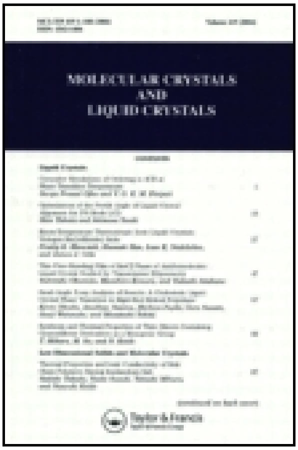

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Electrically Tuneable Cholesteric Mirror

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Chiral nematic liquid crystals which possess a large negative dielectric anisotropy ($\Delta\varepsilon < 0$), exhibit a larger dielectric constant parallel to the helical axis than perpendicular to it. In a liquid crystal cell with homeotropic boundary conditions, the direction of the helical axis is parallel to the cell surfaces and the sample adopts a pseudo focal conic texture. On the application of a suitable AC field, the director is rotated, such that the helix direction is now perpendicular to the surface and the sample adopts a Grandjean texture. The wavelength of reflected light in this "field On" state is a function of temperature and the magnitude of the applied field. In this paper we show that highly twisted chiral nematic liquid crystals, which possess a large negative dielectric anisotropy are potentially useful as optical modulators and in electrically tuneable mirrors.

Keywords: Liquid crystals; chiral nematic; discotic; calamitic; reflection spectroscopy; electrooptics

INTRODUCTION

Chiral nematic liquid crystals possessing a positive dielectric anisotropy ($\Delta\varepsilon>0$), often very low ($\Delta\varepsilon\approx 0$), have been widely studied and their physical properties and potential applications in flat panel display devices have been reported [1-4]. The symbol $\Delta\varepsilon$ refers here to the low-frequency anisotropy, whereas ε_a relates to the high-frequency dielectric constants, which corresponds to the optical anisotropy n_a.

The direction of helical orientation in the chiral nematic phase is very much governed by the boundary conditions imposed on the sample, and there are two possibilities to consider. The first possibility is 'planar helix geometry', whereby the helical axis is aligned in the plane of the substrate surface and the sample adopts a pseudo focal texture, when viewed between crossed polarisers. The second possibility is 'perpendicular helix geometry', whereby the helical axis is oriented in a direction perpendicular to the substrate surface and the sample adopts a Grandjean texture. Only in the second case, the sample will exhibit bright colour effects due to selective Bragg-like reflection (Equation 1), if the helical pitch (p) of the chiral nematic phase corresponds to an optical wavelength in the visible range.

$$\lambda(\theta) = \bar{n} \cdot p \cdot \cos\theta \qquad (1)$$

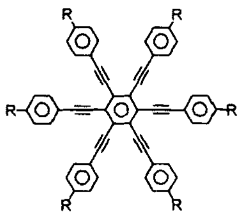
Therefore, chiral nematic liquid crystals, which possess a large negative $\Delta\varepsilon$, and which are aligned such that the sample adopts a planar helix geometry, should respond to the application of a suitable AC field such that the direction of the helical axis reorientates due to the alignment of the dielectric anisotropy of the constituent molecules with the applied field. Therefore, the liquid crystal cell may be 'switched' from the pseudo focal texture to the Grandjean texture.

The mean refractice index $\bar{n}$ appears due to refraction at the sample surface and the angle θ describes the direction of light incidence with respect to the twist axis inside the sample (Figure 1). Consequently, the wavelength of reflected light in the "field On" state must be a function of the temperature dependent helical pitch and the magnitude of the applied electric field. This behaviour was first observed in discotic chiral nematic phases (N_D^*) of chiral radial multiynes, which possess a negative dielectric anisotropy and a negative birefringence [5]. Extensive research has been undertaken on calamitic liquid crystals with respect to the relationship between molecular structure and anchoring behaviour. It is conceivable that such liquid crystals with a negative dielectric anisotropy may be suitable candidates for electrically tuneable reflective displays based on highly twisted cholesteric phases. In order to study this effect in calamitic liquid crystals, we have in addition, begun investigations on three such promising systems: two pure chiral compounds (**III** and **IV**) with relatively strong transverse dipole moments, which exhibit chiral nematic phases that can selectively reflect visible light [7,8], and a binary mixture comprising a low melting achiral nematogen (**V**) doped with a highly twisting chiral material (**VI**) [9,10].

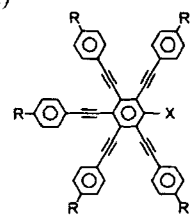
EXPERIMENTAL

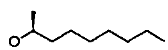
For our investigations on the discotic chiral nematic phase we used mixtures of the discotic nematic host **I** and the chiral dopant **II**. A high twisted N_D^*-phase which show selective reflection of red visible light was obtained by a composition of about 21 wt% **II** in **I** [6].

I)



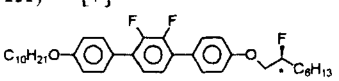
II)



	X:	R:	K T/°C N_D T/°C Iso
I)	-	C_9H_{19}	• 59 • 82 •
II)	$OC_{16}H_{33}$		isotropic liquid [5]

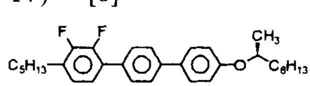
21 wt% **II** in **I** : K 59 (N_D^* 49) Iso (°C)

III) [7]



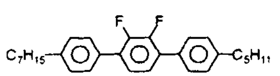
K 88.6 C* 154.9 N* 157.3 BPI 158 I (°C)

IV) [8]



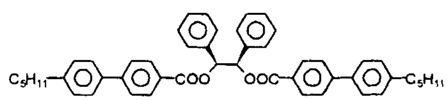
K 38.5 C* 51.5 N* 59.5 BPII 61.5 I (°C)

V) [9]



K 36.5 (C 24.0) N 111.0 Iso (°C)

VI) [10]



Chiral dopant (non liquid crystalline)

For all observations in reflection we used a Leitz Ortholux-II-Pol microscope in the reflection mode equipped with *left* or *right* circular polarizers. The spectra were recorded by a Diode-Array Photoresearch Spectrometer PR-703 mounted on the microscope. We used commercial EHC (Japan) test cells (ITO-electrodes) with either polyimide coated and rubbed surfaces (planar director / homeotropic helix alignment) or *n*-hexadecyltrimethyl-ammoniumbromide treated surfaces (homeotropic director / planar helix alignment).

RESULTS AND DISCUSSION

Due to the general tendency of the discotic nematic phase to adopt a homeotropic director alignment, at best only a bad homeotropic helix orientation of the discotic cholesteric phase could be achieved in rubbed test cells [5,6]. AC electric fields were applied to help attain the homeotropic helix alignment (Figure 1 right).

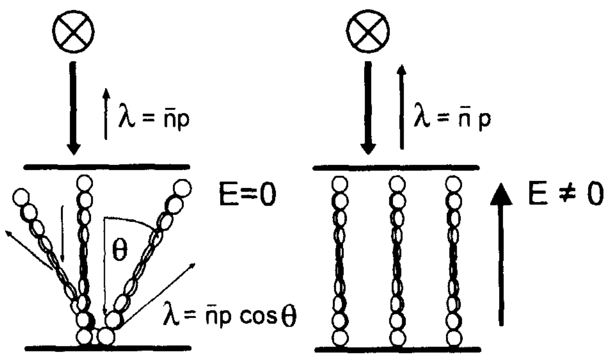


FIGURE 1. Schematic representation of the electric field induced orientational effect on highly twisted discotic cholesteric materials.

The micrographs in Figure 2 show how the selective reflection changes under the influence of the electric field (displayed). In order to exclude electrohydrodynamic effects, which would disturb the Grandjean texture, we chose high frequencies of the applied electric square wave field where no relaxation processes were observed.

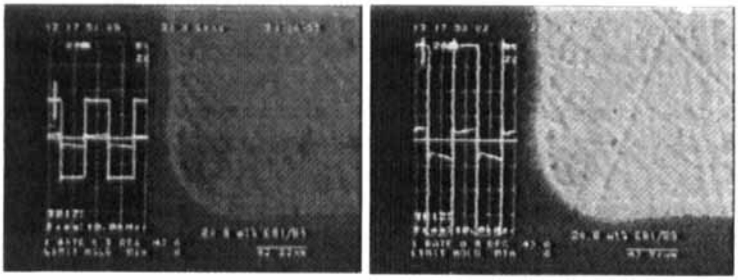


FIGURE 2. Reflection micrographs (illuminated with left circularly polarized light, T=42 °C). Curve of the electrode in a 10 µm EHC cell with polyimide coated and rubbed surfaces containing a discotic cholesteric mixture (21 wt% **II** in **I**). Applied electric field: 10 kHz square wave with 50 Vpp (left) and 160 Vpp (right).

The left circularly polarized reflected light indicates a left-handed helical structure of the N_D^*-phase. The micrographs (Figure 2) together with the reflection spectra in Figure 3 clearly show that the intensity of the selectively reflected light increases with increasing electric field strength.

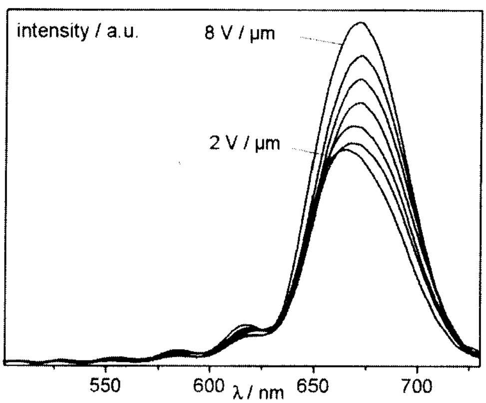


FIGURE 3. Selective reflection spectra of the discotic chiral nematic phase in the cell shown in Figure 2 for various field strength (10 kHz square) at T=38 °C.

It is not obvious from the micrographs because of the colour-adaptation of the CCD-camera, that the maximum wavelength shifts to higher values with increasing electric field as shown in Figure 4a.

The change of the maximum wavelength with the field strength can be explained by light that is selectively scattered on the chiral structures with an inclined helical axis under the angle θ with respect to the sample normal. According to the Bragg-law (Equation 1) such reflection is shifted to shorter wavelengths. Although this light is not directly back-reflected, it could be added to the spectra observed normal to the sample due to multiple scattering within the sample and the interfaces. The contribution of this light to the spectral characteristics vanishes, while improving the Grandjean texture, by increasing the AC electric field.

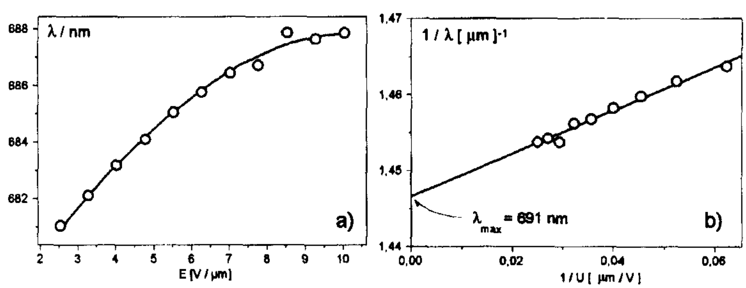


FIGURE 4. **a)** Field dependence of the Bragg wavelength from the spectra shown in Figure 3. **b)** Extrapolation to the Bragg wavelength $\lambda_0 = \bar{n} \cdot p$ for infinite field strength (10 kHz square) at T=38 °C.

A saturation wavelength should appear at high field strength, when the whole sample is perfectly planar-aligned ($\lambda_0 = \bar{n} \cdot p$). This maximum wavelength is extrapolated to be about 691 nm as shown in Figure 4b. The Grandjean texture relaxes into the less-reflective intermediate orientation when the electric field is turned off. For the discotic material the field induced alignment was fully reversible.

Calamitic liquid crystals with a large negative dielectric anisotropy should exhibit the same behaviour in a cell with planar helix boundary conditions. Compound **III** forms a highly twisted N*-phase by itself exhibiting selective reflection of right circularly polarized light.

The temperature dependence as well as the field dependence of the reflection spectra in Figure 5 look almost alike. We suppose that the colour shift in the field dependence also results from the change in temperature due to conductive heating at high field strength.

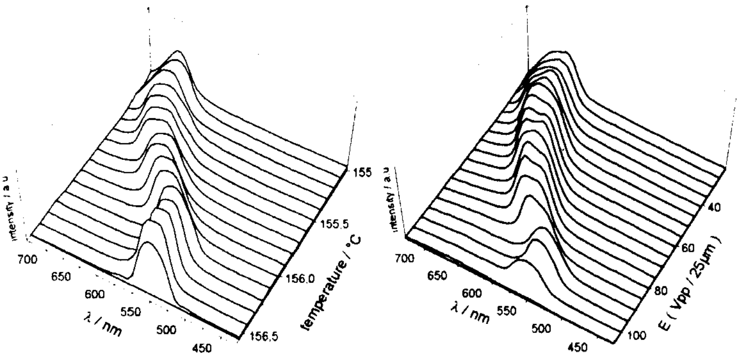


FIGURE 5. Temperature and electric field dependence (T=155 °C) of selective reflection spectra of compound **III** in a 25 μm EHC cell (planar helix boundary conditions, 100 kHz square wave).

Compound **III** does not appear to be very suitable due to the high and narrow temperature range of the N*-phase. Another promising candidate was compound **IV** which forms a right handed N*-phase at moderate temperature. Figure **6a** shows how the selective reflection appears in a sample with an initial pseudo focal conic texture that changes into the Grandjean texture by increasing the amplitude of the electric field (ie. switching to the "on" state).

Decreasing the electric field also results in a decrease in the reflection intensity. Unfortunately, the homeotropic anchoring of the EHC cells appeared to be too weak for the calamitic compounds used, consequently a complete relaxation of the planar aligned phase into the previous focal conic texture does not occur (Fig. **6b**). Furthermore the relaxation process when switching off the electric field is rather slow (in the order of seconds).

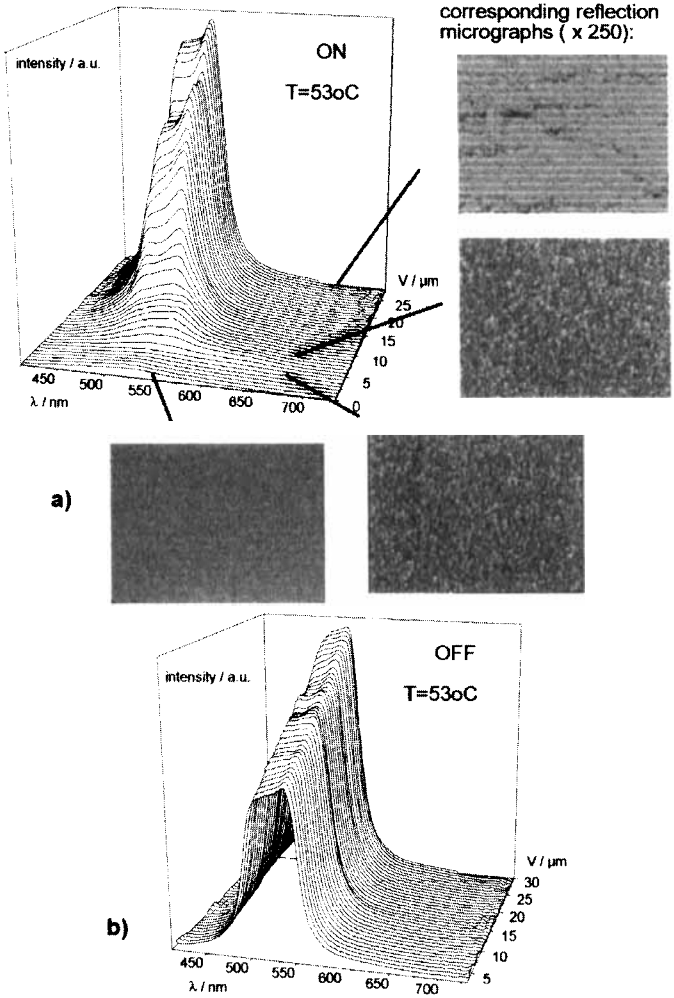


FIGURE 6. Electric field dependence of the selective reflection spectra of compound **IV** in a 10 µm EHC cell (planar helix boundary conditions, 100 kHz square wave). Increasing (**a**), and decreasing (**b**), the amplitude of the electric field shows a pronounced hysteresis.
See Color Plate I at the back of this issue.

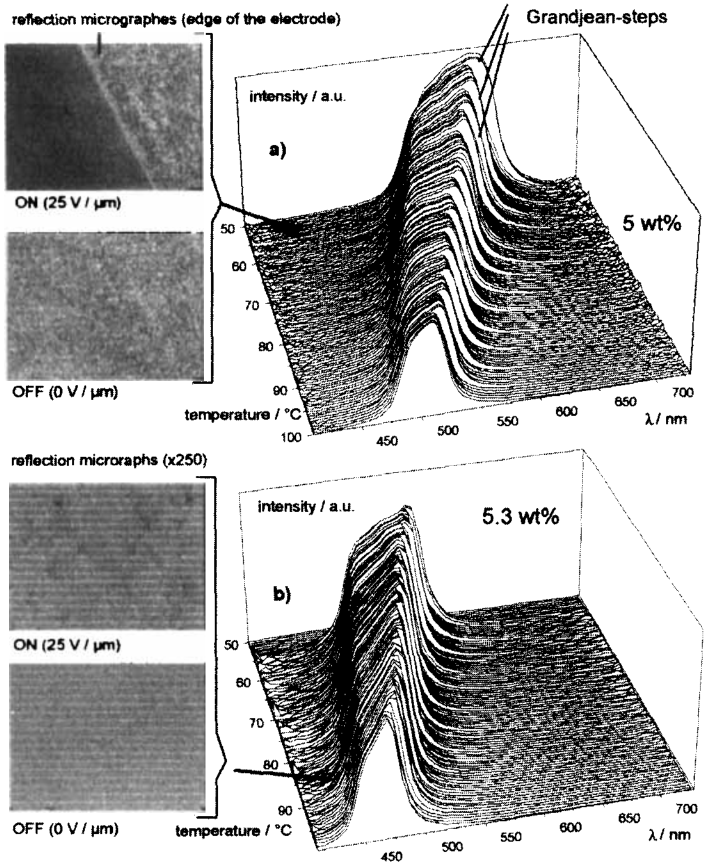


FIGURE 7. Temperature dependence of selective reflection spectra for 5 wt% (**a**) and 5.3 wt% **VI** in **V** (**b**), each in a 10 µm EHC cell with planar helix orientation (applied square wave field: 25 V / µm, 100 kHz). The reflected light is right circularly polarized.
See Color Plate II at the back of this issue.

CONCLUSIONS

The results suggest that highly twisted chiral nematic liquid crystals, which possess a large negative dielectric anisotropy, are potentially useful as optical modulators and electrically tuneable mirrors. In order to improve the relaxation into the non-reflective "field Off" state, alternative orientation layers with strong homeotropic director anchoring of the liquid crystal should be tested. In this context two frequency chiral nematic materials, which could be switched "On" and "Off" by adjusting the frequency of the applied electric field to the positive or negative dielectric anisotropies are highly interesting. Further investigations should also include the dynamics of the orientation and reorientation process.

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References

[1] J.S. Patel, R.B. Meyer, *Phys. Rev. Lett.*, **58,** 1538 (1987).
[2] W. Greubel, *Appl. Phys. Lett.*, **25,** 5 (1974).
[3] E. Lueder, *CEI-Europe,* Course **698,** "Flat Panel Display Technology" (1996).
[4] G.P. Crawford, *SAMPE Journal,* **32**(4), 22 (1996).
[5] M. Langner, K, Praefcke, D. D. Krüerke, G. Heppke, *J. Mater. Chem.*, **5**(4), 693 (1995).
[6] C.J Booth, D. Krüerke, G. Heppke, *J. Mater. Chem.*, **6**(6), 927 (1996).
[7] N. Gough, M. Hird, R.L. Lewis, D.D. Parghi, *Proc. of the 17. ILCC,* **P3–49** (1998).
[8] M. E. Glendenning, *Ph. D. Thesis,* University of Hull, England, (1998).
[9] G. W. Gray, M. Hird, D. Lacey, K. J. Toyne, *J. Chem. Soc. Perkin Trans. **II,*** 2041 (1989).
[10] G. Heppke, D. Lötzsch, F. Oestreicher, *Z. Naturforsch.*, **41a,** 1214 (1984).