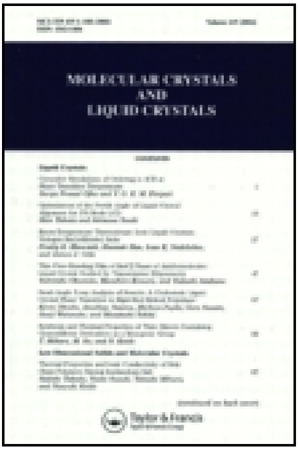

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A Wall Induced Electro-Optic Effect at a Solid-Nematic Liquid Crystal Interface under an External Electric Field

Doo-Hwan You [a], Young Jin Kim [a b], Seong-Sik Park [a c] & Sin-Doo Lee [a]

[a] School of Electrical Engineering, Seoul National University, Kwanak P. O. Box 34, Seoul, 151-742, Korea

[b] Department of Physics, Electrical Engineering and Intercollege Materials Research Laboratory, The Pennsylvania State University, University Park, PA, 16802, USA

[c] Orion Electric Co., Ltd., 257 Gongdan-dong, Gumi, 730-030, Korea

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A Wall Induced Electro-Optic Effect at a Solid-Nematic Liquid Crystal Interface under an External Electric Field

DOO-HWAN YOU, YOUNG JIN KIM*, SEONG-SIK PARK† and SIN-DOO LEE

School of Electrical Engineering, Seoul National University, Kwanak P. O. Box 34, Seoul 151–742, Korea

A domain-wall is experimentally observed along a curved surface of an elongated glass spacer dispersed in a twisted nematic (TN) liquid crystal (LC) cell. The cylindrical optical fibers coated with two different polyimides (PI) for either homogeneous or homeotropic alignment are used as spacers in the TN cells. The formation of the walls/defects around the fiber spacers depends on the nature of the LC alignment at the fibers and the magnitude of the applied voltage. It is found that the domain-wall grows along the curved surface of the fiber spacer monotonically with increasing the electric field, and reaches a maximum around the Fredericks transition. The wall induced effect on the electro-optic performances of TN LC displays is also discussed.

Keywords: domain wall; twisted nematic; wall induced effect

INTRODUCTION

Spacers are widely used to maintain the uniformity of the cell thickness in liquid crystal displays (LCDs)[1]. However, for some types of spacers, the molecules are strongly anchored on the surfaces of the spacers, which destroys the uniform alignment of the molecules in a LC cell. The nonuniformity of the LC alignment produces some domain-walls and/or defects around the spacers[2], and thus the electro-optic (EO) characteristics of the LC cell becomes deteriorated. However, a detailed study on the walls

* Present address: Department of Physics, Electrical Engineering, and Intercollege Materials Research Laboratory, The Pennsylvania State University, University Park, PA 16802, USA.

† Present address: Orion Electric Co., Ltd., 257 Gongdan-dong, Gumi 730–030, Korea.

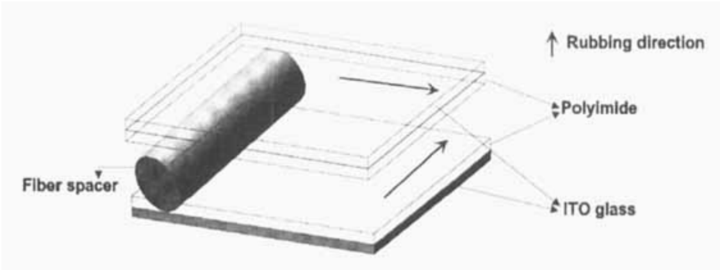


FIGURE 1 The structure of the $\pi/2-$ twisted LC cell.

grown around the spacers in the LC cells and the associated wall induced effect has not been carried out so far.

In the present work, we report on the formation of the walls/defects of LC around spacers and the associated EO effect in a twisted structure of a nematic liquid crystal. Microscopic as well as EO measurements are made as a function of an external electric field in three differently twisted (0, $\pi/2$, and π) LC cells. Moreover, the curved surface of the glass fiber is treated to produce either homogeneous or homeotropic alignment.

EXPERIMENTAL

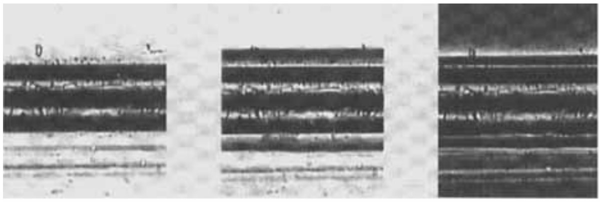
Three differently twisted (0, $\pi/2$, and π) LC cells were used in this study. The cells were made with indium-tin-oxide coated glass substrates. Two inner surfaces of each cell were coated with SE-3140 polyimide (PI) of Nissan Chemical Co., followed by rubbing, for homogeneous alignment. The fiber spacers of 100 μm thick were coated with either the SE-3140 homogeneous PI or the JALS-204 homeotropic PI of Japan Synthetic Rubber Co. to study the growth mechanism of the domain-walls around the spacers. The LC used was ZLI-2293 of E. Merck which has positive dielectric anisotropy ($\Delta\epsilon = 10$). For the homogeneously treated fiber spacer, the molecular director on the fiber surface is parallel to the fiber axis. For the homeotropically treated spacer, the director is oriented normal to the fiber surface so that a radially splayed structure is formed.

The fiber spacers lie along one of two rubbing axes for the $\pi/2-$ twisted cell. For the $0-$ and $\pi-$ twisted cells, the fibers make an angle of $\pi/4$ with respect to the rubbing axis. By symmetry, the LC director in the middle of each cell is then located at an angle of $\pi/4$ with respect to the fiber. In such geometry, the optical observation of the wall developed near the fiber spacer is easily made. A proper amount of a chiral dopant was added to the LC to produce a uniformly twisted structure with no reverse-twisted domains. The structure of the $\pi/2-$ twisted LC cell is shown in Fig. 1.

Each cell was placed between crossed polarizers such that the polarizer (or the analyzer) makes an angle of $\pi/4$ to one of the two rubbing axes. A square wave voltage with variable amplitudes at 100 Hz was applied to each cell. Together with microscopic observations, the transmitted light intensity through each cell was measured as a function of the applied voltage. A He-Ne laser of 632.8 nm in wavelength was used as a light source. Note that the transmitted intensities were measured in both the area around the fibers and the uniformly aligned area.

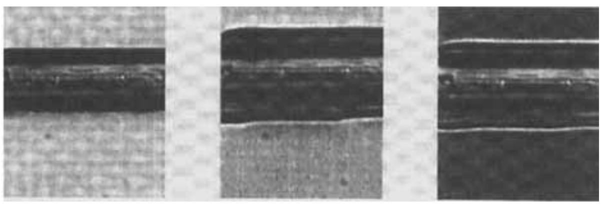
RESULTS AND DISCUSSION

A domain-wall was developed along the fiber with increasing the applied voltage. Figures 2 and 3 show the dynamic growth of the wall around the homeotropically treated fiber spacer and that around the homogeneously treated one in the $\pi/2-$ twisted cell at three different voltages, respectively. In the homogeneous case, no defect/wall was observed under no electric field since no out-of-plane molecular tilt is involved and only in-plane splay deformation exists. In the case of the homeotropic case, however, a wall, which is associated with radially splayed, out-of-plane tilt as well as in-plane splay deformation, was developed. In both cases, as the applied voltage increases, the width of the wall develops continuously, reaches a maximum at a certain voltage, and then disappears in



(a) (b) (c)

FIGURE 2 The dynamic growth of the domain-wall around a homeotropic spacer in the $\pi/2-$ twisted cell. The applied voltage is (a) 0 V, (b) 2.7 V, and (c) 4.0 V at 100 Hz.



(a) (b) (c)

FIGURE 3 The dynamic growth of the domain-wall around a homogeneous spacer in the $\pi/2-$ twisted cell. The applied voltage is (a) 0 V, (b) 2.8 V, and (c) 4.0 V at 100 Hz.

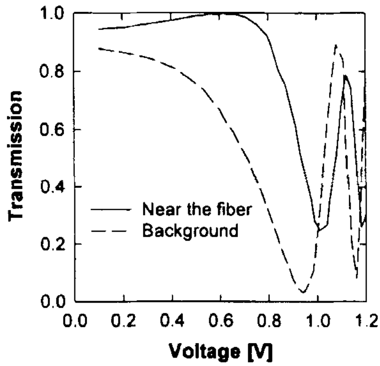


FIGURE 4 The ac transmitted intensities through an area around the fiber spacer and a uniformly aligned region in the $\pi/2-$ twisted LC cell as a function of the applied voltage. The uniformly aligned region is represented by a dashed line (background) .

the high voltage regime. Under an optical polarizing microscope, the wall appears as a brighter or a darker stripe than the uniformly aligned area, depending on the polarizer geometry.

The voltage at which the maximum width of the wall observed was found to be slightly higher than the Fredericks threshold[3] of the LC. The range of the operating voltage for the LC cell covers the voltage at which the wall width has a maximum. This implies that the walls around the spacers play a significant role in the EO characteristics of the LC cell for practical applications.

Figure 4 shows the transmitted light intensities through an area around the fiber and a uniformly aligned region in the $\pi/2-$ twisted cell as a function of the applied voltage. The voltage is the square wave at 100 Hz. At high voltages, the transmitted intensities exhibit light modulation due to the change in the birefringence of the LC and the difference between the two regions is relatively small. In the low field regime, however, a large difference is clearly seen. In both cases, there exists a certain volt-

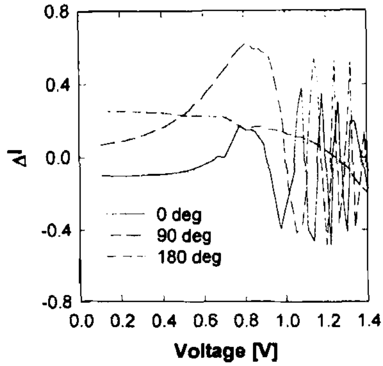


FIGURE 5 The difference in the transmitted intensity between an area around the fiber and a uniformly aligned region as a function of the applied voltage. The solid, dashed, and dotted lines represent the 0-, $\pi/2-$, and $\pi-$ twisted LC cells.

age at which a minimum intensity is obtained, and such voltage for the fiber region is larger than that in a uniform region. As the applied voltage increases, no intensity difference between the two regions is observed. In fact, the walls/defects are easily observable under the condition for obtaining the minimum intensity. This results from the phase difference associated with the domain-wall created by the fiber spacer.

In Fig. 5, the differences in the transmitted intensities between an area around the fiber spacer and a uniformly aligned region are shown as a function of the applied voltage for the three cases. These results describe how the degree of twist affects the EO performances of the TN cells. The $\pi/2-$ twisted cell exhibits the largest difference among the three cells we studied. It should be noted that the first peak of the transmitted intensity comes from the wall effect around spacers, and the other peaks result from the change in the effective birefringence of LC and the phase difference induced by the walls/defects. The magnitude and the width of the peak depend on the magnitude of the twist angle. The voltage at which the

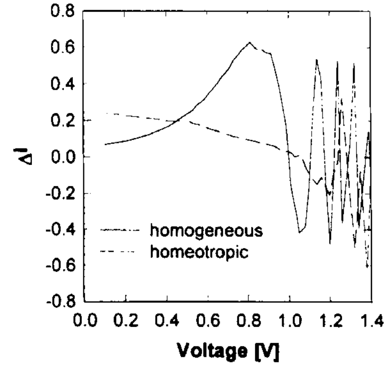


FIGURE 6 The difference in the transmitted intensity between the homogeneous and the homeotropic spacers in the $\pi/2-$ twisted cell as a function of the applied voltage. The solid and dashed lines represent the homogeneous and the homeotropic spacers.

first peak appears increases with the twist angle, which is consistent with the fact that the Fredericks threshold increases with the twist angle.

The surface effect of the spacers whether with homogeneous or with homeotropic alignment is shown in Fig. 6. The fiber spacer coated with homeotropic PI exhibits much smaller intensity difference than that with homogeneous one. This indicates that the EO effect associated with the walls/defects depends strongly on the nature of the LC alignment on the spacers. The surface anchoring energy of homeotropic PI is weaker than that of homogeneous one. Accordingly, the LC director on a weakly anchored surface is easily distorted, and the size of the wall/defect becomes reduced. By employing the idea behind the observed wall effect, the extrapolation length can be estimated by measuring the size of the wall around spacers. In the area of LC technologies such as super-twisted nematic and thin-film-transistor LC displays, one should take into account the wall induced effect around the spacers.

CONCLUSIONS

We have demonstrated experimentally the EO effect associated with the walls/defects around spacers. The EO effect is strongly affected by the degree of the twist in the LC cell. It was found that the EO effect due to the walls/defects around spacers are predominantly governed by the surface properties of the spacers. In the $\pi/2-$ twisted cell, the walls/defects around the spacers influence significantly the EO performances of the LC cell when the surfaces of the spacers tend to align the molecules homogeneously. This leads to the conclusion that the aligning nature of the spacers at a microscopic level needs to be considered for improving the image quality of a LC display.

Acknowledgements

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