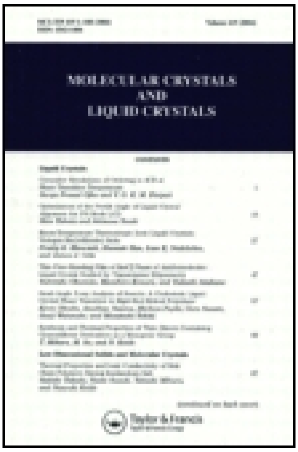

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

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Version of record first published: 04 Oct 2006

Mol. Cryst. Liq. Cryst., 1997, Vol. 301, pp. 307–312
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POLARIZATION CROSSTALK IN CLC FILMS AT OBLIQUE ANGLES OF INCIDENCE

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Abstract The polarization crosstalk of cholesteric liquid crystal (CLC) films is studied experimentally and numerically as a function of incidence angle, film thickness and CLC refractive indices. Here, *polarization crosstalk* is used to describe the ability of planar texture CLC to discriminate between left-, and right-hand circularly polarized (LCP and RCP) light, in either reflection or transmission. To quantify the amount of crosstalk for a given wavelength and angle of incidence, the contrast, η, is introduced, such that $\eta=|A_{RCP} - A_{LCP}|/2$, where $A_{RCP(LCP)}$ is CLC transmittance or reflectance using RCP(LCP) light. When $\eta \sim 0.5$, a CLC film provides good discrimination for RCP and LCP light; when $\eta \sim 0$, RCP and LCP light are equally reflected and transmitted from the film. This concept is applied to the study of two CLCs, one with $\Delta n/n_a=0.068$, and the other with $\Delta n/n_a=0.12$, and good agreement between experiment and theory are obtained.

INTRODUCTION

It has been suggested that cholesteric liquid crystal (CLC) films be utilized as polarizing dichroic filters in reflective[1] and projection[2] display technologies, and as notch filters[3] to enhance the color purity of absorptive-dye-based color filters. Many of these applications require using CLC filters at oblique angles of incidence, and so it is important to understand, and to be able to characterize, the performance of CLCs at oblique angles.

Detailed studies[2, 4] of the optical characteristics of CLC films at non-normal incidence have been performed. In the present work, the selective reflection property of CLC films at oblique angles of incidence is characterized in terms their *contrast*, η, which is defined as

$$\eta(\lambda_c,\theta)=\frac{|T_{RCP}(\lambda_c,\theta)-T_{LCP}(\lambda_c,\theta)|}{2}=\frac{|R_{RCP}(\lambda_c,\theta)-R_{LCP}(\lambda_c,\theta)|}{2}. \qquad (1)$$

Here, $T_{RCP,LCP}$ and $R_{RCP,LCP}$ are the transmittance and reflectance of incident right-, or left-hand circularly polarized (RCP or LCP) light at an angle of incidence θ and wavelength λ_c, which lies at the center of the selective reflection band. (The restriction to this particular wavelength is a matter of convenience.) Note that η can be derived from either a reflectance or transmittance measurement. It has the following interpretation. When η~0.5, a CLC film reflects nearly all incident light of the same circular polarization handedness as the (chiral) material. In the other extreme, when η~0, the CLC film reflects and transmits both RCP and LCP to the same extent.

The contrast of two disparate CLC materials is studied both experimentally and numerically in this paper. The materials are BL088 (Merck) with a birefringence that was measured at Reveo to be Δn=0.2028, an average index of n_a=1.69 (for visible wavelengths) and a pitch of p=+310 nm. The second material is a mixture of a CLC polymer (Wacker Chemie, GmbH) and low-molecular-weight chiral nematics. The optical indices of the second material were also measured at Reveo and found to be Δn=0.1057 and n_a=1.55 (at visible wavelengths); the pitch is p= - 420 nm. Both L=5- and 20-μm-thick samples were investigated experimentally, while samples with normalized thicknesses of L/p=5, 10, 20, 40 were investigated numerically. Details of the experimental measurements and numerical simulations is presented in the following two sections.

EXPERIMENT

A goniometer was built to study the angular dependence of selective reflection of CLCs. A schematic diagram of the set up is shown in Fig. 1. Monochromatic light is produced by a tungsten filament lamp (LS) that is coupled to a 1/8-m monochromator with a resolution of ~1 nm. After being collimated by a lens (L), light is polarized by the combination of a Glan-Thompson prism polarizer (GT) and a Fresnel rhomb (FR).

By rotating the GT, both RCP or LCP light can be produced. The polarization purity of light from this circular polarizer was measured to be better than 400:1 from 350-900 nm. The probe light then passes through an aperture (AP), to stop the beam down to a 1x4 mm^2 beam size at the sample. The sample is mounted on a rotation stage that shares the same axis of rotation as that of the detection optics. Reflected or transmitted light is detected by a photo-multiplier tube (PMT) and sent to a personal computer (PC) via a digital oscilloscope.

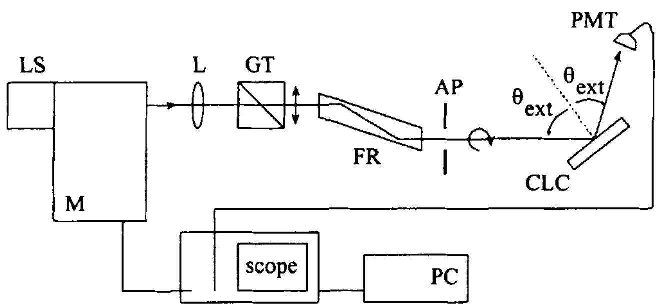

FIGURE 1 A schematic diagram of the experimental apparatus.

Representative spectra for a 20-μm-thick film of BL088 CLC material, taken at normal incidence and at θ_{ext}=60° are shown in Fig. 2. This film has a very high normalized thickness of *L/p*=65, and therefore, a high degree of crosstalk is occurring between RCP and LCP light in the center of the reflection band when the external angle of incidence is θ_{ext}=60°. Using spectra such as these, the contrast, as defined in Eq. (1), was derived for both CLCs under consideration. Contrast is plotted in Fig. 3 as a function of *internal angle of incidence*, θ_{int}, where the internal angle of incidence is derived from Snell's law, using the reasonable assumption that the index of refraction of the substrates is equal to the average CLC indices. In most cases, the data points represent an average of two similar values, derived from reflectance and transmittance spectra. In order to make a comparison with the results of numerical simulation, η was derived from the spectra after properly accounting for Fresnel reflection losses at the two substrate-air interfaces. The major trend that emerges from the data of Fig. 3 is that contrast suffers as CLC thickness increases, when θ_{int} is held fixed.

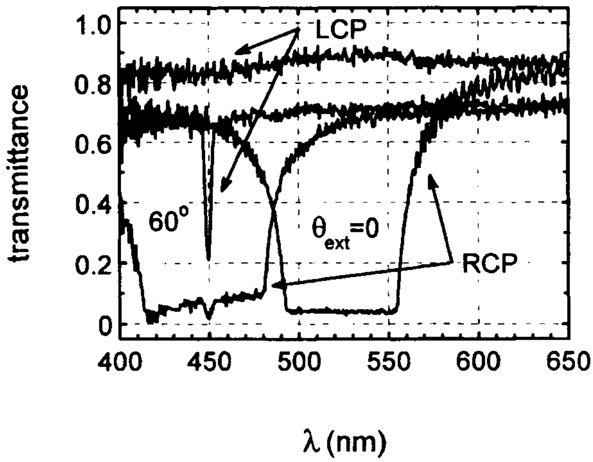

FIGURE 2 Transmittance of a 20-μm-thick BL088 CLC film.

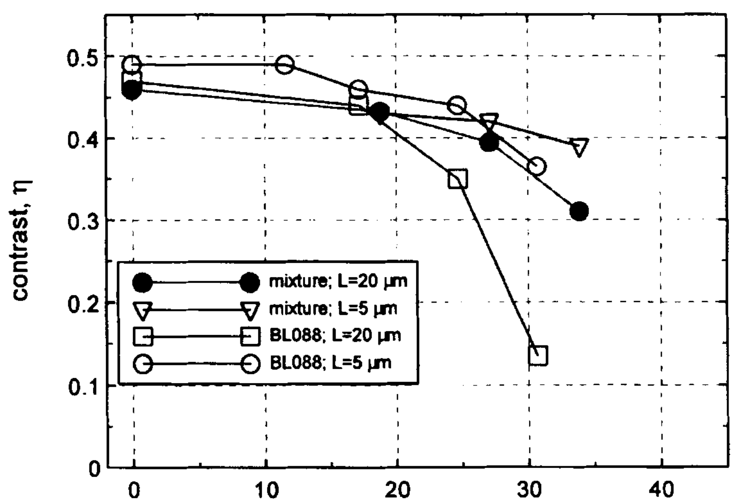

FIGURE 3 Measured contrast vs. internal angle of incidence for two materials.

NUMERICAL SIMULATION

In order to be able to predict CLC contrast values for different materials, a simulation was performed to generate CLC spectra at oblique angles of incidence. The simulation adopted here is the well-documented Berreman's 4x4 matrix method[5]. Parameters of the CLC materials studied experimentally were used as input for the code. In the code, however, a much larger range of sample thickness values was chosen: L/p=5, 10, 20, 40. Also, the substrate indices were taken to be equal to the average CLC indices, which implies that $\theta_{ext}=\theta_{int}$ in the simulation. A comparison of simulated and measured spectra is given in Fig. 4; agreement is quite good. Figure 5 shows contrast for BL088 CLC as a function of θ_{int}, as derived from the numerical data. As in experiment, it is seen that contrast suffers as CLC film thickness increases. In addition, it is seen that contrast, or crosstalk, will change less over a range of incidence angles for thinner samples, than for thicker samples. This, of course, is at the expense of reflectivity or transmittance at near-normal incidence.

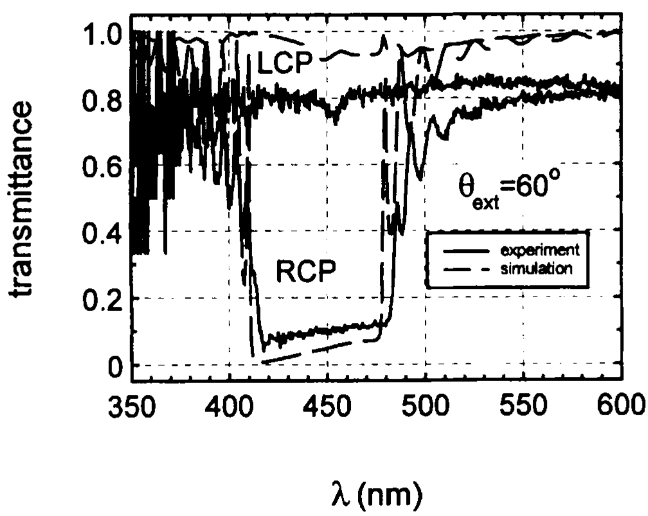

FIGURE 4 A comparison between experiment and simulation at θ_{ext}=60°.

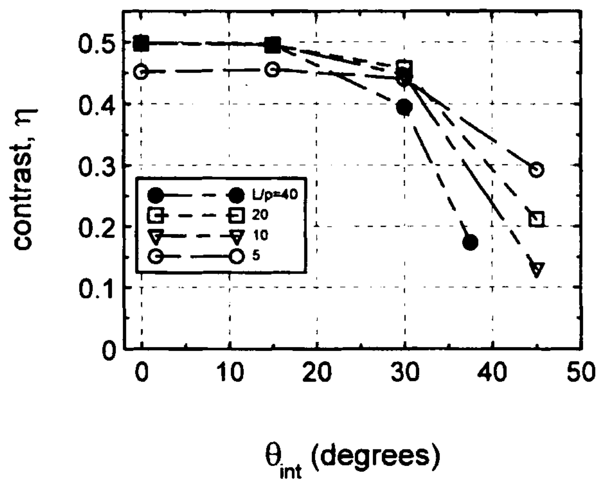

FIGURE 5 Contrast, derived from numerical data.

CONCLUSIONS

The utility of the contrast, η, to characterize crosstalk in CLC films at oblique angles of incidence has been demonstrated. The contrast may be derived from either reflectance or transmittance spectra, making it a bit more general than a statement of extinction ratio, for example, which in general is dependent on whether it was derived from reflectance or transmittance data.

ACKNOWLEDGMENT

This work was supported by a grant from the BMDO, under contract number DAAH04-95-C-0046.

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