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Pretilt Direction of Liquid Crystal Molecules on an Ion-Beam-Treated SiO_x Films

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The pretilt direction (PD) of liquid crystal (LC) molecules on an ion-beam (IB) treated SiO_x layer is systematically examined. Using a contact angle (CA) method and scanning probe microscopy (SPM), we can clearly determine the PD of LC molecules. the PD of the LC molecules on an IB-treated SiO_x film aligns along the direction in which the CA and the surface roughness are low.

Keywords liquid crystal; pretilt direction; SiO_x; ion beam; contact angle; scanning probe microscopy

Introduction

As a result of the rapid development of liquid-crystal display (LCD) technology in recent years, LCDs are now widely used in television (TV) applications [1]. The uniform alignment of LC molecules is a key requirement in the manufacture of LCDs [2, 3]. As such, LC molecules on alignment surfaces have attracted considerable attention in the fields of basic and applied science. Various techniques have been introduced to achieve nematic LC alignment, including the mechanical rubbing method [4], photoalignment [5], oblique evaporation of inorganic films [6], and ion-beam (IB) alignment [7]. In 2001, the IB alignment method was introduced by the IBM group to overcome the drawbacks of rubbing, such as the generation of static charge and debris.

In this study, we demonstrate that surface morphologies play an important role in determining the pretilt direction (PD) of LC molecules in IB-treated SiO_x films. Using a contact angle (CA) method and scanning probe microscopy (SPM), we can clearly determine the PD of LC molecules.

Experimental

IB-treated SiO_x films were prepared as follows: SiO_x films were deposited on indium-tin-oxide-coated glass substrates using a radio-frequency (RF) magnetron sputtering system. High-purity argon gas (purity: 99.999%) was used as the reaction gas in the chamber. In our experiment, we adjusted the thickness of the deposited films up to 50 nm at a deposition temperature of 150°C. A cold hollow cathode (CHC)-type ion source was used to produce the ion beam. In order to collimate the ion beam, two perforated grids were used

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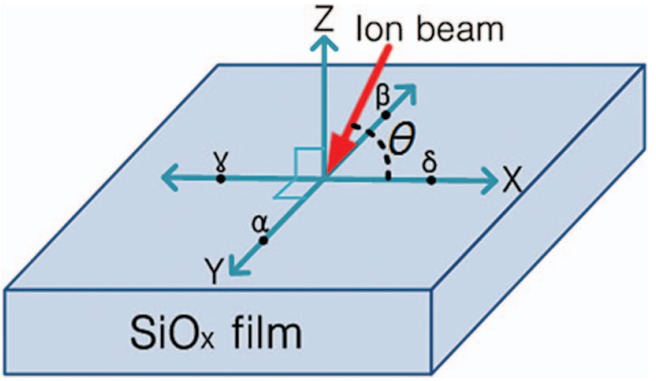

Figure 1. Experimental geometry of an IB-treated SiO_x surface (IB direction: $\theta = 80^\circ$ on the x-z plane).

as electrofocusing lenses. Argon gas was fed to the ion source through the CHC. Discharge ignition was achieved in the cathode at nominal discharge voltages and gas flow rates. A neutraliser filament outside the ion source served as the source of electrons required to compensate for the spatial charges of the IB and thus reduce the repulsive forces between the ions. The IB energy, exposure time, and IB flux density of the SiO_x film surfaces were 70 eV, 1–30 s, and 3.12×10^{13} $Ar^+/s\ cm^2$, respectively. The x-z plane projection of the IB was along the x-axis of the coordinate system, as illustrated in Fig. 1.

The surface morphologies of the alignment layers (SiO_x films) were determined by damping force microscopy (DFM) and friction force microscopy (FFM) (Seiko SPA 400). The tip-dependent deterioration of the surface morphology was minimised by repeating measurements using a new tip. The wetting properties of the surfaces were determined by performing measurements using the static CA method. The CAs along the azimuthal directions were measured by increasing and then decreasing the volume of a drop of water deposited on the alignment layer surface. The IB-treated SiO_x films were placed on a rotation stage with a resolution of 0.01°. The recorded images were digitized and analysed with a software routine that determines the tangent at the point of contact between the drop and the surface.

Results and Discussion

The PD of the LC molecules on the SiO_x film surfaces was determined by measuring the azimuthal CA on these film surfaces. On the pure SiO_x film, the azimuthal CA was typically approximately 11°, irrespective of the azimuthal direction. It has already been reported [8, 9] that LC molecules can be vertically aligned on SiO_x film surfaces when the exposure time is less than 3 s and homogeneously aligned when the exposure time is more than 4 s [8.9]. In this study, the PD of the LC molecules on the IB-treated SiO_x film surfaces was evaluated in the δ-direction using the crystal rotation method. As illustrated in Fig. 2, with an IB exposure time of 1 s, the azimuthal CAs on the SiO_x film surfaces were found to be 65.89° (α-direction), 65.98° (β-direction), 61.43° (γ-direction), and 55.65° (δ-direction). The observed CAs along the α- and β-direction, perpendicular to the IB exposure direction, were symmetrical, whereas those along the γ- and δ-directions were asymmetrical. The detected CA along the γ-direction was larger than that along the δ-direction.

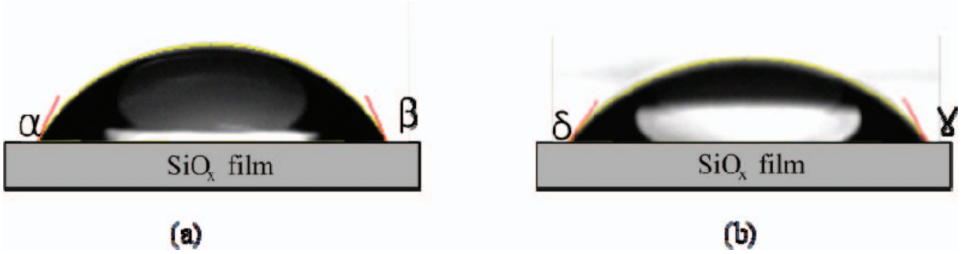

Figure 2. CA along the (a) α-, β-directions and (b) γ-, δ-directions on the IB-treated SiO_x surfaces.

The azimuthal CAs on the IB-treated SiO_x surfaces are depicted as a function of exposure time in Table I. It was found that the LC molecules could be vertically aligned in the case of large CAs (55∼66°, exposure time: 1∼3 s), and homogeneously aligned in the case of small CAs (28–35°, exposure time: 4–30 s). In the case of an exposure time of 2 s with homeotropic LC alignment, the azimuthal CAs were as follows: 64.41° (α-direction), 64.51° (β-direction), 64.06° (γ-direction), and 60.28° (δ-direction). In the case of an exposure time of 10 s with homogeneous LC alignment, the azimuthal CAs were as follows: 32.5° (α-direction), 32.58° (β-direction), 31.94° (γ-direction), and 29.63° (δ-direction). Thus, we conclude that, for all cases, the PD of the LC molecules aligns along the direction in which the CAs are low.

In order to obtain information on the relationship between the azimuthal CAs and surface morphologies, DFM and FFM on the SiO_x surfaces were performed. Fig. 3 depicts the surface morphologies of the IB-treated SiO_x film obtained by DFM. Before IB-treating, the preferred direction of the surface morphologies on the SiO_x surfaces is random, and nearly the same azimuthal CAs are displayed in all directions. In contrast, after IB exposure, anisotropy was partially generated along the exposure direction on the SiO_x film surface. Eventually, this directionally fine nanogroove-like-surface structure can result in the formation of anisotropic CAs along the azimuthal direction on the SiO_x film surface. Figure 4 presents the FFM images obtained by scanning in the γ- and δ-direction on the SiO_x surface. The images reveal that the roughness in the γ-direction is larger than the roughness in the δ-direction. This result explains why the CA is larger in the γ-direction than in the δ-direction on the SiO_x surfaces. We measured the root-mean-square (r.m.s.) roughness from the FFM image along the γ- and δ-direction as a function of exposure time, as illustrated in Fig. 5. Before the IB exposure, the roughness was nearly identical for the

Table 1. Azimuthal CA values along the α-, β-, γ-, ans δ-directions on the SiO_x film surfaces as a function of exposure time

Exposure time (sec)	θ_α	θ_β	θ_γ	θ_δ
1	65.89°	65.98°	61.43°	55.65°
2	64.41°	64.51°	64.06°	60.28°
10	32.5°	32.58°	31.94°	29.63°
30	34.17°	34.08°	33.18°	30.71°

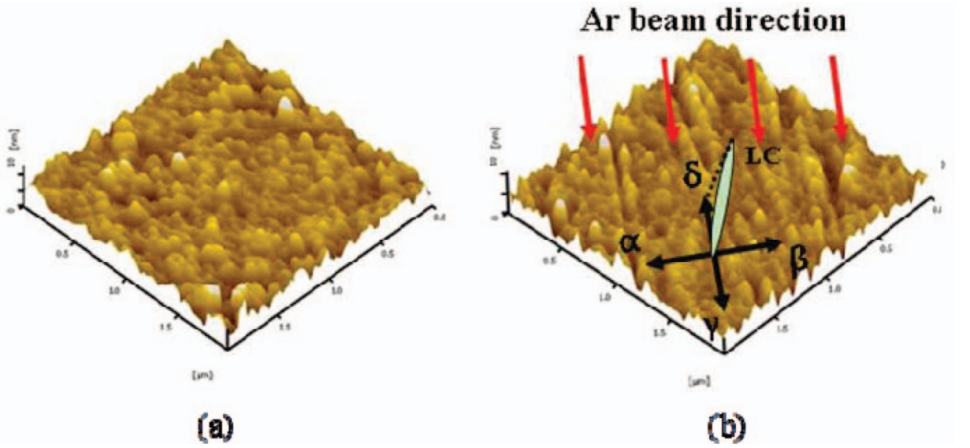

Figure 3. The AFM images on SiOx surfaces (a) before IB exposure and (b) after IB exposure during 1 s.

two directions. However, when the exposure time was more than 1 s, it is evident that the roughness in the γ-direction grew larger than that in the δ-direction.

The study results suggest that the surface morphology induced on the film determines the direction of the LC alignment. In addition, the fine difference in the surface roughness along the directions parallel and antiparallel to the IB exposure direction determines the PD of the LC molecules, which align in the direction of low roughness. These results correspond with those of the PD of LCs on rubbed polyimide surfaces [10].

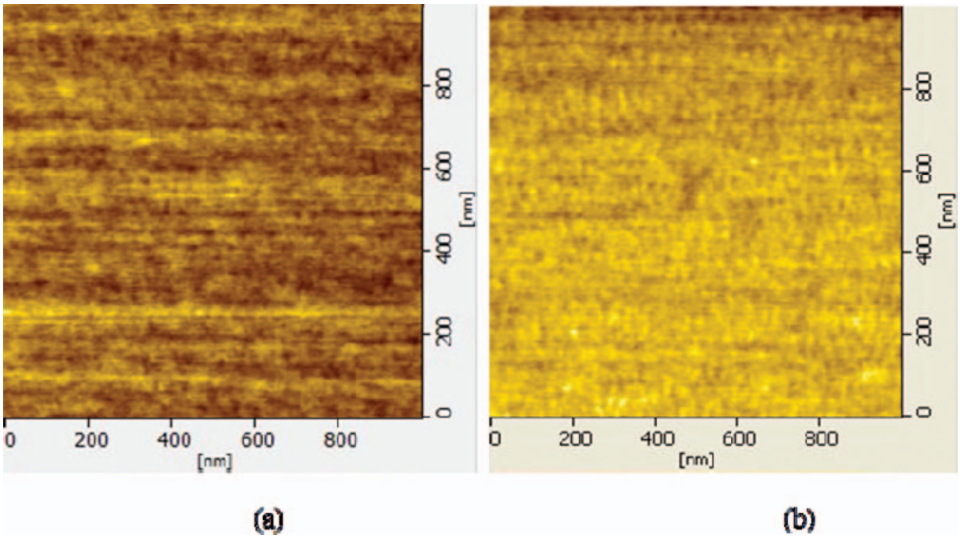

Figure 4. The FFM images of scanning in (a) γ- direction and (b) δ- direction on SiO_x surface.

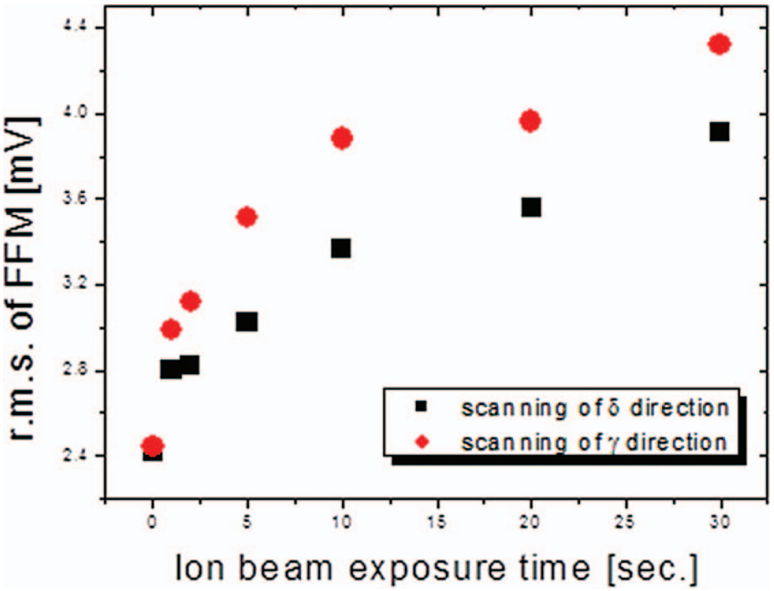

Figure 5. The r.m.s. roughness of FFM on SiO_x surfaces as a function of IB exposure time.

Conclusions

We systematically examined the PD of LC molecules on IB-treated SiO_x surfaces through CA and SPM measurements. IB treatment can induce anisotropy and asymmetry in the CAs and can also induce SiO_x surface roughness. The azimuthal CAs on an IB-treated surface are closely related to the surface morphologies. This study demonstrated that the PD of the LC molecules on an IB-treated SiO_x film aligns along the direction in which the CA and the surface roughness are low.

Acknowledgment

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