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Flexible bistable chiral splay nematic display mode using reactive mesogens

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Proposed herein is a flexible bistable chiral splay nematic display mode with an enhanced memory retention time under external distortion. By adopting the polymerized reactive-mesogen structure mixed in a liquid crystal layer, local anchoring energy is generated on the boundary between the polymer structures, and the relaxation from the π-twisted state to the initial splay state could be interrupted. As a result, the memory retention time becomes significantly longer, and the stability against the external distortion is enhanced.

Keywords: BCSN-LC; dual mode; retention time; flexible display; reactive mesogen

1. Introduction

In the present age of the rapid spread of digital information, the significance of the individual mobile display has been magnified. Among the diversified display technologies for mobile applications such as multifunctional smartphones, subcompact laptops, and multimedia players with other functionalities, the bistable chiral splay nematic liquid crystal (BCSN-LC) mode is focused on due to its functionality as a dual-dome liquid crystal display (LCD) – that is, the dynamic and memory modes [1,2]. The BCSN-LC mode can be switched between the dynamic mode, an optically compensated bend mode with fast switching characteristics, and the memory mode, a twist nematic mode with a long retention time [3,4]. Between these two LC modes, the memory mode has considerable significance because it is responsible for displaying the texture or still images with low power consumption, which is expected to agree fully with the requirements of mobile display devices. Until now, however, the memory retention time determined by the stability of the π-twisted LC arrangement is limited despite the utmost efforts that have been exerted to extend it, such as the development of the multidimensional alignment method [5–7]. Yet the permanent memory retention time could not be achieved in the BCSN-LC mode. Moreover, when applying the BCSN-LC mode on the flexible applications [8], its memory characteristic might be impeded under external distortion.

In this paper, the flexible BCSN mode is proposed using polymerized reactive mesogen (RM) in a π-twisted state to improve the memory retention time under external distortion. In the BCSN-LC mode, the π-twisted state could be obtained through LC relaxation after eliminating the vertical electric field over the high-bend LC state and be returned to the initial splay state after a certain time. When the BCSN-LC cell with RM monomers in the LC layer was exposed to UV light at the stable π-twisted state, the polymer network structure was formed along the LC molecules that had a π-twisted alignment and acted as an obstructer that disrupted the return to the initial splay state. As a result, the memory retention time of a flexible BCSN-LCD device could be improved even under external deformation.

2. Cell preparation for the experiments

Figure 1 shows the schematic diagram of the fabrication processes for the flexible BCSN-LC device with the RM network structure. The previous step of the process involved two plastic (as polycarbonate) substrates deposited with indium tin oxide for a transparent electrode being coated with a polyimide (PI) alignment layer (AL22620, JSR Inc.) for planar LC alignment to the substrates. The spin-coated PI layers were soft-baked to an evaporate solvent under 100°C for 10 min and were cured to polymerization under 210°C for 1 h. The alignment layer was rubbed for unidirectional LC alignment. For the stabilization of the LC alignment, column-shaped microstructures with 200 μm periodicity were formed on the alignment layer through the conventional photolithography process. The designed microstructure had four columns with 5 μm height, and the diameter and lateral spacing of the microstructures were 15 and 10 μm, respectively. The interval between the rigid spacers was 150 μm. The commercial negative

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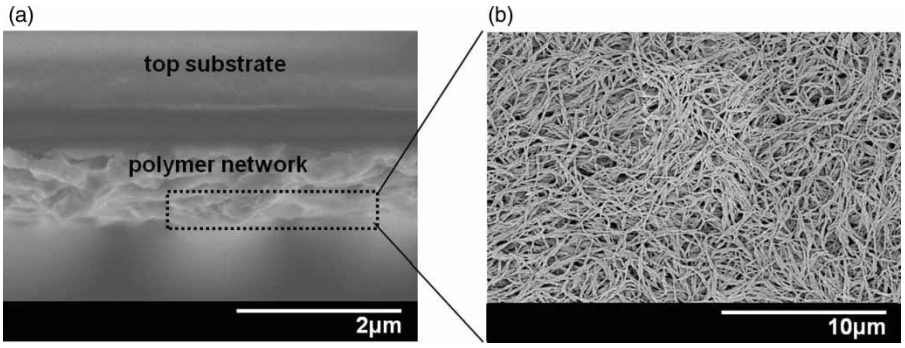

Figure 2. FESEM images of the polymer networks formed in the fabricated BCSN-LC cell: (a) cross-section image and (b) surface image from the normal to the top after splitting the top and bottom substrates.

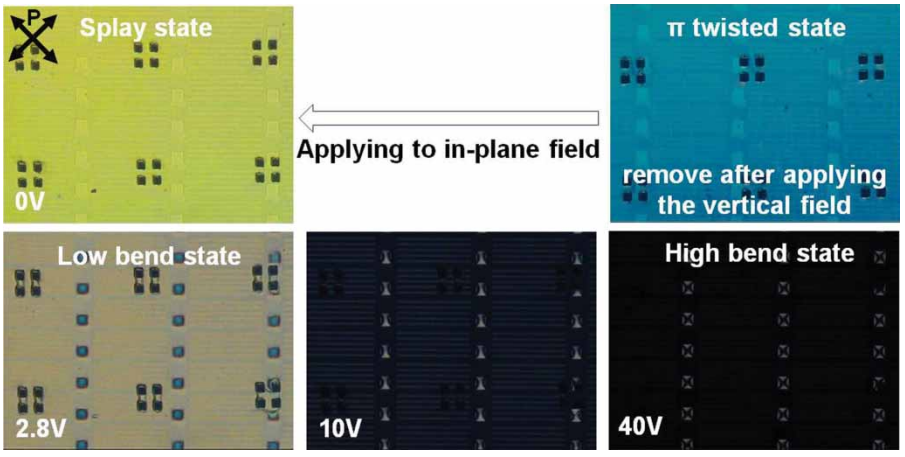

Figure 3. Microscopic textures of the driving properties between two stable states in the proposed flexible BCSN device.

the dynamic mode, the BCSN-LC device switched between the bright low-bend state at a low voltage (2.8 V) and the dark high-bend state at a higher voltage (40 V). After removing the high electric field, the LC molecules were rearranged to the π-twisted state. The π-twisted state presents the memory state. To switch the π-twisted state to the splay state, a horizontal fringe field generated by applying 30 V between the patterned electrodes was used. After removing the horizontal fringe field, the fabricated BCSN-LC cell was relaxed to the initial splay state.

Generally, when the flexible LC device undergoes external distortion such as bending and pressing, it is hard to retain its electro-optic (EO) characteristics due to the change in the cell gap. That is, the LC molecules are severely distorted, and the EO characteristics, such as the transmittance of the LC device, are dramatically changed by the dependence on a degree of external distortion. To confirm the stabilized optical characteristics of the proposed flexible BCSN-LC cell, the reliability of the EO characteristics was investigated in the memory mode. First, the transmittance changes at the memory state were measured with the 1000-time bending distortion of $R = 2.5$ cm (R is the radius of the bending curvature) and with the 1000-time pressing distortion of 3 N/cm^2 pressure. The initial transmittance in the memory mode could be maintained against the repeated bending deformation within 5%, as shown in Figure 4. This means that the LC alignment is stabilized at the π-twisted state and is not considerably changed under repeated bending and pressing distortion by the rigid wall structures and RM networks.

To compare the stability of the proposed flexible BCSN-LC mode with that of the conventional one, the retention time of the memory state was estimated by measuring the transmittance after the 1000-time bending distortion of $R = 2.5$ cm. The three prepared cells were conventional BCSN cells without an RM polymer network structure and the proposed BCSN cell with an RM polymer structure before/after bending distortion. As the rubbing direction was parallel to the input polarizer, the splay state was shown to be dark under the crossed polarizers. Thus, if the memory state collapses to the splay state, the transmittance should show a dark state. Figure 5 shows the retention time characteristics of the memory state for the three BCSN cells. The retention time of the BCSN-LC cell with the RM network structure was three times longer than that of the normal BCSN cell without RMs. Besides, the enhanced memory retention time of the proposed device with RM networks was hardly changed after considerable bending

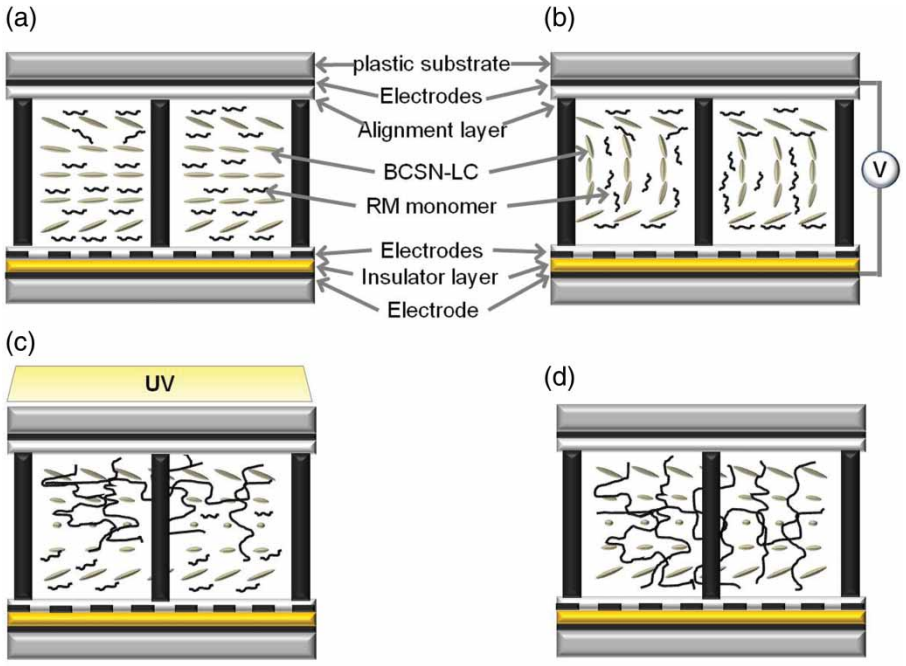

Figure 1. Schematic diagram of the fabrication for achieving a flexible BCSN-LC device: (a) the initial splay state in the BCSN-LC mode with LC and RMs; (b) LC reorientation in the high-bend state by the vertical electric field; (c) UV irradiation in the π-twisted state after the removal of the vertical electric field; and (d) π-twisted state of the BCSN-LC mode with polymerized RM networks.

photoresist of SU-8 2005 (MicroChem Co.) was used for the microstructures. The SU-8 2005 photoresist was spin-coated on the bottom plastic substrate and was soft-baked at 100°C for 2 min to remove the solvent in the resist layer. The Xenon lamp (365 nm, 300 W) that was used as a light source was exposed for 15 s. After irradiating the UV light, the substrate with microstructures was heated at 100°C for 10 min and was developed with MicroChem's SU-8 developer. Under the optimized pressing and thermal curing conditions, a bottom substrate with microstructures was assembled in parallel-rubbed directions with the top-rubbed PI substrate without the microstructure. Nematic LCs (ZKC-5085XX, Chisso Co.) and chiral dopant (R-811, Merck Ltd.) with the right-handed helical molecular sense were mixed to determine the tendency of twist formation of the LC molecules. The proportion of the cell gap to the pitch (d/p) was 0.18. A photoinitiator (1.4 wt%, Irgacure651, Ciba Specialty Chemicals Inc.) and an RM (3 wt%, Merck Co.) were added to an LC–chiral dopant mixture. The BCSN-LC mixture was stirred in an isotropic phase for 24 h. Through capillary action in the isotropic phase, the BCSN-LC mixture was injected between both substrates with a parallel-rubbed PI alignment layer to maintain the 5 μm cell gap. The BCSN-LC molecules of the experimental cell were aligned in the splay state due to the parallel-rubbed PI surface condition (Figure 1(a)). In the BCSN-LC cell, a 30 V and 1 kHz electric fields were applied for 10 s to transform the initial splay state to a high-bend state (Figure 1(b)). After removing the electric field, the LC molecules were relaxed to the π-twisted state with the topologically same phase as the high-bend state [9]. When the π-twisted state was stable, UV light (365 nm wavelength, 0.5 mW/cm^2 intensity for 30 min) was irradiated onto the cell to compose the polymer network structure with RM for stabilizing the π-twisted state in the LC mixture (Figure 1(c)). Through this process, a flexible BCSN-LC device with the proposed concept could be created.

3. Results and discussion

In the proposed flexible BCSN device, the polymer network structure formed via a UV irradiation process in the π-twisted state was expected to function as a supporter for the enhanced memory retention time. Figure 2 shows the field emission scanning electron microscopic (FESEM) images of the (a) cross-section and (b) surface of the RM network structure after washing off the LC molecules with hexane for 24 h. Through phase separation and polymerization of the RM monomers, a coarse 1.2-μm-thick polymer network was formed on the substrate adjacent to the UV light source. This RM network structure generated a local anchoring force to retain the π-twisted LC alignment in the partially small bulk region. Thus, a flexible BCSN-LC cell with an improved memory retention time could be manufactured.

Figure 3 shows the polarizing microscopic textures of the operating characteristics in the fabricated BCSN-LC cell. The initial splay state was bright under the crossed polarizers as the rubbing direction was rotated by 45° to the transmission axes of the crossed polarizers. For driving in

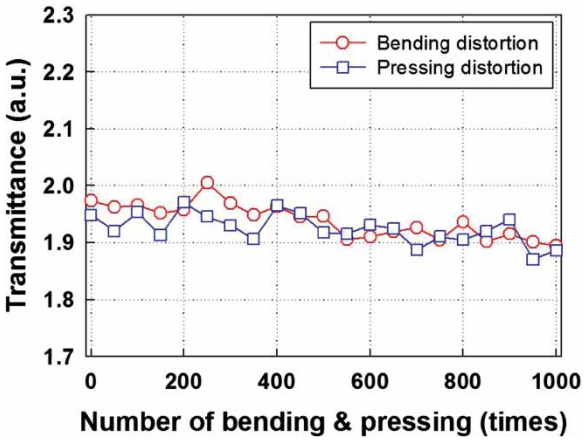

Figure 4. The measured transmittance in the memory mode of the flexible BCSN cell proposed in this work under repeated bending and pressing distortions.

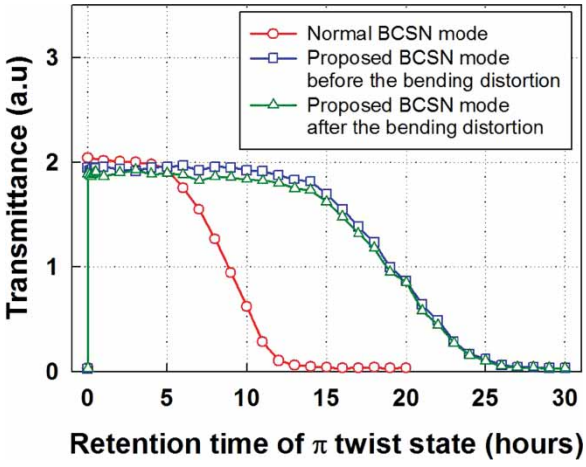

Figure 5. The measured transmittance in the memory mode of the flexible BCSN cell proposed in this work under repeated bending and pressing distortions.

distortion. Eventually, the proposed flexible device could obtain enhanced memory characteristics through the RM networks that generate local anchoring energy to retain the π-twisted LC mode. Moreover, the rigid wall and polymerized RM network structures could sustain the stable EO characteristics from the external distortions.

4. Summary

In this work, a flexible BCSN-LC device with an enhanced retention time of the memory mode was proposed. The polymerized RMs in the LC layer were formed by the polymer network structure along the alignment of the LC molecules, which had a π-twisted structure and which generated local anchoring energy at the boundary between the RM polymer and the LC molecules. As a result, the retention time of the memory mode could be greatly enhanced and the memory state remained highly stable even under external distortion. In addition, by adopting the polymer network structure, large process margins such as the d/p, cell gap, and material constants of LCs, which are very sensitive to the normal BCSN mode without RMs, could be obtained to realize the dual mode. It is expected that the proposed device will prove to be very useful for flexible displays with low power consumption.

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