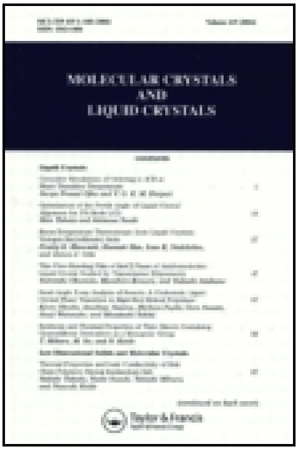
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ANOMALOUS FIELD-INDUCED DIRECTOR DEFORMATION IN A HOMOGENEOUS THIN NEMATIC LIQUID CRYSTAL CELL

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We have investigated the voltage dependence of the light transmittance for homogeneous thin nematic liquid crystal (NLC) cells composed of 4-pentyl-4′-cyanobiphenyl (5CB), which were confined between two glass plates. The substrate surfaces with polyimide layers were rubbed unidirectionally to make a uniform planar director orientation with a strong surface anchoring condition. An NLC cell was set between polarizer and analyzer. The He-Ne laser beam was passed through the NLC slab oriented with its optic axis parallel to the linearly polarized direction of the light beam. The light transmitted through the analyzer, which was crossed with the polarizer, was detected as a function of the applied voltage. In zero electric field it is expected that the director will have a uniform planar alignment and this orientation gives a minimum intensity of the light transmitted. When the voltage is applied to the NLC cell, the director for 5CB with its positive dielectric anisotropy rotates to orient parallel to the electric field. The voltage dependence of the light transmittance showed an anomalous result; that is, light leakage was observed for a certain voltage. This was interpreted by considering the director deformation at the boundaries between rubbed and non-rubbed regions of the polyimide surface.

Keywords: nematic liquid crystal; director distribution; surface anchoring; optical anisotropy; continuum theory

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1. INTRODUCTION

Electro-optic effects in a nematic liquid crystal (NLC) cell are important and of interest in the fields of both basic material science and device applications [1]. In order to control electro-optic effects the director distribution in the bulk and at the surfaces have been widely investigated both experimentally and theoretically. It is well-known that the director distribution in the bulk of a LC cell is affected by the substrate surface, as well as by externally applied fields, such as electric and magnetic fields [2]. The nematic phase is especially sensitive to external agents, in particular, to surface forces. Macroscopically, the surface effects are manifested via the director orientation in the bulk. It is important when investigating the director deformation caused by the surface anchoring in an NLC slab to understand the director distribution directly from observation of the slab. Optical methods are commonly used to measure the director distribution in a NLC cell.

In this study we have investigated the voltage dependence of the light transmittance for thin nematic liquid crystal cells with uniform planar produced by different surface treatments.

2. EXPERIMENTAL

The nematogen studied in our experiments was 4-pentyl-4′-cyanobiphenyl (5CB, Merck Japan Co., Ltd.). Three thin nematic sandwich cells with different surface treatments were prepared. The glass plates of the cells were coated with a thin layer of transparent In_2O_3 to act as electrodes. Each cell was held together by a special glue which is stable in the presence of the cyanobiphenyl and can be cured using UV radiation for a few minutes. The In_2O_3 coated glass surfaces of a 9.1 μm thick cell (A) were rubbed unidirectionally in an antiparallel manner to produce uniform planar director alignment. The surfaces of a 4.6 μm thick cell (B) were coated with a thin polyimide film (SE-7492, Nissan Chemical Industries Co., Ltd.) and also rubbed unidirectionally in an antiparallel manner to produce uniform planar director alignment. This corresponds to the so-called strong anchoring condition. We have also used a photo-alignment method, which is a rubbing free technique, to make a 5.0 μm thick cell (C). The photopolymer material used was LPP-F301CP (Nissan Chemical Industries Co., Ltd.). The substrate was then baked and exposed to linearly polarized ultraviolet (UV) light with an irradiation angle 30° from the substrate normal. The intensity of the UV light was 20 mJ/cm^2 at the substrate. The values of the film thickness for each cell were measured by optical interference with an error of $\pm 0.1\%$. The experimental setup used to measure the voltage dependence of the light transmittance is shown schematically in Figure 1. The output of a He-Ne laser (Spectra Physics Co., model-117A, output stability within $\pm 0.1\%$) was linearly polarized. The laser beam was passed through the NLC slab with its optic axis at angle of 0° (extinction setup) or 45° (diagonal setup) with respect to the polarization direction of the beam. The resulting elliptically polarized light passes through the analyzer, which is crossed with the polarizer. A function generator was used to provide a 1 KHz sinusoidal ac voltage to the cell. By changing the intensity of the voltage, the director orientation rotates towards the normal to the substrate surface, since the dielectric anisotropy of 5CB is positive.

3. RESULTS AND DISCUSSION

Normalized light transmittances, measured as a function of the applied voltage for the cell (A), are given in Figure 2. Here, open and closed circles show the results for which the rubbing direction is diagonal (diagonal setup) and parallel (extinction setup) to the polarization direction of the beam, respectively. When the voltage is applied to the NLC cell, the director for 5CB with its positive dielectric anisotropy rotates to orient parallel to the electric field. The light transmittance for the diagonal setup decreases with increasing voltage. This non-oscillatory decrease is due to the small change of the optical retardation with the director rotation because of a high pretilt angle for the preparation of cell (A). As is generally expected, the intensity of the light transmittance for the extinction setup does not change with the director rotation. This is a normal result because the director rotation for the extinction setup does not produce any optical change to the linearly polarized incident light beam.

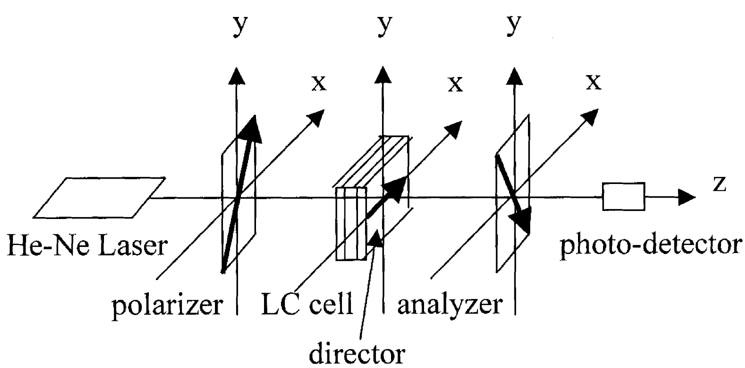

FIGURE 1 The experimental setup used to measure the voltage dependence of the light transmittance.

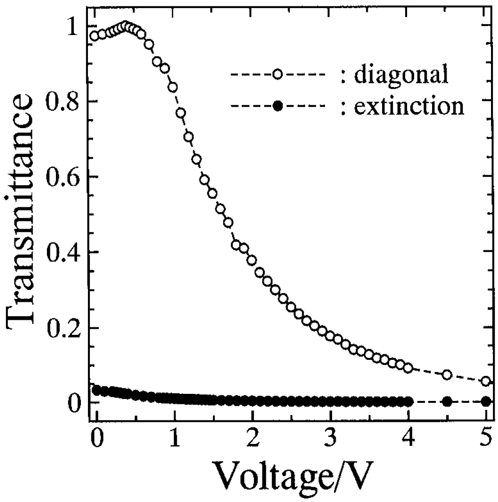

FIGURE 2 Normalized light transmittance measured as a function of the electric voltage for the cell (A).

Figure 3 shows the normalized light transmittance as a function of the electric voltage for cell (B). In this figure open and closed circles show the results for which the rubbing direction is diagonal (diagonal setup) and parallel (extinction setup) with the polarization direction of the beam,

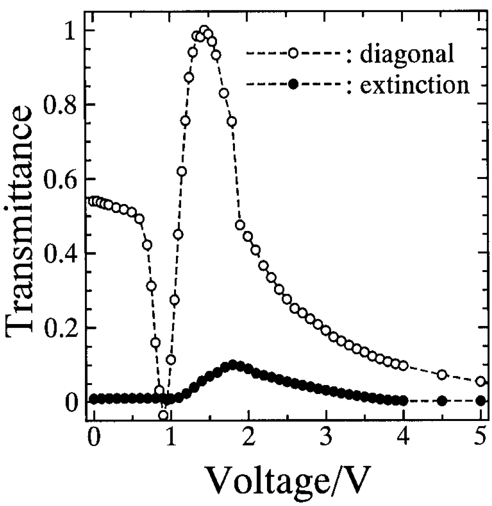

FIGURE 3 Normalized light transmittance measured as a function of the electric voltage for the cell (B).

respectively. The light transmittance for the diagonal setup exhibits an oscillatory decrease due to the change of the optical retardation of the cell with increasing voltage because of a small pretilt angle of 4° from the substrate surface. However the voltage dependence of the light transmittance for the extinction setup shows an anomalous result. That is, light leakage was observed for a certain voltage. This means that the director does not rotate as a monodomain in a plane defined by the rubbing direction and the electric field.

We now consider why the light leakage appears only for cell (B) with polyimide layers for the extinction setup. There are two differences in the preparation of cells (A) and (B). One is the surface anchoring energy, whose values of cells (A) and (B) are of the order of $10^{-6}\,J/m^2$ and $10^{-3}\,J/m^2$ [3], respectively. The other is the periodical grooves made on the polyimide layers of cell (B) [4] by the rubbing treatment, but not on the transparent electrodes of cell (A). It is well- known that rubbing an In_2O_3 surface produces a weak anchoring condition and this gives a high pretilt angle. The top view of the surface topology made by rubbing is shown schematically in Figure 4. In this figure a black region indicates a groove made by a rubbing fiber. The rubbing treatment of the polyimide layers using a fiber will induce a periodic change of the surface anchoring strength. It may be apparent that the surface anchoring energy on the groove is stronger than that on an unrubbed region. Consequently there are boundary regions (shown as dotted lines in Figure 4) with different surface anchoring strengths around the interfaces between the rubbed and non-rubbed surfaces. When a voltage is applied to the cell, the directors in such a region start to rotate with different pretilt angles due to the different surface anchoring strengths. The rotation angle of the director on a strong anchoring surface is smaller than

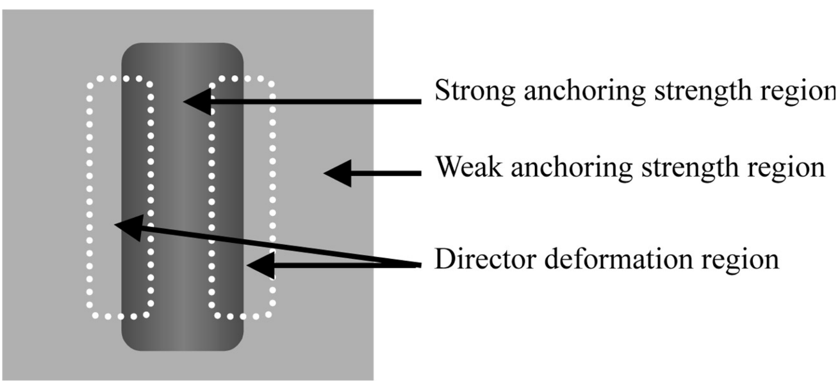

FIGURE 4 Model of the surface topology made by rubbing. The black region shows the groove made by a rubbing fiber.

that on a weak anchoring surface. The difference in the rotation angle of the directors induces a deviation of the director from being parallel to the rubbing direction to being normal to it. This director deformation minimizes the total excess free energy including the elastic and dielectric energies. As a result on the director deformation in the x-y plane light leakage can be observed as shown in Figure 3. We have performed polarizing microscopic observation to confirm this phenomenological explanation. Figure 5 shows the photograph of part of the cell taken using the polarizing microscope in the extinction setup. It is clear from this figure that the light leakage, indicated by the dotted line in the figure, appears around the boundary and along the rubbing direction. As indicated in the figure the line interval of the light leakage is estimated to be approximately 15 μm, which corresponds to the diameter of the fiber used for rubbing. This is good evidence that light leakage appears around the groove. In Figure 5 light leakage around the spacers, which is used to keep the film thickness constant, are observed. This light leakage is due to the director deformation around the spacers and is beyond the scope of this study.

Finally, we discuss the effect of strong anchoring on the anomalous light leakage. To confirm the present model, we carried out an experiment of the light transmittance using cell (C) with photo-alignment layers. A photo-alignment layer, whose surface anchoring energy is of the order of 10^{-4} J/m^2 a value slightly smaller than that of cell (B), produces a homogeneous director orientation with a high pretilt angle and does not make any topological change on the alignment layer. Figure 6 shows the normalized light transmittance measured as a function of the electric voltage for cell (C). In this figure open and closed circles show the results for which an

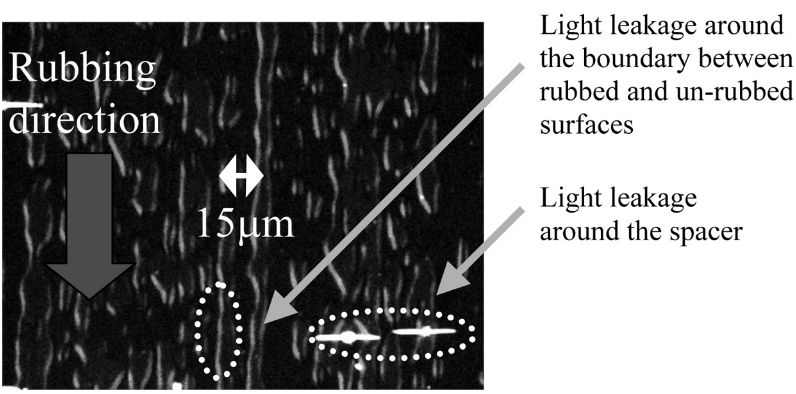

FIGURE 5 Photograph of part of cell (B) obtained using the polarizing microscope in the extinction setup.

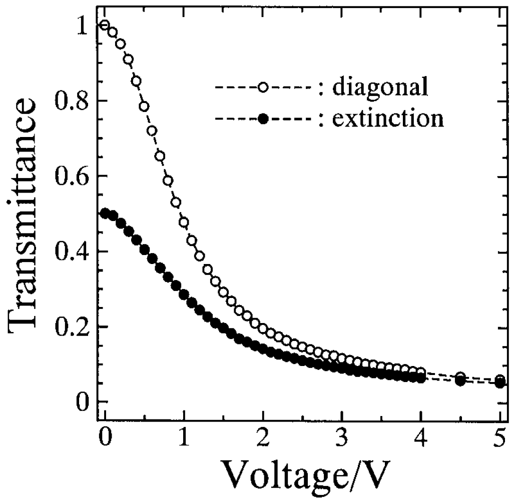

FIGURE 6 Normalized light transmittance measured as a function of the voltage for cell (C).

easy direction is diagonal (diagonal setup) and parallel (extinction setup) with the polarization direction of the beam, respectively. The light transmittance for the diagonal setup gives a monotonous decrease due to the small change of the optical retardation of the cell with increasing voltage as found for cell (A), because of the high pretilt angle of 40° at the surface. The intensity of the light transmittance for the extinction setup does not change with the director rotation as well as that for the cell (A). That is, the photo-alignment layer does not induce an anomalous light leakage. A uniform anchoring condition does not give an anomalous electric field induced light transmittance. In fact no peak associated with the anomalous light leakage is observed in the experimental result as shown in Figure 6. It has been interpreted from these experimental results that the anomalous light transmittance is induced by the director deformation due to the periodical change of the surface anchoring strength along the direction normal to the rubbing direction. A detailed theoretical study using continuum theory is in progress to elucidate the appearance of the anomalous light leakage.

5. CONCLUSION

We have investigated the voltage dependence of the light transmittance for homogeneous thin NLC cells composed of 5CB. The light transmittance for the cell with rubbed polyimide layers showed an anomalous light leakage in the extinction setup. A uniform anchoring condition did not give such an anomalous light transmittance. It has been interpreted from the experimental results that the anomalous optical leakage was induced by the director deformation resulting from a periodical change of the surface anchoring strength along the direction normal to the rubbing direction. The exact analysis of the director deformation induced by the periodic change of the surface anchoring energy is now in progress in order to elucidate the appearance of the anomalous light leakage.

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