Stamping-assisted Fabrication Technique of the Bidirectional Alignment Layer for Wide-Viewing Twisted-Nematic Liquid Crystal Displays

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Abstract

A stamping-assisted rubbing technique for generating bidirectional alignment in the fabrication of wide-viewing twisted-nematic (TN) liquid crystal displays (LCDs) was developed. A patterned layer of a fluorinated acrylate polymer was transferred onto the first rubbed alignment layer prepared on a substrate by stamping. The fluorinated acrylate polymer provides a protective layer that covers the first alignment layer during the second rubbing process to facilitate the bidirectional alignment of the LC molecules. The LC cell in the twisted geometry with two bidirectional-alignment layers showed stable electro-optic properties and wide-viewing characteristics. The stamping-assisted rubbing technique serves as a mask-free alignment method of producing multidomains for wide-viewing LCDs.

Keywords: stamping-assisted rubbing, liquid crystal, fluorinated acrylate polymer, wide-viewing

1. Introduction

Liquid crystal displays (LCDs) based on the twisted-nematic (TN) mode have been widely used for flat panels in notebook computers and cellular phones due to their simplicity and cost-effectiveness in terms of manufacturing. Their asymmetric and narrow-viewing-angle characteristics, however, are among the serious drawbacks for large-size applications like television sets. To improve the viewing properties of the TN-LCDs, either an optical-film compensation method or an approach to the fabrication of multidomains has been commonly employed [1-3]. The film compensation method, however, is high-cost, and the multidomain approach requires complicated fabrication processes through the photo-alignment or multirubbing process. Another way of improving the viewing properties of the TN-LCDs involves the use of an intrinsic wide-viewing mode, such as the patterned vertical-alignment (PVA) and in-plain switching (IPS) modes, which replaced the conventional TN mode but still involves several issues related to electro-optical (EO) performance, process cost, and fabrication complexity [4-9]. For example, notebook computers based on the PVA mode suffer from low transmission efficiency and high processing cost. Therefore, a new wide-viewing TN technology with potential for simpler processes and better electro-optic (EO) properties should be developed.

In this work, a stamping-assisted rubbing method [10] of fabricating a wide-viewing TN-LCD with bidirectional-alignment layers was developed. A patterned, protective layer of a fluorinated acrylate polymer was transferred onto the first rubbed alignment layer prepared on a substrate by stamping. The fluorinated acrylate polymer covers the first alignment layer during the second rubbing process, facilitating the bidirectional alignment of the LC molecules. The regions below the patterns of the protective polymer layer preserve the alignment capability generated initially by the first rubbing process. As shown in Fig. 1(a), in the LC cell where the two directions of the bidirectional LC alignment were assembled perpendicular to each other, four different TN domains corresponding to two clockwise and two counterclockwise directions were produced. The four domains experienced both splay and twist deformation. The twist directors of the adjacent domains were different from each other [11]. The top view of such cell is schematically shown in Fig. 1(b). The developed stamping-assisted rubbing technique requires no photolithographic process and is thus simple and versatile. It is thus ideal for the manufac-

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2. Experiment Considerations

The stamping-assisted rubbing technique for achieving bidirectional alignment is illustrated in Fig. 2. The alignment layer of polyimide (PI) (JALS 146-R50, Japan Synthetic Rubber) was first spin-coated on a substrate and then rubbed unidirectionally to promote homogeneous alignment, as shown in Fig. 2(a). To generate bidirectional LC alignment, a protective layer (Novec EGC-1700, Sumitomo 3M) on a patterned stamping mold of PDMS was transferred onto the first rubbed PI by stamping, and was cured at room temperature, as shown in Fig. 2(b). Note that EGC-1700 is a fluorinated acrylate polymer carried in a hydrofluoroether solvent that does not chemically affect the alignment layer. The second rubbing process was then performed on the regions not covered with a protective layer, along the direction opposite to the first rubbing direction. The substrate was rubbed twice to ensure the saturation of the tilt bias angle [12]. Finally, the protective layer was dissolved in the hydrofluoroether solvent, and bidirectional alignment was readily achieved, as shown in Fig. 2(d). For the fabrication of the TN-LC cell, two substrates with bidirectional alignment were assembled such that the rubbing directions on the two substrates were perpendicular to each other. The cell thickness was maintained using 3-μm-thick glass spacers. The LC (ZLI-2293, Merck Ltd.) with a positive dielectric anisotropy was injected into the cell by capillary action at room temperature. The birefringence and dielectric anisotropy of ZLI-2293 were Δn=0.13 and Δε=10.0, respectively.

A square-wave voltage at the frequency of 1 kHz was applied to the TN-LC cell to measure the EO transmission and dynamic response time. The measurements were carried out using a digitizing oscilloscope (WaveRunner 6030, Lecory) and a light source of an He-Ne laser with a 632.8 nm wavelength, at room temperature.

3. Results and Discussion

The microscopic textures of the TN-LC cell with bidirectional alignment shown in Fig. 3 were observed with the use of a polarizing optical microscope (Optiphot2-pol, Nikon), under crossed polarizers and at different applied voltages. Under no applied voltage, the LC molecules were twisted. The wave-guiding effect thus resulted a normally white state, as shown in Fig. 3(a). At the voltage of 1.4 V (below the threshold), essentially no change was observed, as shown in Fig. 3(b). At 1.8 V (above the threshold), the LC molecules were partially aligned perpendicular to the substrate, and the transmission was reduced, as shown in Fig. 3(c). At the relatively high voltage of 3.3 V, the LC molecules were mostly reoriented perpendicular to the substrate. As a result, no transmission was produced, as shown in Fig. 3(d). It should be noted that each square pattern enclosed by four disclination lines indeed represent four different domains. The adjacent domain has the opposite twisting direction, which can be well understood from Fig. 1(b).
Fig. 4(a) and (b) show the normalized EO transmission and the dynamic response of the developed four-domain TN-LC cell in the presence of a bipolar voltage in a square-wave form at 1 kHz, respectively. The EO properties were measured under crossed polarizers. The contrast ratio of about 100:1 was achieved, as shown in Fig. 4(a). In Fig. 4(b), the black and gray curves represent the EO response of the developed TN-LC cell and the applied voltage, respectively. It was found that the rising time was $\tau_r=18$ ms and the falling time was $\tau_f=10$ ms when the applied voltage was 3 V. These response times are fast enough for video rate applications without an image-sticking effect.

The viewing angle characteristics of the developed TN-LC cell with four domains at 5 V, measured using a spatial photometer (EZ contrast 160R, ELDIM), are shown in Fig. 5. A conventional TN-LC cell with a single domain exhibits asymmetric and narrow viewing properties, as shown in Fig. 5(a). In contrast, the developed four-domain TN cell with no compensation film shows quite symmetric viewing properties with respect to the axes of the polarizers in the vertical and horizontal directions. This is attributed to the optical compensation among the four differently twisted domains produced by the bidirectional alignment in the TN geometry, as schematically shown in Fig. 1(a) and (b).
4. Conclusion

A new technology for fabricating wide-viewing TN-LCDs with bidirectional alignment achieved using a stamping-assisted rubbing process was demonstrated herein. With the help of an inert protective layer of a fluorinated acrylate polymer, the second rubbing process was successfully employed, causing mechanical and chemical damage to the first rubbed alignment layer. The approach employed herein is basically mask-free and has potential for the simple and cost-effective fabrication of large-size TN-LCDs.

References


