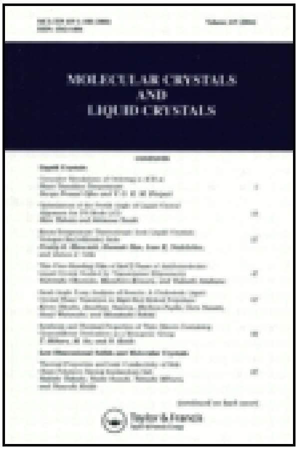

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Lyotropic Chromonic Liquid Crystals for Optical Applications - an Optical Retardation Plate for Twisted Nematic Cells

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Version of record first published: 18 Oct 2010

Mol. Cryst. Liq. Cryst., Vol. 409, pp. 21–28, 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490435486

LYOTROPIC CHROMONIC LIQUID CRYSTALS FOR OPTICAL APPLICATIONS – AN OPTICAL RETARDATION PLATE FOR TWISTED NEMATIC CELLS

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An aqueous solution of disodium cromoglycate (cromolyn) is known to form the chromonic N phase (i.e. a nematic lyotropic columnar phase) at room temperature and concentration range 13–17%, and the corresponding N twisted nematic phase if chiral dopants are added. We have produced lyotropic liquid crystal films and cells with a uniform planar alignment and cells with twisted optic axis using L amino acids as chiral dopants. The optical retardation of the lyotropic twisted nematic (TN) cells was chosen to match that of active TN cells in the normally black (NB) TN device. When two cells are placed together between crossed polarizers, the birefringence effects cancel for all viewing directions, thus providing achromatic dark state, high head-on contrast, and a wide viewing cone.*

Keywords: lyotropic chromonic liquid crystals; optical compensation; twisted nematic devices

1. INTRODUCTION

An ideal display should provide high contrast and wide viewing angles free of grayscale inversion while exhibiting good color rendition with an achromatic dark state. The standard uncompensated twisted nematic device falls short in these areas. Certain applications demand a normally black twisted nematic (NB TN) display mode. The NB TN display is dark when no voltage is applied. This display mode has relatively symmetric viewing cone, but suffers from problems with chromaticity and contrast for head-on viewing. In order to improve the optical performance of the NB TN display one

This research was supported by the National Science Foundation Science and Technology Center for Advanced Liquid Crystalline Optical Materials (ALCOM) under Contract N. DMR 89-20147

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should compensate an undesirable positive birefringence of the non-activated TN cell by employing a compensation plate that features negative birefringence and twisted optic axis. In our previous work we approximated the twisted structure of the compensation film by stacking several layers of polymer uniaxial film having negative birefringence and optic axis in the film plane [1]. The result was the achievement of an achromatic black state and the improvement of overall optical performance. However, this approach was impractical from the manufacturer's standpoint. Thus we continued the search for a single negative birefringence film with a twisted optic axis. To this end, we have made a film of this type by forming a planar cholesteric structure from a thermotropic discotic material doped with chiral discotic [2]. Unfortunately, the latter type of the film possessed a multi-domain structure that prevented its display applications. In the current work, we describe the production of optical elements based on cells filled with lyotropic liquid crystal, that are suitable for compensation of NB TN displays. The work summarizes our efforts in making optical elements featuring negative birefringence and twisted optic axis.

2. MATERIALS AND SAMPLES

The lyotropic liquid crystal used in our work is disodium cromoglycate (variously known as cromolyn) manufactured by Aldrich Co. The molecules are plank-like with a polyaromatic rigid core and a hydrophilic ionic solubilizing group at the periphery. At a concentration range of 13–17% (wt.), the aqueous solution forms a nematic phase [3,4] (referred to as the chromonic N phase [5]). Because of the hydrophobic nature of the center of the molecule and the hydrophilic properties of the periphery, the molecules assemble into stacks with degenerate molecule orientation in the molecular plane. We studied two types of samples: thin oriented films and sealed cells filled with the lyotropic nematic liquid crystal. The films were produced by shearing of the nematic mixture on glass substrates and subsequent water evaporation at room temperature. The molecular alignment in the films occurred at the time of shearing and was controlled by the water concentration and by the setting of the casting equipment controlling the thickness of the layer. The thickness of oriented cromolyn films was estimated using atomic force microscopy and was about 120 nm. Planar cells were fabricated using glass substrates covered with rubbed polyimide (grade 7511 by Nissan Co.) as an alignment layer. The glass plates were separated with fiber spacers made by EM Industries (thickness varied from 4 to 25 μm). Cells were filled with cromolyn-water solutions and sealed with epoxy glue to prevent water evaporation. Using the amino acids [4] L-alanine, L-lysine as chiral dopants at concentration about 1% (wt.)

we obtained single domain 90° twisted nematic cells with an area greater than 4 square inches. At the higher dopant concentrations (above 8%(wt.)), we observed fingerprint textures typical for cholesterics that allowed us to estimate the twisting power of the dopants and optimize their concentration according to the desired twist angle. We manufactured and studied both 90° twisted nematic cells and cells with a uniform planar director distribution. Both films and cells were non-absorbent and demonstrated low dispersion of visible light.

We studied cells filled with lyotropic liquid crystal as compensators of NB TN devices. The basic element of the studied devices was a liquid crystal cell with 90° twisted director configuration (TN cell). The 4–5 micron thick cells were filled with nematic fluid ZLI-4792 (manufactured by Merck). The cells with lyotropic material and thermotropic nematic had the opposite twist sense and were put together between crossed dichroic polarizers in a way that their director configurations mirrored each other. The optical retardation of the active and the compensating cell matched exactly, though the first one was filled with positive birefringence material and the other one – with negative. The display was driven between 0 V (dark state) and 6 V (bright state).

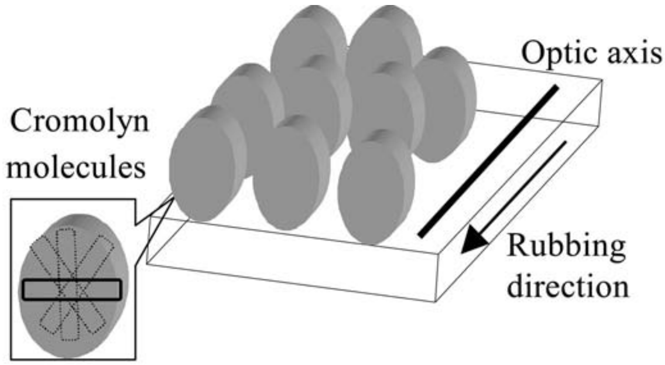
3. MEASUREMENT TECHNIQUES

In order to estimate the optic axis distribution in thin films and planar cells made of lyotropic material we applied a null ellipsometry technique based on the de Sénarmont method. The details of the technique can be found in the reference [6]. Result of the measurement is an experimental curve that represents phase shift in a birefringent sample versus the incidence angle of a testing laser beam. The curve is very characteristic to the film. From the shape of the curve it is possible to determine the relationship between three principal refractive indices, absolute values of birefringence, the sign of the birefringent medium (negative or positive), and the alignment of the optic axis.

To characterize the viewing angle performance of compensated devices we estimated the contrast ratio versus the viewing angle by measuring the transmission of the device at various angles when the device operated between dark and bright states (correspondent to applied 0 and 6 V, respectively). The ratio between the transmitted luminance at each angle was calculated and the result was plotted in the form of iso-contrast curves in polar coordinates. The periphery of the diagram corresponds to the azimuthal angle and the radius corresponds to the polar angle.

The center of the diagram corresponds to head-on viewing and any other pair of angles corresponds to the off-normal direction.

(a)



(b)

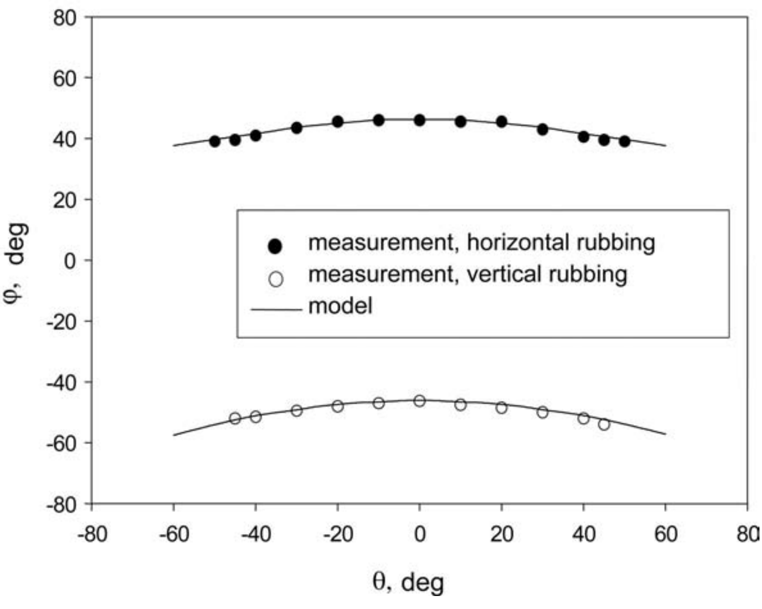


FIGURE 1 Molecular alignment (a) and phase shift φ vs incidence angle θ curve for cromolyn cell (b).

4. OPTICAL CHARACTERISTICS OF THIN FILMS AND PLANAR CELLS

We measured the phase shift versus the incidence angle curves for both thin films of cromolyn and planar cells filled with cromolyn-water mixtures. Figure. 1 shows the characteristic curves that reflect basic features of both films and cells. The structures are uniaxial with the lower refractive index along the director and the higher refractive index in the molecular plane. The birefringence of the cromolyn-water mixtures depended on the concentration and was about $\Delta n = -0.02$ at cromolyn concentration of 15% (wt). The birefringence of aligned cromolyn films was about $\Delta n = -0.15$. We did not detect any measurable pretilt angle for either films or cells. Figure. (1a) shows possible molecular alignment on the polyimide alignment layer. As a result of averaging over possible molecular orientations the material has optical characteristics similar to discotic liquid crystals [8]. For this reason we schematically represent the structure of this phase as a discotic phase.

The birefringence measurements of planar lyotropic cells provided us with data that allowed us to build lyotropic TN cells with optical birefringence that was exactly the same as for active TN cells in NB TN device. Separate studies of fingerprint textures of lyotropic cells doped

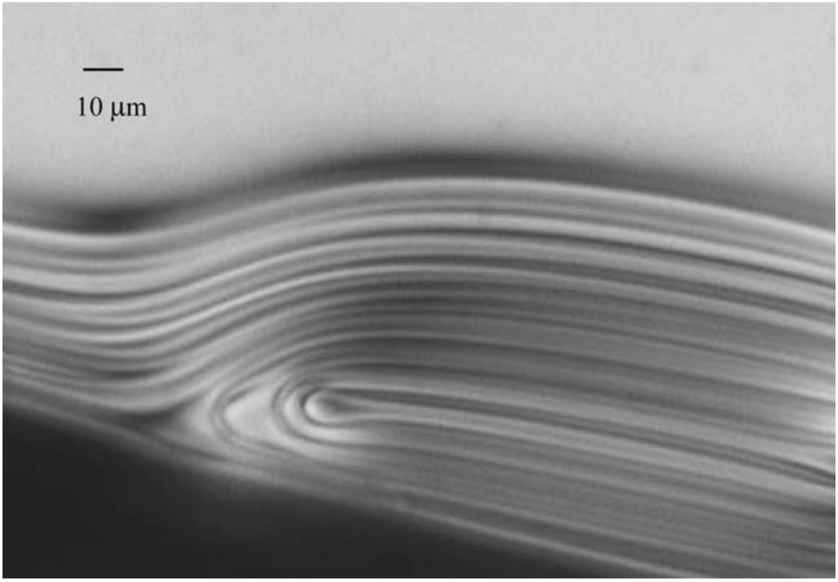
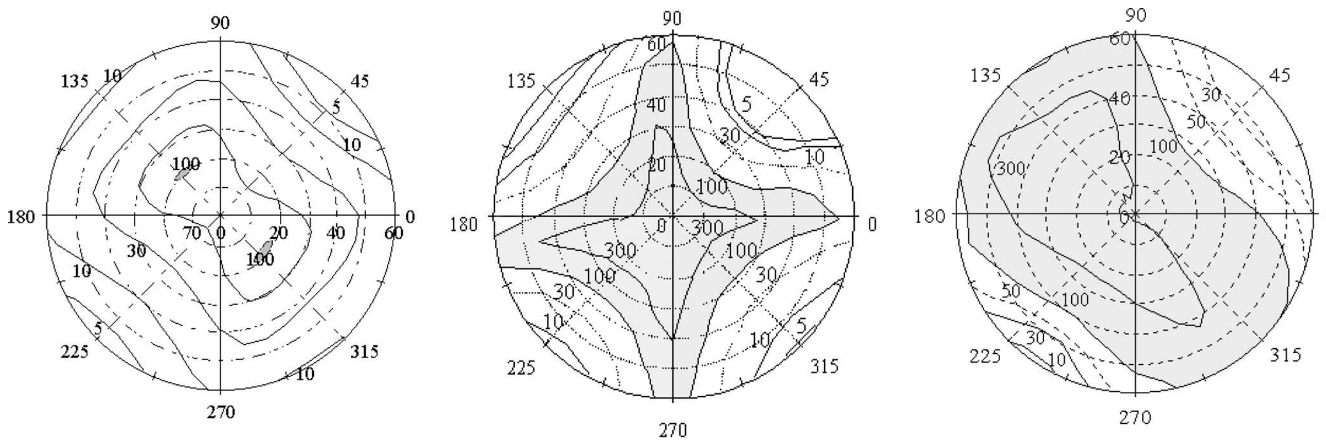


FIGURE 2 Fingerprint texture of cromolyn cell doped with L-alanine.



(a) (b) (c)

FIGURE 3 Iso-contrast plot for: (a) uncompensated NB TN display (model), (b) NB TN display compensated with the lyotropic TN cell, (c) NB TN display compensated with the lyotropic TN cell and the lyotropic planar cell.

with L-alanine (Fig. 2) provided the twisting powers of the dopants (htp $\sim 1\,\mu m^{-1}$. The handedness of the twist sense in two cells was the opposite. When two cells were placed between crossed polarizers, the birefringence effects cancel for all viewing directions, thus providing an achromatic dark state and a wide viewing angle. The latter was confirmed experimentally by measuring the optical performance of the compensated display. Figure. 3(a) shows iso-contrast curves for the uncompensated NB TN device modeled using method described in detail in the reference [1]. Shaded regions in Figure 3 correspond to viewing directions for which the contrast ratio exceeds 100:1. Comparison with the iso-contrast curves for the compensated NB TN display (Fig. 3(b)) shows substantial improvement in head-on contrast (350:1 versus 70:1 for uncompensated one). The shape of the iso-contrast curves (determined primarily by dark state luminance) is similar to iso-luminance curves for dichroic polarizers. The dark state is achromatic at all viewing directions at the polar angles up to 45° (Fig. 4). The residual light leakage observed at wide angles is due to unaccounted birefringence of polymer films used as protective layers in standard dichroic polarizers. We improved the display performance further by employing an additional optical element that was also based on lyotropic cell. In the latter case a single planar cell filled with cromolyn possessing optical retardation about-180 nm compensates the birefringence effects

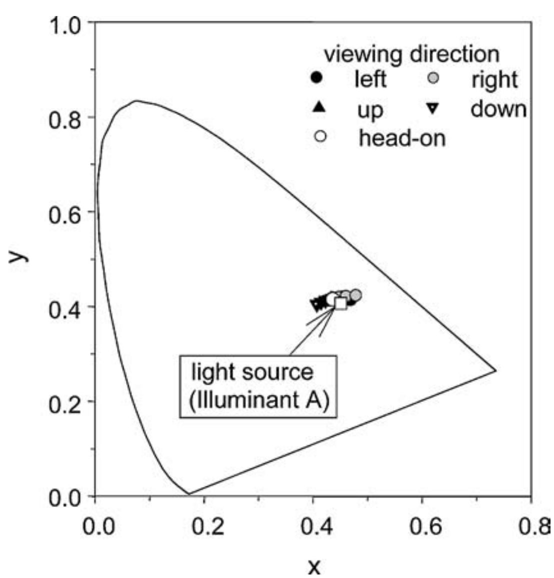


FIGURE 4 Dark state color coordinates CIE 1931 at the polar angels up to 45° for NB TN display compensated with the lyotropic TN cell.

from polarizer protective layers (Fig. 3(c)). The NB TN display compensated with both planar and TN lyotropic cells has contrast ratio up to 50:1 at polar angles up to 40°. Despite the relatively poor control of the optical retardation of the cromolyn cells due to the narrow temperature range of the chromonic N phase, proposed inexpensive and easy to manufacture compensators provide achromatic dark state and wide viewing cone for NB TN devices.

REFERENCES

[1] Sergan, T., Liu, W., Kelly, J., & Yoshimi, H. (1998). *Jpn. J. Appl. Phys.*, *37*, 889.
[2] Sergan, T., Sonpatki, M., Kelly, J., & Chien, L. C. (2001). *Mol. Cryst. Liq. Cryst.*, *359*, 245.
[3] Lee, H. & Labes, M. M. (1983). *Mol. Cryst. Liq. Cryst.*, *91*, 53.
[4] Lee, H. & Labes, M. M. (1982). *Mol. Cryst. Liq. Cryst.*, *84*, 137.
[5] Yaroschuk, O., Sergan, T., Lindau, J., Lee, S. N., Kelly, J., & Chien, L. C. (2001). *J. Chem. Phys.*, *114*, 5330.
[6] Sergan, T., Sonpatki, M., Kelly, J., & Chien, L. C. (2001). *Mol. Cryst. Liq. Cryst.*, *359*, 259.