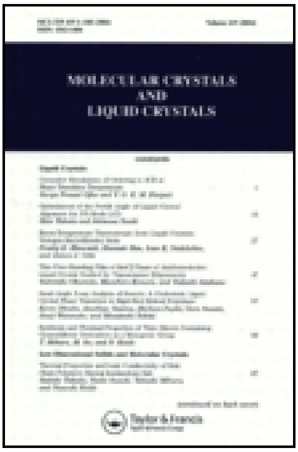

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Liquid Crystal Alignment on Electron Beam Irradiated Substrate

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The anisotropy of the substrate is responsible for inducing alignment of liquid crystal. Several techniques such as mechanical contact, light and plasma irradiation, which can create the anisotropy, are being tried to apply in commercial products. In this research, electron beam irradiation was used to induce liquid crystal alignment. A tilted electron irradiation of around $10^{16}/cm^2$ supposed to induce planar alignment in a lecithin-coated substrate. Polar anchoring was weakened by one order of magnitude, as compared to a rubbed PI layer, and the azimuthal anchoring was significantly weakened. An electron-beam-irradiated PI layer seemed not to induce the alignment.

Keywords Alignment; electron beam; liquid crystal

1. Introduction

The regular and uniform alignment of a liquid crystal (LC) is essential for the fabrication of high quality LC displays. Anisotropy of the alignment layer induces alignment within the LC, and various techniques and tools can be used to create anisotropy [1,2]. In fact, there are several alignment techniques including rubbing, photo alignment, ion beam irradiation, and plasma treatment [3–9].

Rubbing is the most widely used technique for the commercial fabrication of LC display. However, it has some issues like the generation of debris and difficulties in applying the technique to large substrates [7]. The other techniques are effectively non-contact methods and avoid the drawbacks of conventional rubbing, but suffer their own problems in regards to commercial mass production. Specifically, the reliable alignment of the material for each individual technique is a critical requirement. Although a lot of research has been invested in improving this reliability, there is a still much more work to be done.

In this paper, we introduce a new technique for aligning the LC. Electron beam (EB) irradiation was used as a non-contact alignment tool. As with light, ion, and plasma irradiation, a uniform and directional EB is expected to interact anisotropically with the alignment material, thereby producing anisotropy on the alignment

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layer. And it expects to align LC uniformly. This paper describes the experimental processes and various aspects of the alignment properties.

2. Experimental Methods

The EB irradiation was applied to several different alignment layers. The electron energy used was 0.8 MeV (EB Tech.) and the electron density applied to the substrate was controlled in the range of $10^{15}\sim10^{17}/cm^2$. The EB machine and the sample under test were exposed to air. The irradiation time ranged was from several seconds to 2 h. The EB irradiation was intermittently suspended midway through the process to avoid over-heating due to electron scattering. In most cases, the EB was irradiated in the air at an angle of incidence of 45° to the substrate, as shown in Figure 1. The divergence in front of the sample was limited because the EB emerged from the machine with certain divergence angle, and was expected to scatter before reaching the sample. Therefore, a small hole was made in a thick (about 1 cm) brass block at a 45° angle and then placed just above the sample, so as to limit the beam divergence angle to within 10°.

The alignment layers of lecithin, various polyimides (PIs), and bare glass were tested. The lecithin makes a monolayer on the ITO glass substrate and homeotropically aligns the LC. The AL-3046 PI induces planar alignment and the RN-1517 PI induces homeotropic alignment. The ITO glass and the bare glass were also investigated.

Two EB irradiated substrates were joined together using an epoxy with a 10 μm spacer. The same was done to an EB irradiated substrate with a rubbed PI layer. 5CB (4-cyano-4′-pentylbiphenyl from Merck) was used as the LC, and was injected at the isotropic phase and the LC cooled down to the nematic phase. All experiments were performed at room temperature for the nematic phase.

A polarizing optical microscope was used to observe the texture. The high electric field technique was used for measuring the polar anchoring, and the angle of director deviation from the direction of the easy axis in the twist cell gave the azimuthal anchoring. The crystal rotation method was used to measure the pretilt angle.

3. Results and Discussion

First, the texture of the lecithin-coated ITO substrate was observed using EB irradiation. Figure 2 shows the texture of the cell in the crossed polarizers across

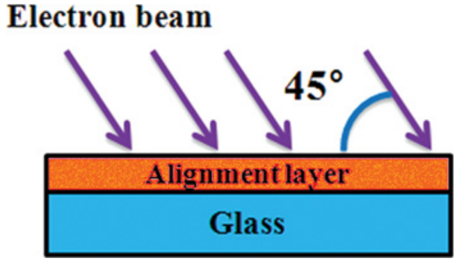

Figure 1. Experimental configuration of EB irradiation. To induce anisotropy as other techniques, the substrate was tilted at 45 degree to the beam direction. (Figure appears in color online.)

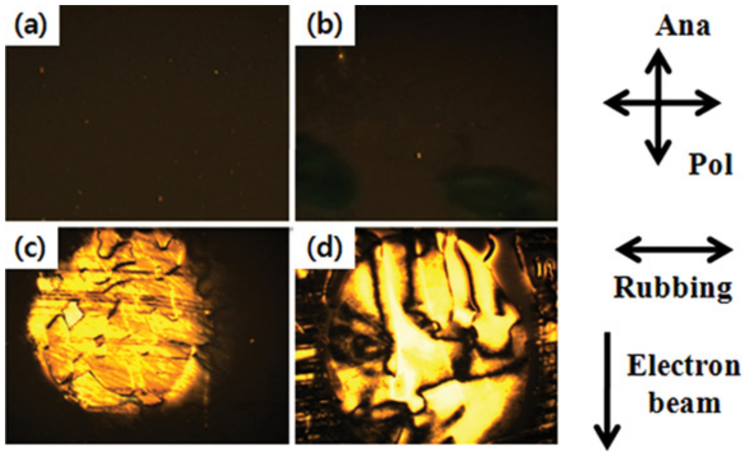

Figure 2. Texture across different beam densities for lecithin-coated substrate. The irradiated electron densities used were (a) $2 \times 10^{15}/\text{cm}^2$, (b) $1 \times 10^{16}/\text{cm}^2$, (c) $2 \times 10^{16}/\text{cm}^2$, and (d) $1 \times 10^{17}/\text{cm}^2$, respectively. The EB was irradiated through a tilted hole; hence, the texture in the inner region of the circle changed, as compared to the surrounding outer homeotropic region. The cell consisted of a uniformly rubbed substrate and an EB irradiated lecithin substrate. (Figure appears in color online.)

different electron densities. As the cell consisted of a uniformly rubbed PI layer and a lecithin-coated substrate, a hybrid LC alignment should have occurred before any EB irradiation. As the electron density was increased, the vertical alignment was lost and the substrate induced planar or tilted alignment. Even, the alignment was not perfect in Figure 2(c) and (d), the direction of the LC is rather tilted with an appreciable azimuthal angle relative to the rubbing direction.

Figure 3 shows the electric response of the EB irradiated substrate. Figure 3(a) shows that the EB irradiated region is barely different to the non-irradiated region without an applied electric field. The difference in texture got clear with applied electric field is increased. The electrical response of the EB irradiated region occurs at a higher voltage than the non-irradiated region.

The boundary between the non-irradiated and irradiated regions frequently exhibits interesting peculiarities. In some cases, they show well-aligned image compared to the center of the irradiation region, and in other cases they show irregular alignment. This is thought to result from the unpredictable electron scattering around the boundary of the brass hole.

Figure 4 shows the polar and azimuthal anchoring strength of the EB irradiated substrate. The polar anchoring coefficient was measured using a high electric field technique, and the azimuthal anchoring coefficient was obtained by measuring the direction of deviation from the easy axis in the twist cell [10,11]. The polar anchoring strength indicated that it was not so weak; however, the azimuthal anchoring strength was very weak. In the case of polar anchoring measured by the high electric field technique, extra error is expected from the non-uniformly aligned LC cell. From the relatively small variation of capacitance in the effective voltage range, we expect that does not vitally affect to the anchoring coefficient [12].

The polar anchoring strength can also be deduced from the electric response shown in Figure 3. A higher electric field is required in the EB irradiated region

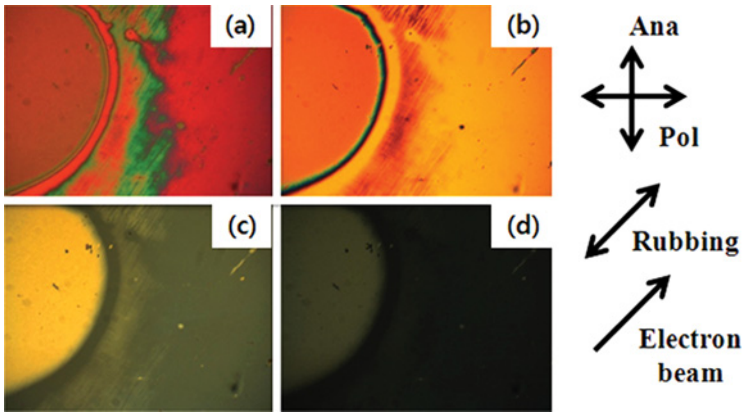

Figure 3. Change in texture of LC cell when external electric field was applied. The applied electric field strengths were (a) 0 V/μm, (b) 0.2 V/μm, (c) 0.5 V/μm, and (d) 1.0 V/μm, respectively. The applied electric field was a 10 kHz sinusoidal wave. The irradiated EB had a density of $1 \times 10^{17}/\text{cm}^2$. The cell consisted of two substrates: a lecithin-coated ITO substrate with EB irradiation in the oval region and a uniformly rubbed PI-coated substrate. (Figure appears in color online.)

compared to the outer region in order to create sufficient darkness, as shown in Figure 3(d). This means that the EB irradiated region has a higher polar anchoring than that of the lecithin surface. Furthermore, the LC was aligned homeotropically throughout the cell when the lecithin-coated substrate and the ITO-coated substate were combined. This implies that the polar anchoring of the ITO surface is weaker than that of the lecithin surface. Therefore, the polar anchoring strength shown in Figure 4(a) was not merely created by the lecithin or the ITO substrates, but was in fact induced by the EB irradation. In the case of the pretilt angle, there was no clear indication that this effect has occurred.

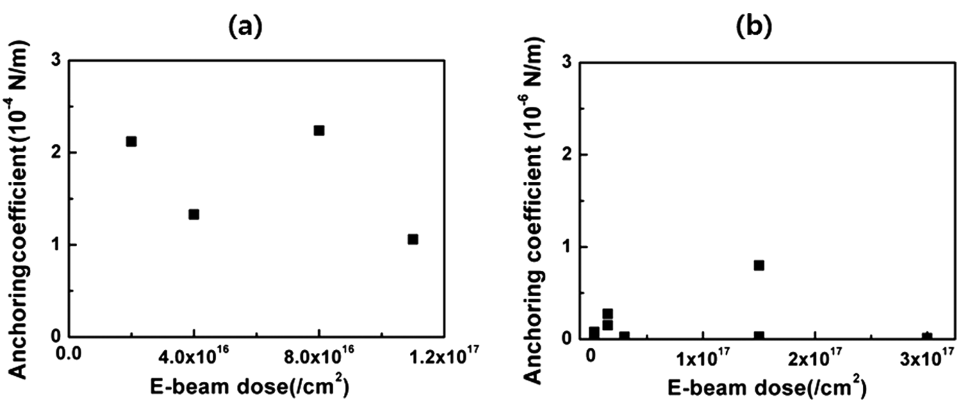

Figure 4. (a) The polar and (b) azimuthal anchoring coefficient of the EB irradiated lecithin coated ITO substrate across different electron density. In both cases the cell was manufactured by combining an EB irradiated substrate with a rubbed PI substrate.

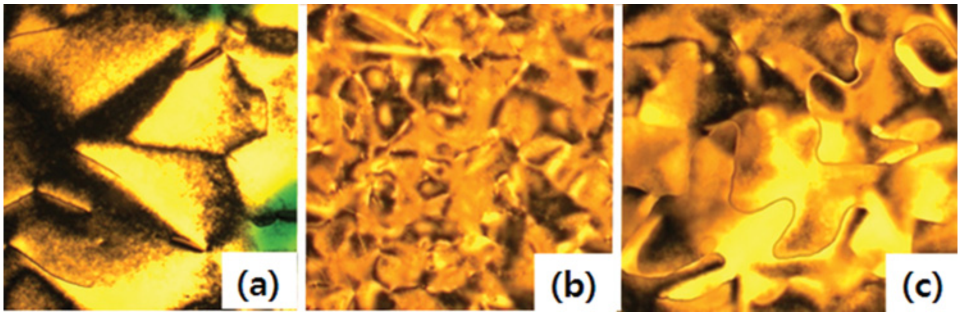

Figure 5. Texture of different PI coated substrates using an EB irradiation of $1 \times 10^{16}/cm^2$. The alignment layers were (a) AL-3046 prior to baking at 220°C, (b) AL-3046 after baking at 220°C for 1 h, and (c) RN-1517 after baking at 220°C for 1 h. (Figure appears in color online.)

Two kinds of PI layer were also tested. AL-3046 was used for planar alignment and RN-1517 was used for homeotropic alignment. Layers of each PI were prepared using standard processes and some were also rubbed using the conventional method. Figure 5 shows the results of several trials. There was no evidence of alignment in the texture, and no clear change in the LC alignment even as the electron density was increased.

The EB irradiation also deteriorated the alignment of the rubbed PI layer. As the EB irradiation on the rubbed PI layer was increased, the alignment quality got worse. In other words, disclination started to appear in the texture as the EB irradiation was increased, until finally the layer lost alignment. There was very little difference in the anchoring strength with irradiation direction. For a tilted irradiation, the polar anchoring decreased as the EB irradiation increased, as shown in Figure 6(a). For a vertical irradiation, the polar anchoring remained approximately constant across the experimental range; however, the azimuthal anchoring decreased as the EB irradiation increased, as shown in Figure 6(b). There was no indication of change in the pretilt angle.

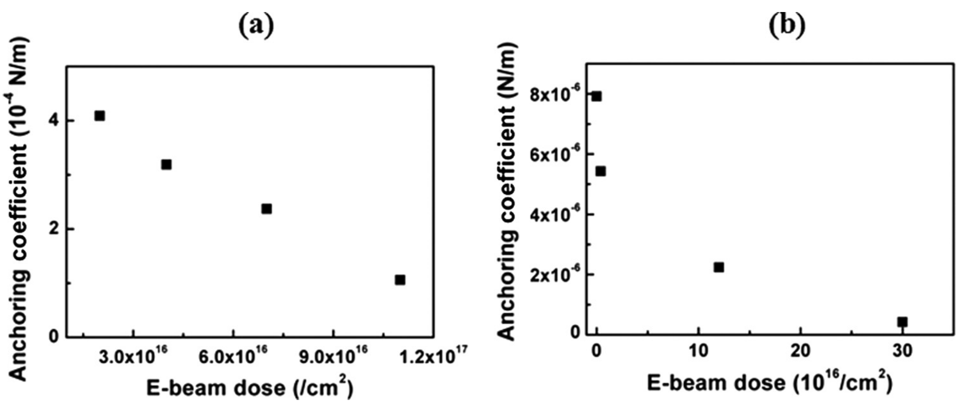

Figure 6. The change in anchoring strength as the irradiated electron density was increased on a rubbed PI layer. (a) Polar anchoring coefficient with tilted EB irradiation along rubbing direction. (b) Azimuthal anchoring coefficient with normal EB irradiation to the substrate.

4. Conclusions

We attempted to induce alignment across several different alignment layers using EB irradiation. The lecithin-coated ITO substrate aligned the LC into a planar state with reasonable polar anchoring strength but very weak azimuthal anchoring strength. In contrast, the PI layer showed no evidence of achieving alignment; in fact, it reduced the alignment quality on the rubbed layer.

In our experiments, we used an EB of very high energy in air. Therefore, during the irradiation process, there was significant electron scattering in the air and on the substrate, which deteriorated the quality of the EB. Better experimental conditions involving low electron energy in vacuum can potentially yield optimal results.

Acknowledgment

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[12] In the high electric field technique, the non-uniformity in this experiment is responsible for the reducing the slope in 1/CV versus retardation curve. However, in the limit of highest voltage, we expect the same y-intercept in the curve. The non-uniformity brings the variation of the slope as much as the ratio of capacatance ($\delta C/C$) and it varies as the function of voltage. C is the capacitance and δC is the variation of capacitance from non-uniformity. In the experimental range, the maximum value of the $\delta C/C$ was about 0.03 and the error of anchoring coefficient is expected to be less than 20% of results.