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Relationship Between the Pretilt Angle and the Anchoring Strength in Nematic Liquid Crystal on Rubbed Polyimide Surface

논 문
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Abstract

The relationship between the high pretilt angle and the surface anchoring strength in nematic liquid crystal (NLC), 4-n-pentyl-4′-cyanobiphenyl (5CB), on rubbed polyimide (PI) surface containing trifluoromethyl moieties was investigated. High pretilt angles of 5CB are strongly related to the low surface energy due to a more existence of the trifluoromethyl moieties at the low rubbing strength (RS). High pretilt angles of 5CB may be attributed to the van der Waals (VDW) dispersion interaction between the LC molecules and polymer surface that has the low surface energy. The polar anchoring strength of 5CB strongly depends on the surface ordering on rubbed PI surface containing trifluoromethyl moieties ; it increases with increasing the RS.

Key Words(중요용어) : Polyimide surface, Nematic liquid crystal (NLC), Rubbing strength, Anchoring strength, Surface ordering

1. INTRODUCTION

Liquid crystal displays (LCDs) are widely used in every possible field of application, including, for example, watches, electronic games, notebook computer, and color television. Interfacial properties between the LC molecules and the alignment surfaces are key to understand the alignment mechanism of LCs. Rubbed polyimide (PI) surfaces have been widely used to align LC molecules. The pretilt angle prevents the creation of disclinations in LC cells. The pretilt angle is also very important in order to avoid stripe domains in super (S) TN-LCD. The generation of pretilt angle in NLC on various alignment layers by unidirectional rubbing has been demonstrated and discussed[1~7]. Recently, we have reported the generation of high pretilt angle in NLC, 5CB, on rubbed PI surfaces containing trifluoromethyl moieties[7]. The existence of the trifluoromethyl moieties in the special PI, and its appearance in the surface region are considered to be responsible for high pretilt angle generation at weak rubbing region.

The anchoring strength (energy) between the LCs and the alignment layers on treated substrate surfaces has been demonstrated and discussed by many investigators[8~12]. In a previous work, we have reported the first measurement of the temperature dependence of the polar (out-of-plane tilt) anchoring strength of weakly rubbed PI surfaces in 5CB[10]. We also reported the polar anchoring strength of 5CB on various PI-LB surfaces as a function of temperature[12, 13]. Recently, we have reported the effects of high pretilt angle on the anchoring strength in NLC on rubbed PI surface containing trifluoromethyl moieties[11]. In this work, we

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report the relationship between the high pretilt angle and the polar anchoring strength in 5CB, on rubbed PI surfaces containing trifluoromethyl moieties. In addition, the effects of the surface ordering on the surface anchoring strength are discussed.

2. EXPERIMENTAL

Figure 1 shows the chemical structure of the polymer material used in this study. The PI films were coated on indium-tin-oxide (ITO) coated glass substrates by spin-coating, and were imidized at 250℃ for 1 hr. The thickness of PI layers was about 500Å. The PI films were rubbed using a machine equipped with a nylon roller (Y_0-15-N, Yoshikawa Chemical Industries Co., Ltd.). The definition of the rubbing strength, RS was given in previous papers[3, 7]. LC cells were assembled with the antiparallel to rubbing direction. The LC layer thickness was set at 60.0±0.5μm. To measure pretilt angles, we used the crystal rotation method for values up to 10° and the magneto capacitive null method for values above 10°[14]. The measurement of pretilt angle was done at room temperature (22 ℃). The surface tension of the rubbed PI surface is obtained from the measurement of the contact angles of water and methylene iodide on rubbed PI surfaces. Also, we measured the induced optical retardation on rubbed PI surface containing trifluoromethyl moieties[7]. To analyze the surface atomic concentration with an electron spectroscope for chemical analysis (ESCA) instrument (ULVAL PHI Co., Ltd., Model 5400) was used. The depth dependence of the relative concentration F/C (%) was measured by changing the setting angle of the X-ray detector ; the X-ray radiation detected in the normal direction to the sample and that at 75° from the normal give the data at 12 and 3nm depth. Next, we measured the anchoring strength by using "high electric-field techniques"[8, 9]. We measured the optical retardation (R) and the electric capacitance (C) as a function of the applied voltage (V) in order to determine the polar anchoring strength. Figure 2 shows the measuring system of polar anchoring strength. The optical retardation measurement system consists of a polarizer, an acousto-optic modulator (PEM), and an analyzer. The output signal is detected by a photodiode. The electric capacitance of the LC cell is obtained by measuring the out-of-phase component of the current produced by changing the voltage which is applied to the cell. The extrapolation length de is determined by using the relationship between the measured values of the electric capacitance C and the optical retardation R : [8, 9]

$$\frac{R}{R_o} = \frac{I_o}{CV} \cdot \frac{2d_e}{d} \quad when\ V > 6\ V_{th} \tag{1}$$

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

The polar anchoring energy A is obtained from the following relation : [8, 9]

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

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 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 measured by measuring the optical retardation induced on the substrate surface above the clearing temperature T_c[15].

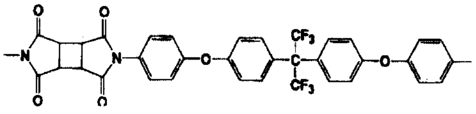

Fig. 1. Chemical structure of the polymer.

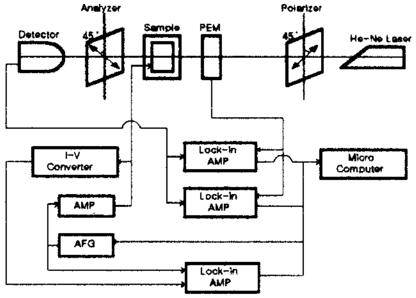

Fig. 2. Measuring system of polar anchoring strength.

3. RESULTS AND DISCUSSION

Figure 3 shows the induced optical retardation on rubbed PI surface containing trifluoromethyl moieties as a function of RS. The induced optical retardation increases with increasing the RS ; it is attributed by increasing the re-arrangement of the polymer chain by the rubbing. Figure 4 shows the generation of pretilt angles in 5CB on rubbed PI surface containing trifluoromethyl moieties as a function of RS. The pretilt angle of 5CB is generated around 45° in a weak RS region (RS=76.5mm), and then it tends to decrease with increasing the RS. In a very weak rubbing region about RS=50mm, no well aligned texture was obtained. However, well aligned texture was observed above the RS=76mm. It is shown that the peak of pretilt angle shows the uniform alignment of LCs. Figure 5 shows the surface tension on rubbed PI surfaces containing trifluoromethyl moieties as a function of RS. The surface tension increases with increasing the RS at a weak rubbing region, and then saturates above the RS=150mm. Figure 6 shows the dependence of the pretilt angle on the surface tension in 5CB on rubbed PI surface containing trifluoromethyl moieties. The pretilt angle of 5CB linearly decreases with increasing the surface tension. It is considered that the high pretilt angles of 5CB is attributed to the van der Waals (VDW) dispersion interaction between the LC molecules and polymer surface. Figure 7 shows the analysis of the surface atomic concentration of F/C (%) on rubbed PI surface as a function of RS. It is shown that the F/C (%) ratio at a depth of 3nm decreases with increasing the RS. It is considered that the low surface tension may be attributed to the large F/C (%) at the low RS region. From these results, we suggest that the high pretilt angles of 5CB are strongly related to the low surface tension due to more existence of the trifluoromethyl moieties at the low RS. Therefore, the high pretilt angles of 5CB may be attributed to the VDW dispersion interaction between the LC molecules and polymer surface that has the low surface energy. Also, the medium and low pretilt angles at the high RS may be caused by the combination of VDW dispersion and the steric interaction between the LC molecules and the polymer surface which the asymmetrical triangular structure formed by the unidirectional rubbing.

Figure 8 shows the extrapolation length d_e of 5CB for a weak rubbing on rubbed PI surfaces containing trifluoromethyl moieties as a function of temperature. The extrapolation length d_e of 5CB tends to diverge near the clearing temparature T_c. A similar behaviour was previously observed on PI-LB[12, 13] and SiO surfaces[9]. It is considered that the extrapolation length d_e of 5CB is increased because of rapidly decreasing surface ordering near the clearing temperature T_c. The dependence of the RS of the extrapolation length d_e in 5CB on rubbed PI surfaces containing trifluoromethyl moieties is shown in Fig. 9. The extrapolation length d_e of 5CB decreases with increasing the RS above the RS=76mm. However, the extrapolation length d_e of 5CB is approximately 50nm ; it is strongly attributed to the high pretilt angle of about 45°. Therefore, we consider that the polar anchoring strength of 5CB increases with increasing the RS. The polar anchoring energy of 5CB is approximately 1×10^{-4} (J/m^2) at a weak rubbing region (RS=76mm), and then increased to about 1×10^{-3} (J/m^2) at the RS=114mm as shown in Fig. 10. Figure 11 shows the surface order parameter S_s of 5CB on rubbed PI surface containing trifluoromethyl moieties as a function of RS. The surface order parameter S_S of 5CB is approximately 0 in a very weak rubbing region and then increases with the RS, and then saturates with the RS. The surface order parameter S_S of 5CB may be increasesed by increasing there-arrangement of polymer chain ; it is strongly related to the surface anchoring strength. From these results, we suggest that the polar anchoring strength of 5CB strongly depends on the surface ordering on rubbed PI surface containing trifluoromethyl moieties.

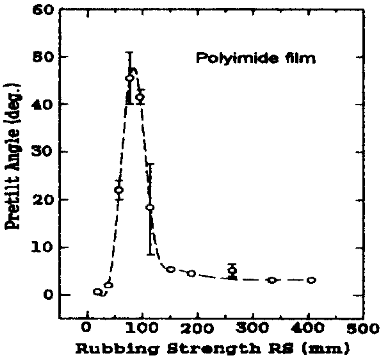

Fig. 4. Pretilt angles of the 5CB on rubbed PI surface containing trifluoromethyl moieties as a function of RS.

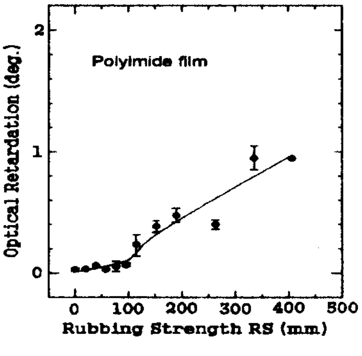

Fig. 3. Induced optical retardation on rubbed PI surface containing trifluoromethyl moieties as a function of RS.

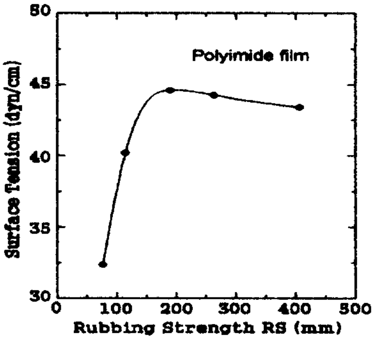

Fig. 5. Surface tension on rubbed PI surfaces containing trifluoromethyl moieties as a function of RS.

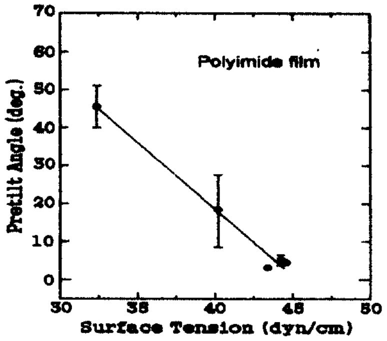

Fig. 6. Dependence of the pretilt angle on the surface tension in 5CB on rubbed PI surface containing trifluoromethyl moieties.

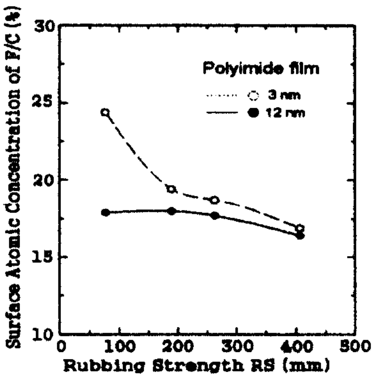

Fig. 7. Surface atomic concentration of F/C(%) on rubbed PI surface as a function of RS.

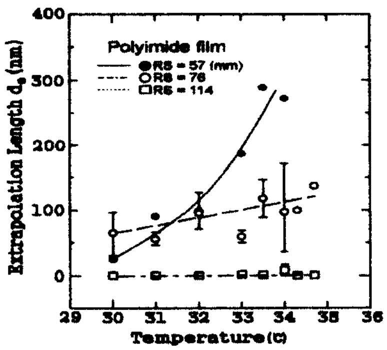

Fig. 8. Extrapolation length d_e of 5CB on rubbed PI surfaces containing trifluoromethyl moieties as a function of temperature.

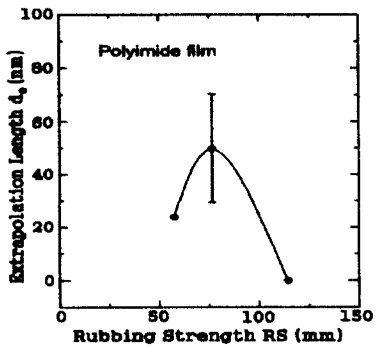

Fig. 9. Extrapolation length d_e of 5CB on rubbed PI surfaces containing trifluoromethyl moieties as function of RS.

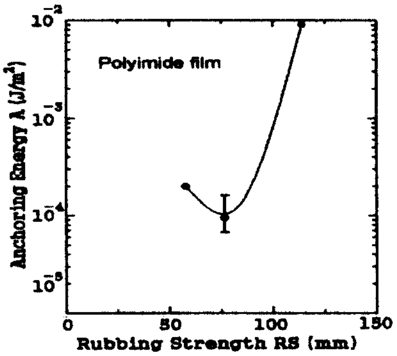

Fig. 10. Polar anchoring energy of 5CB on rubbed PI surfaces containing trifluoromethyl moieties as a function of RS.

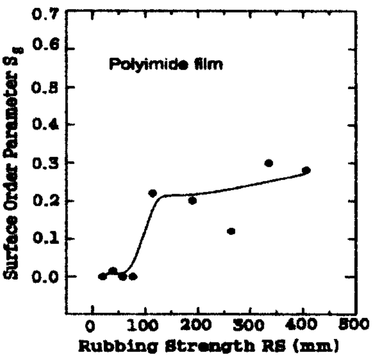

Fig. 11. Surface order parameter S_s of 5CB on rubbed PI surface containing trifluoromethyl moieties as a function of RS.

4. CONCLUSION

In summary, we have investigated the generation of high pretilt angle and the polar anchoring strength in NLC, 5CB, on rubbed PI surface containing trifluoromethyl moieties. High pretilt angles of 5CB are attributed to the VDW dispersion interaction between the LC molecules and polymer surface that has the low surface energy. Also, the medium and low pretilt angles at high RS are caused by the combination of VDW dispersion and the steric interaction between the LC molecules and the polymer surface which the asymmetric triangular structure formed by the unidirectional rubbing. The polar anchoring strength of 5CB strongly depends on the surface order parameter S_S on rubbed PI surface containing trifluoromethyl moieties.

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