The Laminating process for Single Substrate Flexible LCD

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Abstract

The laminating technique for developing flexible liquid crystal display was demonstrated by using a thin UV curable polymer film and a plastic substrate with patterned polymer wall structure. We adopted the rigid wall structure to provide a solid mechanical support for the stable molecular alignment of liquid crystals (LCs) in the device. The cover film was prepared to have an ability of aligning LC molecules by patterning a micro-groove structure using the soft-lithographic process. These two substrates can be assembled tightly by the laminating and one-step UV irradiation process because of the adhesive nature of the used UV curable polymers. Proposed method can be used to fabricate the flexible LC display with simplicity and also be applicable for a cost-effective roll-to-roll process.

1. Introduction

The flexible display can create the new-concept applications that can not be realized by the conventional display technologies using rigid glass substrates due to their exclusive attributes such as thinner packaging, lighter weight, flexibility, wearable properties, and lower manufacturing cost through continuous roll-to-roll process [1-4].

In recent days, among the numerous approaches for realizing the flexible displays, flexible liquid crystal displays (LCDs) substituting plastic substrate for conventional glass substrate in LCD technology gather the spotlight because of their good electro-optical characteristics and well-established processes. Particularly for making flexible LCDs lager and cheaper and more free in design, single substrate flexible LCDs have been developed constantly [5-10]. But, for the successful commercialization, the demerits such as complexity of the fabrication, defects in the pixel due to the residual polymers, and the weakness for the external mechanical shock should be solved to obtain high quality display performances.

In this work, we proposed the novel fabricating process for a single substrate flexible LCD by laminating a thin cover film of UV curable polymer. To maintain a uniform and constant cell gap of the device when the display is distorted mechanically, the periodic rigid walls were formed on the bottom plastic substrate in first step of the fabrication. Then the thin cover film is laminated with a soft-roller and is attached to the bottom structure by simple UV irradiation process due to the adhesive nature of used UV curable polymers. Due to the micro-grooves in the cover film prepared by the soft-lithographic process, this cover film can align the liquid crystal (LC) molecules homogeneously.

2. Experimental

Figure 1 shows the schematic diagram for preparing the thin cover film with the micro-grooves on the supporting flexible layer. We used commercial UV curable polymer of NOA 68 from Norland Products as the cover film due to its great flexibility and chemical durability. The PDMS (poly-dimethysiloxane) (GE Silicon) was employed as the supporting layer since it has better mechanical and chemical stability proved by the wide usages in the soft-lithography and more importantly, has the good elastic property which is appropriate for the lamination process.

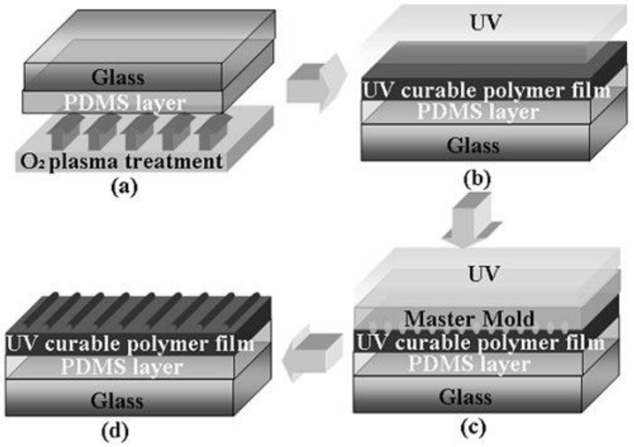

Fig. 1. The schematic diagram for the fabricating the functional cover film of UV curable polymer film. (a) O_2 plasma treatment after creating the supporting film of PDMS. (b) Spin-coating of UV curable polymer on the PDMS layer and partial curing process with weak UV. (c) Soft-lithographic patterning process of the cover film by stamping a master mold and curing with UV irradiation. (d) Removing the master mold.

In the first step of fabrication, we spin-coated a PDMS uniformly on the flat glass substrate. Due to highly hydrophobic properties of the PDMS, the UV curable polymer can not be coated on the PDMS surface without the surface treatment. After introducing the hydrophilic property to the surface of PDMS by O_2 plasma treatment (Fig. 1 (a)), we can form the thin cover film of UV curable polymer uniformly. We irradiated the UV in a short time to reduce the liquidity of NOA68 film at the initial pre-polymerization step as depicted in Fig. 1(b). To pattern the micro-grooves in the cover film, the pre-designed master mold was imprinted on this partially cured NOA68 film. The master mold in this study has the periodic groove pattern with the pitch of 4μm and the height of 1μm. As the master mold, we used the PDMS layer since it can be detached easily after stamping due to their low surface energy. The master mold of PDMS was fabricated by stamping a micro-grooved structure of quartz prepared by the conventional photo-lithographic process. Using the soft-lithographic process, it is easy to fabricate multiple replicas without additional complex steps.

After transferring the patterns of master mold to the thin cover film, the UV was irradiated to stabilize the film of UV curable polymer without exceeding the dosages for pre-curing scheme (see, Fig. 1 (c)). Since the adhesion properties of the inter-layers are different at the upper interface (master mold-cover film) and the lower interface (cover film-supporting layer), we can easily remove the master mold without damaging the cover film after the stabilizing process as shown in Fig. 1 (d).

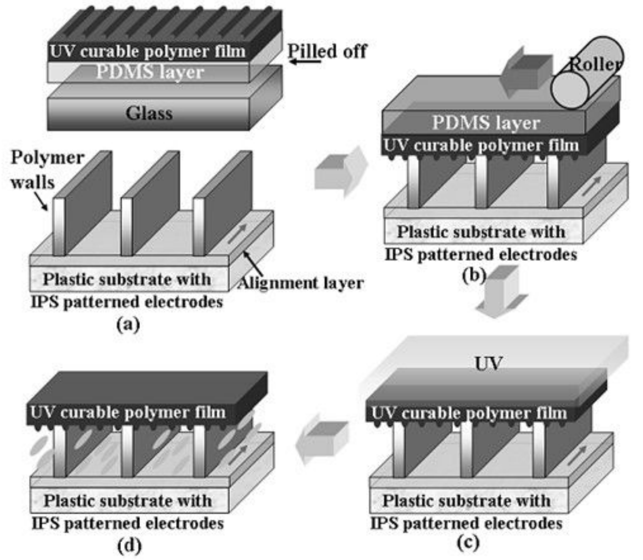

Fig.2 The schematic diagram of the laminating process for single substrate flexible LCD. (a) Preparation of the thin cover film on the supporting layer and the bottom plastic substrate with polymer walls. (b) Laminating process by soft roller. (c) UV irradiation for solidification and tight bonding of cover film after removing the PDMS layer. (d) LC injection and resultant single substrate flexible LCD.

The fabrication process of the single substrate flexible LCD we proposed is schematically shown in Fig. 2. In the bottom structure, the periodic polymer wall formed on the flexible plastic substrate by using the photo-lithography as shown in Fig. 2(a). The alignment layer was previously spin-coated on the plastic with unidirectional rubbing process. To apply the electric filed, a transparent electrode of ITO (indium tin oxide) was patterned on the plastic substrate. The polymer walls were made by the conventional photoresist of SU-8 (MicroChem. Co.), and PC (polycarbonate) was used as the plastic substrate. The height (i.e., the cell gap of the device) and the width of the polymer wall was 6μm and 30μm, respectively and the distance between the walls (i.e., pixel region) was 100μm. The cover film on the PDMS layer which is prepared in previous steps was pilled off from the glass substrate and then was laminated on the bottom structure by a soft roller. In this structure, we adopted the in-plane switching mode [11] for driving of the device, thus the direction of the micro-grooves set to be parallel to that of the rubbing at the bottom substrate (see, Fig. 2(b)). Interdigital ITO electrodes (width: 10μm, pitch: 30μm) was patterned as the chevron shape inclined about 45° with respect to the wall direction.

After pilling off the PDMS layer from the cover film of UV curable polymer, it is irradiated by UV during the long period for fully cured structure (Fig. 2(c)). By filling the LCs with capillary action, we can create the flexible single substrate LCD sample as shown in Fig. 2(d). The material used in this study is the homogeneous alignment layer of RN1199 (Nissan Chemical Ind., Ltd.) and nematic LC of ZKC5085 (Chisso Co.). The laminating process can be performed at the room temperature.

3. Results and discussion

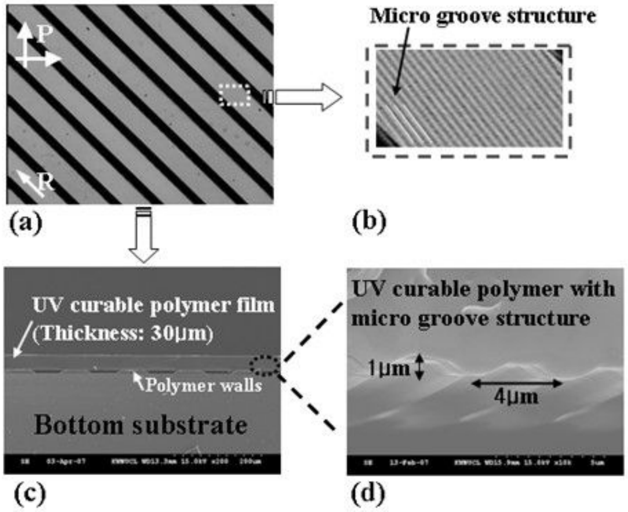

Fig.3 (a) The microscopic texture of the sample. (b) Magnified microscopic image of the texture. (c) Cross-sectional image of the sample. (d) Magnified cross-sectional image showing the micro groove structure.

Figure 3(a) and (b) show the microscopic textures of our experimental sample. The uniform alignment of LC molecules was verified by observing the leakage of light under crossed polarizer by rotating the direction of rubbing. The dark lines represent the polymer walls. This planar alignment of LCs was achieved by the rubbed alignment layer on the bottom substrate and the micro-grooves on the cover film, simultaneously. In a magnified photo, we can easily observe the micro-grooves in the sample. To verify the existence of those micro-structures, we opened the sample and washed the LCs to photo the cross-sectional view. Figure 3(c), (d) show the cross-sectional images of proposed single substrate LCD sample. We can clearly see the formation of polymer walls, the attachment between two layers, and the existence of the micro-grooves in the cover film of UV curable polymer. The thickness of total UV curable polymer layer was 30μm and the measured pitch and height of the micro-grooves was 4μm and 1μm, respectively. This is well matched to the specification of the master mold which means the transferring process of the pattern with soft-lithography is almost ideal.

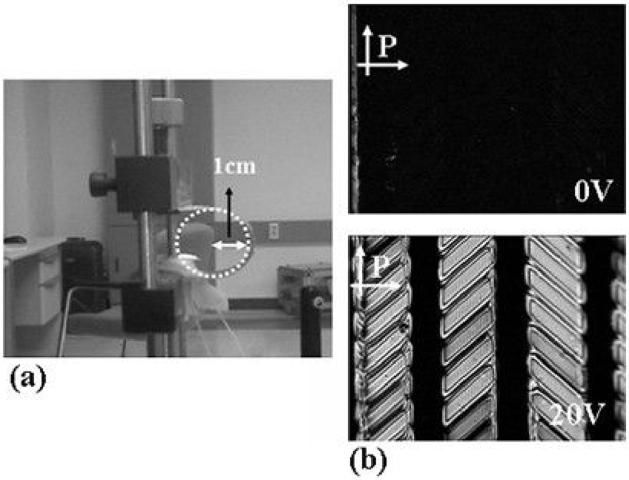

Fig.4 (a) The experimental setup for a bending deformation test. (b) Microscopic textures of our single substrate sample at applied voltage of 0V and 25V in the bent state.

We measured the bending stability of our sample by increasing the bending distortions as depicted in Fig. 4(a). From the experiment, our single substrate sample was not broken after engaging the deformation of R = 1cm (R is the radius of curvature at the bending circumstance). This result proves that our laminating process tightly binds the plastic substrate and the thin cover film of UV curable polymer under extreme bending condition.

Figure 4(b) shows the microscopic textures at applied voltages of 0V, 20V in the bending deformation of R = 3.5cm. Initial planar alignment of LCs was not disturbed by the bending deformation by observing the dark images at 0V. We also verified the stable operation of IPS mode by obtaining the bright textures at an applied voltage of 20V. Note that still slight changes in brightness of the pixels were observed and the challenge for enhancing the mechanical stability of proposed device remains to be explored.

4. Conclusion

We proposed a novel method for fabricating flexible display using a laminating technique. Experimental results showed the single substrate sample prepared by this technique can tolerate the high bending deformation of R = 1cm with fine electro-optic characteristics. This method is expected to be highly useful to fabricate a single substrate flexible LCD having high flexibility and mechanical stability with simple process.

5. Acknowledgements

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5. References

1. G. P. Crawford, Flexible Flat Panel Displays, John Wiley and Sons, New York, p5 (2005).
2. F. Matsumoto, T. Nagata, T. Miyabori, H. Tanaka and S. Tsushima, *SID '93 Digest*, p965 (1993).
3. J. L. West, M. Rouberol, J. J. Francl, J. W. Doane and M. Pfeiffer, *Asia Display '95 Conference paper*, p55 (1995).
4. R. Buerkle, R.Klette, E. Lueder, R. Bunz and T. Kallfass, *SID '97 Digest*, p55 (1995).
5. I. Kim, D. Kang, D. M. Agra-Kooijman, S. Kumar and J.-H. Kim, *J. Appl. Phys.*, 44, pp7699-7701 (2002).
6. H.Sato, H. Fujikake, Y. Iino, M. Kawakita and H. Kikuchi, *Jpn. J. Appl. Phys.*, 41, pp5302-5306 (2002).
7. Y. Kim, J. Francl, B. Taheri and. J. L. West, *Appl. Phys. Lett.*, 72, p2253 (1998).
8. J.-W. Jung, M. Y. Jin, H.-R. Kim, Y.-J. Lee and J.-H. Kim, *Jpn. J. Appl. Phys.*, **44**, p8547 (2005).
9. R. Penterman, S. I. Klink, H. D. Koning, G. Nisato, and D. J. Broer, Nature, 417, p55 (2002).
10. Y.-T. Kim, J.-H. Hong, T.-Y. Yoon, and S.-D. Lee, *Appl. Phys. Lett.*, 88, p263501 (2006).
11. Masahito Oh-e and Katsumi Kondo, Appl. Phys. Lett., 67, p3895 (1995).