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The relationship between the polar anchoring strength and the memory capability of surface-stabilized ferroelectric liquid crystals on rubbed polyimide surfaces

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The relationship between the polar (out-of-plane tilt) anchoring strength and the memory capability of surface-stabilized ferroelectric liquid crystal displays (SSFLCD) with rubbed polyimide (PI) surfaces as alignment layers has been investigated. The polar anchoring strength of nematic liquid crystals (NLC) on rubbed PI surfaces with low polymer concentration is weak compared to that on PI surfaces with high polymer concentration. However, we have found that the memory capability of SSFLC on rubbed PI surfaces with low polymer concentration is high compared to that on rubbed PI surfaces with high polymer concentration. It is expected that the weak anchoring strength is attributed to the good memory capability of the SSFLCD on rubbed PI surfaces.

The surface-stabilized ferroelectric liquid crystal display (SSFLCD) is known for its fast response time and memory capability (bistability) [1]. The uniform alignment of LCs on treated substrate surfaces is very important for both fundamental research and technology [2]. In most LC devices, homogeneous LC alignment with a pretilt angle is prepared using various surface alignment layers such as rubbed PI [3–10], obliquely evaporated SiO [11], PI–Langmuir–Blodgett (LB) [12, 13], rubbed polystyrene (PS) [14], and polypyrrole (PP) [15] surfaces. Rubbing is the widely used technique for LC alignment. However the detailed mechanism of LC alignment on rubbed surfaces is not yet fully understood. In a previous paper, Ikeno *et al.* [16] reported on the memory capability of SSFLCDs by measuring the time dependence of the optical response on rubbed PI surfaces and PI–LB surfaces. The excellent memory capability of SSFLCDs on PI–LB surfaces was clearly observed in his study. Also, Nitta *et al.* [17] studied the memory capability of charge-transfer complex doped SSFLCDs on rubbed PI surfaces and demonstrated excellent memory capability. However, the relationship between the polar anchoring strength and the memory capability of SSFLCDs is not yet reported. Previously, we showed that the polar anchoring strength of 5CB is strong on weakly rubbed PI surfaces [18], and reported the relationship between the polar anchoring strength and the pretilt angle of 5CB on rubbed PI surfaces with trifluoromethyl moieties [19]. It was demonstrated that the polar anchoring strength of 5CB with a high pretilt angle is very small, due to the combination of the micro-surface excluded volume effect and the anisotropic dispersion force between the LCs and the substrate surfaces on weakly rubbed PI surfaces with trifluoromethyl moieties.

In this paper, we report the relationship between the polar anchoring strength and the memory capability of SSFLCDs on rubbed PI surfaces.

The molecular structure of the polymer used in this study (Nissan Chemical Industries Co., Ltd.) is shown in figure 1. The precursors were coated on indium–tin oxide (ITO) coated glass substrates by spin-coating, and imidized at 250°C for one hour. We prepared the two PI films by changing the polymer concentration; one with a high polymer concentration (3 wt %) and the other with a low polymer concentration (0·15 wt %) in solvent. The PI coating conditions were kept the same. The PI films were rubbed using a machine equipped with a nylon roller (Y_0-15-N, Yoshikawa Chemical Industries Co., Ltd.). The

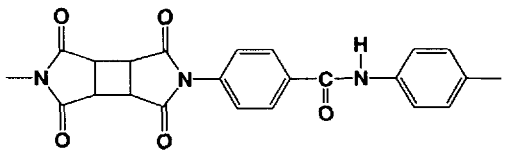

Figure 1. Molecular structure of the polymer used.

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definition of the rubbing strength, *RS*, was given in previous papers [8, 9, 12], and it is given by

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

where N is the number of times the substrates were rubbed ($N = 1$, in this work), M is the depth of the fibres of the fabric deformed due to the pressed contact (mm), n is the rotational speed of the drum (1000 rpm), v is the translational speed of the substrate (7·0 mm s^{-1}), and r is the radius of the drum.

To measure the polar anchoring strengths, sandwich-type cells with thickness of 60 ± 0·5 μm were assembled with two substrates keeping the rubbing directions antiparallel to each other. For memory capability measurements of SSFLCDs, cells were assembled keeping the rubbed surfaces parallel to each other and with a thickness of 1·5 μm. The FLC material used in this study was ZLI-3654 (from Merck Japan Ltd).

To measure the polar anchoring strength, we used the 'high electric-field technique', developed by Yokohama and co-workers [20, 21]. The extrapolation length d_e, was evaluated using the relationship between the measured values of the electric capacitance (C) and the optical retardation (R):

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

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

The polar anchoring energy A is obtained from the following relation:

$$A = K/d_e, \qquad (3)$$

where K is the effective elastic constant given by $K = K_1 \cos^2\theta_0 + K_3 \sin^2\theta_0$, K_1, K_3, and θ_0 are the elastic constants for the splay and bend deformations, and the pretilt angle, respectively. We used the measured elastic constants in this work. The memory capability of the SSFLCD is determined by measuring the time dependence of the optical response [16, 17].

We determined that the film thicknesses of polyimide were 50 nm (3 wt %) and 6 nm (0·15 wt %).

Figure 2 shows the extrapolation length of 5CB on two kinds of rubbed PI surfaces with polymer concentrations of 3 wt % and 0·15 wt % as a function of *RS*. Although the decrease of the extrapolation length with increasing *RS* is not very strong from these data, it shows a small gradual decrease, suggesting that the polar anchoring strength depends on the *RS*. Also, we have found that the extrapolation length of 5CB on a rubbed PI surface with low polymer concentration (0·15 wt %) is larger compared to that on the surface with high polymer concentration (3 wt %), which indicates that the polar anchoring strength of NLC is weaker on rubbed PI surfaces with low polymer concentration (0·15 wt %) than that with high polymer concentration (3 wt %).

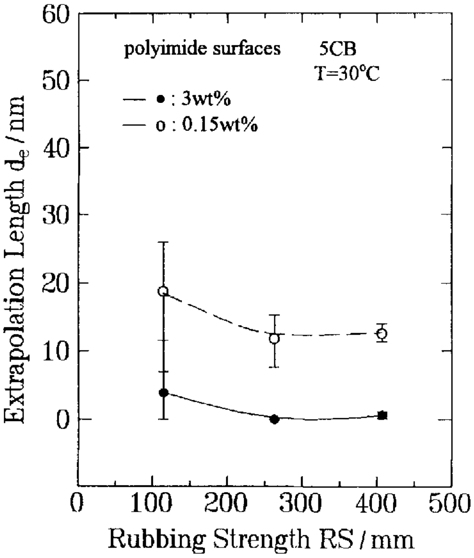

Figure 2. Extrapolation length of 5CB on two kinds of rubbed PI surfaces with polymer concentrations of 3 wt % and 0·15 wt % as a function of *RS*.

Figures 3 (*a*)–(*c*) show the memory ratio (per cent) of SSFLCDs as a function of applied voltage prepared with two kinds of rubbed PI surfaces (polymer concentrations of 3 wt % and 0·15 wt %). It is clear that the memory ratio of SSFLCDs prepared on rubbed PI surfaces with low polymer concentration is high compared to that prepared on rubbed PI surfaces with high polymer concentration for the 3 values of *RS* used. This good memory capability of SSFLCDs is attributed to the weak anchoring strength of the rubbed PI surfaces with low polymer concentration. Also, we have found that the memory capability for *RS* = 114 mm or 406 mm is higher than that obtained for *RS* = 262 mm.

In conclusion, we have investigated the behaviour of the polar anchoring strength and the memory capability of SSFLCDs on rubbed PI surfaces, with different polymer concentrations, for the first time. We have found that good memory capability of SSFLCDs can be achieved by using rubbed PI surfaces with a low polymer concentration. Finally, the memory capability of SSFLCDs is expected to depend on the anchoring strength between the PI surfaces and the LC molecules.

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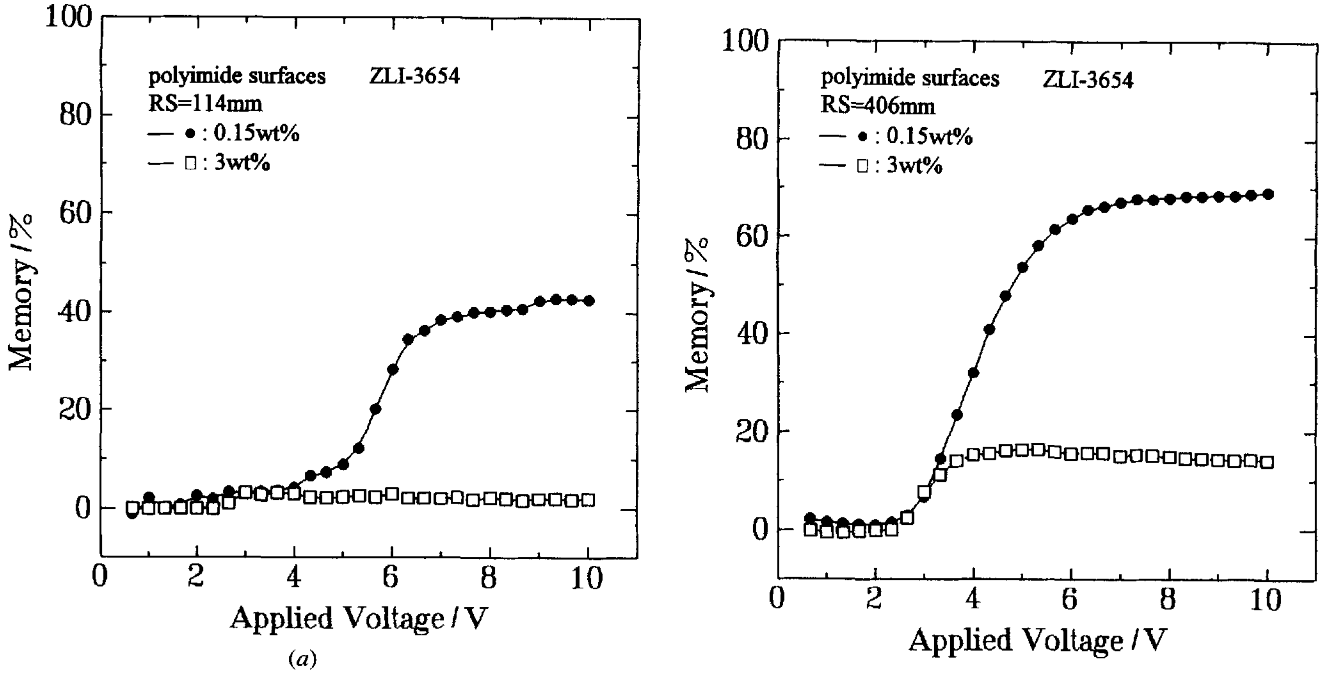
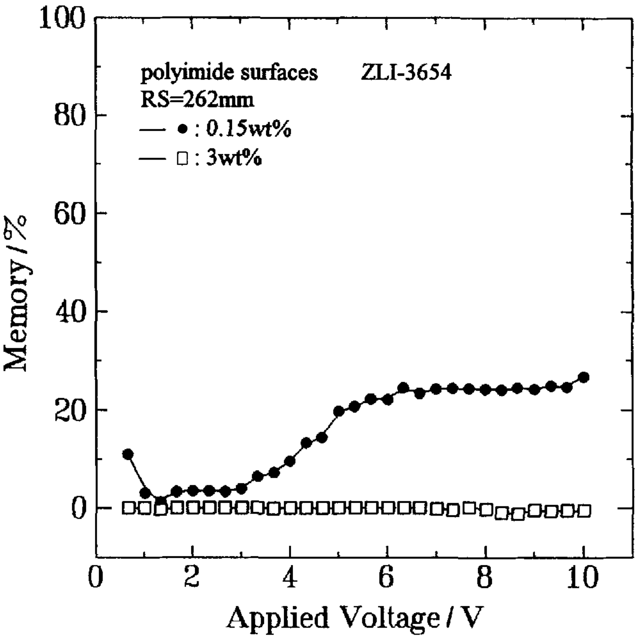


(*a*)

(*c*)



(*b*)

Figure 3. Memory ratio (per cent) of SSFLCDs as a function of applied voltage prepared with two kinds of rubbed PI surfaces (polymer concentration of 3 wt % and 0·15 wt %). (*a*) *RS* = 114 mm; (*b*) *RS* = 262 mm; (*c*) *RS* = 406 mm.

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