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Relationship between surface anchoring strength and surface ordering on weakly rubbed polyimide surfaces

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We have investigated the relationship between the polar anchoring strength and surface ordering in a nematic liquid crystal on two kinds of weakly rubbed polyimide (PI) surfaces. The polar anchoring strength of 5CB on weakly rubbed PI surfaces, both with and without side chains, increases with rubbing strength and with decreasing temperature. The surface order parameter of 5CB on these surfaces increases with rubbing strength, suggesting that the polar anchoring strength on rubbed PI surfaces is related to the surface order parameter.

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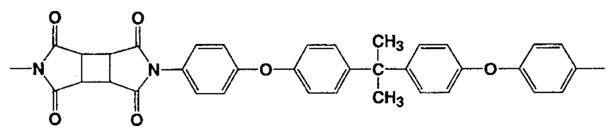
1. Introduction

Since twisted nematic (TN) liquid crystal display (LCD) devices are widely utilized for information display, the uniform alignment of LCs on substrate surfaces is important, from both the technological and scientific viewpoint. Interfacial interactions between LCs and alignment surfaces, as characterized by the anchoring strength or energy, are key to the alignment mechanisms of LCs and these have been widely studied [1–9].

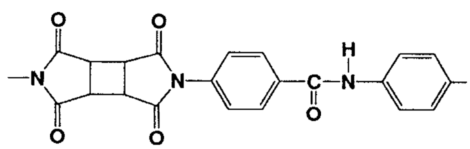
In previous work, we reported the first measurement of the temperature dependence of the polar (out-of-plane tilt) anchoring strength of the nematic LC 4-*n*-pentyl-4′-cyanobiphenyl (5CB) on weakly rubbed polyimide (PI) surfaces, a commonly used alignment substrate. We also reported the temperature dependence of the polar anchoring strength of 5CB on various PI-LB surfaces [10, 11]. In this paper, we report the relationship between the polar anchoring strength and the surface ordering of 5CB on rubbed PI surfaces.

2. Experimental

The molecular structures of the two kinds of polymer material used are shown in figure 1. The PI films were coated onto indium tin oxide (ITO) coated glass substrates by spin-coating, and were imidized at 250°C for 1 h. The thickness of the PI layers was about 500 Å. The PI films were rubbed using a machine equipped with a nylon roller (Y_o-15-N, Yoshikawa Chemical Industries Co. Ltd.). The definition of the rubbing strength, *RS*, was given in previous papers [12, 13]. LC cells were assembled with antiparallel rubbing directions; the LC layer thickness was set at $60 \pm 0.5\,\mu m$. We investigated the anchoring strength using the 'high electric-field' technique [3–5], measuring the optical retardation R and the electric capacitance C as a function of applied voltage V.



PI - A



PI - B

Figure 1. Polymer molecular structure.

Figure 2 shows the system for measurement of the anchoring strength. The optical retardation measurement system consists of a polarizer, an acousto-optic modulator, and an analyser. The output signal is detected by a photodiode. The electrical capacitance of the LC cell is obtained by measuring the out-of-phase component of the current produced by changing the voltage applied to the cell. The extrapolation length d_e is determined by using the relationship between the measured values of the electric capacitance and the

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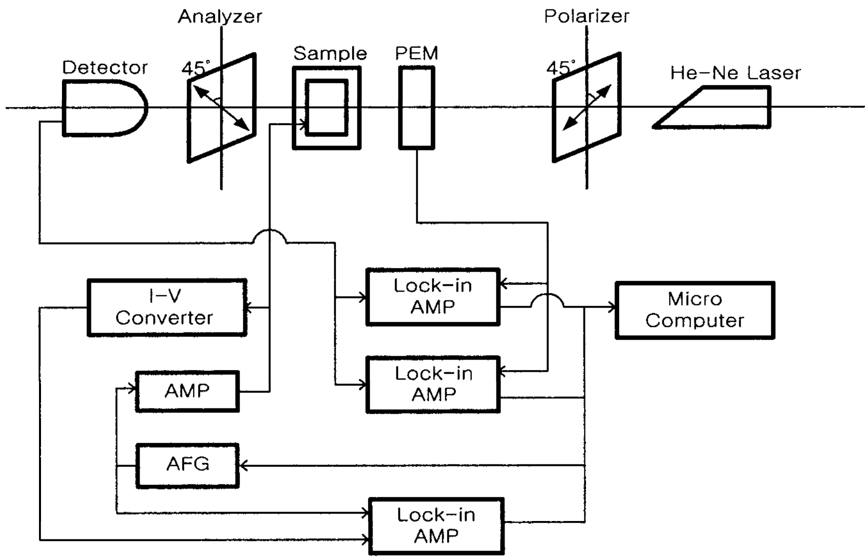

Figure 2. Measuring system for polar anchoring strength.

optical retardation:

$$\frac{R}{R_0} = \frac{I_0}{CV} - \frac{2d_e}{d}, \quad \text{when } V \gg 6V_{th} \tag{1}$$

where I_0 is a proportionality constant depending on the LC material, V is the applied voltage, and d is the LC medium thickness.

The polar anchoring energy A is obtained from following relation:

$$A = K/d_e \tag{2}$$

where K is the effective elastic constant given by $K = K_1 \cos^2 \theta_0 + K_3 \sin^2 \theta_0$, where K_1, K_3, and θ_0 stand for the elastic constants of the splay and bend deformations, and the pretilt angle, respectively. We used the measured elastic constants in this work. The surface order parameter was determined by measuring the optical retardation induced on the substrate surface above the nematic–isotropic transition temperature T_c [14].

3. Results and discussion

Figure 3 shows the measued values of d_e which, for the weakness rubbing strength ($RS = 57$ mm), tend to diverge as the clearing temperature T_c is approached. Similar behaviour is obtained for both polyimides and has been previously observed for PI-LC [10, 11] and SiO surfaces [1–5]. Since K decreases with increasing temperature T, this temperature dependence of d_e indicates that the polar anchoring energy A gradually weakens with increasing T.

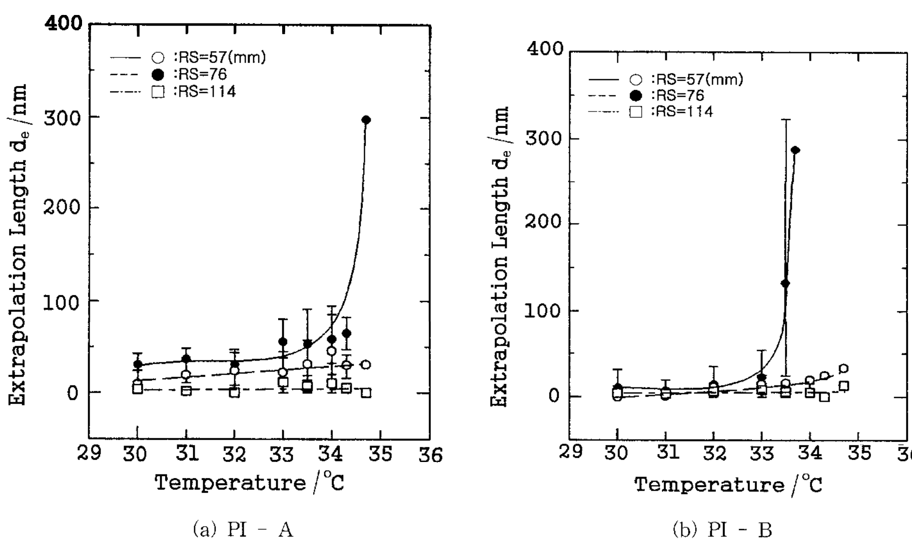

Figure 3. Temperature dependence of the extrapolation length in 5CB on weakly rubbed PI surfaces.

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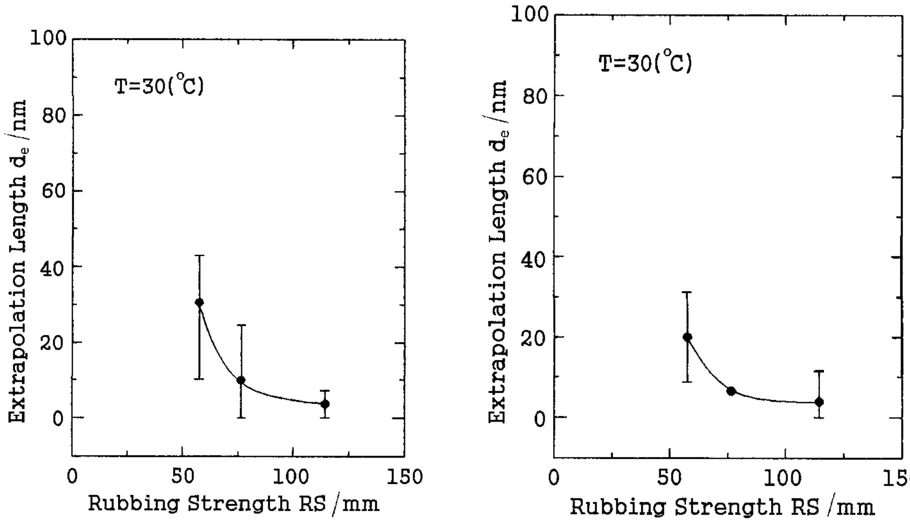


(a) PI - A (b) PI - B

Figure 4. Dependence of the extrapolation length on the rubbing strength in 5CB on weakly rubbed PI surfaces.

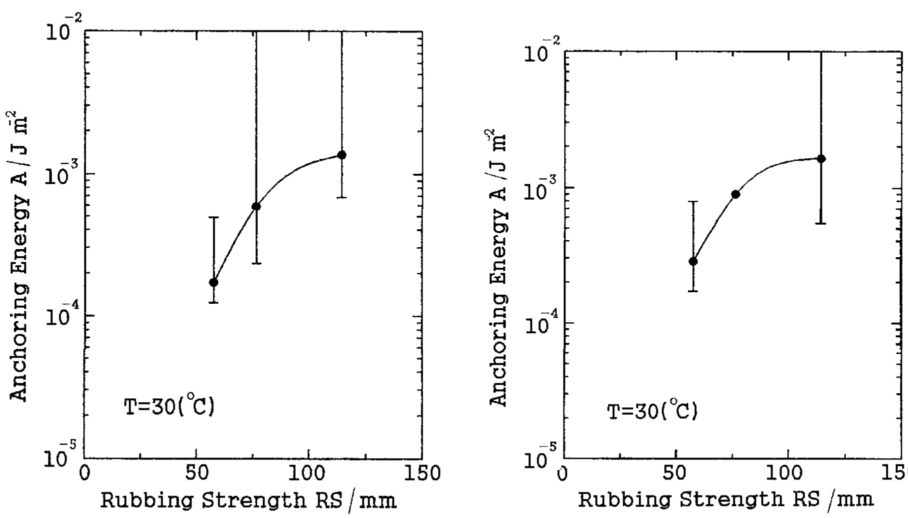
The dependence of d_e on *RS* is given in figure 4, which shows that d_e decreases with increasing *RS* in a similar way for the two PIs. Since *K* is independent of *RS*, we can conclude that *A* increases with *RS*, as shown in figure 5, where $A \sim 2 \times 10^{-4}$ J m^{-2} at *RS* = 57 mm (weak rubbing) and then increases with increasing *RS*. Similar effects are observed with both PIs.

Figure 6 shows the residual retardation induced on the two weakly rubbed PI surfaces as a function of $T > T_c$. The residual optical retardation of 5CB increases with *RS*, with PI-B showing a much larger effect at the largest *RS* value.

Figure 7 shows the surface order parameter of 5CB on the two rubbed PI surfaces as a function of *RS*. On the rubbed PI-A surface it initially increases with increasing *RS* and then saturates above *RS* = 189 mm. A high 5CB surface order parameter is obtained above *RS* = 189 mm. The surface ordering of 5CB appears to increase due to the increase of LC aligning capability with increasing *RS*. For the PI-B surface, the 5CB surface order parameter increases with increasing *RS* for small *RS*, and then peaks and decreases with increasing *RS*, a behaviour different from that of the PI-A surface. Thus the surface order behaviour differs strongly between the PI materials used.

4. Conclusions

In summary, a good relationship between the polar anchoring strength and the surface order parameter was



(a) PI - A (b) PI - B

Figure 5. Dependence of the polar anchoring strength on the rubbing strength in 5CB on weakly rubbed PI-A surfaces with side chain.

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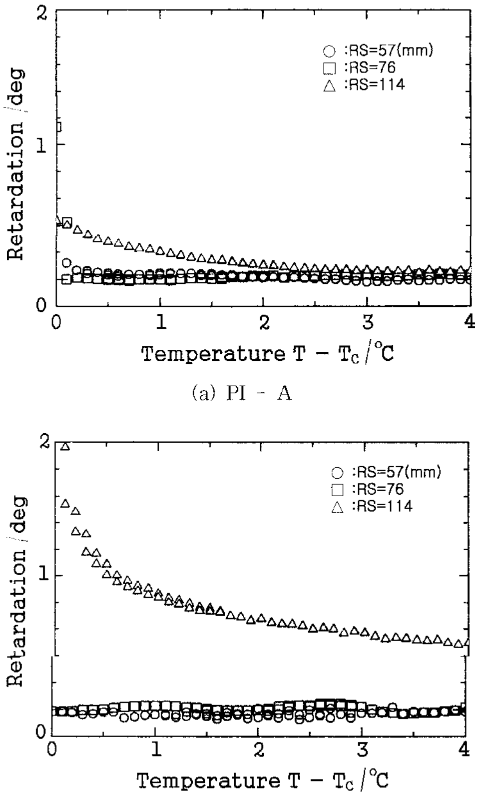

(a) PI - A

(b) PI - B

Figure 6. Residual optical retardation induced on the two weakly rubbed PI surfaces as a function of temperature above the clearing temperature T_c.

observed. The polar anchoring energy of 5CB is about $2 \times 10^{-4}\,\mathrm{J\,m^{-2}}$ and then increases with increasing *RS* on the weakly rubbed surface with side chain at 30°C; similar results are obtained on the weakly rubbed PI surface without side chain. The surface order parameter of 5CB on rubbed PI surfaces increases with increasing *RS* at a weak rubbing region; it is strongly related to the characteristics of the PI material. We conclude that the polar anchoring strength of a NLC may be strongly attributed to the surface order parameter on rubbed PI surfaces.

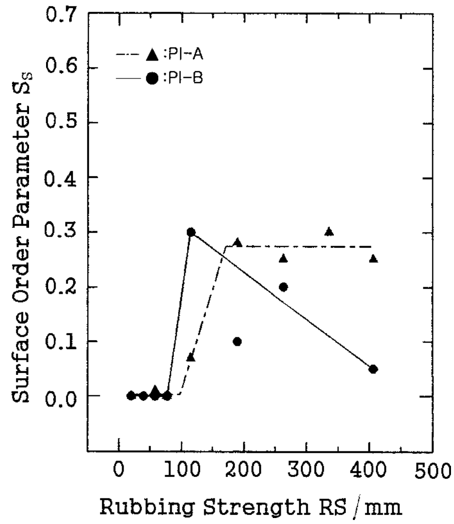

Figure 7. Surface order parameter of 5CB on the two rubbed PI surfaces as a function of *RS*.

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