Polymer-Stabilized Deformed-Helix Ferroelectric Liquid Crystal Device in Vertical Aligned Configuration

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Abstract

We propose a vertically aligned deformed-helix ferroelectric liquid crystal device (VA-DHFLCD) with the stabilized smectic layer against a field-induced deformation. The polymer structure enhanced the stability of the smectic layer against the vertical electric field near the edges of in-plane electrodes. As a result, our device could be obtained the stable operating over the strong electrical field.

1. Introduction

Liquid crystal displays (LCDs) have been extensively studied and used for a wide range of display applications because of their several advantages such as light weight, low power consumption, high resolution, and so on. In particular, the advances in liquid crystal (LC) materials and display technologies have led to the development of fast response time for reducing image blur. However, these LC modes still have a lack of the electrical switching characteristic which is not fast enough to obtain the fast moving picture and three-dimensional displays.

On the contrary, ferroelectric liquid crystal displays (FLCDs) have attracted great attention due to the fast electro-optic response resulting from a direct coupling between the spontaneous polarization of the FLCs and an electric field [1,2]. Especially, the vertically aligned (VA) structure of deformed-helix FLCs (DHFLCs) has attracted interest in display and fiber-optic applications since its excellent features such as fast response time and complete dark state [3,4]. In the VA-DHFLC, the in-plane switching electrodes were used for electro-optic switching [5]. In such configuration, however, the light leakage near the electrode edges was observed due to the irrecoverable layer deformation by the strong vertical field [4,6].

In this work, we propose the VA-DHFLC device with the stabilized smectic layer against the field-induced deformation of the VA-DHFLCs with introducing the reactive mesogen (RM). After exposure of ultra-violet (UV) light, the polymerized RM structure enhanced the stability of the smectic layers against the vertical electric field on the edges of the in-plane electrodes. As a result, we could obtain the VA-DHFLC device with the stable operating characteristics even under a strong electrical field.

2. Experiment

The FLC material used here was KCFLC3 (Kingstone Chemicals Limited) with helical pitch (> 8 μm). The phase transition sequence is as follow: isotropic (115 °C) → N* (96.5 °C) → SmA (82.0 °C) → SmC*. The spontaneous polarization and the molecular tilt angle are P_s = 23 nC/cm^2 and θ_t = 22.5°, respectively. To create a short helical pitch (≤ 0.2 μm), a chiral dopant was added to the FLC. For polymer structure, the RM (1 wt.%, RM257, E. Merck) was mixed into the DHFLC mixture. The polyimide (PI) of AL1H659 (Japan Synthetic Rubber Co.) was coated on the glass substrate with inter-digital electrodes of the indium-tin oxide (ITO), whose width and interval were 10 and 15 μm, respectively. The PI coated substrate was cured at 180 °C for 1 h to promote a homeotropic alignment. The cell gap was maintained using glass spacers of 4 μm. The DHFLC mixture was filled into the sandwiched cell by a capillary action near 140 °C (transition temperature to the isotropic state of DHFLC mixture). The assembled cell with RM was irradiated with UV light (0.027 mW/cm^2 at a wavelength of 365 nm) at 60 °C (SmC* phase) for 4 h for polymerization.

3. Results and Discussion

Figure 1 shows the schematic diagram of our VA-DHFLC configuration with the RM. In the absence of an applied electric field, the VA-DHFLC structure exhibits an optical isotropy since its helical pitch is smaller than visible light. When no electric field is applied, a completely dark state is obtained under crossed polarizers. On the other hand, in the presence of the in-plane electric field, the FLC molecules are gradually unwound on the smectic cone due to the interaction between the spontaneous polarization and the external electric field [7]. In such circumstance, the azimuthal symmetry of the molecular distribution (isotropy) is broken and thus birefringence is produced in the FLC layer.

In general, a high voltage was required to obtain a large birefringence enough to reach a maximum bright state. However, the high applied voltage in the in-plane electrode structure inevitably produces the strong vertical field near the edges of the electrodes. The strong vertical field gives rise to the undesirable deformation of the smectic layers, which degrades the electro-optic (EO) properties of the devices. To suppress the smectic layer deformation by the vertical field, the polymer structure was introduced. The polymer structure was achieved by mixing the RM monomers into the DHFLCs and exposing UV light to the RM-DHFLC mixture as shown in Fig. 1.

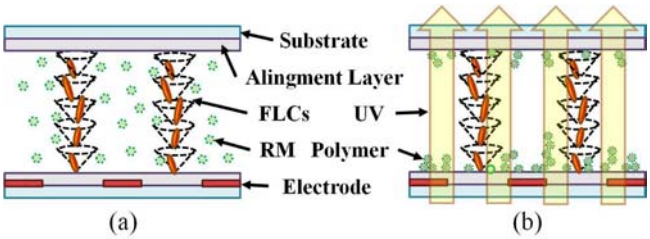

Fig. 1 The fabricating procedure of the VA-DHFLC with the RMs. (a) The RM-DHFLC mixture was injected into the sandwiched cell and (b) UV light was exposed to the cell for the polymerization.

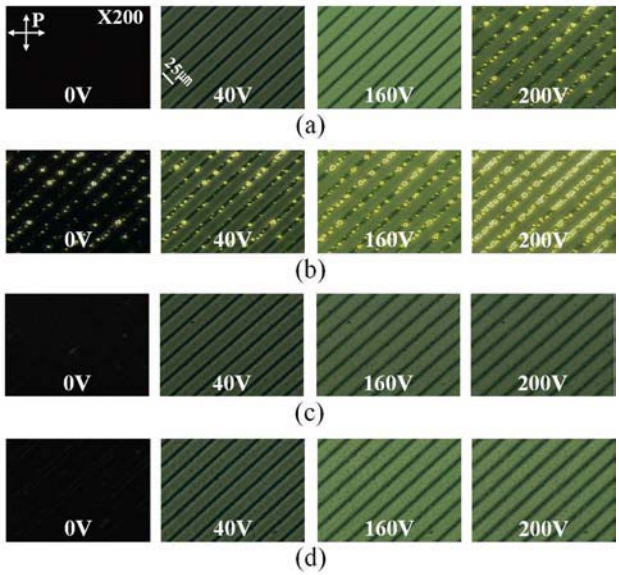

Fig. 2 The microscopic textures of experimental cells: the conventional VA-DHFLC cell as a function of the applied voltage (from 0 to 200 V) (a) at first operation and (b) at second operation. The proposed VA-DHFLC cell as a function of the applied voltage (c) at first operation and (d) at second operation.

Figure 2 shows the microscopic textures under crossed polarizers of the conventional VA-DHFLC cell and the polymer-stabilized VA-DHFLC cell for various applied voltage from 0 to 200 V (13.3 V/μm). At first, the conventional VA-DHFLC cell was stable up to the driving voltage of 160 V and then LC alignment break occurring along the borders of the operating region at the applied voltage of 200 V, as shown in Fig. 2(a). Secondly, the defect of LC alignment still existed on electrode even in the voltage-off state [Fig. 2(b)]. The broken alignment was gradually increased as increasing the applied voltage, as shown in Fig. 2(b). The broken alignment was not recovered by itself except for thermal annealing process. The defects are produced by the strong vertical field on the electrodes edge due to the irrecoverable layer deformation by the strong vertical field [4, 6].

In contrast, the stable LC alignment on proposed VA-DHFLC was observed up to the applied voltage of 200 V as shown in Fig. 2(c). Also, the polymer-stabilized VA-DHFLC exhibited the stable LC alignment even under repeatedly applied voltage as shown in Fig. 2(d). The polymeric structure enhanced the stability of the smectic layer against the vertical electric field and thus the reliable switching characteristics were obtained by introducing the polymer structure.

4. Conclusion

We proposed a polymer-stabilized VA-DHFLCD with the stabilized smectic layers against the field-induced layer deformation. The smectic layer was stabilized by the polymerization of the RM mixed into the DHFLC. The polymer structure suppressed the layer deformation near the edges of the electrodes. As a result, in our polymer-stabilized VA-DHFLCD, the reliable EO properties were achieved even under high applied field.

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