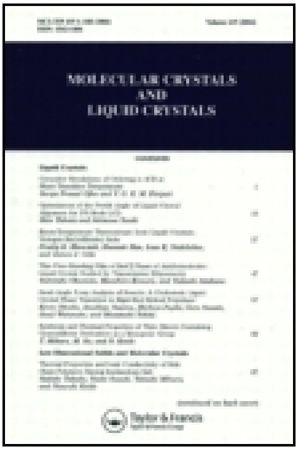


Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Tortional Torque Effects of Twisted Nematic Bulk on the Polymer Surface Alignment

Rumiko Yamaguchi [a] & Susumu Sato [a]

[a] Department of Electrical and Electronic Engineering, Akita University, Tegata gakuencho 1-1, Akita City, 010-8502, JAPAN

Version of record first published: 24 Sep 2006

To cite this article: Rumiko Yamaguchi & Susumu Sato (2001): Tortional Torque Effects of Twisted Nematic Bulk on the Polymer Surface Alignment, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 367:1, 379-386

To link to this article: http://dx.doi.org/10.1080/10587250108028658

Mol. Cryst. and Liq. Cryst., 2001, Vol. 367, pp. 379-386
Reprints available directly from the publisher
Photocopying permitted by license only

Published by license under the
Gordon and Breach Science Publishers imprint,
a member of the Taylor & Francis Group,
Printed in the USA

Tortional Torque Effects of Twisted Nematic Bulk on the Polymer Surface Alignment

RUMIKO YAMAGUCHI and SUSUMU SATO

Department of Electrical and Electronic Engineering, Akita University,
Tegata gakuencho 1-1, Akita City 010–8502, JAPAN

A twist angle reduction with time is reported in a twisted nematic (TN) cell with rubbed polymer (polyvinyl acetate, polyvinyl alcohol, and polymethyl methacrylate) alignment films. An azimuthal anchoring energy measured in the TN cell with various twist angles of 0~±90° depends on the twist angle, when using these polymers. Moreover, a sticking phenomenon on the twist angle due to the applied voltage is observed. These results indicate that polymer molecules at the surface reorient and the easy axis deviates from the rubbing direction by the tortional torque of the TN bulk.

Keywords: twisted nematic; alignment surface; azimuthal anchoring energy; polyvinyl alcohol; polyvinyl acetate; polymethyl methacrylate

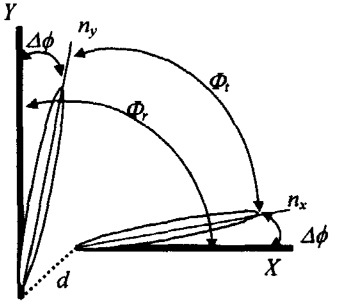
INTRODUCTION

A solid surface for the alignment of liquid crystal (LC) molecules has been an attractive subject for LC device applications and physical researches, because the director distribution in the bulk of the LC layer is affected by the surface, as well as by the external field. An azimuthal anchoring E_a is one of the key parameters for characterizing the alignment surface. E_a can be measured by several methods, for example, the observation of defect line width in the homogeneous cell[1] and torque balance method in the twisted nematic (TN) cell.[2] Recently, we have reported that E_a increases in the homogeneously oriented LC cell with polymer coated substrates, with the passage of time after the LC injection into the empty cell.[3] It is considered that the homogeneously orientated LC bulk influences the polymer molecular orientation at the LC/polymer interface.

In this paper, effects of the TN bulk on the polymer surface are experimentally discussed. Alignment properties are investigated in TN cells with different strength of tortional torque, and a novel type of the sticking in the TN cell due to applying voltage is also reported.

EXPERIMENTAL

Polyvinyl acetate (PVAC), polymethyl methacrylate (PMMA) and polyvinyl-alcohol (PVA) with a saponification degree of 78.5 ~ 82.0mol% are used in this study as a alignment surface. PVAC, PMMA and PVA were respectively dissolved in methanol, benzene and pure water, and the solutions were spin-coated on a slide glass substrate. The substrates were then baked at 100°C for 10 min. The nematic LC employed was 4-cyano-4'-n-pentylbphenyl (5CB). The cell thickness was controlled using plastic beads and measured in the empty cell by a light interference method. The polymer surfaces were strongly rubbed and those surfaces produce very small pretilt angles of less than 0.3°.



X, Y : rubbing direction
n_x, n_y : surface LC director
Φ_t : twist angle
Φ_r : angle between rubbing direction of X and Y
$\Delta\phi$: deviation of n_x, n_y from x, y
d : thickness of LC layer

FIGURE 1 Schematic diagram of the TN LC frame and symbols used in this paper.

RESULTS AND DISCUSSION

Figure 1 shows the relation between the frame of the TN cell and symbols used in this paper. Transmission images of the TN cells with PVAC coated substrates and PMMA coated substrates are shown in Figs. 2(a) ~ (c) and 2(d) ~ (j), respectively. The angle between rubbing directions Φ_r is 90°. Under parallel polarizers, images were very dark immediately after the LC injecting into the empty cell, however they became gradually bright, which indicates the decrease in the twist angle Φ_t. Figure 2 (c) shows that Φ_t decreases to almost 0°, and the LC director is ±45° to the rubbing direction at each side of the disclination line. The reduction rate in the cell with PMMA coated substrates is slower than that in the cell with PVAC coated substrates, as shown in Figs. 2(d), (e) and (f). Figure 3 quantitatively shows the Φ_t reduction after injecting the LC in the empty cell with PMMA coated substrates.

It is easily suggested that the decrease in the twist angle is due to the reduction of E_a. There might be possibility that the softening due to the penetration of LC molecules into the polymer reduces E_a. However, this assumption is rejected, since the anchoring energy increases with time in the homogeneously oriented LC cell.[3] Next, we assume that the in-plane

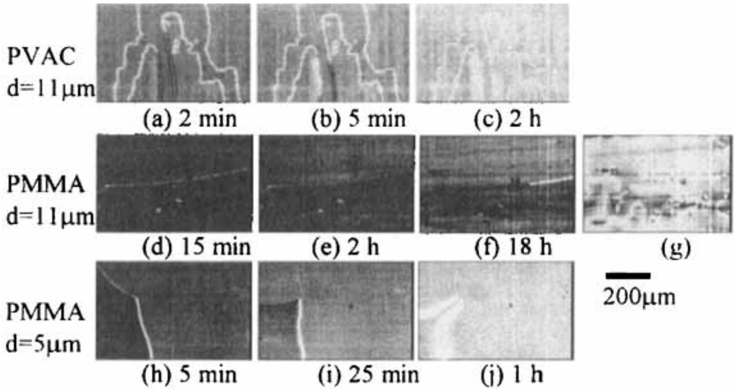


FIGURE 2 Transmission micrographs of TN cells with (a)-(c) PVAC and (d)-(j) PMMA substrates at each passage of time from the LC injection into the empty cell. (g) is the image after heating to the I phase and cool to N phase.

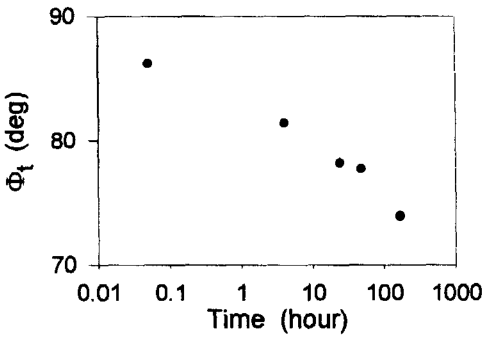


FIGURE 3 Φ_t reduction with time in the TN cell with PMMA coated substrates and cell thickness of 11.5 μm.

gliding or the rotation of LC molecules occurs on the rubbed polymer surface. However, when the cell was heated to the isotropic phase and cooled to the nematic phase, the alignment state did not return to the initial state [cf. Fig. 2(g)] against results reported in refs. [4] and [5]. On the other hand, the rubbed polymer surface was thermally stable in the homogeneously oriented LC cell. Therefore, this assumption is also rejected.

Through above discussion, we believe that the bulk orientation of the twisted LC affects to the polymer molecular orientation. Polymer chains at the surface are initially oriented to the rubbing direction and LC molecules also align to the direction, that is called as an easy axis. If polymer molecules strongly couple and rotate with LC molecules by tortional torque F_b $(=K_{22}\Phi_t^2/2d)$, the easy axis might deviate from the rubbing direction. This assumption is reasonable to explain faster and larger Φ_t reduction in the thinner cell, as shown in Figs. 2(h), (i) and (j), since the thinner cell has stronger F_b.

On the other hand, relations between disclination width w and E_a are known to be $E_a w^2 \propto Kd$.[6-8] This equation indicates that the narrower disclination width must be observed in the thinner cell if E_a is independent of the cell thickness. However, we can see wider disclination lines in the thinner cell on referring to Fig. 2(d) and (h). These images show that E_a in the thinner cell is smaller than that in the thicker cell. It is reasonable to suppose that the larger rotation of polymer chains makes their order and the surface anchoring lower.

Next, relations between Φ_t and Φ_r in the TN cell are measured in detail. It is known that these are given by the torque balance equation written as $E_a\sin(\Phi_r-\Phi_t) = 2K_{22}\Phi_t/d$, if the chiral pitch of the LC is infinite. For this equation, it is interesting whether the specific value of E_a is obtained for an arbitrary value of Φ_t, or not, since F_b is a function of Φ_t. We prepared the LC cell where Φ_r of 0°~±90° can be continuously obtained,[9] as shown in Fig. 4(a). The cell consists of the unidirectionally rubbed PI substrate and circularly rubbed PMMA substrate. Figures 4(b) and (c) show transmission images of the cell between crossed and parallel polarizers, respectively. The reverse twist defect line always appears across the center point of the circular alignment. The transmission distributions 4 hours and 7days after the LC injection were measured and are shown in Fig. 4(d).

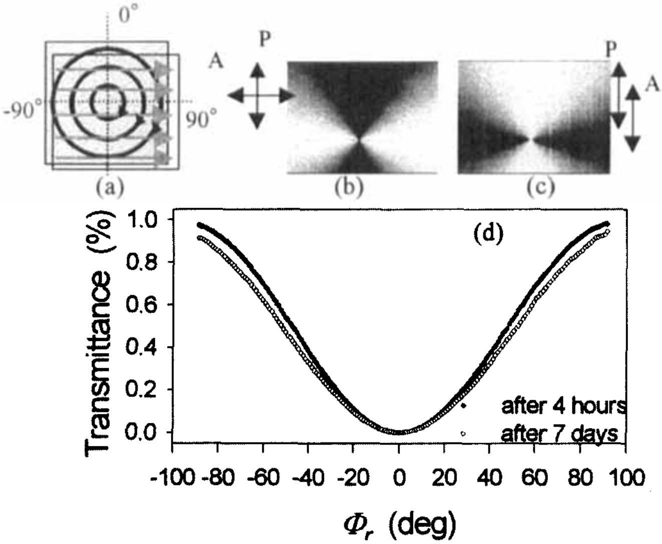


FIGURE 4 (a) The cell with variable Φ_r from 0 to ±90° and transmission images between (b) crossed and (c) parallel polarizers in the cell with a unidirectionally rubbed PI substrate and a circularly rubbed PMMA substrate. (d) The transmission distributions 4 hours and 7days after the LC injection between crossed polarizers, Cell thickness is 11.5 μm.

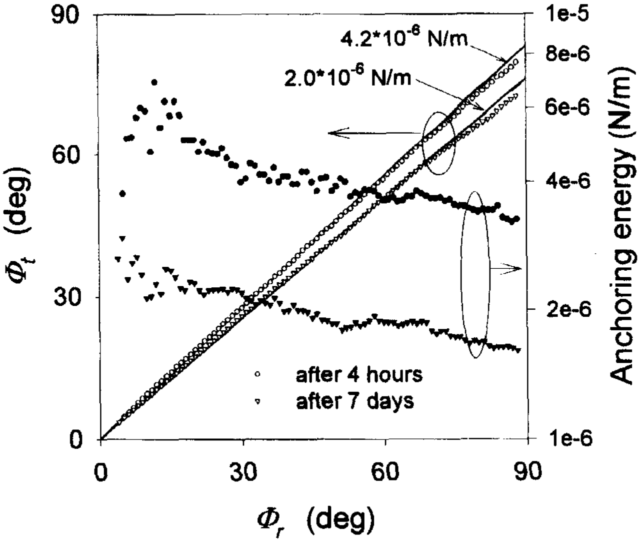


FIGURE 5 Φ_t and E_a distributions calculated using data of Fig.4 (d), as a function of Φ_r. Closed circles show measured values. Solid and broken lines show theoretical values.

From these trasmission values, Φ_t is calculated using the Jones optical propagation matrix, assuming that $\Delta\phi$ on the PI surface is 0°. Φ_t distribution is shown in Fig. 5, as a function of Φ_r. The theoretical Φ_t is also calculated using E_a as a fitting parameter. It has been reported that measured Φ_t is well fitted to the theoretical one on the rubbed PI surface.[10] Seeing our data, however, the measured Φ_t is larger at Φ_r of 0°~30° and smaller at Φ_r of 60°~90° than the theoretical one. Assuming that the easy axis is corresponds to the rubbing direction, E_a is calculated using measured Φ_t, as a function of Φ_r, and shown as closed circles and triangles in Fig. 5. Lower E_a is obtained at larger Φ_r even if on the same rubbed surface. Relations between $\Delta\phi$ [=1/2(Φ_r-Φ_t)] and Φ_t were also investigated in the cell with unidirectionally and circularly rubbed PVA surfaces, as shown in Fig. 6. The theoretical relations between $\Delta\phi$ and Φ_t are almost linear, when E_a is above 5×10^{-6} N/m. However, the measured $\Delta\phi$ exponentially increases.

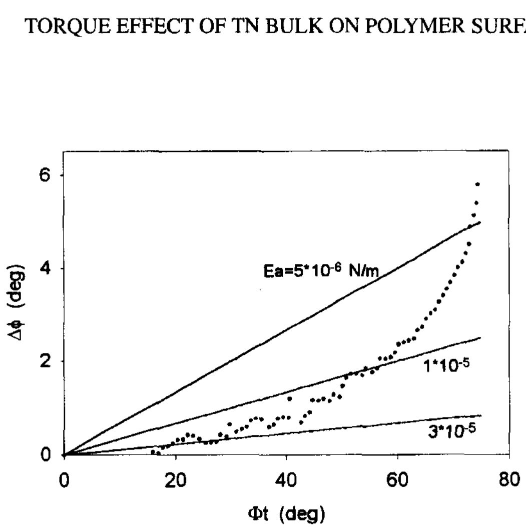


FIGURE 6 Measured (closed circles) and theoretical (solid lines) relations between Φ_t and Φ_r in the TN cell with rubbed PVA substrates.

These results indicate that larger Φ_t, that is stronger F_b, causes larger deviation of easy axis from the rubbing direction and lower order, as well as the discussion about the thinner TN cell. Moreover, the large deviation from the theoretical curve shows that PVA surface molecules are easy to move, compared to the PMMA surface. It is reasonable that the glass transition temperature (T_g) of PVA is 60°C and is lower than that of PMMA (=105°C). The T_g of PVAC is 29°C and the surface can not hold the twisted LC orientation.

The tortional torque effect on the polymer surface is demonstrated in another investigation. The saturation voltage of 3.5 V was partly applied to the 90° TN cell for 40 hours immediately after the LC injection, as shown in Fig. 7(a). When the voltage was removed, the twist angle of about 86° was larger, compared to that of 78° in the area without the experience of the voltage application, as shown in Fig. 7(b). Since the tortional torque of the homeotropically orientated LC bulk is too small to rotate polymer chains at the surface, the twist angle does not decrease during the saturation voltage application. This is a novel type of sticking effect due to applying the voltage in early time of cell fabrication.

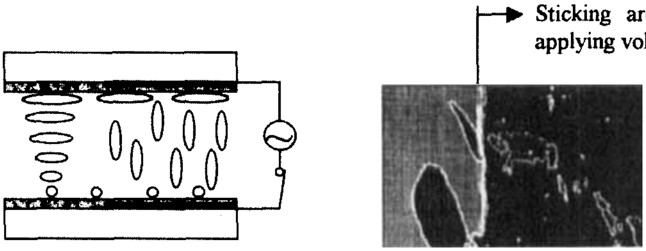

Sticking area due to applying voltage

FIGURE 7 Sticking phenomenon in the TN cell with rubbed PMMA substrates. (a) Schematic diagram of the LC cell and (b) transmission image after applying voltage for 40 h and then removing.

CONCLUSIONS

The tortional torque effect of the LC bulk on the alignment surface is experimentally discussed. The twist angle Φ_t decreases with time and the relation between measured values of Φ_t and Φ_r are not fitted to the theoretical values. A new type of the sticking effect on the twist angle is observed. These phenomena are due to the reorientation of polymer molecules at the rubbed surface by the tortional torque of the LC bulk, which shows the active effect of the LC bulk on the polymer interface.

References

[1] X.T. Li, D.H. Pei, S. Kobayashi and Y. Iimura, Jpn. J. Appl. Phys., **36**, L432 (1997).
[2] T. Akahane, H. Kaneko and M. Kimura, Jpn. J. Appl. Phys., **35**, 4434 (1996).
[3] R. Yamaguchi and S. Sato, Jpn. J. Appl. Phys., **39** L681 (2000).
[4] P. Vetter, Y. Ohmura and T. Uchida, Jpn. J. Appl. Phys., **32**, L1239 (1993).
[5] V.P. Vorflusev, H.-S. Kitzerow and V.G. Chigrinov, Appl. Phys. Lett., **70**, 3359 (1997).
[6] M. Kleman and C. Williams, Philos. Mag., **28**, 725 (1973).
[7] G. Ryschenkow and M. Kleman, J. Chem. Phys., **64**, 404 (1976).
[8] W.J.A. Goossens, Mol. Cryst. & Liq. Cryst., **124**, 124 (1985).
[9] R. Yamaguchi, T. Tonegi and S. Sato, Proc. 5th Asian Symposium Information Display, p. 181 (1999).
[10] S. Ruipeng, H. Ximin, M. Kai, W. Zongkai and J. Min, Phys. Rev. E, **50**, 1253 (1994).