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러빙처리된 폴리스타이렌막 표면에있어서의 표면 액정 배향에관한 이방성 분산력의 효과

Anisotropic Dispersion Force Effects for Surface Liquid Crystal Alignment on Rubbed Polystyrene Surfaces

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We have studied the anisotropic dispersion force effects for surfaces alignment of liquid crystals (LCs) on rubbed polystyrene (PS) surfaces by unidirection. In microphotographs of the textures, we obtained the nematic (N) LCs are shown to align in both direction parallel and perpendicular to the rubbing for region up to medium rubbing, however to align in the direction perpendicular to the rubbing for strong rubbing region. We suggest that the anisotropic dispersion force is very important rather than macro-surface groove effect to uniform alignment of LCs. We also measured the temperature dependence of extrapolation length of 5CB on rubbed PS surfaces for strong rubbing. It is shown that the polar anchoring strength of 5CB is very weak on rubbed PS surface compared to the rubbed polyimide (PI) surface.

1. Introduction

For LC science and technology, uniform alignment of liquid crystals (LCs) on substrate surfaces is very important.[1] Interfacial properties between the LCs and the alignment surfaces are very important in understanding the mechanism of LCs. For aligning LC molecules, the rubbed polymer surfaces have been widely used, but the detailed mechanism of LC alignment are not yet fully understood. The LC alignment effects on rubbed polymer surfaces are demonstrated by many researchers.[2-5]

Nakajima et al. previously reported the alignment of surface stabilized ferroelectric LC (SSFLC) on rubbed PS surfaces by rubbing treatment.[6] The anchoring strength (energy) between the LCs and the alignment layers on treated substrate surfaces was demonstrated and discussed by many investigators.[6-8] We recently reported the polar (out-of-plane tilt) anchoring strength of 5CB on various orientation films.[8,9] Regarding the theoretical models for the unidirectional alignment of liquid crystal molecules on the anisotropic substrates are: groove theory by Berreman[10] for a topologically anisotropic substrate and anisotropic van der Waals (dispersion) force by Okano et al.[11,12] In this paper, we report the anisotropic dispersion force effects in characterization of LC alignments and polar anchoring strength for homogeneously aligned 5CB on rubbed PS surfaces, where the domination of dispersion force effect over groove effect in the strongly rubbed PS is demonstrated.

2. Experimental

The polymer molecular structure used in this study is shown in Fig. 1.

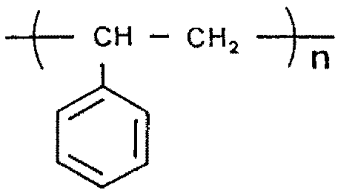

Fig. 1. Used polystyrene molecular structure

The PS films (Japan Synthetic Rubber Co., Ltd.) were coated on indium-tin-oxide (ITO) coated glass substrates by spin-coating, and were imidized at 100oC for 1h. The PS films were rubbed using a machine equipped with a nylon roller (Yo-15-N, Yoshikawa Chemical Industries Co., Ltd.). The definition of the rubbing strength, RS, was given in previous papers.[4,5] The LCs were assembled in sandwich-type cells with antiparallel-rubbed surface. All LC layers were 60±0.5 m. For measuring pretilt angles, we used the crystal rotation method.[13] The pretilt angle measurements were done at room temperature (~22℃). The LC orientation capability was evaluated by measuring induced optical retardation of PS films and observation of microphotographs of the textures of sample cells with PS orientation layers.

We measured the optical retardation (R) and the electric capacitance (C) of a sample cell as a function of applied voltage (V) in order to determine the polar anchoring strength ; this method is called high-electric field technique.[1,7] The extrapolation length, de, was evaluated by using the relationship between the measured values of the electric capacitance and the optical retardation :

$$\frac{R}{R_0} = \frac{I_0}{CV} - \frac{2d_0}{d}, \text{ when } V >> 6V_{th} \quad (1)$$

where Io 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 following relation:

$$A = \frac{K}{d_e}, \quad (2)$$

where K is the effective elastic constant which is given by $K = K_1\cos^2\theta + K\sin^2\theta$, where K_1, K_3, and θ stand for the elastic constant of the splay and bend deformation, and the pretilt angle, respectively. We used measured elastic constants in this work.

We determined the surface ordering by measuring the temperature dependence of the residual optical retardation at above the Tc.[14]

3. Results and Discussion

Figure 2 shows the induced optical retardation of the rubbed PS films as a function of RS. The major axis of the optical indicatrix of the rubbed PS surfaces is perpendicular to the rubbing direction. This result is in agreement with the previous report.[6] We consider that the major axis of the optical indicatrix is attributed to the polarization due to electron benzene rings in PS. In this study, we used the material in which the benzene rings are perpendicular to main chain in PS. The induced optical retardation is small because of cancellation of dipole in both direction parallel and perpendicular to the rubbing in PS.

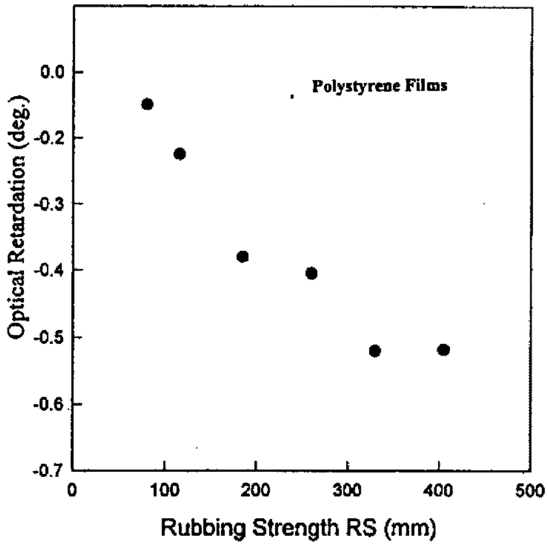

Fig. 2. Induced optical retardation on rubbed polystyrene surfaces versus rubbing strength.

The microphotographs of the textures on rubbed PS surfaces in 5CB at three kinds of RS under the crossnicols configuration are shown in Fig. 3. Figure 3 (a) and (b) shows that the aligned NLCs are shown non uniform up to medium rubbing. It is shown that the NLCs are aligned in both direction parallel (main chain direction) and perpendicular (benzene rings direction) to the rubbing for region up to medium rubbing. Figure 3 (c) shows the monodomain alignment is obtained for strong rubbing. We obtained the pretilt angle is 0 on rubbed PS surfaces for strong rubbing. We consider that the disclination lines in the texture of NLCs for strong rubbing are generated because of the absence of a surface pretilt angle. The aligned NLCs are shown to align in the direction perpendicular to the rubbing. From these results, we can suggest that at the medium rubbing strength, there occurs a competition between the parallel and perpendicular alignments, the former may be due to micro-surface groove effect to rubbing direction and the later may be due to dispersion force ; and at the strong rubbing the dispersion force may be dominate the macro-surface groove effect. It is considered that the micro-surface groove is important rather than macro-surface groove to uniform alignment of LCs. Consequently, we suggest that the anisotropic dispersion force is very important rather than macro-surface groove effect on PS surfaces.

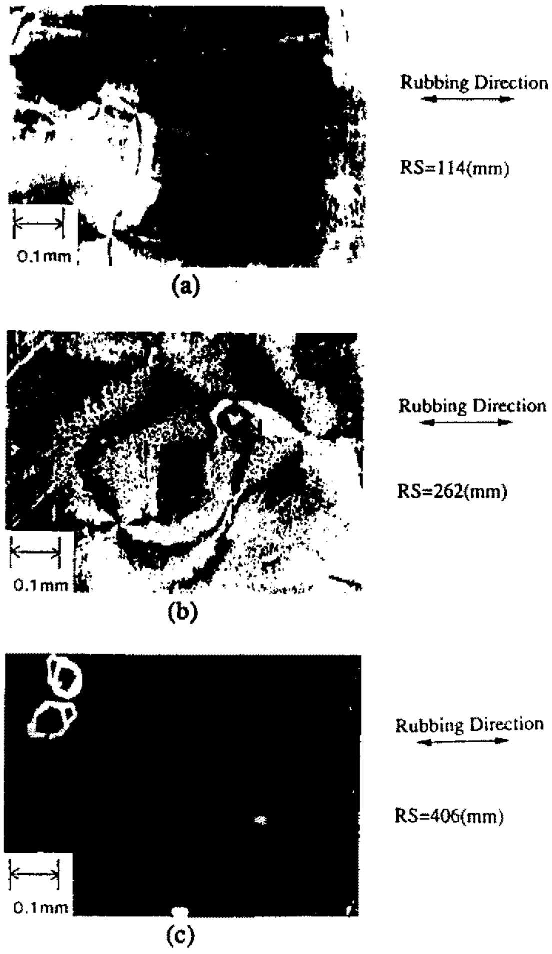

Fig. 3. Microphotographs of the textures for NLC, 5CB, on three kinds of the rubbed polystyrene surfaces. (a) RS=114 mm; (b) RS=262 mm; (c) RS=406 mm.

The characterizations of the unidirectional alignment of LCs between the groove and the birefringence on various orientation surfaces are shown in Table I.

Table I. The characterization of the unidirectional alignment of LCs between the groove and birefringence on various orientation films.

Rubbing direction	Groove	Slow axis (Δn)	LC direction	Orientation films
↔	↔	↔	↔	Rubbed PI
•	•	↔	↔	PI-LB
↔	↔	↕	↕	Rubbed PS
•	↔	•	↔	Micro Groove

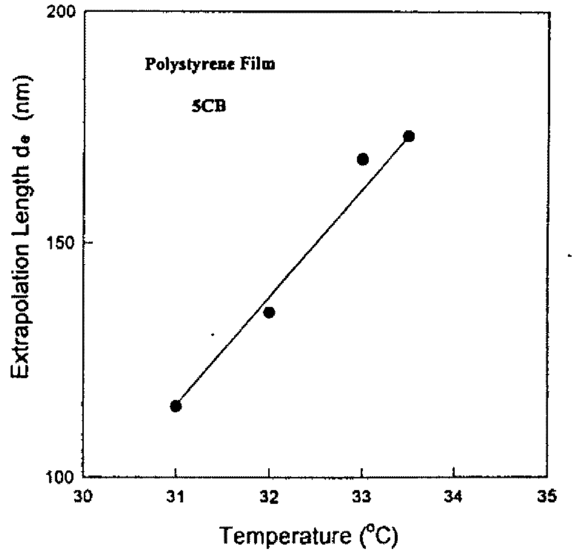

Fig. 4. Temperature dependence of extrapolation length in 5CB on rubbed polystyrene surface for strong rubbing (RS=406 mm). (T_c=35.3℃)

In a rubbed PI, the direction of grooves and slow axis coincides, thus it is difficult to distinguish the importance in the aligning capability between two effects. The dispersion force works most effectively in the frequency region of UV light (band edge absorption), so it is necessary to characterize an orientation layer by the anisotropy in the UV absorption spectra.[15] The characterization by the birefringence at a visible region is useful when it coincides with the axis of the anisotropic UV spectrum. In the benzene ring this relationship holds. For this reason the characterization by the birefringence is a just for convenience.

Figure 4 shows the temperature dependence of extrapolation length of 5CB for strong rubbing on rubbed PS surfaces. The extrapolation length is very large, about 120nm at 31℃. It is shown that the polar anchoring strength is very weak compared to standard rubbed PI surfaces. The polar anchoring energy of 5CB is about 5×10^{-5} (J/m^2) at 31℃ on rubbed PS surface for strong rubbing. The extrapolation length tends to diverge near the T_c (T_c=35.3Å). This indicates the anchoring strength weaken with temperature. A similar behaviour is previously observed on rubbed PI,[8] and SiO evaporated surfaces.[16] This divergent behavior is thought that the extrapolation length increases because of rapidly decreasing of the surface ordering near the Tc.

4. Conclusions

We investigated the anisotropic dispersion force effects for aligning LCs on rubbed PS surfaces. In conclusions, we studied that the NLCs are aligned in perpendicular to the rubbing direction by anisotropic dispersion force due to benzene rings. We suggest that the anisotropic dispersion force is very important rather than macro-surface groove effect to uniform alignment of LCs. We also suggest that the low polarization of the orientation surfaces is attributed to weak anchoring strength.

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