Materials and Rubbing Dependence on Azimuthal Anchoring Energy of Rubbed Polyimide Surfaces

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To study the alignment of liquid crystal molecules, the relationship between the optical phase retardation of rubbed polyimide films and the azimuthal anchoring energy was reported. For this work, we investigated the effects of the side chain of polyimide and the rubbing parameter on optical phase retardation of the rubbed polyimide surfaces and azimuthal anchoring energy. One main chain type and two side chain type polyimide were used.

1. Introduction

For an optimal electrooptic performance of a liquid crystal display (LCD), it is essential to get a uniform alignment of the liquid crystal molecules. The study of the alignment of nematic liquid crystals has been established in various forms, e.g., oblique evaporating,[1] rubbing,[2−8] and nonrubbing,[9] for many years. The rubbing method is a standard technique in liquid crystal display technology because of its high productivity.

When the liquid crystal molecules align in a direction such that the free engergy of the system is minimized without external energy, the surface aligning energy becomes zero. In general, this aligning direction is called an easy axis. However, the liquid crystal molecules deviate from the easy axis if an external energy is imposed onto the system.

It is well-known that the anchoring energy strongly influences the performance of liquid crystal display devices.[1,3−6] The liquid crystal fills the cavity between two polyimide surfaces that act as an alignment layer. Thus, it has become of interest to investigate the relationship between polyimide (PI) surfaces and liquid crystal molecules on interface. The rubbing induced the molecular orientation, and the degree of orientation was established by measuring the optical phase retardation (retardation).[2,7−8,10] On the basis of these results, we can assume that the realigning of the polyimide affects the director distribution of the rubbing direction.

In this study, therefore, the relationship between the optical phase retardation of rubbed polyimide films and the azimuthal anchoring energy was studied. For this work, we investigated the effects of the side chain of polyimide and the rubbing parameter on optical phase retardation of the rubbed polyimide surfaces and azimuthal anchoring energy. One main chain type and two side chain type polyimide were used.

2. Experiments

The three kinds of polyimide, one main chain type (AL-1051, JSR Co.) and two side chain type (AL-8044 and JALS-246, JSR Co.), were coated on ITO glass substrates and precured for 30 min at 80 °C and cured at 180 °C for 1 h. The approximate thickness of the resulting polyimide films was about 800 Å. Rubbing was done with nylon velvet.

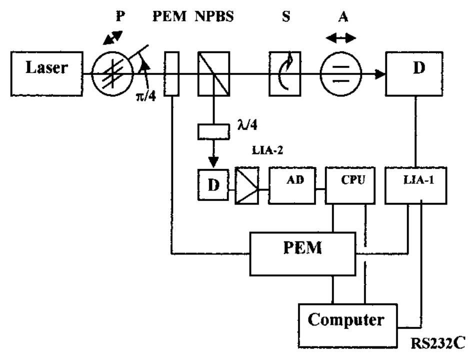

Figure 1. System setup for measurement of optical phase retardation of the rubbed polyimide films: laser = He−Ne laser, P = polarizer, PEM = photoelastic modulator (PEM), NPBS = nonpolarized beam splitter (mirror), S = rotatable sample, A = analyzer, D = detector, LIA-1 = dc amplifier and LIA-2 = ac amplifier, CPU = computer, AD = A/D converter.

The rubbing strength (RS) was calculated as follows:[2]

$$\mathrm{RS} = \gamma L \tag{1}$$

where γ is a characteristic of the rubbing process including the rubbing pressure, the fiber density in the rubbing material, the coefficient of friction, etc. L is the total length of the rubbing fiber in contact with a certain point of the substrate and is expressed by

$$L = Nl\left(1 + \frac{2\pi rn}{60v}\right) \tag{2}$$

where N is the cumulative number of rubbing (rubbing times), L is the contact length of the rubbing fiber to the surface, r is the radius of the rubbing roller, n is the number of revolutions per minute (rpm) of the roller, and v is the transverse velocity of the roller.

The system of measuring optical phase retardation of rubbed polyimide films is shown in Figure 1.

The wedge cell for the measurement of the deviation angle was assembled with the top and bottom ITO glass rubbed in parallel directions with respect to each other. The nematic liquid

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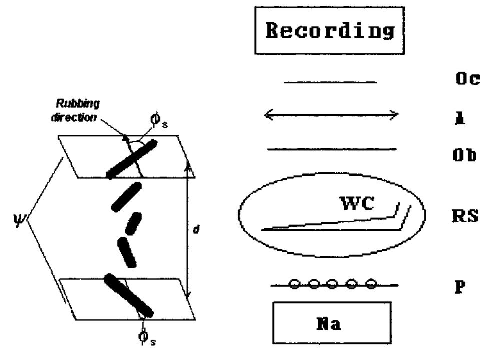
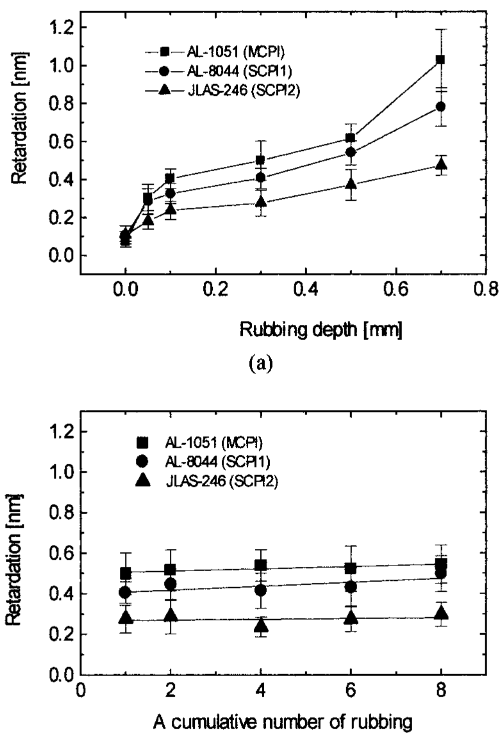


(a) (b)

Figure 2. System setup for measurement of azimuthal anchoring energy of liquid crystal: ψ = total twist angle (=$2\phi_s$), ϕ_s = deviation angle, Oc = ocular, A = analyzer, Ob = objective, WC = wedge cell, RS = rotatable stage, P = polarizer, Na = sodium lamp.



(b)

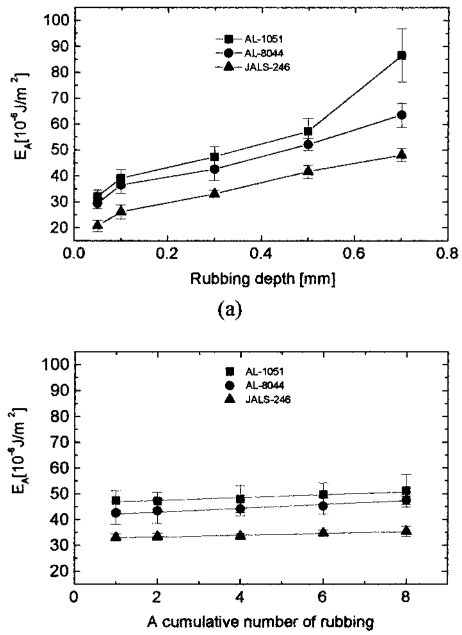
Figure 3. Retardation of the rubbed polyimide films as a function of (a) rubbing depth and (b) cumulative number of rubbing at constant 0.3 mm rubbing depth.

crystal was filled in the wedge cells, and it was in a desiccator for about 1 day for alignment stability.

The azimuthal anchoring energy (E_A) was calculated by using the torque balance method:[3,4]

$$E_A = K_{22}\frac{\pi - 4\phi_s}{d \sin 2\phi_s} = K_{22}\frac{\pi - 2\psi}{d \sin \psi} \quad (3)$$

where K_{22} is the twist elastic constant of the liquid crystal (5.2×10^{-12} N), d is the cell gap in the first disclination ($d = (2k + 1)P_0/4$, $K = 0$ in the first disclination region and P_0 is the natural pitch (13.94 μm) of the liquid crystal). ψ is the twist angle of the director of the liquid crystal molecule. ϕ_s is the deviation angle between the rubbing direction and the director of liquid crystal molecules on the rubbed surface as shown in Figure 2. The optical microscope is used for measuring the twist angle (ψ) in the region of the first disclination line.



(b)

Figure 4. Azimuthal anchoring energy of nematic liquid crystal as a function of r (a) rubbing depth and (b) cumulative number of rubbing at constant 0.3 mm rubbing depth.

3. Results and Discussion

In Figure 3a, the optical phase retardation monotonically increased and was not saturated with an increase in the rubbing depth. This tendency of the rubbing depth appeared in the surface free energy of rubbed PI surfaces and pretilt angle of the liquid crystal.[11] On the other hand, the optical phase retardation changed little with increasing rubbing times at a constant rubbing depth of 0.3 mm (Figure 3b). The optical phase retardation of a rubbed PI with side chains was smaller than that of rubbed PI without them. It might be caused by the side chain effect. It seems that polyimides realign well in the rubbing direction with an increase of rubbing depth, and the bigger retardation is obtained.[12,13]

This effect is understandable if one considers that the tiny areas of contact between the fibrous rubbing material and the polyimide surface constitute only a minute fraction of the surface's area. As rubbing proceeds, these isolated contact areas will leave behind a narrow "streak" of deformation in the polyimide surface, and the polyimide located in the contact areas will be elongated and aligned along the rubbing direction. Therefore, the anisotropic elongation of the polyimide will create an optical retardation of the polyimide film. At first, the contact areas will encounter only virgin surface, and the alignment density of polyimide will increase in the fraction of the total area that has been affected by the increase of rubbing depth. But as the rubbing times accumulates, the streaks begin to overlap, and the anisotropy elongation and the alignment density of polyimide will not show a further increase. On the other hand, the side chain may repress the anisotropic elongation of the polyimide by rubbing. This is called the side chain effect.

The azimuthal anchoring energy is calculated by the torque balance method from the data of the deviation angle. As shown in Figure 4a, the azimuthal anchoring energy monotonically increased with an increase of rubbing depth regardless of the

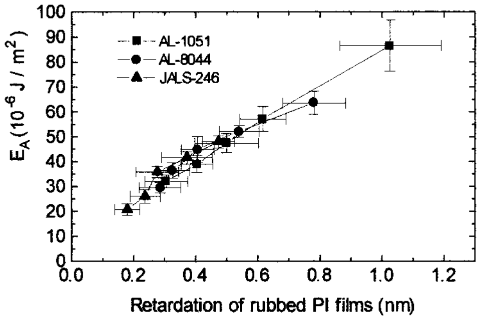


Figure 5. Relationship between the optical phase retardation of rubbed polyimide films and the azimuthal anchoring energy of nematic liqud crystal (LC:MLC-6012).

PI type. It means that the director is well aligned in the rubbing direction with the increase of rubbing depth. On the other hand, it was little changed by the increase of rubbing times on AL-1051, AL-8044, and JALS-246. It means that the deviation angle of the director to rubbing direction rarely depends on the rubbing times on the polyimide film. The azimuthal anchoring energy of the PI with the side chains was smaller than that of the PI without them. It means that the director is well aligned in the rubbing direction in rubbed PI surfaces without the side chain rather than one with the side chain. It can be assumed that the director distribution depends on polyimide-realigning. Therefore, we try to find the relationship between director distribution in the rubbing direction and the realignment of polyimide.

Figure 5 shows the relationship between optical phase retardation of rubbed polyimide films and azimuthal anchoring energy from the data of Figures 3a 4a. We found that the azimuthal anchoring energy of the nematic liquid crystal increased in a straight line as the optical phase retardation of rubbed polyimide films increased, regardless of the type of polyimide. From these results, we suggested that the increase of the realignment of polyimide by elongation on rubbed PI films decreases the deviation angle of the LC director from the rubbing direction and increases the azimuthal anchoring energy of the nematic liquid crystal. Otherwise, the three kinds of polyimide was only used to get the relationship between the realignment of polyimide and the azimuthal anchoring energy. Therefore, more experiments on many other polyimide films are needed to establish their relationship.

4. Conclusion

The optical phase retardation of rubbed polyimide films was increased with increasing rubbing depth. It is little increased with increasing rubbing times. It was smaller with the side chains than without them. It would be due to the realignment and the side chain effect of the polyimide.

The azimuthal anchoring energy of a nematic liquid crystal on rubbed polyimide surfaces was incresed if the rubbing depth was deeper regardless of the types of polyimide used. However, it may not depend on the increase of rubbing times. It was larger with the side chains than without them.

We propose that the azimuthal anchoring energy of a nematic liquid crystal depends on the realignment of rubbed polymimide.

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