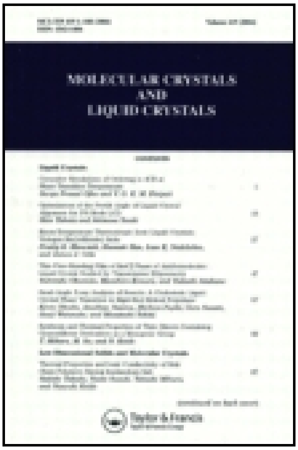

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Using Replica Molding Method to Fabricate Alignment-Layer Free Flexible Liquid Crystal Devices

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Many kinds of processes have been used to make flexible LCDs. In this paper, we fabricate a flexible LC device by replica molding method – using Poly(dimethylsiloxane) (PDMS) rather than plastic to be the substrate. The PDMS can not only act as the substrate but also the alignment-layer in flexible LCDs; thus there is no need to coat additional alignment-layer on the flexible substrates. One significant achievement of our method is to increase the flexibility of rollable LC devices. The other one is to decrease the processing steps compared with those in other conventional processes.

Keywords: flexible LCD; replica molding

PACS numbers: 77.84.Nh; 42.79.Kr; 85.60.Pg

I. INTRODUCTION

A lot of attention has been paid to flexible displays because they have many unique features such as lightness, thin packaging and portability. As for the substrates, although glass ones are often used in conventional LCDs, they are inflexible and fragile. Recently, glass substrates are commonly replaced by plastic or bendable substrates such as polyethylene terephthalate (PET) film because of flexibility and thinness. E-papers can be one of the most commonly known examples. At the same time, aligning liquid crystals (LCs) uniformly on

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plastic or bendable substrates becomes a crucial problem during flexible display manufacturing process. An available way to align LCs is coating polymer layer and then making microgrooves above. These kinds of methods include rubbing and nano-imprint lithography [1,2]. However, since that the substrates coated with polymer layers are bended for many times, the cracks of the polymer layer will get bigger and bigger as time goes by. In order to solve this problem, we have tried to make the bendable materials serve not only as substrates but also as alignment-layers; naturally, how to achieve the above two goals all together is undoubtedly an important research focus in our research. If both objects are achieved, we can definitely lessen the steps in the process of fabricating flexible displays.

In this paper, we fabricate grating nanostructures directly on flexible substrates to align LCs by using replica molding method [3]. We have chosen replica molding method for many reasons. First, replica molding method is an efficient way to duplicate the structure on the surface of a mold with the benefits of low fabrication costs, high-throughput, simple fabrication, and the capability to duplicate nanometer scale structures over many centimeters; since that curing and peeling PDMS substrates do not destroy the original mold, we can use the mold to make additional substrates by repeating the preceding steps; in the end, the cured polymers will possess almost the same dimensions and topologies of the mold; Second, it is replica molding method that allows us to duplicate three-dimensional topologies in a single step. Without it, we have to execute complicated steps such as exposure and etching when we conduct traditional photo lithography; in addition, it is rather difficult for us to make three-dimensional patterns via the classical method. Third, replica molding method lets us duplicate soft and flexible materials directly, which is an important feature that electron beam lithography and photo lithography do not possess. For the reasons above, replica molding method has been functioned to produce a wide range of structured surfaces such as diffraction gratings [4], compact disks [5,6] and micro devices [7].

In our research, we established many improvements via replica molding method: the flexible PDMS and the alignment layer that are integrated into an alignment substrate can avoid cracks that occur often in traditional polymer alignment layer during the bending processes; our method has increased the flexibility of rollable LC devices so that they might have more applications in flexible displays. Last but not least, the flexible LC device fabricated by this method was found to possess low driving voltage and comparable response time, which enables us to consume less power while maintaining better image fluency when we use it in displays.

II. EXPERIMENTS

We used replica molding method to produce flexible LC devices. It includes three simple steps: dropping, curing and peeling. Figure 1 is the flowchart of the fabrication process. First, we use droppers to drop PDMS on the silicon mold. Then we bake PDMS at 90°C for 90 minutes in an oven. The PDMS can readily convert into solid elastomers by cross-linking. After it is cured, we peel PDMS off from the rigid mold along the grating vector. The formulation, application, and fabrication of PDMS elastomers have been studied extensively in Ref. [8].

What we've demonstrated here is the process of using replica molding method to fabricate flexible substrates. The mold is the silicon wafer with microgrooves patterned during traditional photolithography process. The wafer is covered with photoresist by spin coating. The photoresist-coated wafer is then baked to eliminate excess solvent. After baking, the photoresist is exposed to a pattern of ultraviolet light. The following chemical change allows some of the photoresist to be removed by developer. In the etching step,

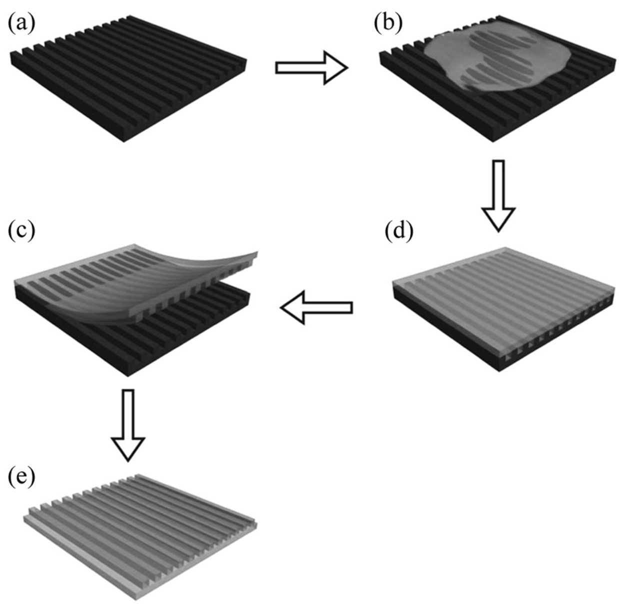

FIGURE 1 Flowchart of fabrication processes for PDMS substrates. (a) Silicon mold; (b) Dropping PDMS to mold; (c) Baking PDMS at 90°C for 90 minutes; (d) Peeling PDMS off from the mold; (e) Flexible PDMS substrate.

plasma helps to remove the uppermost layer of the substrate in the areas that are not protected by photoresist. Finally, the remained photoresist is removed from the substrate. The pattern of mold is a grating of 1 μm pitch and the width of the line is 500 nm. If the pitch is too larger, they will not have enough good ability to align LC molecules. The PDMS is commercially available from Dow Corning Corporation. It is supplied as a two-part kit: a liquid silicone rubber base and a curing agent. In order to function it properly, we mix the curing agent and liquid silicone rubber base at a ratio of 1:5. We have also mixed them at the ratio from 1:6 to 1:10; since that the results are almost the same, we can see that the ratio of mixture do not influence our outcome. The PDMS elastomer is isotropic and homogeneous with good thermal stability up to 186°C. Substrates made up of this material can be deformed mechanically to fit the patterns and relief structures on the mold surfaces.

In order to make electrode layers, we use RF magnetron sputter to coat indium tin oxide (ITO) layers on the microgroove surface of the PDMS substrates. After that the two patterned PDMS substrates are arranged to be a 90° twisted-nematic (TN) cell with a 4.0 μm cell gap via spraying silica spacer. The LC material is nematic LC MJ9915 offered by Chung-Hwa Picture Tube Company. After using uncured PDMS to seal the substrates, we insert cell into polarizer and analyzer (they are perpendicular to each other). And we use the 632.8 nm line He-Ne laser as the source to measure the electro-optical (EO) transmittance and the response time.

III. RESULTS AND DISCUSSION

Figure 2(a) shows the atomic force microscopy (AFM) image of grating nanostructures on a mold coated by photoresist in contact mode. Figure 2(b) shows the AFM image of grating nanostructures on PDMS; we have prepared our sample by replicating from a silicon mold. The heights (peak to valley) of the grating nanostructures on the original mold are 55.7 nm, while the heights of the PDMS grating nanostructures are 64.0 nm. Because we've peeled PDMS off from the mold, the heights of the PDMS are slightly larger than those of the mold. This result indicate that using replica molding method to duplicate PDMS substrates for flexible displays is feasible because it can copy the groove as well as we wish or even better.

Figure 3(a) shows the normally white state (the analyzer and polarizer are orthogonal) where a large percentage of the pattern is uniformly white. And Figure 3(b) shows the normally black state (the analyzer and polarizer are parallel) where cell is almost dark black.

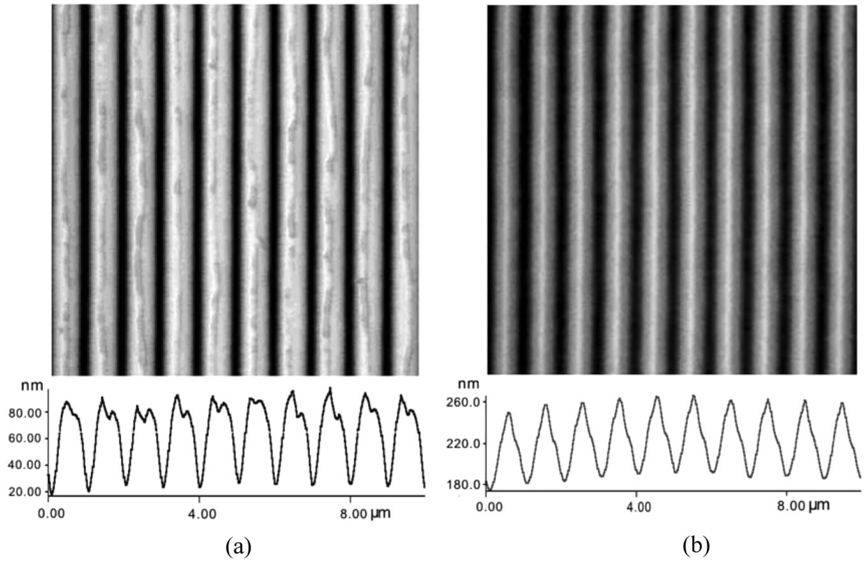

FIGURE 2 AFM image of (a) Grating nanostructures on a mold (the heights are 55.7 nm) and (b) Grating nanostructures on a PDMS produced by replication from the silicon mold (the heights are 64.0 nm).

From Figure 3, we can see that the PDMS substrates have great ability to align LC molecules just as conventional polyimide (PI) does. Figure 4 shows the normalized EO transmittance of our flexible LC

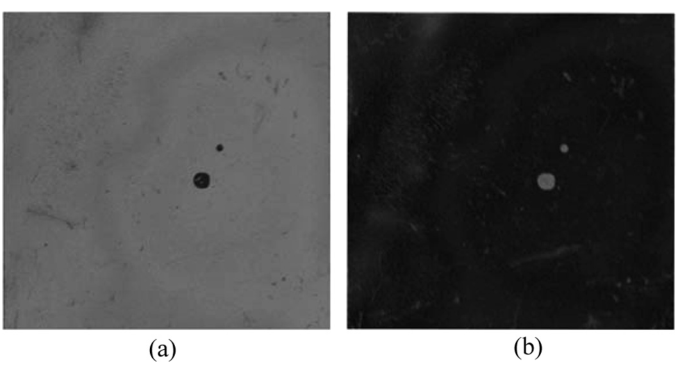

FIGURE 3 The cell of 90° twisted-nematic LCs (PDMS substrates). (a) Normally white state (the analyzer and polarizer are orthogonal); (b) Normally black state (the analyzer and polarizer are parallel).

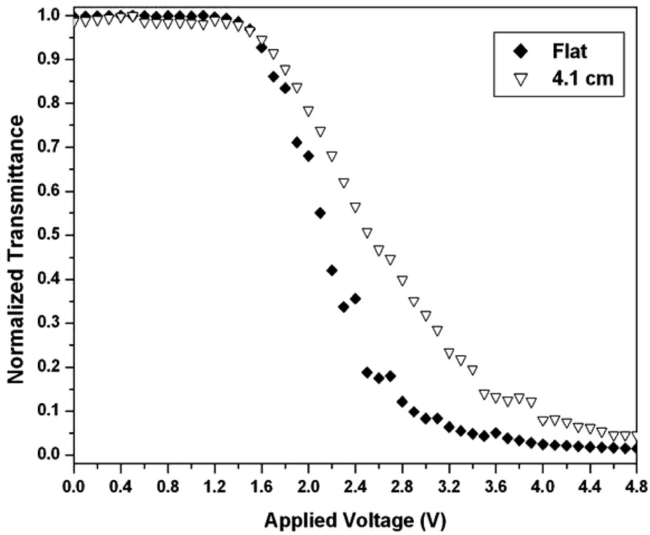

FIGURE 4 Normalized transmittance as a function of applied voltage of LC cell with PDMS substrates under flat state and bent state of curve radius of 4.1 cm.

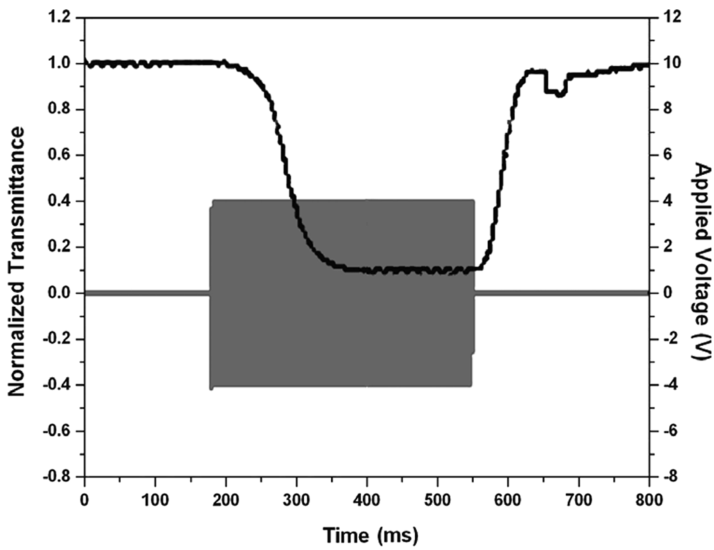

FIGURE 5 The falling and rising times of flat LC cell with PDMS substrates, $\tau_{90-10} = 80.6\,\text{ms}$ and $\tau_{10-90} = 48.4\,\text{ms}$ under the applied voltage 4 V (1 kHz square waveform).

cell fabricated by replica molding method in the flat state and bent state of the curve radius of 4.1 cm. The EO transmittance began to decrease at about 1.5 volts in the normally white mode; the contrast ratio of flat state and bent state were 217 and 22, respectively. The results imply that bending may cause the cell gap unstable to present a good dark state after high voltage was applied. We can add the structure of wall to the mold; therefore, there will be a wall structure on the PDMS substrate to enhance the stability of cell gaps and good dark state in the future research.

The response time of flat LC cell with PDMS substrates was about 48.4 ms (see Fig. 5). It was better than most flexible devices and could make images more fluent. The driving voltage (1.5 V) was as low as that of the conventional LCDs so that it could consume less power. In this research, since that ITO layers serving as conductive materials may not have sufficient flexibility to match the PDMS substrates, the use of conductive polymer substituting for ITOs in order to increase the degree of bending would be an important extended research target in the future.

IV. CONCLUSIONS

In conclusion, replica molding method is truly an efficient method to duplicate substrates for flexible displays. Via this method, we can successfully transfer the microgroove pattern from silicon mold to PDMS. The PDMS can readily convert into solid elastomers by cross-linking and the LC molecules can thus align immediately on the patterned PDMS substrates without coating additional polymer layers in order to align LCs. It is clear that we have combined the alignment-layers and substrates together successfully. They are both made by PDMS. Also, the flexible LC cell fabricated by this method has low driving voltage and comparable response time so that it can consume less power while possessing better image fluency. It is truly an important milestone for the soft flexible displays and its further applications.

REFERENCES

[1] Chou, S. Y., Krauss, P. R., & Renstrom, P. J. (1996). *J. Vac. Sci. Technol.*, *B14*, 4129.
[2] Kim, Y. T., Hwang, S., Hong, J. H., & Lee, S. D. (2006). *Appl. Phys. Lett.*, *89*, 173506.
[3] Xia, Y. & Whitesides Annu, G. M. (1998). *Rev. Mater. Sci.*, *28*, 153.
[4] Hutley, M. C. (1982). *Diffraction Gratings*, Academic, New York.
[5] Haverkorn van Rijsewijk, H. C., Legierse, P. E. J., & Thomas, G. E. (1982). *Philips Tech. Rev*, *40*, 287.

[6] Terris, B. D., Mamin, H. J., Best, M. E., Logan, J. A., Rugar, D., & Rishton, S. A. (1996). *Appl. Phys. Lett.*, *69*, 4262.
[7] Kiewit, D. A. (1973). *Rev. Sci. Instrum.*, *44*, 1741.
[8] Xia, Y., McClelland, J. J., Gupta, R., Qin, D., Zhao, X. M., Sohn, L. L., Celoua, R. J., & Whitesides, G. M. (1997). *Adv. Mater.*, *9*, 147.