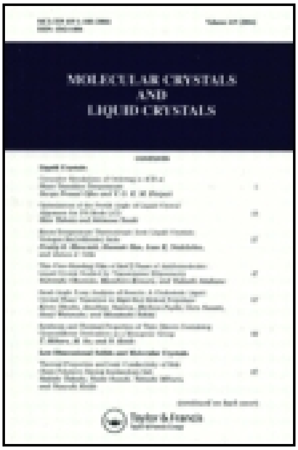


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Optical Investigation of Disclination Lines in Multidomain Twisted Nematic Liquid Crystal Display Created by Microrubbing

Soney Varghese [a] , Gregory P. Crawford [a] , Cees W. M. Bastiaansen [a] , Dick K. G. de Boer [b] & Dirk J. Broer [b]

[a] Department of Polymer Technology, Faculty of Chemistry and Chemical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

[b] Philips Research Laboratories, Prof. Holstlaan 4, Eindhoven, The Netherlands and Department of Polymer Technology, Faculty of Chemistry and Chemical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

Version of record first published: 31 Aug 2006

To cite this article: Soney Varghese, Gregory P. Crawford, Cees W. M. Bastiaansen, Dick K. G. de Boer & Dirk J. Broer (2005): Optical Investigation of Disclination Lines in Multidomain Twisted Nematic Liquid Crystal Display Created by Microrubbing, Molecular Crystals and Liquid Crystals, 433:1, 51-63

To link to this article: http://dx.doi.org/10.1080/15421400590954687

Mol. Cryst. Liq. Cryst., Vol. 433, pp. 51–63, 2005

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400590954687

Optical Investigation of Disclination Lines in Multidomain Twisted Nematic Liquid Crystal Display Created by Microrubbing

Soney Varghese
Gregory P. Crawford
Cees W. M. Bastiaansen
Department of Polymer Technology, Faculty of Chemistry and Chemical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

Dick K. G. de Boer
Dirk J. Broer
Philips Research Laboratories, Prof. Holstlaan 4, Eindhoven, The Netherlands and Department of Polymer Technology, Faculty of Chemistry and Chemical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

A microrubbing (μ-rubbing) process was utilized to create a four-domain twisted nematic cell with improved viewing angle characteristics in comparison to a single domain twisted nematic display. A metallic sphere of 1 mm in diameter was used to μ-rub homeotropic polyimide, resulting in planar alignment with a 10° pretilt. With our set of initial conditions, a 10° pretilt cannot stabilize the four-domain structure in zero field; however, the four-domain structure is stable for voltages above 1 V. Here we optically study the formation of disclination lines and the stability of the four-domain configuration with respect to the applied voltage. The director orientation of the four-domain cell is simulated using the 2dimMOS simulation software and the optical transmission using extended Jones matrix method. Iso-contrast plots of the four-domain structure are compared with the single domain structure.

Keywords: disclination; four-domain; liquid crystal display; pretilt

Funding of this project was provided by Netherlands University Federation for International Collaboration (Nuffic). The author likes to thank Dr. Sunil K. Narayanankutty, Cochin University of Science and Technology, India, Chris van Heesch, Peter Minten (GTD) at Eindhoven University of Technology for their support.

Address correspondence to Soney Varghese, Department of Polymer Technology, Faculty of Chemistry and Chemical Engineering, Eindhoven University of Technology, P.O. Box 513, Eindhoven, NL-5600 MB, The Netherlands. E-mail: s.varghese@tue.nl

INTRODUCTION

Liquid crystal displays (LCDs) are prominent visual interfaces in many electronic devices, which includes mobile telephones, digital cameras, MP3 players and computer screens. There are a number of liquid crystal configurations utilized depending on the applications, which include the twisted nematic (TN), super twisted nematic (STN) [1], in-plane switching (IPS) [2–4], vertically aligned nematic (VAN) [5–7] and fringe-field switching (FFS) [8,9]. Each of these modes has specific performance advantages and drawbacks for a given application. In particular, the twisted nematic configuration, which is the most ubiquitous mode of operation, suffers from undesirable viewing angle characteristics. There are various ways to improve the viewing angle of TN displays, which include using compensation films [10–14] and employing multidomain alignment [15–18].

In the multidomain alignment each pixel is divided into four subpixels with different orientations to average the transmitted light traversing through the single pixel to improve the viewing angle [19,20]. Photoalignment has been proposed to create multidomain alignment in a non-contact way, in which photopolymers such as cinnamates and coumarins are polymerized with UV light using photolithography shadow masks [21,22]. An alternative way to accomplish the four-domain alignment has been done by applying photolithographic layers directly on the polyimide layer and performing a reverse rubbing process [23]. Oblique evaporation of SiO_2 followed by lithographic technique has also been used to create multidomain alignment [19,20]. Other researchers have applied surface patterning techniques to create spatially separated rubbing directions. Nanorubbing with the tip of atomic force microscopy was also employed to pattern polyimide for grating applications [24]. Recently Honma and coworkers successfully fabricated polarization independent liquid crystal gratings by the μ-rubbing process [25].

Here we report on the microrubbing (μ-rubbing) process where a metallic sphere is used to spatially pattern the polyimide through a reverse rubbing method. We have employed this technique to create a four-domain alignment in a simple way. In this contribution we investigate the transmission near the disclination lines of the four-domain structure. Optical simulations of the director orientation and transmission characteristics are also described.

EXPERIMENTAL

The ITO coated glass substrate was spin coated (5 s at 1000 rpm followed by 40 s at 5000 rpm) with the polyimide precursor AL75114

(JSR electronics). This polyimide is known to support homeotropic boundary conditions. It was then preheated to 100°C for 10 minutes and imidized at 180°C under vacuum for 90 minutes to obtain a transparent film with a thickness of ~150 nm. The liquid crystal E7 (Merck Ltd., Darmstadt, Germany) was used throughout the experiments. This polyimide film was μ-rubbed using a metallic sphere (1 mm diameter). The metallic sphere was in direct contact with the alignment layer as it traversed across the alignment layer (substrate) creating micrometer sized rubbed lines. The velocity of the metallic sphere was 10 mm/minute under a specified load of (150 g) at room temperature. We used our μ-rubbing technique to create multiple domain pixels by rubbing the surface in such a way that neighboring alignment regions are rubbed in opposite directions as schematically depicted in Figure 1a.

Liquid crystal cells were constructed by orienting two μ-rubbed substrates orthogonal to each other, separated by 5 μm spacers and securing them with UV curable glue, edges seals along the sample peripherals. The cells were filled with the liquid crystal E7 via capillary action at 80°C (~20°C above nematic-isotropic transition temperature). The alignment of liquid crystals was studied using polarized light microscopy (Zeiss LM Axioplan). The pretilt angle was measured directly using the crystal rotation method (Autronic, TBA 107). Isocontrast measurements were performed using Eldim conoscope.

RESULTS AND DISCUSSION

Figure 1 shows the apparatus used for the μ-rubbing process, where the homeotropic polyimide was μ-rubbed directly with the 1 mm metallic sphere. A metallic sphere having 8 nm root mean square surface roughness was used for the μ-rubbing process which increased the surface roughness of polyimide from 3 nm to 40 nm. We propose the following physical mechanism for the modification of the alignment surface from homeotropic (before μ-rubbing) to a planar alignment with large pretilt (after μ-rubbing). Polyimides that are known to induce homeotropic anchoring are either doped with long chain aliphatics or they are functionalized with long chain aliphatic molecules. When aliphatic chains pack on a substrate parallel to the substrate normal (highly aligned, compact assembly of aliphatic chains), they are known to induce homeotropic alignment of liquid crystal molecules coming in contact with them [26]. We conjecture that the μ-rubbing process unidirectionally aligns the aliphatic chains at a specific angle as schematically shown in Figure 1b. This mechanism leads to a dramatic change in the anchoring direction for liquid crystal molecules interacting with the surface.

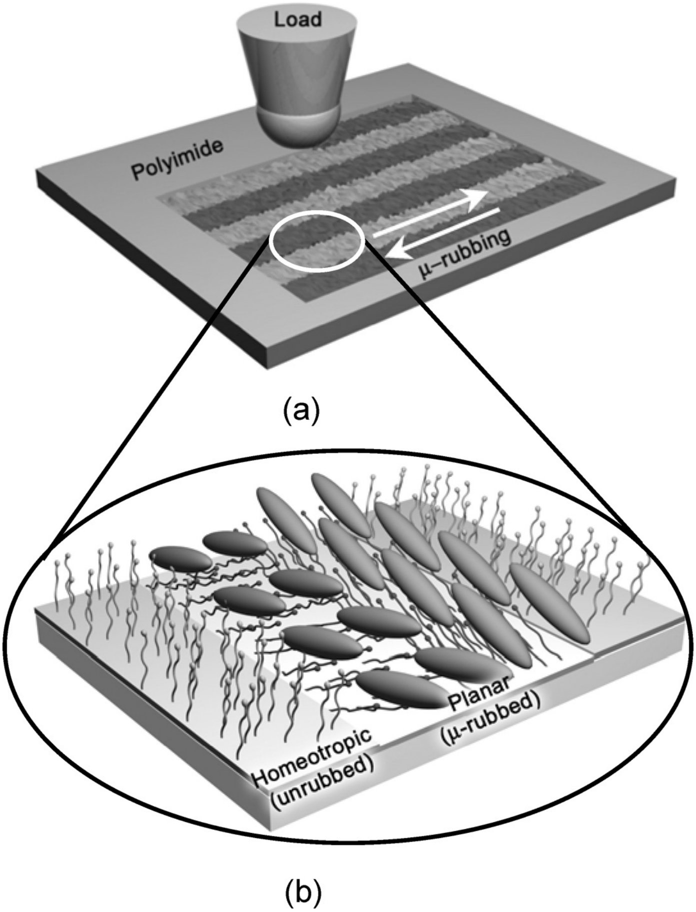


FIGURE 1 Apparatus used for the μ-rubbing process (a), schematic illustration of polyimide surface with aliphatic chains before and after the μ-rubbing process (b).

Figure 2 shows the stability of four-domain and the formation of disclination lines at different voltages. These optical microscopy photographs where taken after applying a higher voltage (5 V) and slowly decreasing so that it completely locks-in (stabilizes) the motion of disclination lines. Below 1 V we could observe the motion of disclination lines indicating the instability of the four-domain but above 1 V, the four-domain structures is stabilized. The twisted states in our samples are completely determined by the pretilt angle. Therefore a large surface pretilt angle is required to offset the energy cost of the generation

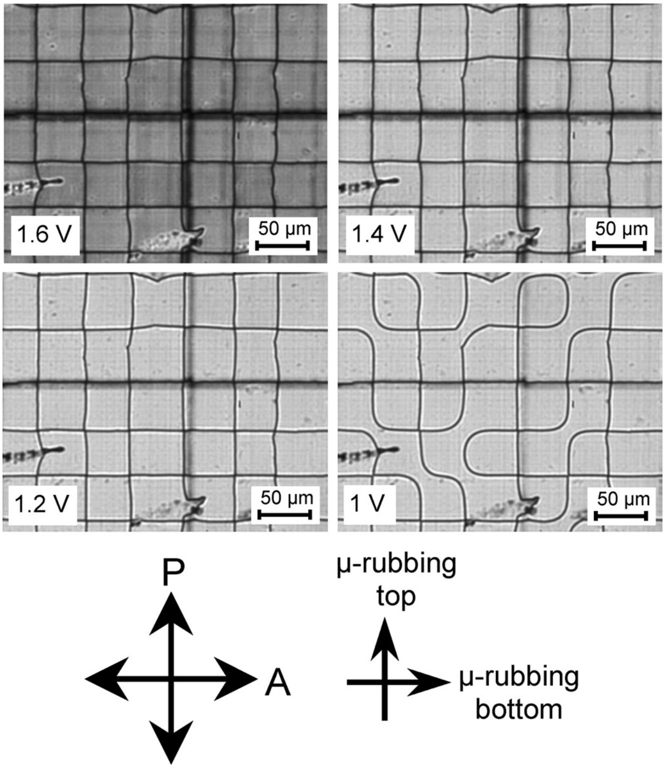


FIGURE 2 Optical microscopy pictures showing the stability of four-domain under different voltages.

of twist disclinations. In order to ascertain the stability of our four-domain samples in zero field, one needs to compare the free energy cost associated with forming disclination lines and the wrong handedness sub-pixel orientations that cost splay energy. In our polarizing microscope photographs stable disclination lines are visible above 1 V when coming down from high voltage.

Using a simple model proposed by Chen and coworkers [19] based on the tilt angle θ, sub-pixel dimensions $L \times L$, and the cell gap d, from the known elastic and defect properties of nematic liquid crystals, the stability condition can be expressed by the following equation: $\theta^2 \geq \pi d/L$. Using $L = 50\,\mu\text{m}$ and $d = 5\,\mu\text{m}$, the predicted minimum pretilt angle, θ_{min}, to stabilize the structure is $\theta_{\text{min}} \sim 30^\circ$. Since our cells only have an initial pretilt of $\sim 10^\circ$, our zero field structures do not have four domain stable structures. Although this model is simple, it is consistent with our findings and well describes the work presented in the literature [19,20]. Therefore in our sample in the zero voltage and low voltage states where the disclination lines disappear or are unstable, the four-domain is believed to transform into a two-domain reverse tilt sample. It is possible to stabilize the four-domain structure using a voltage initialization process and driving the sample with bi-level voltages in practice. This scheme can completely lock-in the motion of disclination lines [20]. We essentially demonstrated this phenomenon by reducing the voltage after domains were stabilized at high voltages.

Figure 3 shows optical micrograph of the stable four-domain structures in which the midplane directors are oriented in four corners indicated by the arrows. The two different bias tilt directions on each substrate define the appropriate sense of the four sub-twisted pixel configuration. Figure 4 shows the intensity profiles obtained by the line scanning across the disclination lines of the optical microscopy images at different voltage ($5\,V \rightarrow 1\,V$). Figure 4 also shows that the intensity of the disclination lines decreases with increasing of voltages

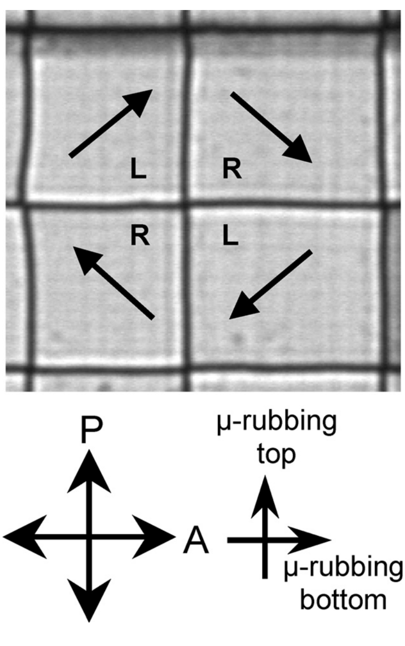


FIGURE 3 Optical microscopy image of the four-domain structure which is stable above 1 V. Directions of midplane directors are indicated by arrows, which are oriented in four corners of the subpixels.

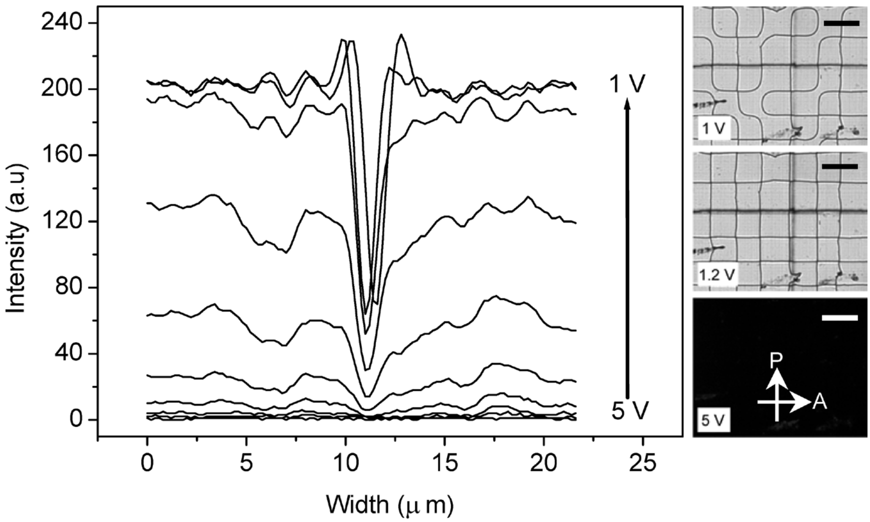


FIGURE 4 Intensity profile from the optical microscopy pictures of the four-domain cell under different fields (1 V to 5 V). The dark line in the optical microscopy (top right) image shows the area of line scanning.

and at 5 V (dark state) they are no longer visible. These defects can lower the brightness but there contribution is very little and they will disappear at higher voltages.

Figure 5 shows the comparison of experimental and optical simulation of the intensity profile of the disclination lines formed in the four-domain cell at 1.25 V. The extended Jones method [27] was used for the calculations on optical transmission of LCD cell, which takes into account single reflection at each surface but neglects multiple reflections and their interference. The theoretical calculations are in good agreement with the experimental data. The two dimensional simulations of director profiles are made with the 2dimMOS software package [28,29] using a vector representation and the finite elemental method with a mesh of triangular elements. Figure 6 shows the optical simulation of the director orientations in the vertical cross section of the four-domain cell. The gray cylinders represent the directors, with the light ends pointing forwards and the dark ends pointing backwards with respect to the plane of drawing. In the calculation the bottom and top substrate possess a pretilt of 10° through out the layer. The top substrate has two parts, left half and right half in which the directors point into opposite directions. At 1.25 V this forms disclination lines in which the director rotates over 180°, giving

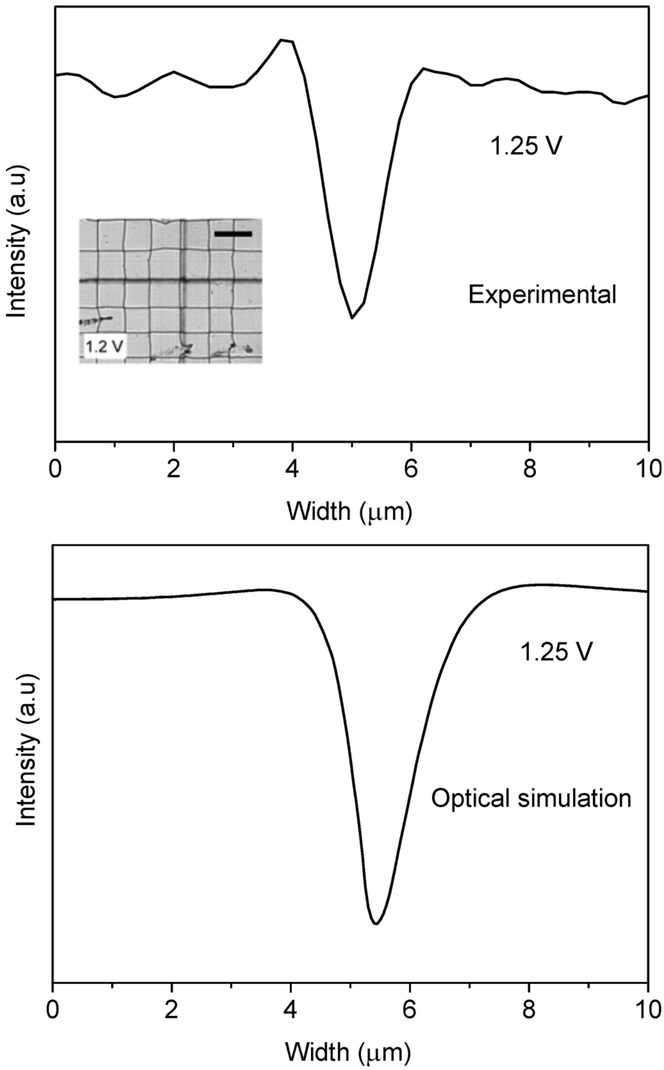
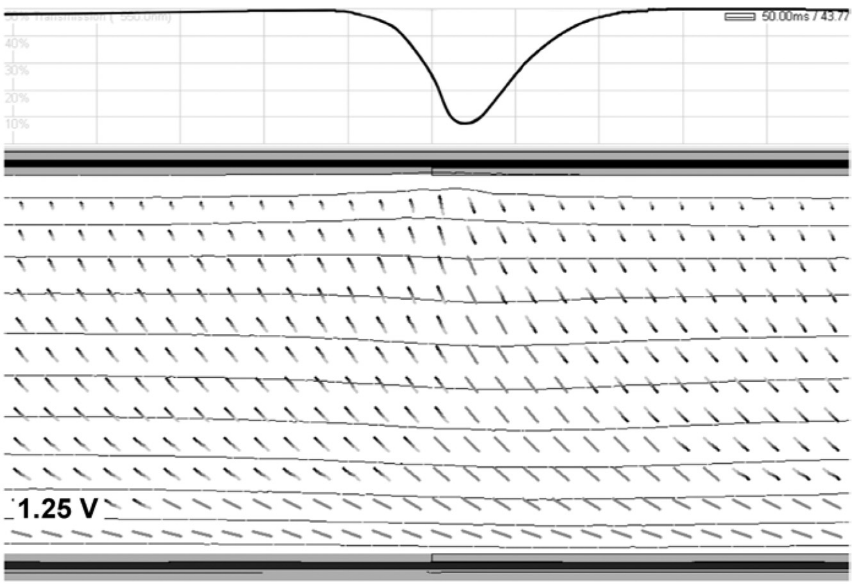


FIGURE 5 Comparison of the experimental **(a)** and calculated **(b)** intensity profile at 1.25 V. Inset **(a)** showing the optical microscopy picture of the disclination lines at 1.2 V, the dark line (top right) shows the scanned area.

rise to dark regions in the transmission as shown in the top of the Figure 6.

Figure 7(a) shows the comparison of transmission/voltage characteristics of our four-domain sample (pretilt, $9.8^{\circ} \pm 0.5$) to a



Top left pretilt = 10°, azimuthal = 0° : Top right pretilt = 10°, azimuthal = 180°

Bottom pretilt = 10°, azimuthal = 90°

FIGURE 6 Results of 2dimMOS calculation for the director orientation of four-domain cell at 1.25 V. Calculated transmittance over the same section is plotted above.

conventional TN cell (with $2.65^{\circ} \pm 0.5$ pretilt angle). There are two notable features that standout in Figure 7(a). First the steepness of the transmission voltage curve of the four-domain is "softened" due to the large pretilt. Second, the brightness is lower in the four-domain sample due to the disclination lines. Both of these effects are expected as a consequence of four-domain alignment. Figure 7(b) shows the transmission voltage characteristics of the four-domain cell when a field is applied from $0\,V \rightarrow 5\,V$ and $5\,V \rightarrow 0\,V$. The slight change in transmittance near the threshold area when coming down from higher voltages is due to the presence of disclination lines. The iso-contrast measurements (ratio of brightness at 1.25 V and at 5 V) of a single domain and a four-domain cell are shown in Figure 8. Comparing these images one can directly understand the improvement in contrast uniformity and symmetry, especially at higher viewing angles. In the direction perpendicular or parallel to one of the polarizers the contrast ratio is 40:1 at angles $> \pm 50^{\circ}$. At 45° to the polarizers a contrast ratio of

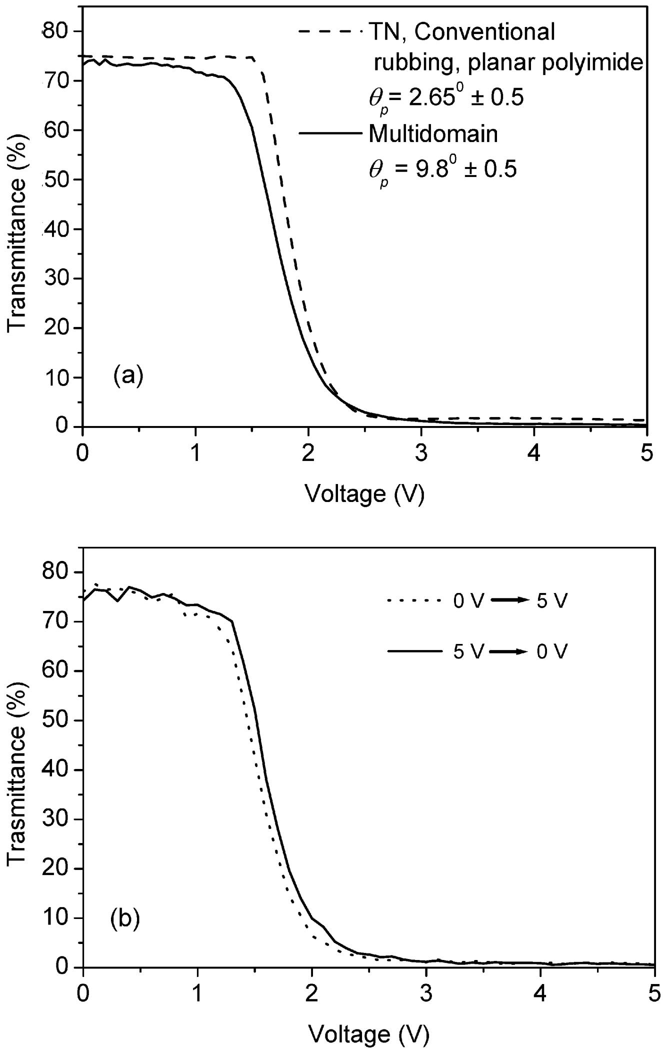


FIGURE 7 (a) Comparison of transmission-voltage characteristics of single domain conventionally rubbed polyimide and four domain twisted nematic cell. (b)Transmission-voltage curve of the four domain cell from 0 V→5 V and 5 V→0 V.

10:1 is possible up to $\pm 30^\circ$. The main reason, however, to use a four-domain structure is to improve the gray scale inversion.

Figure 9 shows the color shift of the four-domain cell in the fully bright state at 60° viewing angle. Due to the self compensation effects

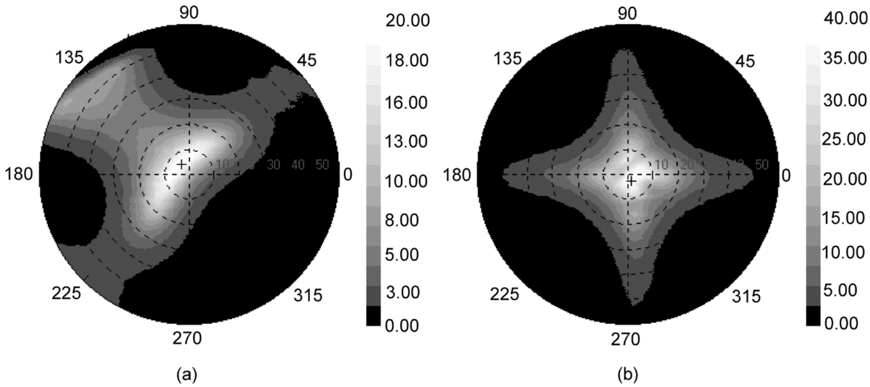


FIGURE 8 The iso-contrast measurement of the single domain **(a)** and four-domain liquid crystal cell **(b)**.

in the four-domain cell, the dependency of white color chromaticity on azimuthal viewing directions is substantially less. All points are concentrated near yellow and white region (x = 0.4 and y = 0.4) indicating narrow distribution of colors. Since the midplane liquid crystal

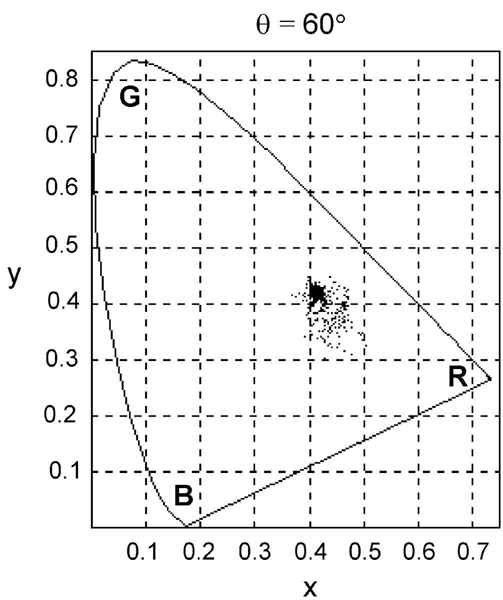


FIGURE 9 Dependence of white color chromaticity of the four domain twisted nematic cell at 60° viewing angle.

directors oriented in four different directions, at 45° with respect to the polarization axes of the polarizers, the azimuthal angle dependency of phase retardation is minimized.

CONCLUSIONS

We have demonstrated and modeled the transmission characteristics near the disclination lines of the four-domain structure formed by a unique μ-rubbing process. To stabilize the four-domain structure we need initialization voltage above 1 V for our 47 μm domains with a 10° pretilt. The optical simulations results are in good agreement with experimental results with respect to the formation of disclination lines at 1.25 V. An attractive and symmetric iso-contrast curve was observed for the cell. This work demonstrates the significance of the display community showing a method to improve the viewing angle characteristics for a TN display. In addition to device applications this work is rich with physical phenomena of switching dynamics and understanding the formation and stabilization of defect lines.

REFERENCES

[1] Li, J., Lee, E. S., Vithana, H., & Bos, P. J. (1996). *Jpn. J. Appl. Phys.*, *35*, L1446.
[2] Soref, R. A. (1974). *J. Appl. Phys.*, *45*, 5466.
[3] Oh-e, M. & Kondo, K. (1995). *Appl. Phys. Lett.*, *67*, 3895.
[4] Oh-e, M. & Kondo, K. (1996). *Appl. Phys. Lett.*, *69*, 623.
[5] Seo, D. S. & Hwang, J. Y. (2000). *Jpn. J. Appl. Phys.*, *39*, L914.
[6] Ohmuro, K., Kataoka, S., Saski, T., & Koike, Y. (1997). *SID97 Digt.*, 845.
[7] Seo, D. S. & Hwang, J. Y. (1999). *Jpn. J. Appl. Phys.*, *38*, L1432.
[8] Lee, S. H., Lee, S. L., & Kim, H. Y. (1998). *Appl. Phys. Lett.*, *73*, 2881.
[9] Hong, S. H., Park, I. C., Kim, H. Y., & Lee, S. H. (2000). *Jpn. J. Appl. Phys.*, *39*, L527.
[10] Yamagishi, N., Watanabe, H., & Yokoyama, K. (1989). *SID89 Digt.*, 316.
[11] Yamagnchi, Y., Miyashita, T., & Uchida, T. (1993). *SID93 Digt.*, 277.
[12] Lu, M. & Yang, K. H. (2000). *Jpn. J. Appl. Phys.*, *39*, L412.
[13] Leenhouts, F. (2000). *Jpn. J. Appl. Phys.*, *39*, L741.
[14] Wu, L. H., Luo, S. J., Hsu, C. S., & Wu, S. T. (2000). *Jpn. J. Appl. Phys.*, *39*, L869.
[15] Li, J., Lee, E. S., Vithana, H., & Bos, P. J. (1996). *Jpn. J. Appl. Phys.*, *35*, L1446.
[16] Yoshida, H., Seino, T., & Koike, Y. (1997). *Jpn. J. Appl. Phys.*, *36*, L1449.
[17] Yang, K. H. (1992). *Jpn. J. Appl. Phys.*, *31*, L1603.
[18] Vithana, H., Johnson, D., Bos, P., Herke, R., Fung, Y. K., & Jamal, S. (1996). *Jpn. J. Appl. Phys.*, *35*, 2222.
[19] Chen, J., Bos, P. J., Johnson, D. L., Bryant, D. R., Li, J., Jamal, S. H., & Kelly, J. R. (1996). *J. Appl. Phys.*, *80*, 1985.
[20] Chen, J., Bos, P. J., Bryant, D. R., Johnson, D. L., Jamal, S. H., & Kelly, J. R. (1995). *Appl. Phys. Lett.*, *67*, 1990.
[21] Schadt, M., Seiberle, H., & Schuster, A. (1996). *Nature*, *381*, 212.
[22] Schadt, M. & Helfrich, W. (1971). *Appl. Phys. Lett.*, *18*, 127.

[23] Chen. J., Bos, P. J., Bryant, D. R., Johnson, D. L., Jamal, S. H., & Kelly, J. R. (1995). *SID95 Digt.*, 865.
[24] Wen, B., Petschek, R. G., & Rosenblatt, C. (2002). *Appl. Opt.*, *41*, 1246.
[25] Honma, M. & Nose, T. (2003). *Jpn. J. Appl. Phys.*, *42*, 6992.
[26] Porte, G. (1976). *J. De Physique*, *37*, 1245.
[27] Yeh, P. (1982). *J. Opt. Soc. Am.*, *72*, 507.
[28] Becker, M. E., Wohler, H., Kamm, M., & Kreis, J. (1996). *Proceedings of SID*, *96*, 596.
[29] 2dimMOS, www.autronic-melchers.com.