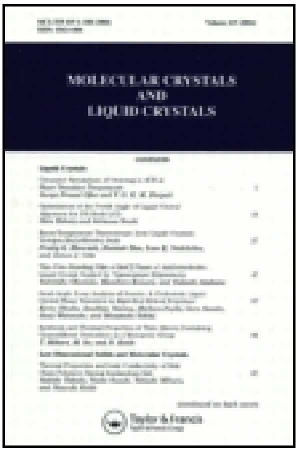

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Liquid Crystal Alignment Induced by Suspension Flow on Polyimide Surfaces

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Liquid Crystal Alignment Induced by Suspension Flow on Polyimide Surfaces

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In order to overcome the drawbacks of the conventional rubbing method, wet rubbing was proposed for the liquid crystal alignment process[1]. It utilizes uni-directional suspension flow over the polyimide layers. The flow induces surface chain orientation and micro-grooves over the threshold stress of 400 Pa., and liquid crystal molecules are aligned to the flow direction. With easy control of operations, the wet rubbing can offer accurate maintenance and surface treatment compared to conventional rubbing.

Keywords: Wet Rubbing; Liquid Crystal Alignment; Suspension Flow

I. INTRODUCTION

Homogeneous alignment of liquid crystal (LC) molecules is a prerequisite for the basic performance of liquid crystal displays (LCDs). It can be met by a proper surface treatment of the substrates between which the LC layer is sandwiched.[2] Thin polymer film, generally polyimide, is coated and then rubbed uniaxially with a cloth to control the direction of LC in contact with the films. The rubbing method has been adopted for the mass production of twisted nematic LCDs because of its simplicity, high production out and low production cost.

In the rubbing process a cylinder, which is covered with a cloth, rotates over the polymer-coated substrate with a constant velocity (v). The rubbing pressure is controlled by the pile impression (l) on the substrate, which is defined as the

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thickness change of the rubbing cloth due to the pressed contact with the substrate. The rubbing strength parameter (L) is defined as[3];

$$L = Nl\left(\frac{v + 2\pi R\Omega}{v}\right), \tag{1}$$

where N is the total number of rubbings, R is the radius of the cylinder, and Ω is the rotation speed.

Even though the pile impression (l) is said to vary with an accuracy of 10 μm [4], reproducibility of covering the cloth and its maintenance are largely dependent upon personal experience so that they may cause a critical problem in processing large-area panels. Also, dry rubbing creates large static charges, which may cause cross-talk, ghosting, or failure of thin film transistors.

In order to overcome such drawbacks, the wet rubbing process is discussed in this report. It utilizes suspensions as the buffing medium, and the polymer surface is polished by the particles in the suspension. The flow gives a uniaxial rubbing effect if shear stress is one directional. Alumina, glass beads, or polymeric beads can be used for the particles in the suspension, and finer treatment is obtained with smaller particles. With a viscous medium, sedimentation of the particle is delayed and the stress level can be controlled by a large margin. The pair of the particle and the medium should prevent possible difficulties; (1) particle aggregation, (2) sedimentation, (3) flow instability, and (4) the post cleaning process.

The conditions in the alignment process can be controlled easily with accuracy by varying the physical properties, such as the particle diameter, density, viscosity of the medium, the particle content, rotation speed of the cylinder, and the gap size between the cylinder and the substrate. In contrast to the well-defined process parameters in the wet rubbing, conventional rubbing requires empirical handling in maintenance, which lowers the reproducibility of the alignment process. In the next section, we describe the wet rubbing process and the effect of surface treatment on LC alignment.

II. EXPERIMENTS

Polyimide layers were used for LC alignment: polyamic acid (SE3310. Nissan Co.) was printed on conductive glasses, and cured at 270°C for one hour.

The suspensions used in the wet rubbing were prepared with glass beads or alumina by dispersing in glycerin. The particle size and the physical properties are listed in Table I.

TABLE I Physical properties of the particles

	Size (μm)	*Density (g/cm³)*
Glass bead	20–80	2.60
Alumina	1.0, 0.3, 0.05	3.97

Two types of flow were generated in the rheometer (PHYSICA RHEOLAB™) and home-made machine, respectively. The former gives a circular flow using a rotating cone, and the other gives a unidirectional flow using a rotating cylinder. The polyimide-coated glass (4 cm × 4 cm) was fixed on the plate. The suspension was driven by the shearing body between the gap. The rheometer also measures the viscosity of the suspensions.

After wet rubbing, layers were sonicated and rinsed with flesh water. Surface morphology was observed by SEM and surface orientation was monitored by the retardation measurement system.[5,6] LC alignment was checked by fabricating LC cells. The gap size of two substrates was kept by 12 μm spacers, and the liquid crystal (E7, E. Merck) was filled by capillary action at 65 °C.

III. RESULTS AND DISCUSSION

Uniform stress field, τ is generated between the rotating cone and substrate. The stress is constant regardless of the position, except the center point, if the cone angle is small[7];

$$\tau = \eta \frac{\Omega}{\theta_c}, \tag{2}$$

where η is viscosity, Ω is angular velocity of the rotating cone, and θ_c is the cone angle [Figure 1 (a)]. The viscosity of the suspension was measured in the rheometer during the suspension flow.

In the home-made machine [Figure 1 (b)], the force per unit width (F_x/W) applied on the plate can be obtained using the lubrication equation. It was assumed that slip does not happen at the interface, and the pressure is diminished at the separation point[8]:

$$\frac{F_x}{W} = \frac{3\sqrt{2}}{2}\eta\Omega R\sqrt{\frac{R}{H_0}}M(\lambda), \tag{3}$$

$$\text{where} \quad M(\lambda) = \left(\tan^{-1}\lambda + \frac{\pi}{2}\right)\left(\lambda^2 - \frac{1}{3}\right) + \lambda$$

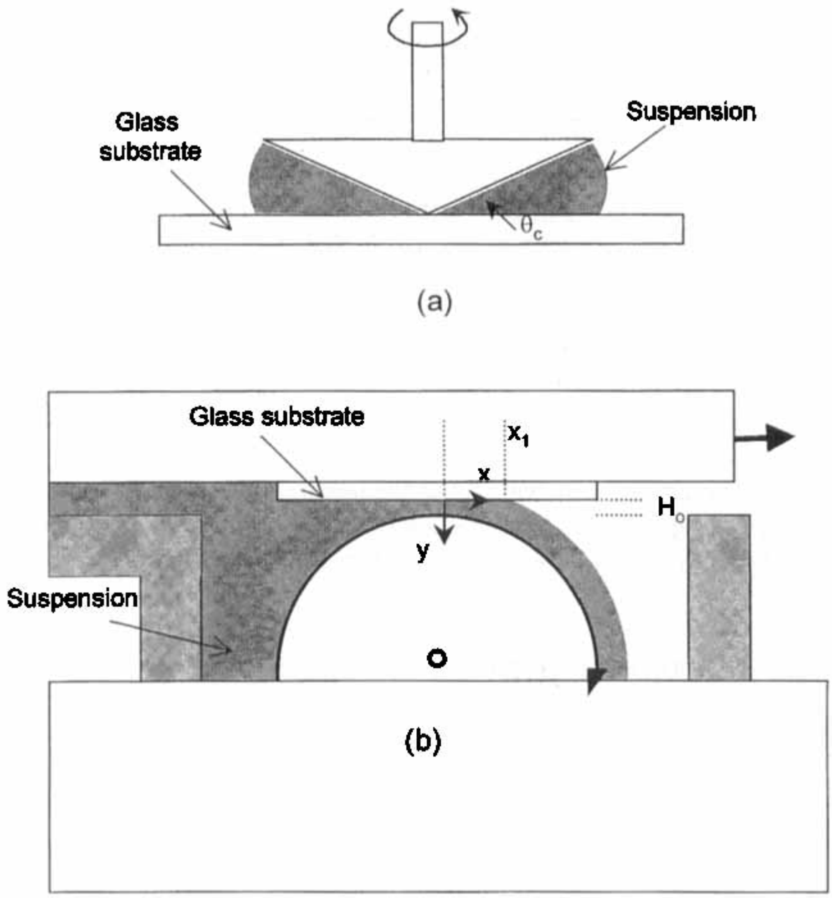

FIGURE 1 Schematic diagrams of (a) rheometric Cone-and-Plate, and (b) home-made wet rubbing machine

The radius, R, of the cylinder was 27.5 mm and the length was 200 mm, which ensures a uniform flow along the cylinder axis. The gap size, H_o, was variable from the minimum value of 1 mm. λ is the dimensionless flow rate defined as;

$$\lambda^2 = \frac{2Q}{R\Omega H_o} - 1 \tag{4}$$

λ corresponds to the dimensionless value of the pressure-diminishing point, x_1.

Figure 2 shows surface morphologies of PI layers after wet rubbing The particles driven by the flow left microgrooves on the alignment layers when 800 Pa of the stress was applied. It was observed that 80 μm glass beads scrubbed the surface and made A-shaped scratches, whereas submicron alumina dug out the surface and made V-shaped microgrooves. The alumina powder made more severe traces than the glass beads which have a lower hardness than the former. The trajectories of the scratches were not so aligned as in the dry rubbing process with cloth. As long as anisotropy exists, it would be enough to induce the orientation of LC molecules because liquid crystal responds to their boundary conditions with an extreme sensitivity.[9] It is obvious that surface rubbing with smaller particle makes a finer treatment, so that any trace did not appear in the observation of submicron resolution [Figure 2 (d)].

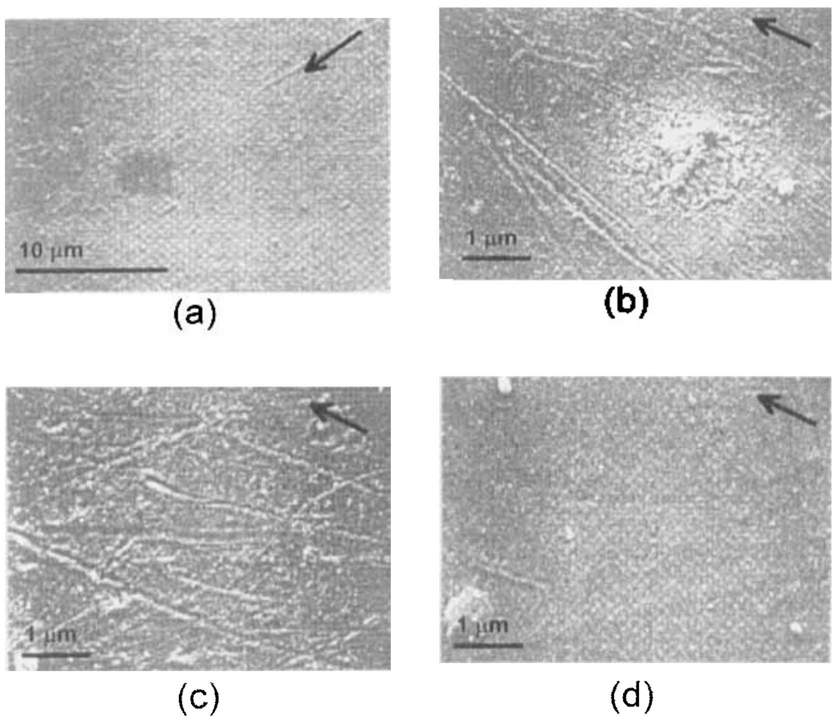

FIGURE 2 Surface morphologies of the polyimide films after the wet rubbing process with various particles in glycerin: (a) 80 μm glass bead, (b) 1.0 μm alumina. (c) 0.3 μm alumina and (d) 0.05 μm alumina. Arrows indicate flow directions

It was possible to detect the orientation of the polymeric chains by retardation measurement. The surface treatment with 8.0 vol.% alumina suspension (0.05 μm) in glycerin increased the retardation by increasing the stress above

400 Pa [Figure 3]. The stress level could not be increased above 1500 Pa because of device limitation. However the retardation value would be saturated after the monotonic increase as observed in conventional rubbing where excessive force is applied.[10] It is also known that the alumina suspension induced higher orientation caused both by the hardness and the size effect [Figure 4].

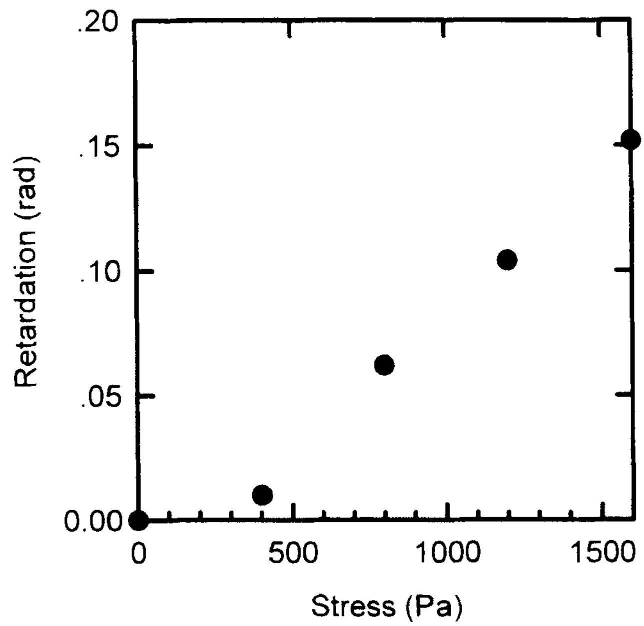

FIGURE 3 Induced retardation on the polyimide surface as the function of the applied stress with 8.0 vol.% alumina suspension (0.05 μm) in glycerin

Interestingly the retardation measurement showed matched behavior with liquid crystal alignment [Figure 5]. When the layers were rubbed in the rheometer, perfect alignment started to appear from 400 Pa. In Figure 5, the cross texture shows the circular alignment of liquid crystal molecules. The liquid crystal directors, in the black part, are parallel or perpendicular to the axis of the crossed polarizers, so that light can not be transmitted and the part becomes black as in the cross texture. The other part transmits light and becomes transparent. Clear cross texture means good alignment. No better alignment was ever obtained below the threshold stress even if the rubbing time was prolonged. It tells us that there is the threshold stress for the orientation of LC molecules on a given PI film.

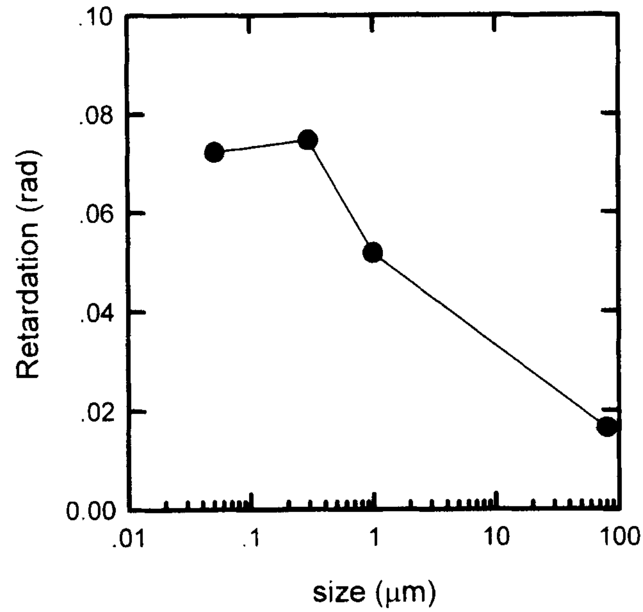

FIGURE 4 Induced retardation on the polyimide surface as the function of the particle size when constant stress (1000 Pa) was applied with 8.0 vol.% suspension

The stress applied by the solid-solid friction in dry rubbing is quite excessive even though the pile impression is minimized. Furthermore reproducibility becomes very low as the friction level lowers. In the fabrication of LC cells the pretilt angle is regulated by changing the rubbing strength as well as the properties of the alignment layers. Therefore exact control of the rubbing strength becomes important in the alignment process. Compared to dry rubbing, wet rubbing can give accurate stress control, as observed in the transient increase of retardation in the low stress region.

The twisted nematic mode was also successfully obtained when LC was sandwiched between the layers treated by uni-directional suspension flow [Figure 6]. The directions of the induced orientation in two substrates are perpendicular each other to make the twisted nematic cells. Microscopic textures under crossed polarizers showed that the cells treated by glass beads have many reverse-twist disclination loops. It might be caused by low stress exerted on the surface and coarse treatment of the large particles. When the surface was treated by alumina particles, it was possible to remove such disclination by improving both effects of the hardness and the size.

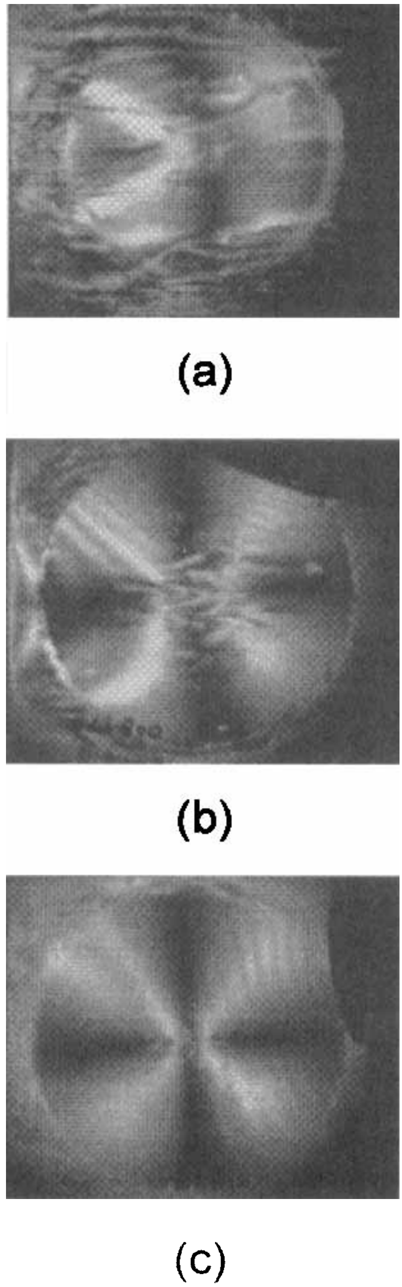

FIGURE 5 Liquid crystal cells under the crossed polarizers. Applied stress was (a) 200 Pa, (b) 300 Pa and (c) 400 Pa

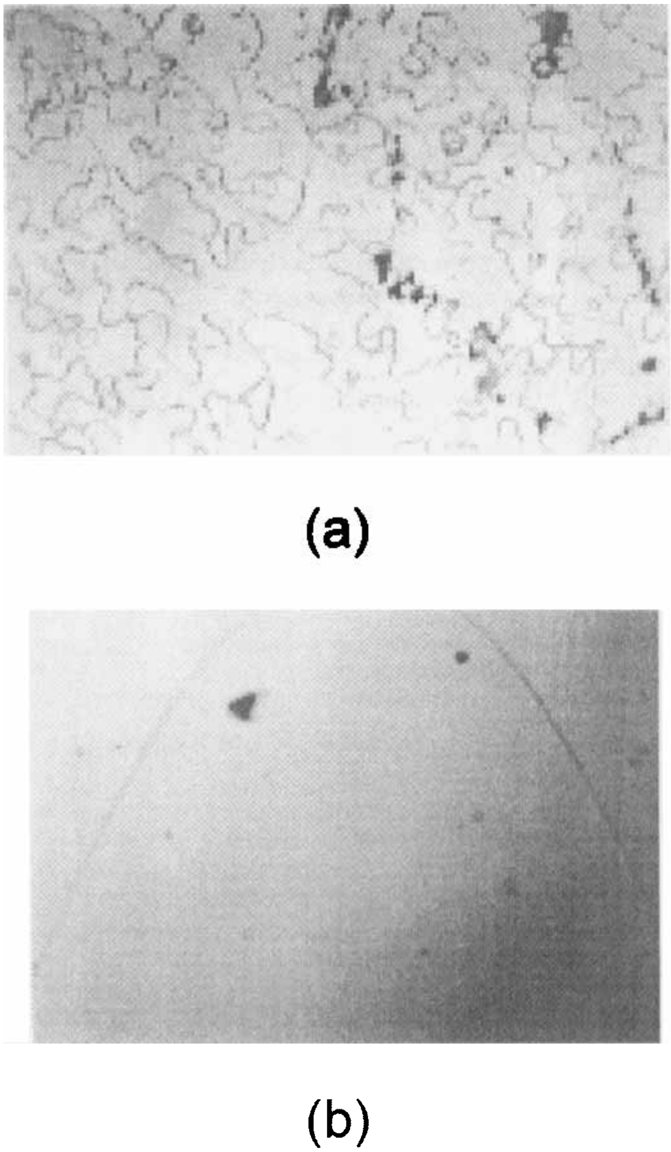

FIGURE 6 Polarized microscopic textures of the twisted nematic cells rubbed with (a) glass beads/glycerin and (b) alumina/glycerin suspension

IV CONCLUSION

By using the suspension flow, it was possible to orient surface chains of the polyimide layers which was confirmed by the generation of retardation. Suspension flow also left microgrooves on the polymeric surface over the threshold stress. Such surface anisotropies induced the orientation of LC molecules to the flow directions. Smaller and harder particles are more effective not only for homogeneous orientation of LC molecules but also for stabilizing the flow field. The wet rubbing method offers easy control of operation and maintenance with accuracy because of the well-defined physical parameters.

Acknowledgements

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