Flexible bistable chiral nematic liquid crystal display with enhanced memory characteristic by surface treatment

Kwang-Soo Bae (Student Member)
Minju Kim
Yeon-Kyu Moon (Student Member)
Youngsik Kim
Chang-Jae Yu (SID Member)
Jae-Hoon Kim (SID Member)

Abstract — We proposed a flexible bistable chiral splay nematic liquid crystal display with the enhanced memory characteristics by the surface treatment with reactive mesogen (RM). With the polymerized RM structure on alignment layers adopted, the energy barrier between splay and π-twisted states in the bistable chiral splay nematic liquid crystal mode is increased because of the enhancement of the azimuthal anchoring energy, and thus, the spontaneous relaxation from the π-twisted state to the initial splay state is remarkably impeded. As a result, the memory retention time became twice as long as that of the conventional cell without the polymerized RM structure, and the stable memory characteristics were maintained against the external deformation.

DOI # 10.1002/jsid.110

1 Introduction

The significance of the individual mobile display has been emphasized in the rapidly changing digital era. Several technologies have been developed for mobile applications such as subcompact laptops, multifunctional smartphone, and multimedia players. Among these, a bistable chiral splay nematic liquid crystal (BCSN-LC) display comes into the spotlight because of its dual operating feature of the dynamic and memory modes.[1,2]

The BCSN-LC display 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 bistability of the bounded liquid crystal (LC) cell with a chirality.[3–5] Especially, the memory mode of the BCSN-LC display has considerable significance in the mobile display devices for displaying textures and/or still images because of its low power consumption. However, the memory retention time in the memory mode, governed by the stability of the π-twisted LC arrangement, is still limited despite various efforts such as the multidimensional alignment method.[6–8] Moreover, in the BCSN-LC mode for flexible applications, the memory characteristics might be readily degraded under external deformation.

In this work, we propose a flexible BCSN-LC display with an improved retention time in a memory mode with the introduction of the polymerized reactive mesogen (RM) structure on alignment layers. In general, the π-twisted state in the BCSN-LC display is obtained through LC relaxation after elimination of a vertical electric field at a high-bend LC state. This π-twisted state is gradually returned to the initial splay state because the splay state has lower energy state than the π-twisted state. The polymerized RM structure increases the azimuthal anchoring energy on alignment layers, which gives rise to a large energy barrier between the splay and π-twsited states. That is to say, the polymerized RM structure impedes the relaxation process from the π-twisted state to the splay one since the enhanced energy barrier. Eventually, we could obtain the enhanced memory characteristics of a flexible BCSN-LC display, and these excellent charactericties could exhibit under the external distortion.

2 Experiment

Figure 1 shows a schematic diagram of the proposed flexible BCSN-LC cell in crossed section. The plastic (as polycarbonate) substrates evaporated with indium tin oxide were coated with a polyimide alignment layer (AL22620, JSR Inc., Japan) for planar LC alignment. The spin-coated polyimide layers on substrates were soft-baked to evaporate a solvent under 100 °C for 10 min followed by hard-baked to polymerize under 200 °C for 1 h. For maintaining the cell thickness and stabilizing the LC alignment against an external distortion, columm-shaped microstructures with 200 μm peoridicity were formed on the alignment layer on the bottom substrate by the photolithography process with photo resist (SU-8 2005, MicroChem, USA). The height and diameter of the microstructure are 5 and 15 μm, respectively. The alignment layers were rubbed for unidirectional LC alignment. For introducing the polymerized RM structure on the alignment, the RMs (0.7 wt.%, E. Merck, Korea) and the photo-initiator (0.1 wt.%, Irgacure651, Ciba Specialty Chemicals, Japan) were dissolved in propylene glycol monomethyl ether acetate, and the RM mixture was spin-coated on the rubbed homogeneous alignment layer. After baking the substrate at 60 °C for 90 s to evaporate solvent, ultraviolet light (365 nm, 1.0 mW/cm^2) was exposed to polymerize the RMs along the rubbing direction. The treated plastic substrates were assembled by thermal pressing process with the same rubbing direction. Nematic LCs (ZKC-5085XX, Chisso, Japan) and chiral dopant (R-811, E. Merck, Korea) with a right-handed helical sense were mixed to generate a twist configuration of the LC molecules. The

Kwang-Soo Bae, Yeon-Kyu Moon, Youngsik Kim, Chang-Jae Yu and Jae-Hoon Kim are with Department of Information Display Engineering, Hanyang University, Seoul 133-791, Korea; telephone +82-2-2220-0343, fax +82-2-2298-0345; e-mail: jhoon@hanyang.ac.kr
Minju Kim, Chang-Jae Yu and Jae-Hoon Kim are with Department of Electronic Engineering, Hanyang University, Seoul 133-791, Korea.

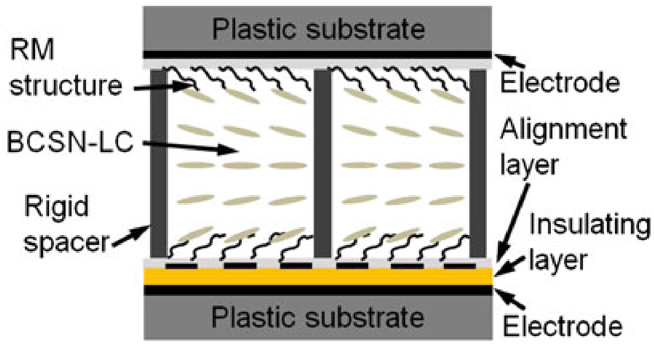

FIGURE 1 — The schematic diagram of the bistable chiral splay nematic liquid crystal (BCSN-LC) device with the polymerized reactive mesogen (RM) structure.

proportion of cell gap to pitch (*d/p*) is 0.2, which is more stable in splay state than in energy boundary condition in which *d/p* is 0.25 between splay and π-twisted state.[9] By capillary action near a nematic–isotropic transition temperature, the BCSN-LC mixture was injected into the sandwiched substrates.

3 Result and discussion

Figure 2 shows the atomic force microscopy images of the surfaces of the conventional cell without the RM structures and the proposed cell with them. Through the RM coating method,[10] the polymerized RM structure with submicrometer height could be formed on alignment layer. The RM structure was formed along the rubbing direction on surface as shown in Fig. 2(b). It is expected that the azimuthal anchoring energy enhanced by RM structure can increase the energy barrier and improve the memory retention time.

For comparing the memory characteristics, we prepared two kinds of flexible BCSN-LC cells with/without polymerized RM structure. The memory characteristics were determined through observing the microscopic textures at the π-twisted state as shown in Fig. 3. In splay state with the rubbing direction coincided with the transmission axis of one of crossed polarizers, the BCSN-LC cells exhibit the dark state. With an external vertical field eliminated, the π-twisted state (bright state) could be achieved in the general BCSN-LC cell. In the RM-structured BCSN-LC cell, the π-twisted state was slowly transited to the splay state as shown in Fig. 3. Whereas the π-twisted state in the conventional cell was maintained for 10 h, that in the RM-structured cell was maintained for 20 h. Generally, the energy barrier between bistable states must be large enough to prevent thermal activation and consequent spontaneous transition.[11] Assuming that the energy barrier between the π-twisted and splay states in BCSN-LC display is quite low, the rapid relaxation from the π-twisted to splay states occurred. In our case, the higher energy barrier, enhanced by the azimuthal anchoring energy originated from the polymerized RM structure, impedes the spontaneous transition and gives rise to the remarkably improved memory characteristics as shown in Fig. 3.

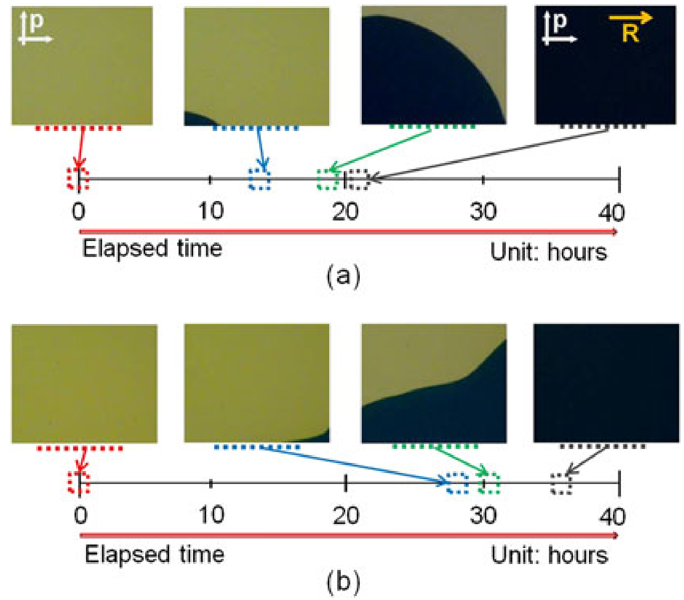

FIGURE 3 — The time-varying textures as the elapsed time of the π-twisted state of (a) the conventional bistable chiral splay nematic liquid crystal cell and (b) the proposed bistable chiral splay nematic liquid crystal cell with the surface treatment.

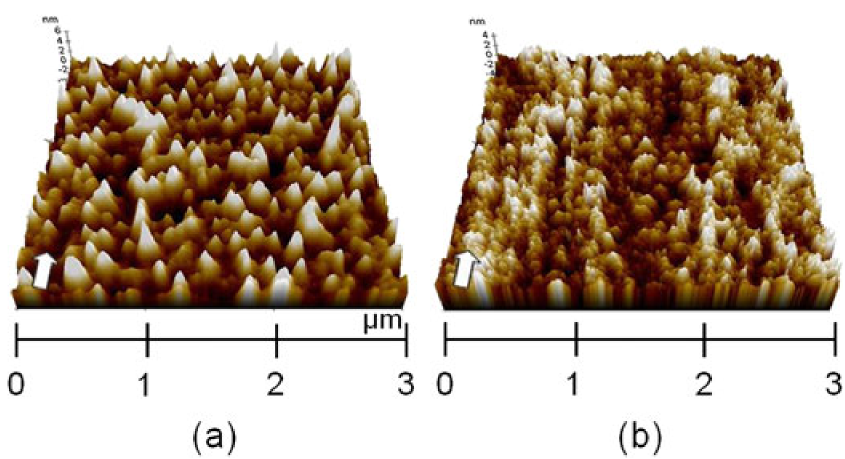

FIGURE 2 — Atomic force microscopy images on the surface of the fabricated BCSN-LC cell: (a) the conventional cell without the polymer structure and (b) proposed cell with it.

When the flexible LCD undergoes external distortions such as bending and pressing, it is hard to maintain its stable electro-optic characteristics, like the transmittance of the LC device, because of the distorted LC alignment by change of the cell thickness. To confirm the stabilization of the memory characteristics of the proposed flexible BCSN-LC cell, the transmittance reliability of the π-twisted state against the external deformation was investigated. First, the transmittance variations at the memory state were measured up to 1000 times bending distortion with $R = 2.5$ cm (R is the radius of the bending curvature) and 1000 times pressing deformation with 3 N/cm^2 pressure. The initial transmittance could be maintained within 5% against the repeated bending deformation as shown in Fig. 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. Also, the memory retention time of the proposed flexible BCSN-LC cell was investigated by measuring the transmittance change after bending deformation. We measured time-varying transmittances of the three cases: a conventional BCSN-LC cell without the polymerized RM structure and the RM-structured BCSN-LC cell before and after bending deformation. As shown in Fig. 5, the memory retention time of the BCSN-LC cell with the RM structure was three times longer than that of the conventional cell. Also, the enhanced memory retention time of the proposed device with RM structure was exhibited even after bending distortion. As a result, our cell could achieve the enhanced memory characteristics through the RM structure, and this remarkable feature could be retained against the significant external distortions.

We fabricated a prototype of a 2-in flexible BCSN-LC device as shown in Fig. 6. In the directly patterned electrodes of characters "HYU" and "DDLAB", the vertical field of 20 V was applied and removed. Therefore, the characters "HYU" and "DDLAB" are represented as the π-twisted state and exhibit the bright states. On the other hand, the other regions remain at the initial splay state and show the dark states.

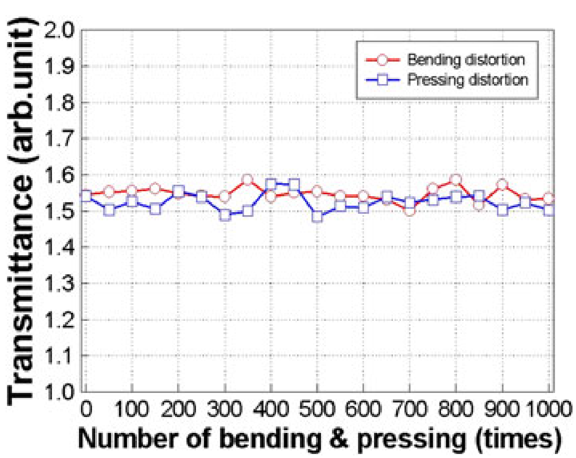

FIGURE 4 — Transmittance in the memory mode of a flexible bistable chiral splay nematic liquid crystal cell under the repeated bending and pressing deformation.

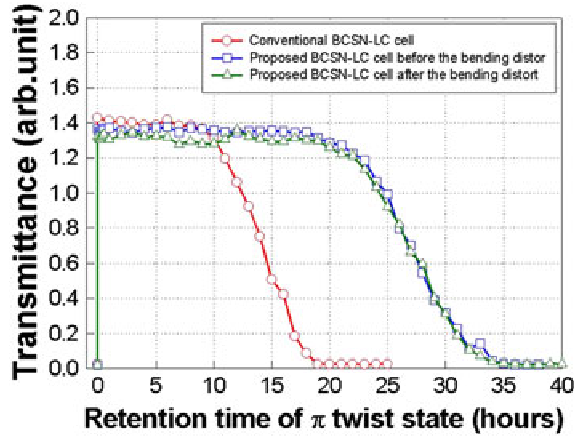

FIGURE 5 — Measured retention times in memory mode of the conventional flexible bistable chiral splay nematic liquid crystal (BCSN-LC) cell without deformation, and the reactive mesogen-structured cell before and after bending deformation.

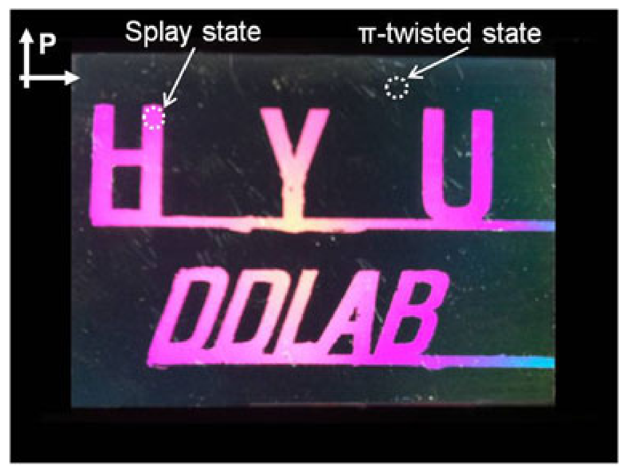

FIGURE 6 — The 2-in bistable chiral splay nematic liquid crystal prototype with directly patterned electrodes of characters "HYU" and "DDLAB".

4 Conclusion

The flexible BCSN-LC device with the enhanced memory characteristics by the surface treatment was demonstrated. The flexible BCSN-LC device proposed here could be operated in more stable memory mode through the increased energy barrier between splay and π-twisted state by the polymerized RM structure on the surface alignment layers. These memory characteristics were also retained even though the external deformation was applied. In conclusion, our study for the improved memory retention time of a flexible BCSN-LC device could overcome the limitation of parameters, which are very sensitive to the normal BCSN-LC device with large process margins, such as the d/p, cell gap, and material constants of LCs. It is expected that the flexible device proposed in this work could be applicable to the next generation mobile display with the low power consumption.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 20110016968) and a grant from Samsung Electronics, Co. Ltd.

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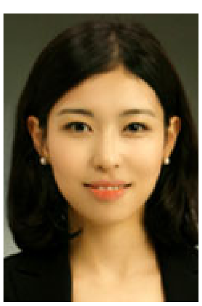
Kwang-Soo Bae received his BS degree in Material Science and Engineering from Ajou University in 2006 and MS degree in Information Display Engineering from Hanyang University in 2008. In 2008, he joined the Department of Information Display Engineering in Hanyang University, Seoul, Korea. His major research interests novel optical devices including display devices using liquid crystals.



Minju Kim received her BS degree in Electronics Engineering from Chungbuk National University in 2011. In 2011, she joined the Department of Electronics and Computer Engineering of Hanyang University, Seoul, Korea, as an MS candidate. Her main research interests include optical devices and display devices using liquid crystals.

Yeon-Kyu Moon received his BS and MS degrees in Material Science and Engineering from Hanyang University, Korea, in 2000 and 2002, respectively. In 2009, he joined the Department of Information Display Engineering of Hanyang University as a PhD candidate. His main research interests include device physics of liquid crystals and display devices using liquid crystals.

Youngsik Kim received his BS degree in Metallurgical Engineering in 1998 and his MS degree in Material Science and Engineering in 2000 from Hanyang Univesity, Seoul, korea. From 2000, he has been with LG Display, Gumi, Korea, where he has been involved in LCD Panel design. In 2011, he joined the Department of Information Display Engineering of Hanyang University as a PhD candidate. His research activities include the device physics of liquid crystals and its mixtures, and surface/interface control.

Chang-Jae Yu received his BS and MS degrees with an honor of Summa Cum Laude in physics from Sogang University, Seoul, Korea, in 1996 and 1998, respectively. He received his PhD degree in Electrical Engineering from Seoul National University, Seoul, Korea, in 2005. From 2006 to 2007, he joined Material Research Laboratory at University of Illinois at Urbana-Champaign, USA. Since 2007, he has been an Assistant Professor in the Department of Electric Engineering, Hanyang University, Seoul, Korea. His main research interests include display and photonic devices using liquid crystals.

Jae-Hoon Kim received his BS degree from Sogang University, Seoul, Korea, in 1987, his MS degree from the University of Oregon, Eugene, and his PhD degree from Sogang University, in 1996, all in physics. He formerly worked at the Liquid Crystal Institute, Kent State University, Kent, OH, as a Research Associate from 1996 to 1999. From 1999 to 2000, he was with Samsung Electronics, Giheung, Korea, where he was involved in the development of patterned vertical alignment liquid crystal displays. In 2000, he joined the Department of Physics of Hallym University, Chuncheon, Korea, as an Assistant Professor. Since March 2004, he has been a Professor in the Department of Electric Engineering, Hanyang University, Seoul, Korea. His main research interests include display and photonic devices using liquid crystals.