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RESEARCH ARTICLE

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Polyimide liquid crystal alignment layers prepared by soft-Lithography

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Abstract Elastomeric replicas of surface relief structures were prepared by molding poly(dimethylsiloxane) (PDMS) precursors against photo-inscribed surface-relief-gratings on azo polymer films. The PI solutions were micro-contact printed with the elastomeric PDMS replica on quartz slides. Good surface-relief-grating structures were formed on the quartz slides. The quartz slides covered with surface-relief-grating polymide (PI) films were then assembled into liquid crystal (LC) cells. The transmittance passing through the cell between crossed polarizers changed periodically with a regular 90° separation of the rotational angle. The pretilt angle of the cell was found to be 2.8°. Results showed that the PI films with surface-relief-grating structures by this micro-contact printing process have good liquid crystal alignment ability. This preparation method of alignment layers can be considered a potentially useful technique in the LC display (LCD) industry in the future.

Keywords PDMS, surface relief gratings, micro-contact printing, alignment layer

1 Introduction

In recent years, new techniques for fabricating liquid crystal (LC) alignment layers have attracted a wide interest [1–4]. The alignment layers, thin polymer layers existing between the LC and the substrate of an LC cell, can induce LC molecules to orient in a predetermined uniform direction and play a key role in determining the function and quality of liquid crystal displays (LCDs). Conventionally, the alignment layers are fabricated by the rubbing method, which produces grooves on the polymer films through contact-rubbing of cloth along a fixed direction. The rubbing procedure, which has lately reached maturity with respect to the preparation process of active matrix liquid crystal displays, still continues to suffer from disadvantages such as electrical and mechanical damages to the underlying layer. This is particularly undesirable, when that layer is a thin film transistor layer, and particularly when large scale LCDs are desired.

More recently, photo-induced surface relief gratings (SRG) have been explored as LC alignment layers [5–7]. Surface relief gratings can be easily photo-inscribed by exposing the azo polymer films to an interfering Ar^+ laser beam pattern [8–10]. The space period and the modulation depth of gratings can be accurately controlled by adjusting the optical setup and the irradiation energy of the light. The surface relief structures can show good capability to induce LC orientation. However, the azo polymers cannot be considered as an ideal LC alignment layer material for its deep yellow or red color.

Soft lithography technique has been used as a powerful tool to fabricate high-quality microstructures and nanostructures [11–17]. It can offer access to non-flat surfaces and systems that are difficult to be fabricated by photolithographic procedures. In this article, a new method for preparing LC alignment layers through soft-lithographic contact printing is described. It is a very convenient way to fabricate LC alignment layers, which could be a promising and useful technology in the future LCD industry.

2 Experimental

The azo polymer BP-AZ-CA (chemical structure is shown in Fig. 1(a)) was used to fabricate SRGs, which were used as masters. The preparation and characterization of the azo polymer have been reported elsewhere [18]. With interfering illumination of Ar^+ laser beams (488 nm) at modest intensities (120 mW/cm^2), significant SRGs were formed on the azo polymer films. Elastomeric replicas of surface relief structures were prepared by molding the poly(dimethylsiloxane) (PDMS) precursor (Dow Corning, Sylgard 184) against the photo-inscribed SRGs of azo polymer films. The polymide (PI) polymer chemical structure is shown in Fig. 1(b), and its preparation was reported in our previous paper [19]. The

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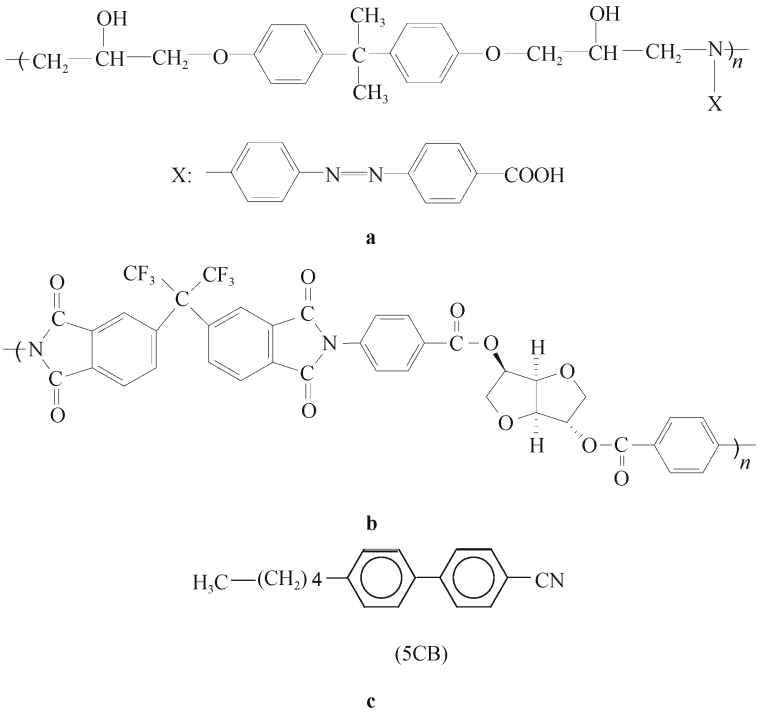

Fig. 1 Chemical structures of the (**a**) azo polymer; (**b**) PI polymer; and (**c**) liquid crystal 5CB

surface images of the surface-relief-gratings were monitored using atomic force microscopy (AFM) (Nanoscope IIIa, tapping mode). The LC cells were filled with nematic LC (5CB) by capillary force. The alignment of LC molecules was monitored by measuring the transmitting light intensity passing through the LC cell set between crossed polarizers.

3 Results and discussion

3.1 SRG fabrication

A *p*-polarized Ar^+ laser beam was used as the light source. Surface relief gratings were optically inscribed on the polymer films with interfering laser beams. The surface profiles of the resulting gratings were recorded by using a Nanoscope atomic force microscope in the tapping mode. Figure 2 shows the AFM image of the surface relief gratings formed on the azo polymer film. The space period and depth of the SRGs are about 830 and 240 nm, respectively. The space period and modulation depth of the gratings can be accurately controlled by adjusting the optical setup and the irradiation energy of the light.

3.2 Stamp preparation and contact printing

Figure 3 shows the schematic illustration of the procedure for PDMS replicas and microcontact printing. The PDMS prepolymer (Dow Corning, Sylgard 184) was obtained by mixing the elastomer base and the curing agent at a ratio of 10:1 (weight/weight). The precursor was poured in molds fixed on

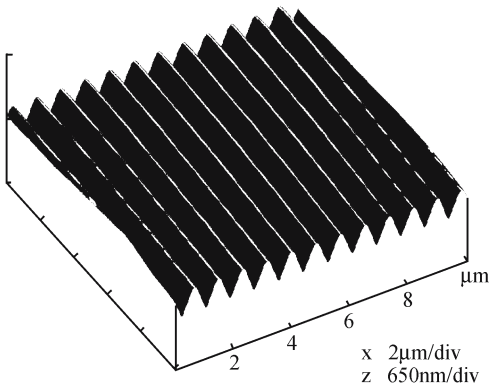

Fig. 2 AFM image of the surface relief gratings formed on the azo polymer film

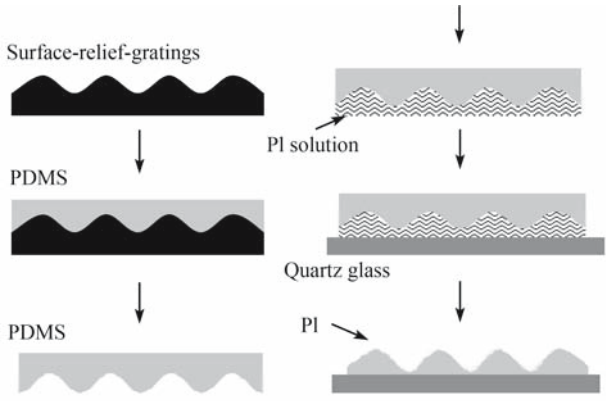

Fig. 3 Schematic illustration of the procedure for PDMS replicas and microcontact printing

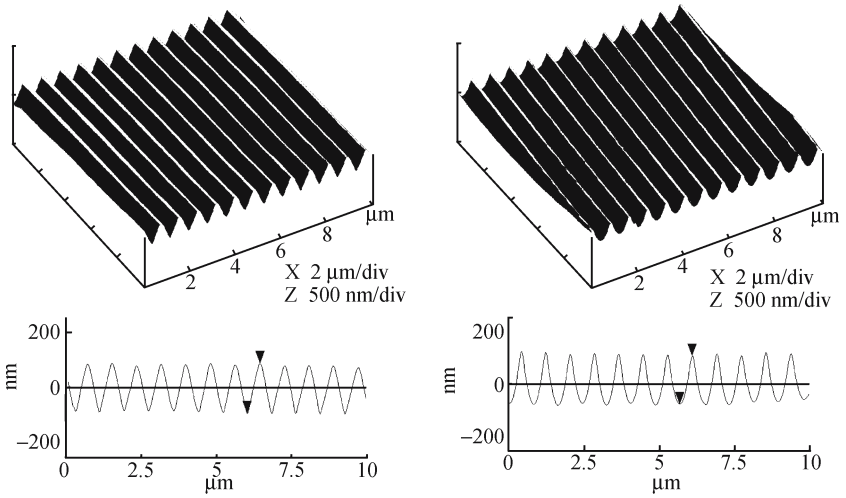

Fig. 4 AFM image of the surface relief structures on (a) PDMS and (b) PI film

the azo polymer films that had been inscribed with SRGs as mentioned above and then cured in a 60°C oven for 4 h. After curing, the PDMS blocks were separated from the molds and used as stamps for contact printing. Figure 4(a) shows the AFM images of the replica surface relief structures of PDMS. It can be seen that the replica surface relief structures have good quality. The modulation depth of the replica SRGs is slightly smaller than that of the master gratings due to the contact of PDMS during polymerization.

Then, PI polymer (chemical structure is shown in Fig. 1(b)) dissolved in tetrahydrofuran (THF) (15 mg/mL) was used as the ink for microcontact printing with the elastomeric PDMS on quartz slides. The PI polymers have some required properties, such as heat stability, photo-stability, high adhesion to glass and silicon chips. The PDMS stamps were dipped into the solution ("ink") for about 1 s and pressed against the substrates in a conformal contact manner for a few seconds. After solvent evaporation, the stamps were peeled off, leaving the printed PI microstructures on the substrates. The printed alignment layers were then dried in a 40°C oven for 24 h after peeling off the stamps. The AFM image of the SRGs formed by microcontact printing is shown in Fig. 4(b).

3.3 Assembly and characterization of LC cell

The quartz slides covered with SRG films were assembled into LC cells, which were filled with a nematic LC (5CB) by capillary force. It was observed that dark and bright images appeared by rotating the LC cell between crossed polarizers under the polarizing optical microscope. This shows the homogeneous alignment of a nematic liquid crystal. The alignment of LC molecules was also monitored by measuring the transmitting light intensity passing through the cell set between the crossed polarizers Fig. (5). The transmitting light intensity changes periodically with a regular 90° cycle of the rotational angle. This observation is qualitatively in agreement with the following equation, expressing the

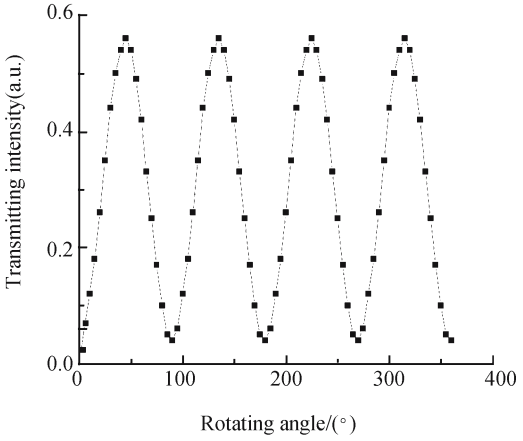

Fig. 5 Plot of the transmitting intensity as a function of rotation angle of the LC cell

relation between the transmitting intensity (I) and the parameters [20]

$$I = I_0 \sin^2(2\chi)\sin^2(\pi h\Delta n/\lambda)$$

where χ is the cell rotating angle relative to the crossed axis of the polarizer, Δn is the birefringence of the liquid crystal, h is the LC layer thickness, and λ is the wavelength of the incident light. When the Δn, h and λ remain constant, the variation in the intensity with the angle χ will show a period of 90°. Thus, the transmitting intensity curve shows that the liquid crystal molecules have a homogeneous uniaxial alignment. This further substantiates the results of the polarized microscopic observations. The pretilt angle of the LC cell was found to be 2.8°.

4 Conclusions

Elastomeric replicas of surface relief structures were successfully prepared by molding a PDMS precursor against

the photo-inscribed SRGs of azo polymer film. Good SRG structures of PI were formed by micro-contact printing with the elastomeric PDMS on quartz slides. The PI polymer films with SRG structures show good LC alignment ability.

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