Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Attainment of Planarly Aligned Liquid Crystal Using Vertical Alignment Polymer Walls

W. Zheng [a] & M.-C. Lee [a]

[a] Department of Photonics, National Sun Yat-Sen University, 70 Lien-Hai Road, Kaohsiung, 80424, Taiwan, R.O.C.

Available online: 11 Jan 2012

To cite this article: W. Zheng & M.-C. Lee (2012): Attainment of Planarly Aligned Liquid Crystal Using Vertical Alignment Polymer Walls, Molecular Crystals and Liquid Crystals, 553:1, 28-35

To link to this article: http://dx.doi.org/10.1080/15421406.2011.609351

Mol. Cryst. Liq. Cryst., Vol. 553: pp. 28–35, 2012

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2011.609351

Attainment of Planarly Aligned Liquid Crystal Using Vertical Alignment Polymer Walls

W. ZHENG* AND M.-C. LEE

Department of Photonics, National Sun Yat-Sen University, 70 Lien-Hai Road, Kaohsiung 80424, Taiwan, R.O.C.

The use of polydimethylsiloxane elastomer as a commanding layer for liquid crystal alignment is studied. The silicon-base elastomer is highly hydrophobic, and found to be capable of vertically aligning liquid crystal. Specific structures can be easily manipulated into the elastomer by means of micro-replica molding technique. Using polydimethylsiloxane walls that are set to be perpendicular to the substrate, a vertical alignment of liquid crystal to the polymer walls can be converted to a planar alignment of the liquid crystal related to the substrate.

Keywords liquid crystal alignment; micro-replica; polydimethylsiloxane alignment walls; polymer confined liquid crystal; alignment conversion

1. Introduction

The uniformity of the orientation of liquid crystal (LC) molecules in a cell is crucial for optimizing the performance of LC devices, which play a very important role in today's flat panel displays. For calamitic LCs that consist of rod-like molecules, depending on the way that the molecules orient against the substrate, two basic types of molecular alignments, the homogeneous and the homeotropic ones, can be classified. In the homogeneous alignment, all molecules lie parallel to the substrate surface with their long axes orienting in the same direction, whereas in the homeotropic, i.e., the vertical alignment (VA), the molecules are orienting perpendicular to the substrate surface. In many applications, a homogenously aligned liquid crystal in a cell is demanded. Up to date, the rubbing polymer, in which a thin layer of polyimide (PI) is deposited onto the inner surfaces of substrates and subsequently the polymer surface is rubbed unidirectionally [1], is the principal technique used to achieve homogenous LC alignment. Although it provides a technique of reliability, durability, ease in handling, and cost effectiveness, the rubbing polymer technique will producet such problems as generation of harmful static charges, dust and scratches on the surface of the alignment layer. Many non-contact surface processing such as ultraviolet [2–4] or ion beam [5,6] irradiation and laser-induced-surface-relief-gratings [7–9] have been developed intending to avoid the problems imposed by rubbing process. We herein report a method in which a planarly aligned LC can be produced using a VA alignment layer. In our

*Address correspondence to W. Zheng, Department of Photonics, National Sun Yat-Sen University, 70 Lien-Hai Road, Kaohsiung 80424, Taiwan, R.O.C. E-mail: wzheng@ymail.com

study, polydimethylsiloxane (PDMS) is used as commanding material to promote LC alignment. PDMS is a highly hydrophobic silicon-based polymeric elastomer and can drive LC molecules to orient vertically, i.e. in the VA mode, on the surface [10]. Using micro-replica molding technique [11], PDMS walls have been fabricated on a substrate surface and set to be perpendicular to the substrate surface. We demanstrate that being forced to anchor vertically at the surface of the PDMS walls, the liquid crystal molecules confined in the cavities encapsulated by the PDMS walls are then aligned parallel to the substrate. This technique of converting liquid crystal alignment from one type to another may create new liquid crystal operation mode, and potentially can be used in fabricating flexible displays. Initial test shows that the confined LC with the polymer-wall-induced alignment can be operated by an external field.

2. Experimental Methods

In the present study, polymer walls were produced using micro-replica molding method [11]. The polymer precursor used for replica was Sylgard 184 (Dow Corning), which is a mixture contained 10 parts base resin and one part curing agent by weight. First of all, the mold was fabricated using conventional photolithography process. In this technique, a negative photoresist resin SU8-GM1060 (Gersteltech Sarl) was spin-coated onto a glass substrate, and followed by a soft baking at 65°C to remove the solvent. The thickness of the photoresist layer was controlled by adjusting the speed of the spiner. The baked photoreist layer was then exposed to 365 nm ultra-veolet (UV). The photoresist layer was patterned to bear a desired topographic structure using a mask. After the UV exposure, the photoresist layer was developed and subsequently thermal cured at 135°C to allow the residual solvent to be complitely removed and the photoresist layer to be fully hardened. Finally, the unexposed part of photoresist was washed out. The procedure of the micro-replica molding process is schematically shown in Fig. 1. The PDMS precursor was spin-coated onto the mold, and was then thermally curing at 130°C for about 1 hr. After thermal curing, PDMS thin film was peered off from the mold. All thermal curing processes, for both SU8 and PDMS, were carried out using a temperature stable PE30/201 oven (Carbolite).

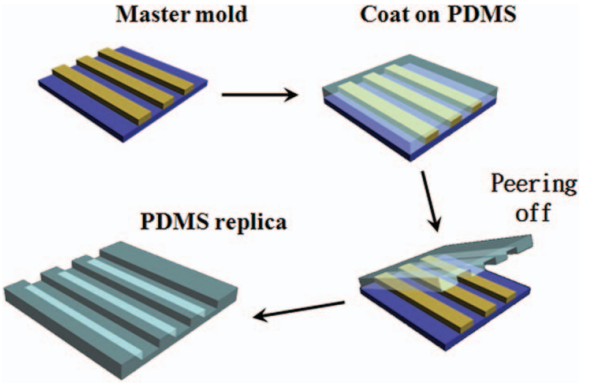

Figure 1. Procedure of the micro-replica molding process for producing PDMS alignment walls.

Cells for LC samples were constructed by sandwiching the PDMSs films borne the microstructures between indium-tin-oxide (ITO) coated glass substrates. Prior to cell assmebly, a thin layer of polyimide JSR-9800 (Nissan Chemical) was spin-coated on the ITO glass substrates intending to promote planar anchoring of LC molecules. No rubbing process was carried out for the polyimide film. For the examination of the molecular alignment, nematic phase mixtures E7 and MLC7028–100, both were purchased from Merck, was used. The LC was injected into the cell at an elevated temperature where the LC was in the isotropic phase, and then cooled down at a rate 1°C/min. The temperature of samples was controlled using a Linkam TMS93 programmable temperature system (Linkam Scientific Instrument Ltd). The LC alignment was examined using polarizing optical microscopy (POM).

3. Results and Discussion

PDMS is a highly hydrophobic material. The contact angle of a droplet of deionized water that was put in contact with the PDMS surface was measured to be 115° at room temperature. The surface free energy of PDMS was found to be, with a value in the range 22–24 mJ/m^2, much lower than that (31 mJ/m^2) of SE-4811 (Nissan Chemical), a comercial PI used to achieve vertical LC alignment in display industry. According to Creagh-Kahn's model [12, 13], a surface with a low energetic level can drive LC molecules to orient perpendicular to the surface. Indeed, in a sandwich-type cell with PDMS coating the inner surfaces of the substrates, the LC exhibited a black appearance, which was not changed on turning the sample, in the POM. The pretilt angles were found to be virtually 90° and maintained unchanged with the surface free energy of the PDMS layer increasing up to 30 mJ/m^2 (Fig. 2). This indicates that the LC sandwiched between PDMS is in vertical alignment.

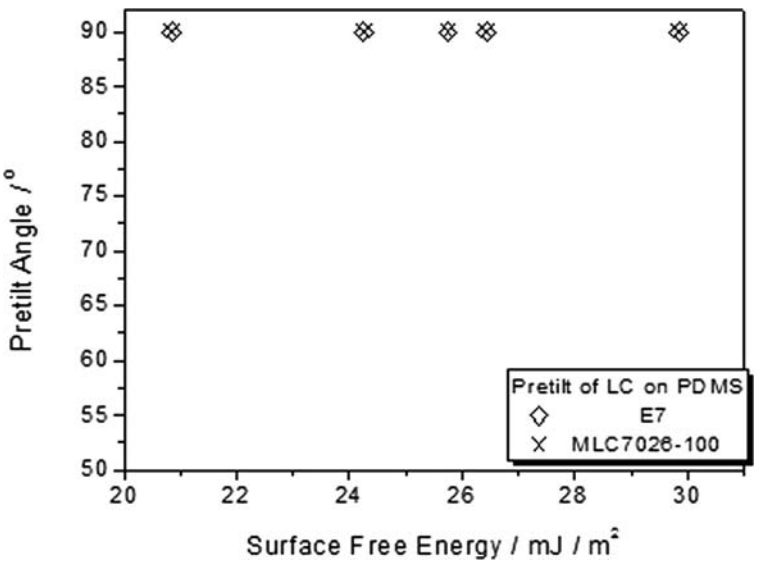

Figure 2. Pretilt angles of nematic LCs on PDMS surface against surface free energy.

In general, the types of the molecular alignment of the LCs are defined based on considering the way the orientation of the molecules related to the substrate. In conventional alignment techniques, the commanding surfaces that are capable of promoting specific LC alignments are normally parallel to the substrate surface. Therefore one type, either homogeneous or homeotropic, molecular alignment can be normally attained on one alignment surface. If one can bend the alignment layer 90° against the substrate while keeping the original molecular alignment of the LC which is in contact with the alignment layer, one can then convert LC alignment from one type to another.

Now that the PDMS thin layer can support vertical LC alignment, the key issue is then to build up PDMS walls which are perpendicular to the substrate. Using micro-replica molding technique, thin layers of PDMS consisted of cavities whose walls are perpendicular to the substrate can be easily produced. The geometrical shape and the spatial distribution of the cavities are easily manipulated into the PDMS using a proper mold, which is produced using a properly patterned mask. In the present study, we considered to produce cylindrical cavities in PDMS thin layers (Fig. 3a). Figure 3b shows the image of a PDMS slab, which

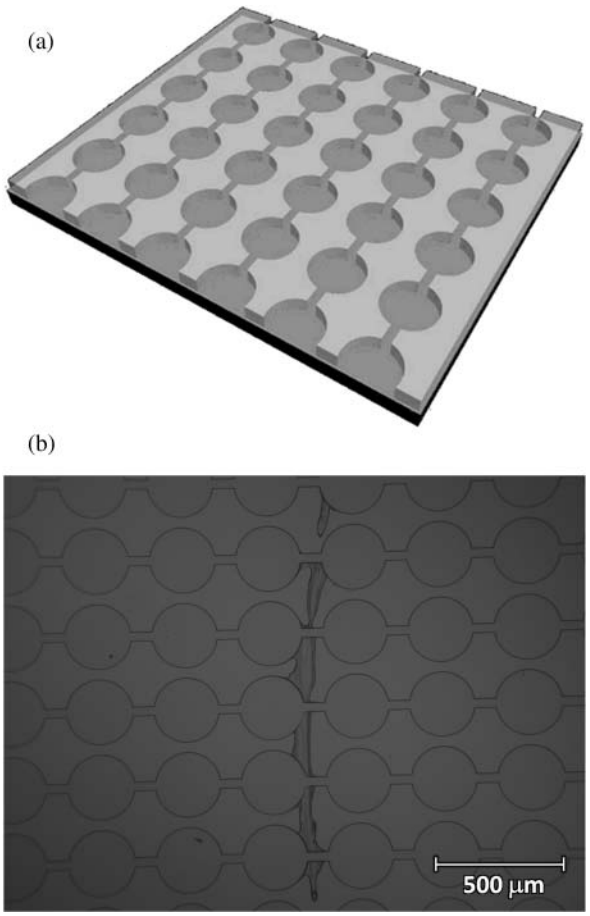

Figure 3. (a) Proposed caved substrate consisting of cylindrical cavities in a PDMS thin slab, and (b) a photograph of the caved PDMS slab produced using micro-replica molding method.

consists of the cylindrical cavities, produced by means of micro-replica molding process. Although we show here the cylindrical cavities in the PDMS slabs, it should be pointed out that cavities with other geometrical shapes are also suitable for the purpose of the LC alignment.

When they were confined in the cylindrical cavity, the LC molecules were driven to anchor vertically to the PDMS walls of the cavities, and oriented parallel to the substrate surface as the PDMS walls are perpendicular to the substrates. Since there is no preferential easy direction on the surfaces of both substrates, the LC molecules in the cavities possess a radial molecular configuration with cylindrical symmetry and exhibited, as illustrated in Fig. 4a, a central radial optical texture with crisscross black brushes extended from the centre of the circular cross-section of the cylinder. The molecular configuration of the LC confined in a cylindrical cavity can be schematically shown in Figure 4b. The disturbed black brush textures, as can be seen in some cavities in Figure 4a, are resulted from a local disorder in the molecular orientation due to an unsmooth surface of the walls. This is

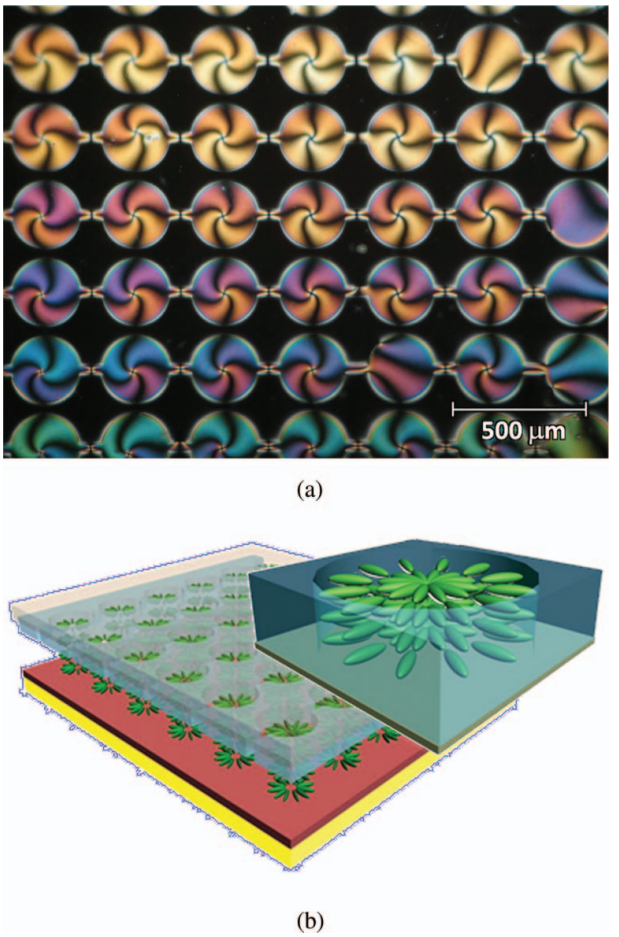

Figure 4. (a) Optical texture of nematic phase E7 confined in cylindrical cavities. (b) A proposed model describing molecular configuration of the liquid crystal confined in the cylindrical cavities.

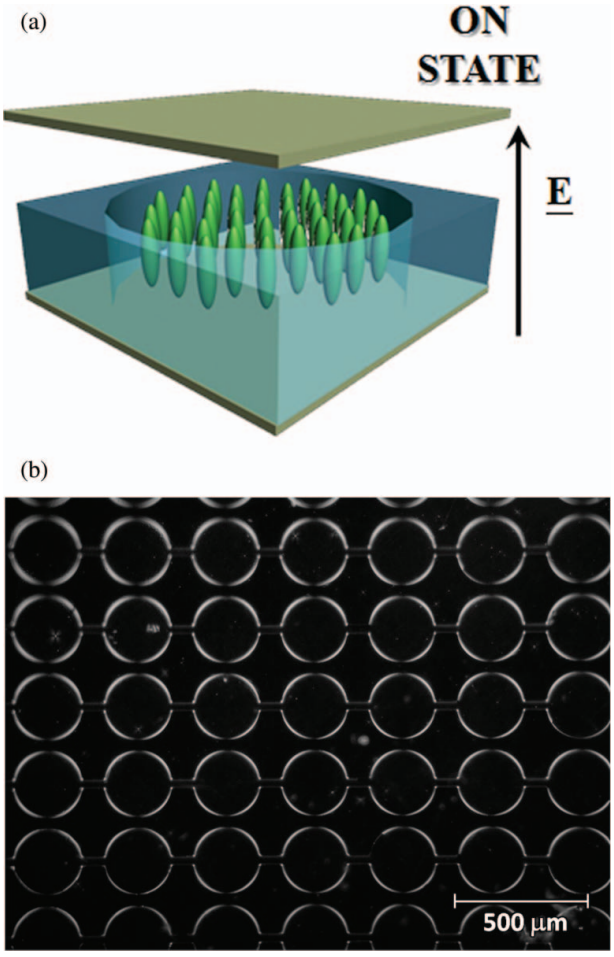

Figure 5. (a) A model showing schematically the orientation of the LC molecules in a cylinder driving by an external field, and (b) the appearance of the sample with LC molecules confined within PDMS cavities in the POM when an electric field is applied.

understandable because the mold produced using simple photolithography process cannot guarantee a perfect surface.

Upon applying a field parallel to the cylinders, the LC molecules were driven to orient perpendicular to the substrate leading to the disappearance in birefringence along the cylinders due to the optical axis of the LC being aligned to this direction (Fig. 5a). As a result, the incident light was blocked and the sample exhibited, as shown in Fig. 5b, a black appearance in the POM. The optical response of the LC sample to an external field again confirms that the LC molecules in the cavities are in planar alignment.

The electrooptical performance of the sample was evaluated. The threshold voltage of the sample was 10.8 V. Figure 6 shows light transmittance of the sample against drive voltage. The contrast ratio can reach 64. The response time, defined as the sum of the rise time t_r and relaxation time t_d corresponding to the field-on and the field-off states, respectively, was 12.9 ms with $t_r = 11.4$ ms. The large threshold and long response time of the sample are understandable since E7 is not a suitable material for this type of device.

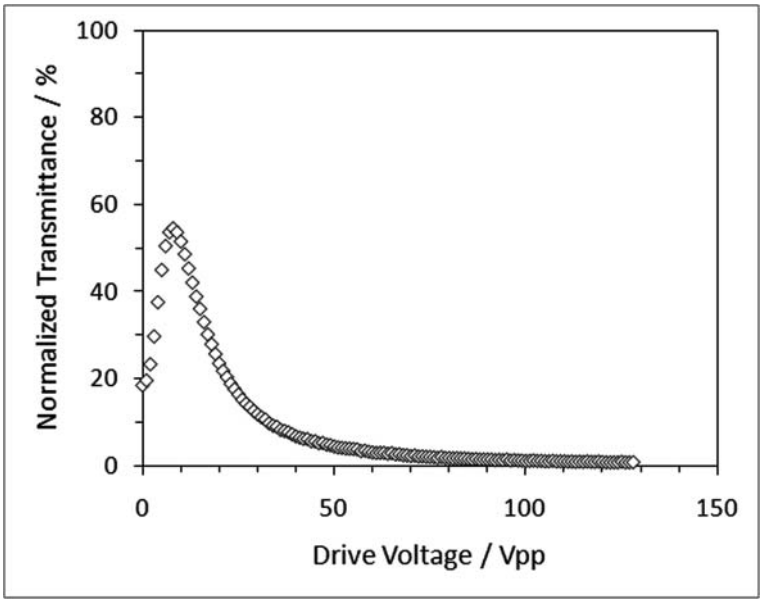

Figure 6. Normalized light transmittance of the sample against driving voltage.

It is noticed that the rise time is longer than the relaxation time. The phenomenon suggests that the PDMS walls may impose a strong anchoring action to the LC molecules.

4. Conclusions and Perspectives

PDMS thin films possess a very low surface free energy, and can be used as commanding layer to support the vertical LC alignment. Specific structures can be manipulated into PDMS by means of micro-replica molding process. Using micro-replica molding technique, we produce PDMS walls on a substrate and set them perpendicular to the substrate. While they are maintained to anchor vertically to the surface of the polymer walls, the LC molecules confined between PDMS walls are aligned planarly to the substrate surface. As a result, the planar alignment of LC can be attained using a vertical alignment layer. Based on this mechanism, planar alignment of LC has been produced in cylindrical cavities. The electrooptical performance of the confined LC is reasonable good.

Acknowledgments

This work is funded by the National Science Council of the Republic of China (NSC99-2221-E110-056) and by National Education Committee of Taiwan through the "Aim for Top Universities Plan."

References

[1] Congnard, J. (1982). *Mol. Cryst. Liq. Cryst.*, *78*(Suppl. 1), 1.
[2] Gibbons, W. M., Shannon, P. J., Sun, S. T., & Swetlin, B. J. (1991). *Nature*, *351*, 49.
[3] Shannon, P. J., Gibbons, W. M., & Sun, S. T. (1994). *Nature*, *368*, 532.
[4] Schadt, M., Seiberle, H., & Shuster, A. (1996). *Nature*, *381*, 212.

[5] Chaudhari, P., Lacey, J., Lien, A., & Speidell, J. (1998). *Jpn. J. Appl. Phys.*, *37*, L55.
[6] Doyle, J. P., Chaudhari, P., Lacey, J. L., Galligan, E. A., Lien, S. C., Callegari, A. C., Lang, N. D., Lu, M., Nakagawa, Y., Nakano, H., Okazaki, N., Odahara, S., Katoh, Y., Saitoh, Y., Sakai, K., Satoh, H., & Shiota, Y. (2003). *Nucl. Instr. and Meth. in Phys. Res. B*, *206*, 467.
[7] Parfenov, A., Tamaoki, N., & Ohnishi, S. (2000). *J. Appl. Phys.*, *87*, 2043.
[8] Dantsker, D., Kumar, J., & Tripathy, S. K. (2001). *J. Appl. Phys.*, *89*, 4318.
[9] Kaneko, F., Kato, T., Baba, A., Shinbo, K., Kato, K., & Advincula, R. C. (2002). *Coloids and Surfaces A: Physicochem. Eng. Aspects*, *198–200*, 805.
[10] Zheng, W., Yang, L. H., & Lee, M. C. Submitted to *Photonics Lett. Pol*.
[11] Knobler, C. M. (1994). *Nature*, *369*, 15.
[12] Creagh, L. T., & Kmetz, A. R. (1973). *Mol. Cryst. Liq. Cryst.*, *24*, 59.
[13] Kahn, F. J., Tayor, C. N., & Schonhorn, H. (1973). *Proc. IEEE*, *61*, 823.