P-122: Fabrication of Single Substrate Flexible LCD by Laminating Functional Polymer Cover Film

Kwang-Soo Bae[1], Hak-Rin Kim[2], Young Min Kim[3], and Jae-Hoon Kim[*1,4]

[1] Department of Information Display Engineering, Hanyang University, Seoul 133-791, Korea

[2] School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu 702-701, Korea

[3]Department of Electronics and Electrical Engineering, Hongik University, Seoul 121-791, Korea

[4] Department of Electronics and Computer Engineering, Hanyang University, Seoul 133-791, Korea

Abstract

We proposed a lamination process of a polymer film with a photo-curable polymer for fabricating flexible liquid crystal (LC) displays on single substrate. In our structure, a cover film layer was tightly attached to the polymer wall structure of a bottom plastic substrate after lamination, and LCs were uniformly aligned by grooves formed on the laminated cover film.

1. Introduction

Flexible displays have attracted much attention due to their good portability such as light weight, thin packing, and flexibility. Among currently available competing technologies, flexible liquid crystal displays (LCDs) are considered to be the most promising ones, in that they have well-established techniques guaranteeing superior visibility with low power consumption. The serious obstacles to successful commercialization of flexible LCDs have been highly nonuniform electro-optic (EO) properties under external mechanical distortions on the plastic substrates, which originated from LC distortion or cell gap variation [1, 3, 4, 5].

Our recent results showed that such problems could be effectively solved by using pixel-isolated liquid crystal (PILC) mode [4, 5], where the stabilization of LC modes and the cell gap uniformity were provided by polymer wall structures. However, previous works required cumbersome anisotropic phase separation from LC/polymer mixtures to make polymer wall structures or to attach the polymer wall structures on one plastic substrate to the other plastic substrate [4, 6, 7].

Therefore, several efforts have been devoted to the development of a simple fabrication process for stable flexible LCDs. Among them, fabrication methods of flexible LCDs on single plastic substrate are regarded to be very suitable ones in applying cost-effective roll-to-roll process [8-10]. In this work, we demonstrate that the PILC mode can be simply obtained by laminating functional cover film, where the top cover film is tightly attached to the polymer wall structures of the bottom plastic film via photo-polymerization and the LCs are well-aligned by the patterned groove structure on the cover films. The proposed lamination method can be achieved by laminating a photo-curable polymer film layer from surface modified elastomeric buffer layers. With the method, it is expected that stable flexible LCDs can be simply fabricated via a cost-effective roll-to-roll mass production.

2. Experimental

Figure 1 shows the schematic diagram of proposed single substrate LCD with laminating polymer cover film. Interdigital electrodes are patterned on a plastic substrate to produce in-plane field in the LC layer. The LCs in our structure are operated by in-plane electric field since the laminated cover film layer does not have electrode.

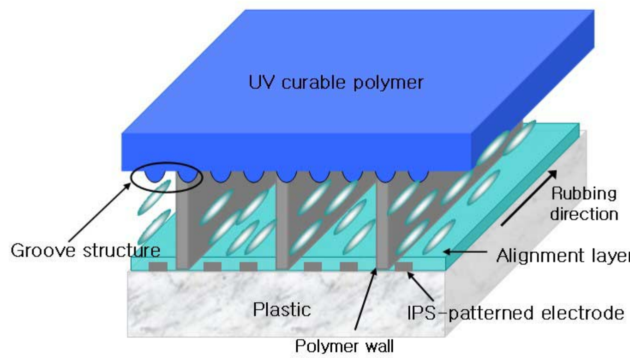

Figure 1. The schematic diagram of proposed single substrate LCD with laminating polymer cover film

The width and the spacing of the electrodes were 10 μm and 30 μm, respectively. Then, for isolating LC molecules and supporting the cell gap uniformity, patterned polymer wall structures are formed on the plastic substrate with electrodes, where the wall structure is formed so that the direction of the walls is 45^{o} with respect to the in-plane field direction. The width and the height of the wall structures were 30 μm and 8 μm, respectively. The spacing between the wall structures in a periodic line type was 100 μm. In our experiment, the polymer wall structure was fabricated by photolithographic method with photoresist, SU-8 (MicroChem. Co.), but the pixel-isolating wall structure can be made by the stamping method, as reported in our previous research [5]. On the plastic substrate, a LC alignment polyimide (PI) layer is spin-coated and cured. In our experiment, RN1199 (Nissan Chemical Ind., Ltd.) was used for a homogeneous LC alignment PI. The rubbing direction (R) of the PI surface was chosen along the wall direction to reduce LC distortion induced by the geometrical effect on LC anchoring of the polymer wall structure. The polymer cover film is laminated on the polymer wall structure of the bottom plastic film by roll pressing. And the film has groove structure for anchoring LC molecule, where the

ISSN/007-0966X/07/3801-0661-$1.00 © 2007 SID

groove direction (G) of the NOA65 film is parallel to R in our demonstration. Therefore, in field-off state, the initial LC texture has a uniform planar geometry. The polymer cover film is fabricated by rigid flat surface (glass substrate is used in our experiment). First of all, the elastomeric PDMS layer is uniformly formed by spin-coating. The PDMS surface is highly hydrophobic, thus no material can be coated uniformly on the PDMS in itself. After slightly weakening its hydrophobicity by O_2 plasma treatment, we can obtain uniform coating of the photo-curable prepolymer (NOA65). On the spin-coated NOA65 film, UV is irradiated in a short period to reduce photo-initiator density near the NOA65 surface and the fluidicity of the film. Then, groove patterns are imprinted on the weakly cured NOA65 film with a patterned PDMS mold by the replica molding method. The periodicity of the groove was 4 μm. The surface of the patterned PDMS mold is not chemically modified. After stabilizing the imprinted groove pattern on the NOA65 film by UV exposure, the patterned PDMS mold structure is removed from the patterned NOA65 film. Since the surface property of the patterned PDMS mold is not changed, while the supporting PDMS film is chemically modified, there is adhesion difference between the top interface and the bottom interface of the NOA65 film, thus the mold can be easily removed from the NOA film keeping the adhesion to the bottom supporting film. After removing the mold structure, the NOA65 is further polymerized to the extent that the polymerization is not fully executed. Finally, the patterned photo-polymer film in partially cured state for our lamination process is prepared on the flexible supporting film.

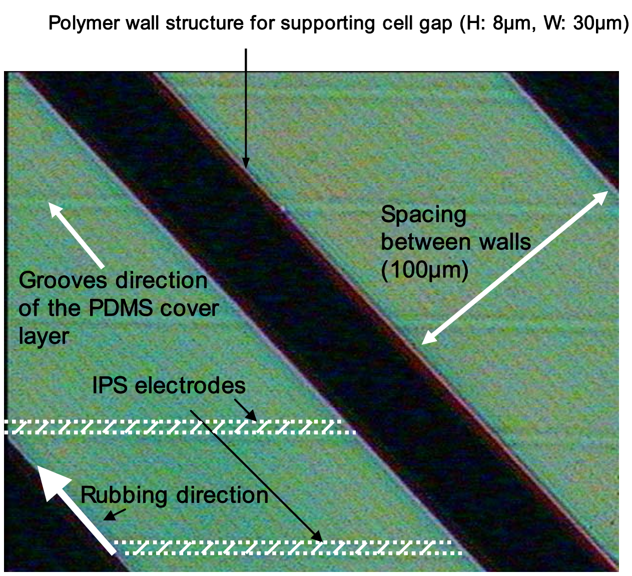

Figure 2. The polarizing microscopic image of the laminated single-substrate LCD, where both of the rubbing direction of the LC alignment layer on the bottom plastic substrate and the groove direction of the top photopolymerized film are 45^o with respect to the transmission axis of the polarizers.

The cured NOA65 film has two roles. One is to provide a boundary surface to confine flow-like LC molecules in a uniform cell thickness with tight adhesion to the top of the polymer wall structure through the photo-polymerized molecules. The other is to work for stable LC anchoring surface through the imprinted groove pattern. In these procedures, the PDMS buffer layers have merits in that the surface energy can be easily modified and they have elastomeric properties which are essential in our lamination process. In addition, soft-lithographic patterns of geometric structures can be easily achieved, which is used for producing or modifying LC anchoring of the laminated film surface [11].

The final structure for confining LC molecules in the PILC mode is prepared by removing the PDMS layer followed by full curing of the photo-polymer with final UV exposure. In spite of the chemical modification of the supporting surface, the adhesion of the NOA65 film to the PDMS surface is still weak, thus the supporting film can be easily detached from the NOA65 film during the above process without giving damages on the attachment between the NOA65 film and the polymer wall structures.

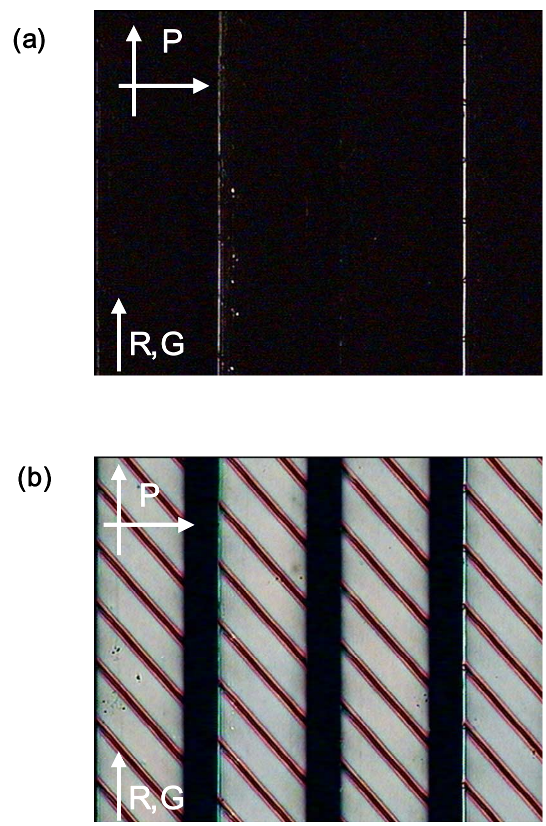

Figure 3. The microscopic images at applied voltages of (a)0V, (b)7V under the crossed polarizer, where the symbols of R, G, P denote the directions of the rubbing on the PI layer of the bottom substrate, grooves on the laminated top substrate, and the direction of the polarizer axis, respectively.

3. Results and Discussion

Figure 2 shows the microscopic image of the fabricated single-substrate LCD, observed between the crossed polarizers. Due to the micro-groove patterns on the laminated photopolymer film, uniform LC alignment could be observed. On the wall spacers, there was no light leakage, which showed that there was no infiltration of LCs in those areas during LC filing and the cover film layer was fully attached to the wall structures in our lamination process. Figure 3 shows the LC-aligning capability of the laminated top film and the electro-optic (EO) effects by the in-plane switching (IPS) electrodes. In Fig. 3, the LC orientation in the field-off state was parallel or orthogonal to the transmission axes of the polarizers. In the field-off state (Fig. 3 (a)), the initial texture showed the dark state because the LCs were aligned in a homogeneneously planar structure along our groove and the rubbing directions. At the boundary of the polymer walls, slight light leakage was observed, which might originate in the non-uniform attachment of the polymer film during lamination process. In our process, the lamination process was executed from the left to right direction in Fig. 3. As increasing the applied voltages (Fig. 3 (b)), the textures became brighter due to in-plane LC reorientation along the field direction. All the LC textures under the applied voltages were also highly uniform.

(a)

(b)

(c)

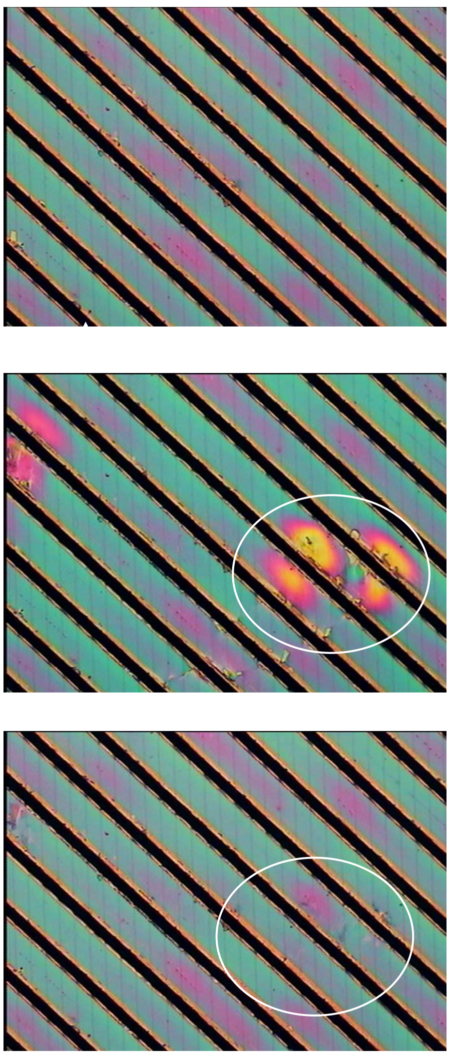

Figure 4. Alignment texture of (a) before and (b) after pressure and (c) passed 30 seconds with sharp tip.

We now describe the alignment stability of single substrate LCD against external mechanical press. Fig. 4 shows alignment texture before and after pressure with sharp tip. The area of the tip is about $0.7mm^2$. Right after the external pressure, we can see the color change due to the reorientation of LC director. After 30 seconds, the alignment is recovered and the alignment texture is exactly same as that of the sample before pressure. Even with various bending conditions, we confirmed that the electro-optic characteristics are not much changed.

Figure 5 shows the phototype single substrate LCD with bending. The contrast ratio and response time are about 130:1 and 20ms, respectively. From the results, we confirmed that we can fabricate stable flexible LCD with single substrate and the electro-optic characteristics are comparable to conventional LCD with glass substrate.

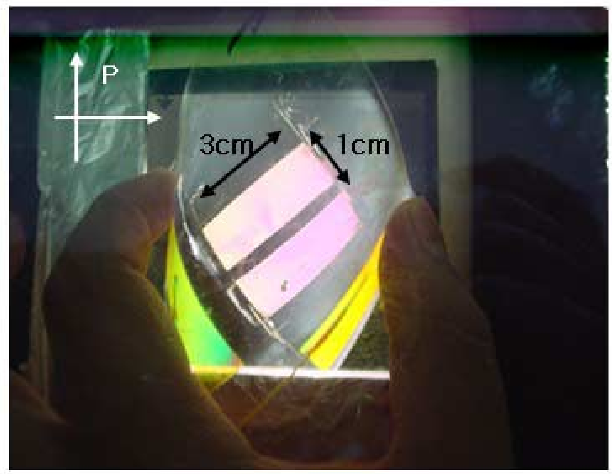

Figure 5. The prototype single substrate LCD with bending

4. Conclusion

We proposed a new fabrication method for fabricating flexible LCDs by lamination process. Our multi-functional cover film enables the PILC mode to be simply constructed without any additional attachment layer. Due to the azimuthal anchoring of the groove structure, any LC mode can be obtained if the flexible electrode is laminated under the cover film. With the proposed methods, fabrication of flexible LCDs can be achieved by roll-to-roll process on a single substrate.

5. Acknowledgements

This research was supported in part by Samsung co. Ltd. and the Korea Research Foundation Grant funded by the Korean Government .

6. References

[1] Y. Kim, J. Francl, B. Taheri and. J. L. West, "A method for the formation of polymer walls in liquid crystal/polymer mixtures", Appl. Phys. Lett., Vol. **72**, pp. 2253-2255, 1998.

[2] I. Kim, D. Kang, D. M. Agra-Kooijman, S. Kumar, and J.-H. Kim, "Fabrication of electro-optic devices using liquid crystals with a single glass substrate", J. Appl. Phys., Vol. **92**, pp. 7699-7701, 2002.

[3] H.Sato, H. Fujikake, Y. Iino, M. Kawakita, and H. Kikuchi, "Flexible Grayscale Ferroelectric Liquid Crystal Device

Containing Polymer Walls and Networks", Jpn. J. Appl. Phys., Vol. **41**, pp. 5302-5306, 2002.

[4] Y. Kim, J. Francl, B. Taheri and. J. L. West, "A method for the formation of polymer walls in liquid crystal/polymer mixtures", Appl. Phys. Lett., Vol. **72**, pp. 2253-2255, 1998.

[5] H.Sato, H. Fujikake, Y. Iino, M. Kawakita, and H. Kikuchi, "Flexible Grayscale Ferroelectric Liquid Crystal Device Containing Polymer Walls and Networks", Jpn. J. Appl. Phys., Vol. **41**, pp. 5302-5306, 2002.

[6] J.–W. Jung, S.-K. Park, S.–B. Kwon, and J.–H. Kim, "Pixel-Isolated Liquid Crystal Mode for Flexible Display Applications", Jpn. J. Appl. Phys., Vol. **43**, pp. 4269-4272, 2004.

[7] S.-J. Jang, J.-W. Jung, H.-R. Kim, M. Y. Jin, and J.-H. Kim, "Stability-Enhanced Pixel Isolation Method for Flexible Liquid Crystal Displays", Jpn. J. Appl. Phys., Vol. **44**, pp. 6670-6673, 2005.

[8] V. Vorflusev and S. Kumar, **"**Phase-Separated Composite Films for Liquid Crystal Displays", Science, Vol. **283**, pp. 1903-1905, 1999.

[9] T. Qian, J.–H. Kim, S. Kumar, and P. L. Taylor, "Phase-separated composite films: Experiment and theory", Phys. Rev. E, Vol. **61**, pp. 4007-4010, 2000.

[10] R. Penterman, S. I. Klink, H. D. Koning, G. Nisato, and D. J. Broer, "Single-Substrate liquid-crystal displays by photo-enforced stratification", Nature, Vol. 417, pp. 55 (2002).

[11] Y.-T. Kim, J.-H. Hong, T.-Y. Yoon, and S.-D. Lee, "Pixel-encapsulated flexible displays with a multi-functional elastomer substrate for self-aligning liquid crystals", Appl. Phys. Lett., Vol. **88**, pp. 263501, 2006.

[12] Y.-T. Kim, S. Hwang, J.-H. Hong, and S.-D. Lee, "Alignment layerless flexible liquid crystal display fabricated by an imprinted technique at ambient temperture", Appl. Phys. Lett., Vol. **89**, pp. 173506, 2006.

[13] Y. Xia and G. M. Whitesides, "Soft Lithography", Angew. Chem., Int. Ed. Vol. **37**, pp. 550-575, 1998.