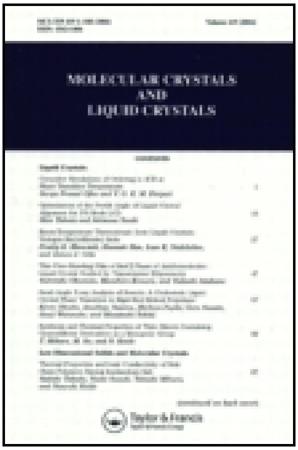

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Vertically-Aligned Liquid Crystal Display with Axial Symmetry using Surface Relief Gratings on Polymer

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A new method of fabricating a vertically aligned liquid crystal display (LCD) using surface relief gratings is presented. The two dimensional surface gratings are produced on a photosensitive polymer by the illumination of the UV light through a photomask. A multi-domain structure is obtained on the grating surface with the homeotropic alignment. The LCD configuration with such axially multi-domain structure along the surface relief exhibits excellent viewing characteristics.

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

INTRODUCTION

A conventional twisted nematic (TN) mode shows narrow viewing properties due to the intrinsically asymmetric alignment. In order to overcome this shortcoming, various multi-domain methods have been devised[1-5]. Especially, a vertically aligned (VA) multi-domain (MD) mode[5] is promising because of its good contrast and wide viewing characteristics. However, the realization of the VAMD mode involves complex processes such as multiple rubbing and elaborate evaporation of aligning materials. Recently, an easy method of controlling the surface morphology has been extensively studied for making microlens arrays[6]. This method is based on the contraction effect of ultra-violet (UV) curable photopolymer. We utilize this technique for producing a multi-domain homeotropic alignment structure where the domain size and the surface inclination are precisely controlled.

In this paper, we propose a wide-viewing LCD mode realized in an axially symmetric vertical alignment (ASVA) configuration. In order to obtain this configuration, we make the micro-groove arrays on an UV curable photopolymer, followed by coating a homeotropically aligning polyimide onto the polymer layer.

EXPERIMENTAL

The UV curable optical adhesive (NOA60, Norland Products Inc.) was spin-coated on the indium-tin-oxide (ITO) glass under the condition of 4000 r.p.m. for 100 seconds. This photopolymer layer was irradiated by the UV light generated from a Xe-Hg lamp with 50 mW/cm^2 through a chromium photomask. The mask has circular apertures of 100 μm in diameter which are arranged in a period of 200 μm. The coated photopolymer layer was subsequently illuminated with the same power in 15 minutes without the photomask to cure the whole area. The fabrication process of the micro-groove arrays is shown in Figure 1. After the curing process, the homeotropic polyimide, JALS204 (Japan Synthetic Rubber), was spin-coated onto the polymer surface. The cell was assembled with the above prepared substrate and the other with only the layer of JALS204. We used 5 μm glass spacers to maintain the cell gap. Our cell was filled with a nematic liquid crystal, EN40 (Chisso), which has negative dielectric anisotropy.

We observed the cell texture as a function of the applied voltage of a bipolar square waveform at the frequency of 1 kHz under an optical polarizing microscope. The iso-contrast map was measured to determine the viewing characteristics.

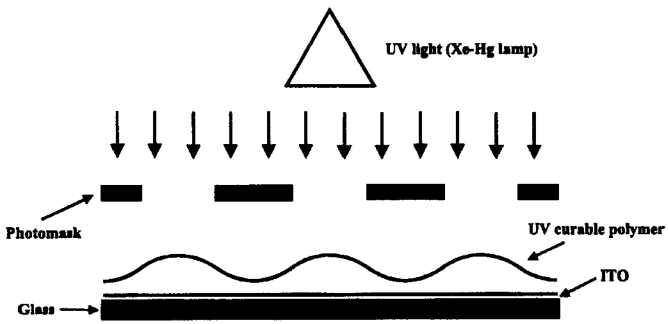

FIGURE 1 Fabrication process of micro-groove arrays.

RESULTS AND DISCUSSION

When the polymer is illuminated through the photomask, the photopolymerized process begins at positions corresponding to the apertures. Then, the difference in density between the illuminated areas and the unilluminated ones causes the contraction effect to make the polymer move into the illuminated region to join the polymerization process. Figure 2 illustrates the micro-groove arrays formed by the illumination through the photomask for one second. The regions inside the circular patterns in Figure 2 correspond to the areas that were illuminated by the UV light. As the illuminated intensity increases, the average height of the micro-grooves increases to some extent. However, in our case, the shape of the micro-groove varies with the increase of the illumination energy. As shown in Figure 3, the shape of the micro-groove follows the square of the sin function when the illumination energy is less than about 5 J/cm^2. When the energy increases further, the photopolymerization process takes place so fast that rounded hills are formed near the edges of the apertures of the photomask.

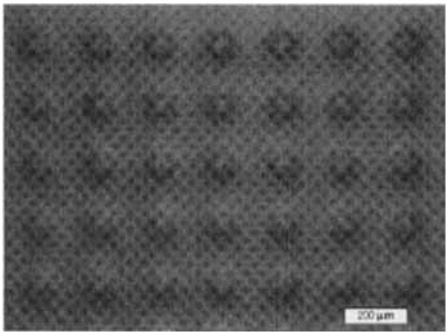

FIGURE 2 The micro-groove arrays on the UV curable polymer.

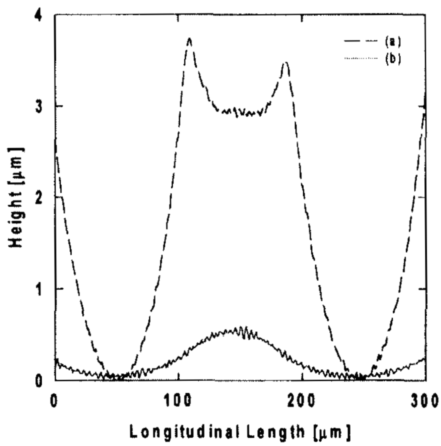

FIGURE 3 The profiles of the micro-grooves: The illumination energy through the photomask are (a) 6.4 J/ cm^2 and (b) 0.42 J/ cm^2.

Based on the above results, the cell with the grating surface was made under the condition of Figure 3 (b) to obtain the continuous distribution of the surface pretilt. Figure 4 shows the electro-optic (EO) transmittance through the cell. A bipolar square waveform at the frequency of 1 kHz was applied to the cell. The Freedericks transition voltage is somewhat higher than that of a conventional VA cell because of the voltage drop across the polymer layer. Therefore, it is needed to reduce the thickness of the photopolymer layer for lowering the Freedericks transition voltage.

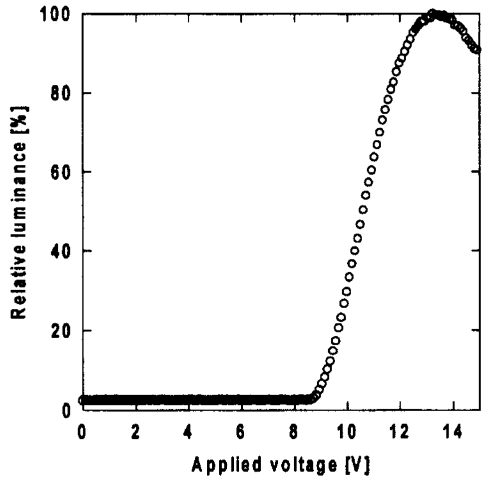

FIGURE 4 The EO transmittance characteristics of the cell.

Figure 5 illustrates the texture of the cell under crossed polarizers. In the case of no applied voltage, LC is homeotropically aligned so that a dark state similar to a normal VA state is obtained. Upon the application of the voltage, the axially symmetric structure can be observed along the micro-groove arrays. As mentioned above, the illuminated region through the photomask upheaves by contraction and redistribution of the photopolymer matrix occurs during the curing process. The dark region under an applied voltage in Figure 5 represents the hill of the grating surface of the photopolymer layer. Around the hill of the grating surface, the actual voltage drop is larger than in the valley region. The important issue on the fabrication process is that the average height of the micro-grooves should be optimized.

When deep grooves are formed, the LC director tends to reorient along the micro-groove surface very strongly[7] so that the whirl of the director on the surface can occur. In our case, the tangential angle of the grating surface is about 0.3 degrees enough to prevent this phenomenon.

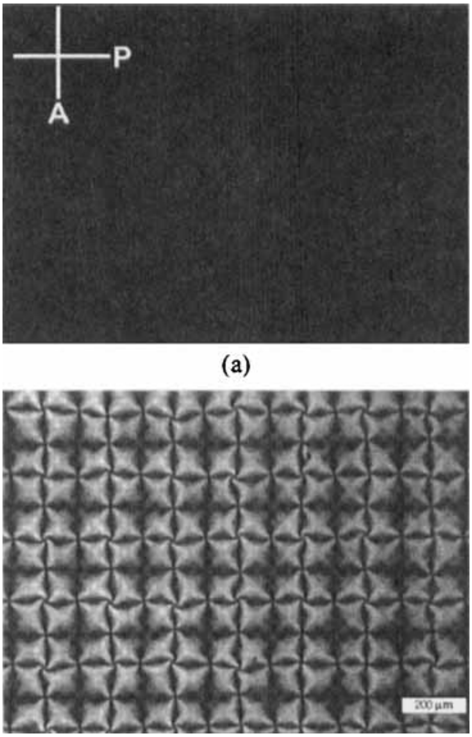

FIGURE 5 Polarized microscopic texture under two different applied voltages: (a) 0 V and (b) 13.6 V.

Figure 7 illustrates the iso-contrast map of the cell. Clearly, the symmetric viewing property can be seen. The ASVA cell has the axially symmetric transmittance property in the ON state. However, the VA mode has the intrinsic leakage of light in the OFF state along the directions off from the polarizers so that it exhibits relatively low contrast along these directions. In order to reduce this undesirable property, an optical compensation film can be used.

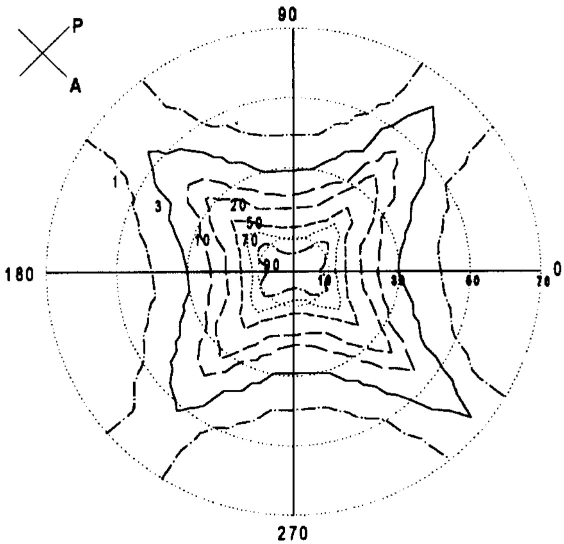

FIGURE 6 Iso-contrast map

In summary, we have demonstrated a wide-viewing LCD mode that is realized in the ASVA configuration. This configuration is obtained using two dimensional surface gratings which induce initially the vertical alignment. The multi-domain size is easily varied and no rubbing process is required. Therefore, in contrast to other multi-domain structures, the ASVA configuration provides defect free structures. Moreover, the perfect dark condition can be obtained in the OFF state, which results in high contrast and wide viewing characteristics.

Acknowledgments

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