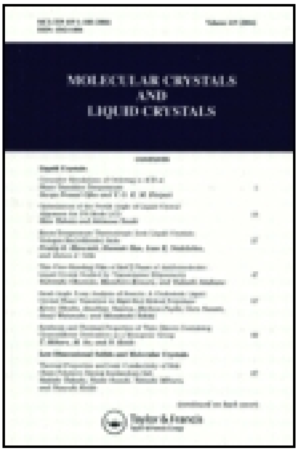

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A Study of Relationship Between the Pretilt Angle and the Polar Anchoring Strength in Nematic Liquid Crystal on Rubbed Polyimide Surfaces

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A STUDY OF RELATIONSHIP BETWEEN THE PRETILT ANGLE AND THE POLAR ANCHORING STRENGTH IN NEMATIC LIQUID CRYSTAL ON RUBBED POLYIMIDE SURFACES

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Abstract We have investigated the effects of high pretilt angle on the polar (out-of-plane tilt) anchoring energy of the nematic liquid crystal (NLC), 4-cyano-4-n-penthylgiphenyl (5CB), on rubbed polyimide (PI) surfaces containing trifluoromethyl moieties. The pretilt angle of 5CB rapidly increases up to about 45 degrees with the rubbing strength, RS. Also, the polar anchoring energy of 5CB initially increases with the RS for weak rubbing and then decreases. From these results, we determined the relationship between the pretilt angle and the anchoring energy on rubbed PI surfaces. We suggest that the polar anchoring energy of 5CB with high pretilt angle is very small because of the combination of the micro-surface excluded volume effect and the van der Waals interaction between the LC molecules and the substrate surface on weakly rubbed PI surfaces containing trifluoromethyl moieties.

INTRODUCTION

Uniform alignment of liquid crystals (LCs) on substrate surfaces is important in LC science and technology. Almost all NLC devices are fabricated by using NLC molecular orientation techniques to obtain well-oriented and defect-free NLC molecular conformations. Most LC devices with pretilted homogeneous LC alignment are prepared using various surface alignment layers such as rubbed PI surfaces,[1-12] obliquely evaporated SiO surfaces,[13] PI Langmuir-Blodgett (LB) surfaces[14,15] rubbed polystyrene (PS) surfaces,[16] and rubbed polypyrrole (PP) surfaces.[17]

The pretilt angle prevents creation of disclinations in LC cells. The pretilt angle is also very important in order to avoid stripe domains in super twisted nematic LC displays (STN-LCD)[18] and surface-stabilized ferroelectric liquid crystal display (SSFLCD).[19] The generation of pretilt angle in nematic LC (NLC) on various alignment layers by unidirectional rubbing has been demonstrated and discussed by many investigators.[3-9,11,17] For aligning LC molecules, rubbed polymer films have been widely used, but the detailed mechanism of LC alignment by rubbing is not yet fully understood.

The anchoring energy (strength) between the LCs and the alignment layer on treated substrate surfaces is very important in understanding LC alignment.[7,9,10,20-22] Also, the relationship between the pretilt angle and the anchoring energy is required to understand the physics of LC alignment, however it is not reported yet.

Recently, we reported the generation of high pretilt angle in the NLC, 5CB, aligned on PI surfaces containing trifluoromethyl moieties.[11] In this paper, we report the relationship between high pretilt angle and the polar (out-of-plane tilt) anchoring energy of 5CB aligned on PI surfaces containing trifluoromethyl moieties.

EXPERIMENTAL

The PI films containing trifluoromethyl moieties (Nissan Chemical Industries Co., Ltd.), which were coated on indium-tin-oxide (ITO) coated glass substrates by spin-coating, were imidized at 250℃ for one hour. The PI films were rubbed using a machine equipped with a nylon roller (Y_0-15-N, Yoshikawa Chemical Industries Co., Ltd.). We adopted the following expression for the rubbing strength, RS :[8,9,11]

$$RS = NM(2\pi rn/v - 1), \qquad (1)$$

where N is the number of times of the substrates rubbed (N=1, in this work), M is the depth of the fibers of the fabric deformed due to the pressed contact (mm), n is the rotation rate of the drum ($1000/60\,s^{-1}$), v is the translation speed of the substrate (7.0mm/s), and r is the radius of the drum.

LC cells were assembled with the antiparallel rub direction. The LC layer thickness was 60±0.5 μm. For measuring pretilt angles, we used the crystal rotation method[23] for values up to 10 degrees and the magneto capacitive null method[23] for values above 10 degrees. The pretilt angle measurements were done at room temperature (22 ℃).

We used the high electric-field technique, to measure the polar anchoring energy.[21,22] We evaluated the extrapolation length de by using the relationship between the measured values of the electric capacitance

(C) and the optical retardation (R):

$$\frac{R}{R_0} = \frac{I_0}{CV} - \frac{2d_e}{d}, \text{ When } V \gg 6V_{th} \quad (2)$$

where I_0 is a proportional constant dependent on the LC materials; V and d stand for the applied voltage and LC medium thickness, respectively.

Also, the polar anchoring energy A is obtained from following relation:

$$A = \frac{K}{d_e} \quad (3)$$

where K is the effective elastic constant which is 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 constant of the splay and bend deformation, and the pretilt angle, respectively. We used measured elastic constants in this work.

RESULTS AND DISCUSSION

Figure 1 shows the pretilt angle of 5CB on rubbed special PI surface containing trifluoromethyl moieties imidized at 250℃ as a function of RS. The pretilt angle of 5CB increases with the RS for weak rubbing but then decreases with the RS for strongly rubbed PI surfaces. We previously reported, that the high pretilt angles of 5CB on rubbed special PI surface containing trifluoromethyl moieties is caused by the fluorine (F) atoms, which is determined by measuring the surface atomic concentration of F/C (carbon) (%) by electron spectroscopy for chemical analysis (ESCA).[11] We suggested that the high pretilt angle generation in 5CB caused by a combination of the steric interaction and the van der Waals interaction between the LC molecules and the substrate surface on rubbed special PI surface.

The typical molecular conformation of NLC, 5CB, is shown in Figure 2. The size of long axis of LC is about 20Å. The LC size nearly coincides with the helicoidal pitch of PI conformation. From the comparision of the LC size and the helicoidal pitch of the PI conformation, it is thought that the LC alignment according to the anisotropic exclude volume effect between the LC and PI. In this way, NLC molecules are aligned accompanying the pretilt angles in the rubbing direction. In the case that substrates are unrubbed standared PI surface, this NLC alignment gives rise to the bulk pretilt angle of NLC to 0 degree

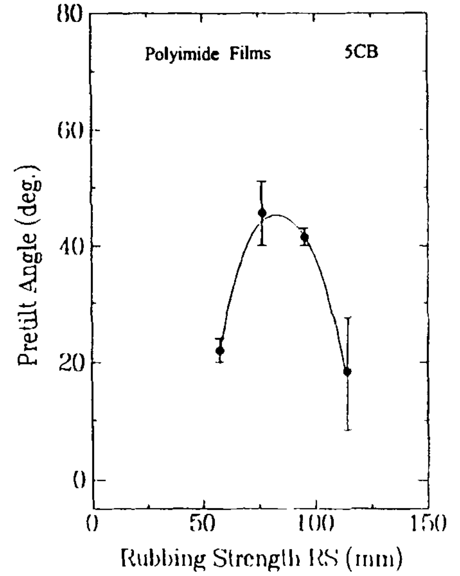

FIGURE 1 Pretilt angle in NLC, 5CB, on rubbed PI surfaces containing trifluoromethyl moieties as a function of RS.

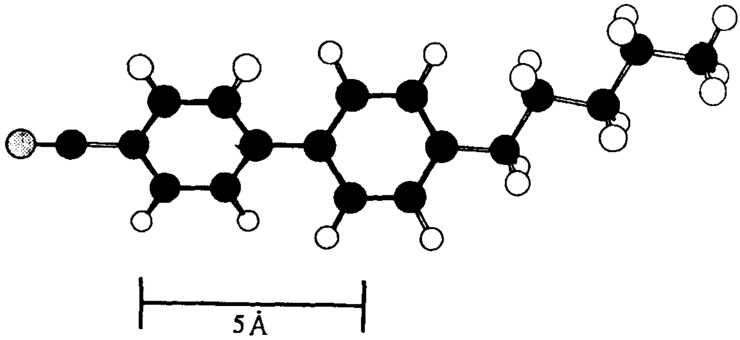

FIGURE 2 Molecular conformation 5CB.

due to the random distribution of NLC molecules even though there are local pretilted domains as shown in Figure 3 (a). In the case of the NLC alignment on rubbed standared PI surface, the alignment of NLC molecules shows the unidirectional generation of the pretilt angle along the inclination of the zig-zag PI chains by a rubbing treatment as shown in Figure 3 (b) and (c). NLC alignment on the weakly rubbed standared PI surface shows the pretilt angle of 1.5 degrees as shown in Figure 3 (b). On the other hand, the pretilt angle of NLC on the strongly rubbed standared PI surface decreases to 1.0 due to the decrease of the inclination of the zig-zag PI chain by strong rubbing as shown in Figure 3 (c).

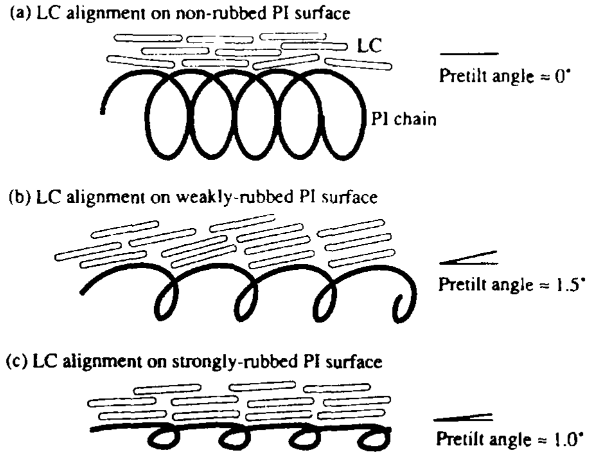

FIGURE 3 Alignment models of NLC on rubbed polyimide surface.

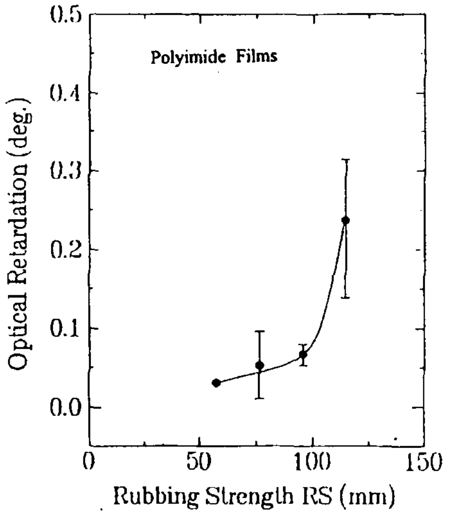

FIGURE 4 The induced Optical retardation on rubbed PI surfaces containing trifluoromethyl moieties as a function of RS.

Figure 4 shows the induced optical retardation of the rubbed PI surface as a function of RS. The induced optical retardation increases with the RS on rubbed PI surface, because of increased orientation of the polymer chains. The polymer chains are oriented by the mechaincal stress and elevated surface temperature produced by rubbing.

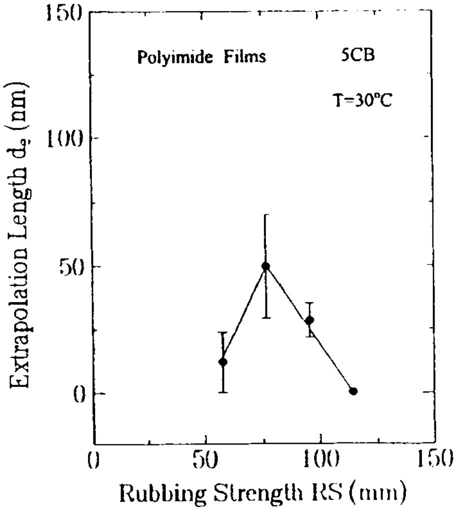

FIGURE 5 The extrapolation length de of 5CB at 30℃ on rubbed PI surface containing trifluoromethyl moieties as a function of RS.

The extrapolation length de of 5CB on rubbed PI surfaces as a function of RS is shown in Figure 5. The extrapolation length de of 5CB increases with the RS for weak rubbing then decreases with the RS. This result is very interesting, was previously assumed considering that the extrapolation length de of 5CB decrease with the RS. We consider that the extrapolation length de of 5CB is large for RS=75mm because of the approximate 50 degrees pretilt angle.

Figure 6 shows the extrapolation length de of 5CB on rubbed PI surfaces as a function of pretilt angle. The extrapolation length de of 5CB increases with the pretilt angle. This result, demonstrated that the anchoring strength of 5CB decreases with increasing pretilt angle. Consequently, the polar anchoring strength of 5CB is strongly related to pretilt angle.

Figure 7 shows the polar anchoring energy of 5CB on rubbed PI surfaces as a function of RS. The polar anchoring energy of 5CB decreases with the RS for weak rubbing and then increases with the RS for stronger rubbing. The polar anchoring energy of 5CB is less than 1×10^{-3} J/cm^2 for weak rubbed PI surfaces.

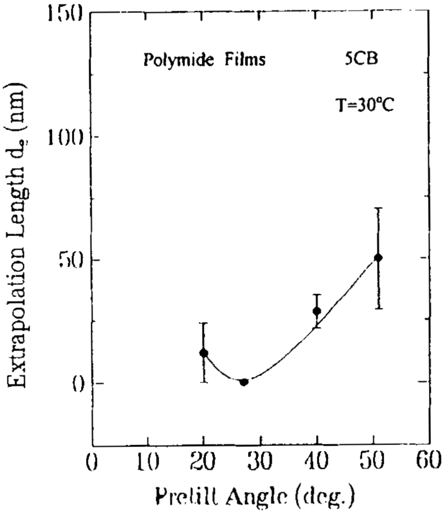

FIGURE 6 The extrapolation length de of 5CB at 30℃ on rubbed PI surface containing trifluoromethyl moieties as a function of pretilt angle.

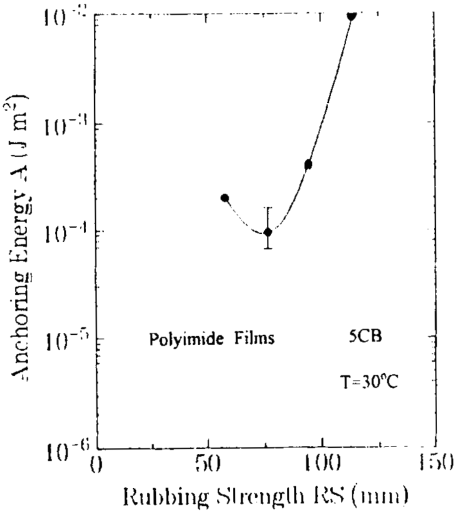

FIGURE 7 The polar anchoring energy of 5CB at 30℃ on rubbed PI surface containing trifluoromethyl moieties as a function of RS.

Figure 8 shows the polar anchoring energy of 5CB on rubbed PI surfaces as a function of pretilt angle. It is shown that the polar anchoring energy of 5CB decreases with the pretilt angle in weak rubbing on rubbed PI surface. The polar anchoring energy of 5CB decreases rapidly above 30 degrees of pretilt angle on rubbed PI surface. Therefore, we conclude that the polar anchoring energy of 5CB decreases with the pretilt angle by combination of the micro-surface excluded volume effect and the anisotropic van der Waals dispersion force[22,24-26] between the LC molecules and the substrate surfaces on rubbed PI surface containing trifluoromethyl moieties.

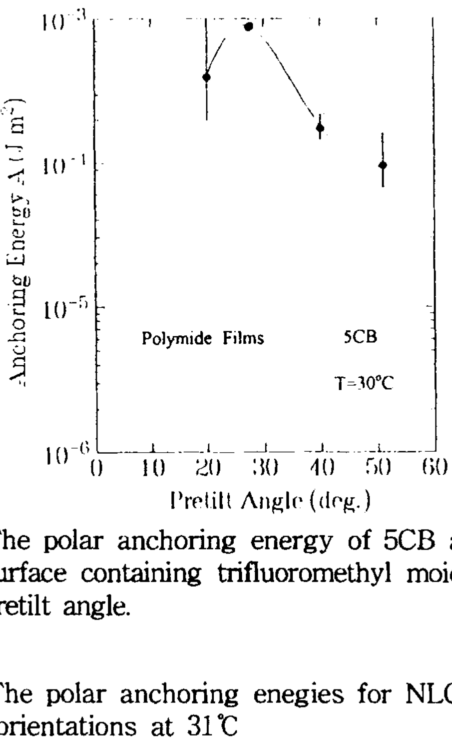

Figure 8 The polar anchoring energy of 5CB at 30℃ on rubbed PI surface containing trifluoromethyl moieties as a function of pretilt angle.

TABLE I The polar anchoring enegies for NLC, 5CB of various orientations at 31℃

Sample cells	Anchoring energy A(J/m^2) T = 31℃ Rubbing strength (mm)		
	0	189	406
Rubbed PI		$> 1\times10^{-3}$	$> 1\times10^{-3}$
Stacked PI-LB	2.5×10^{-4}		
Rubbed PI-LB		$> 1\times10^{-3}$	
SiO 60-degrees	1×10^{-4}		
Rubbed PS			6×10^{-5}
PVCN	1×10^{-4}		

The values shown in Table I form a comparision of the anchoring energy for NLC, 5CB aligned on rubbed PI surface with those for other orientation surfaces such as PI-LB surfaces, 60-degrees obliquely evaporated SiO surfaces, PVCN surfaces, and rubbed PS surfaces. It is clear that the polar anchoring energy of rubbed PI surfaces in 5CB is very large in comparision with other orientation surfaces. The polar anchoring energys are ranked in the following order : rubbed PI surfaces > rubbed PI-LB surfaces > unrubbed PI-LB surfaces > SiO 60-degree surfaces ≈ linearly polarized ultra violation UV irradiation PVCN surfaces > rubbed PS surfaces.

CONCLUSION

We investigated the effects of high pretilt angle on the polar anchoring energy of the 5CB on rubbed special PI surfaces containing trifluoromethyl moieties. The pretilt angle of 5CB rapidly increases up to about 45 degrees with the rubbing strength, RS. Also, we suggest the model of the pretilt angle generation of NLCs by unidirectional rubbing treatment on standared PI surfaces. Finally, we suggest that the polar anchoring energy of 5CB with high pretilt angle is very small because of the combination of the micro-surface excluded volume effect and the van der Waals interaction between the LC molecules and the substrate surface on weakly rubbed PI surfaces containing trifluoromethyl moieties.

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