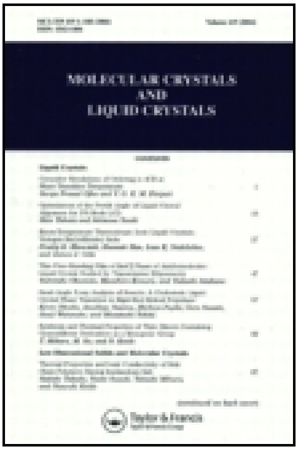

Molecular Crystals and Liquid Crystals

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

Liquid crystal alignment by Holographic surface relief grating inscribed on azo-polymer film

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Version of record first published: 18 Oct 2010

Mol. Cryst. Liq. Cryst., Vol. 424, pp. 75–83, 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490505893

LIQUID CRYSTAL ALIGNMENT BY HOLOGRAPHIC SURFACE RELIEF GRATING INSCRIBED ON AZO-POLYMER FILM

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We found that the surface relief grating (SRG) made the nematic liquid crystal (LC) align along the grating direction. The SRGs were photo-fabricated on a liquid crystalline azobenzene side-chain polymer film by the conventional holographic method. The twisted nematic liquid crystal (TNLC) cell was prepared using two SRG substrates or two rubbed polyimide substrates as alignment layers, and the LC alignment was investigated by measuring the transmittance of a 90°-TNLC cell located between crossed polarizers. The LC aligning process was studied in-situ using the hybrid LC cell with the rubbed polyimide substrate and the SRG substrate as the reference and the test alignment layers, respectively. The in-situ transmission data show that the topological effect by the SRG formation and the intermolecular interaction effect by the azo chromophore alignment compete with each other.

Keywords: anchoring strength; liquid crystal alignment; liquid crystalline azobenzene side-chain polymer; surface relief grating; twisted nematic liquid crystal cell

Received 1 October 2003; accepted 16 January 2004.

This work was supported by the KOSEF through Quantum Photonic Science Research Center at Hanyang University.

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INTRODUCTION

Liquid crystal displays (LCDs) have attracted a strong interest due to their various applications such as portable television, notebook computer, mobile phone, and spatial light modulator. A lot of studies have been performed on the alignment of LC directors, the operation method of LC cell, and the improvement of performance of LC materials [1–12]. The LC alignment is important to understand the LC physics and to improve the performance of LC cell. The LC alignment can be achieved by using the rubbing and photo-alignment methods [13–15]. The rubbing technique has been commonly employed to provide unidirectional orientation of the LC directors on a substrate. However, the rubbing process might cause electrostatic charges, contamination, or scratches on the aligning surface. These shortcomings can be overcome by using the photo-alignment method that is a non-contact method. This not only prevents the surface scratches induced by mechanical rubbing but also simplifies the multi-domain fabrication processes for a wide viewing angle. The photo-alignment of LC directors is achieved by the exposure of a polymer film to linearly polarized UV light [16] or by generating surface relief grating (SRG) on the substrate with two interfering beams [17].

In this contribution, we investigated the alignment of LC directors by using the holographic SRG inscribed on an azo-polymer film. Since the liquid crystalline azobenzene side-chain polymers exhibit a large and reversible photo-induced birefringence or linear dichroism [18,19], we employed a poly(malonic ester) with two azobenzene side groups. This polymer contains two symmetrical azo-chromophores covalently attached to the main chain. The paired mesogenic side groups improve the rigidity of polymer and speed up the formation of optical grating. The LC alignment was investigated by measuring the transmittance of a 90°-TNLC cell located between crossed polarizers. The LC aligning process was investigated *in-situ* using the hybrid LC cell with the rubbed substrate and the SRG substrate as the reference and test alignment layers, respectively. The surface profile of the prepared SRG has been measured by atomic force microscopy (AFM).

EXPERIMENTAL

The SRGs are inscribed onto an azo-polymer film using the conventional holographic method (Fig. 1). The second harmonic of the Nd:YAG laser was used for inscribing the SRG, and the He-Ne laser was used for evaluating the LC alignment on the SRG substrate. The crossing angle of the writing beams and the fluence are 28° and 21 J/cm^2 (*typical*), respectively.

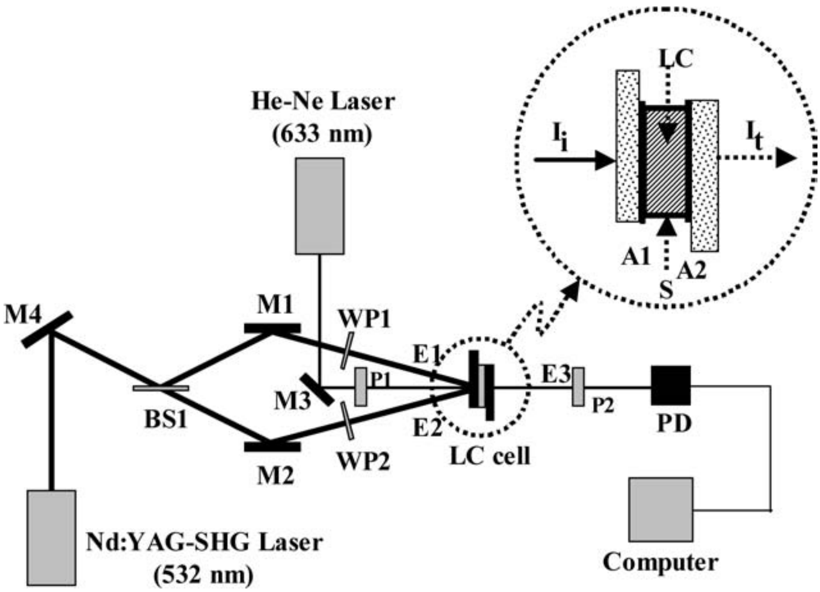

FIGURE 1 Experimental set-up for inscribing the SRG and measuring the transmittance of the TNLC cell, and the geometry of the TNLC cell. (LC, liquid crystal; A1, A2, alignment layers; S, spacer; E1 and E2, writing beams; E3, reading beam; M1-M4, mirrors; BS1, beam spliter; WP1, WP2, wave plates; P1, P2, polarizers, PD, photo diode.)

The used azo-polymer was a poly(malonic ester) with two symmetrical azo-chromophores covalently attached to the main chain (Fig. 2a), and its absorption spectrum shows the broad band absorption with the maximum absorption near 450 nm (Fig. 2b). The surface morphology of the inscribed SRG was observed using the AFM (Fig. 2c). As a result of AFM, the grating spacing of the SRG was measured to be 1.1 μm as expected from the interference fringe spacing. Next, the [SRG/LC/SRG] TNLC cell was prepared using two SRGs as alignment layers. The LC cell was constructed so that the LC layer had a thickness of 100 μm. The front and back alignment layers were attached so that the apparent twist angle between them was 90° (Fig. 1). The used nematic LC is ZLI 3462-000. The LC alignment was investigated by measuring the transmittance of the 90°-TNLC cell located between crossed polarizers (Fig. 1). In order to compare the LC alignment by SRG with that by the conventional rubbing method, we made another TNLC cell [Rub/LC/Rub cell] using two rubbed polyimide substrates as the front and back alignment layers. For the preparation of rubbed substrates, we made the unrubbed polyimide film by spincoating the PMDA-ODA [*poly(pyromelicitic dianhydride-4,4′-oxydianiline*)] polyimide

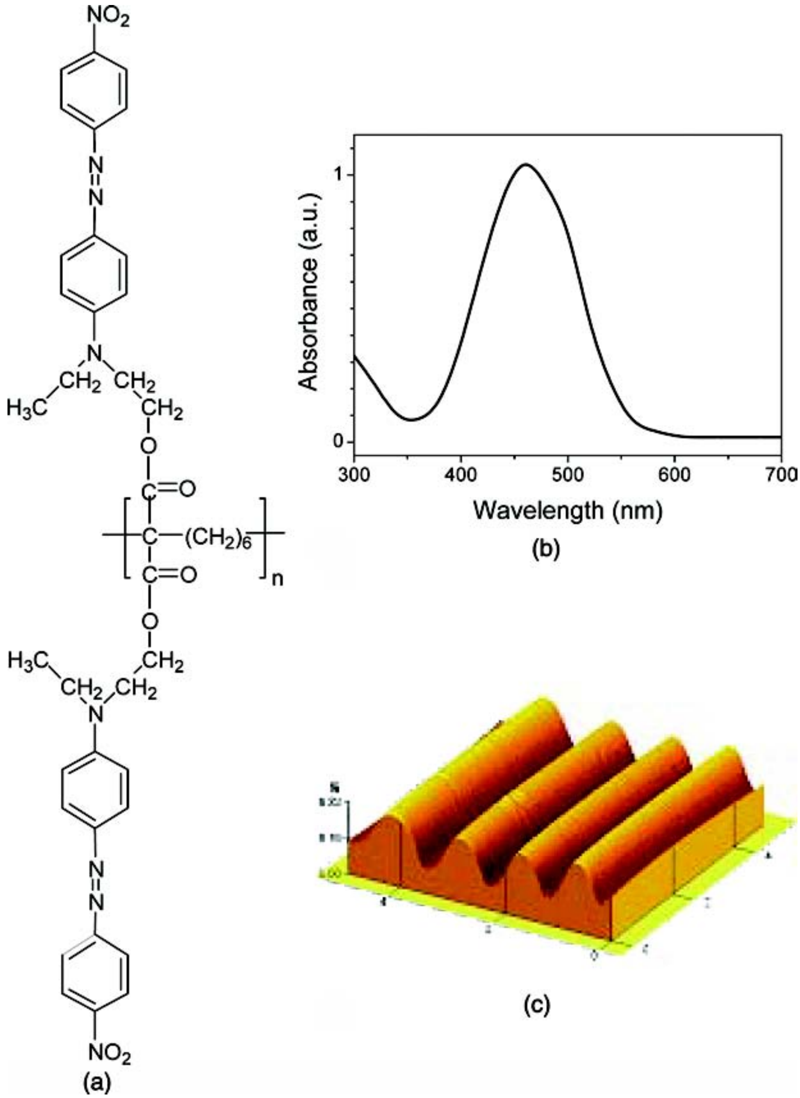

FIGURE 2 a) The molecular structure of the liquid crystalline azobenzene side-chain polymer for inscribing the SRG, b) the absorption spectrum, and c) the AFM image of the SRG inscribed with two orthogonal circular polarized interfering beams.

(Fig. 3a)) on the glass substrate, and then rubbed the unrubbed polyimide film using the rubbing machine. The rubbing strength was adjusted so that the LC directors have a strong anchoring on the rubbed polyimide substrate.

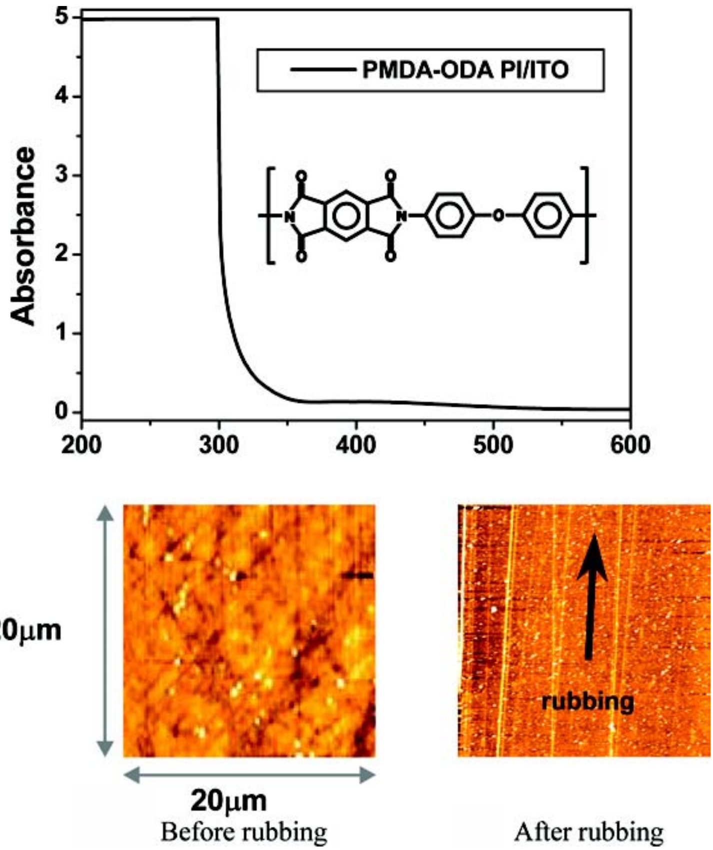

FIGURE 3 a) The absorption spectrum of PMDA-ODA polyimide film and the molecular structure of the polyimide; b) the AFM images of the polyimide film surface before and after the rubbing treatment.

Figure 3b shows the AFM images of the polyimide film before and after the rubbing treatment. It shows that the rubbing treatment gives the mechanical alignment of the polyimide molecules along the rubbing direction even if the rubbing doesn't make the grating-like structure.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 4 shows the transmittances of the SRG/LC/SRG type and Rub/LC/Rub type, TNLC cells as a function of the analyzer direction. In this measurement, the incident polarization direction is fixed so that it coincides with the grating direction of the front substrate. If we assume

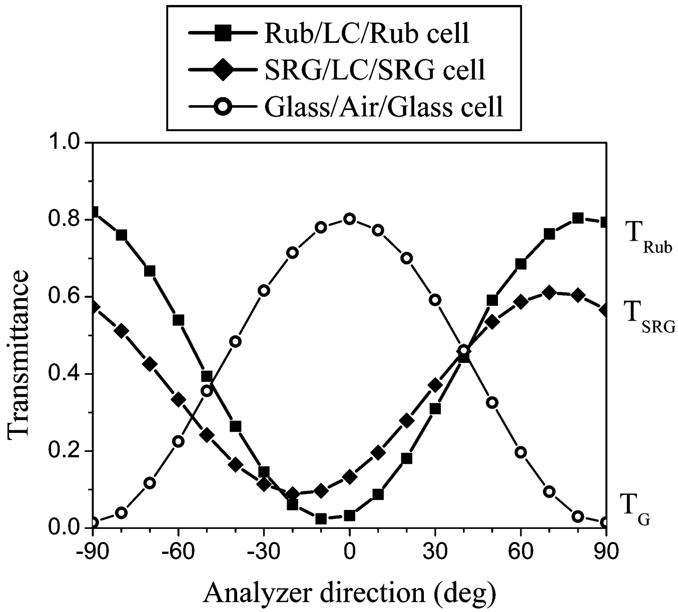

FIGURE 4 Transmittances of a) SRG/LC/SRG type and b) Rub/LC/Rub type, TNLC-cells as a function of the analyzer direction.

that the LC directors on the front and back substrates are aligned along the grating directions of the SRG and the LC directors inside the LC-cell are linearly twisted between the front and back substrates, then the TNLC cell will show the high transmittance at a particular angle near 90° depending on the thickness of the LC layer, the index difference between n_o and n_e, and the anchoring strength. Otherwise, the LC cell will show the minimum transmission at an analyzer-direction (90°) that corresponds to the crossed polarizers. The transmittance data for two kinds of TNLC cells show that the TNLC cells have the maximum transmittance near 90°(T_{SRG} and T_{Rub} curves in Fig. 4). Therefore, we conclude that the SRG substrate as well as the rubbed substrate aligns the LC directors. However, the transmittance of the SRG/LC/SRG cell is lower than that of Rub/LC/Rub cell. One possible reason is that the SRG surface has the lower anchoring energy. It will be improved by controlling the grating period and the relief depth of SRG. In order to find the optimum SRG condition for the LC alignment, we are investigating the LC anchoring properties using the SRG with various grating periods and relief depths.

In order to find the dynamics of the LC alignment by the holographic SRG, we measured *in-situ* the transmittance of the hybrid LC cell placed between crossed polarizers. For this experiment, we prepared the hybrid

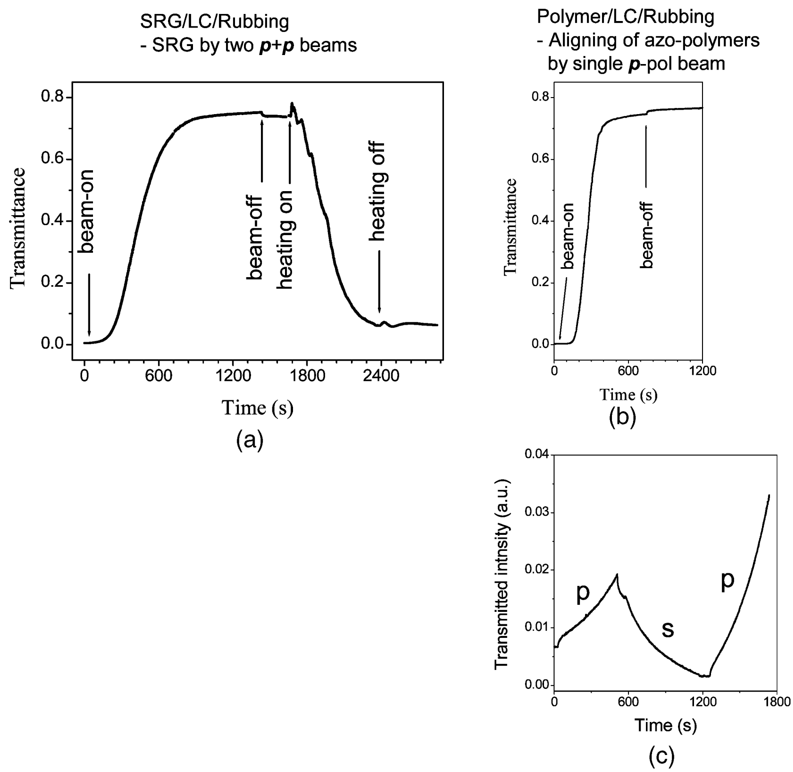

FIGURE 5 Transmittance variations of the SRG/LC/Rub cell due to a) the SRG formation and b) and c) the azo-polymer alignment with p-or s-polarized beam when the SRG/LC/Rub cell is located between crossed polarizers. (This hybrid LC cell uses the rubbed polyimide substrate and the SRG substrate as the reference and test substrates, respectively.)

LC cell using the rubbed polyimide substrate and the random oriented azo-polymer substrate as the reference and test substrates, respectively. Since the twisted structure cannot be formed in the LC cell, only one side of which is aligned, the initial LC cell transmittance is expected to be low before the SRG is formed. While the SRG is inscribing on the front substrate, the transmittance of the LC cell will be increased due to the creation of the twisted structure. In case that two beams superpose in the horizontal plane, the interference pattern will make SRG with a vertical grating. If we set the rubbed polyimide substrate to the horizontal direction, the inscribed SRG will make the 90°-TNLC cell. Figure 5a shows the transmittance of the SRG/LC/Rub cell as a function of time. The experimental result shows that the LC alignment takes place within about 15 minutes.

(If the temperature of LC cell rises above the nematic-isotropic transition temperature, the LC ordering disappears.) This time scale is similar to the photo-isomerization time constant of azo-chromophore in rigid polymer matrix. When the SRG is inscribed on the azo-polymer film using two interfering beams, both SRG and birefringence grating are recorded on the medium. To find whether the rearrangement of the azo-polymer by the photoisomerization affects on the alignment of the LC directors, we performed the single beam experiment. In this case, the SRG formation is impossible but the rearrangements of the azo-polymers are possible. As shown in Figure 5b, p-polarized beam rearranges the azo-polymers through the polarization selective absorption and photoisomerization processes [20], and the vertically aligned azo-polymers makes the LC directors align along their direction. Thus LC cell transmittance was increased to a high value. However, s-polarized beam makes the vertically aligned azo-polymers rotate to the horizontal direction (Fig. 5c). This process made the LC cell transmittance low. Therefore, we conclude that the aligned azo-polymers also align the LC directors. In the SRG inscription by two-beam interference, the topological effect by the SRG formation and the intermolecular interaction effect by the azo-polymer alignment compete with each other.

CONCLUSIONS

We found that the SRG made the nematic LC directors align along the grating direction. The SRGs were photo-fabricated on the liquid crystalline azobenzene side-chain polymer film by the conventional holographic method. The LC alignment was elucidated by measuring the transmittance of a 90°-TNLC cell located between crossed polarizers. The LC aligning process was investigated *in-situ* using the hybrid LC cell with the rubbed polyimide substrate and the SRG substrate as the reference and test alignment layers, respectively. The *in-situ* transmission data show that the topological effect by the SRG formation and the intermolecular interaction effect by the azo chromophore alignment compete with each other.

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