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Gilles Joly[a]; Hassane Azzioui[a]; Noël Isaert[a]; Abdelkader Barroug[a]
[a] Laboratoire de Dynamique et Structure des Matériaux Moléculaires, U.R.A. (CNRS) No. 801, Université des Sciences et Techniques de Lille-Flandres-Artois, France

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Experimental determination of the helicoidal electric field inside a twisted mesophase, in the selective reflection band

by GILLES JOLY, HASSANE AZZIOUI, NOËL ISAERT and ABDELKADER BARROUG

Laboratoire de Dynamique et Structure des Matériaux Moléculaires, U.R.A. (CNRS) No. 801, Université des Sciences et Techniques de Lille-Flandres-Artois, France

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We consider the interface between a twisted birefringent mesophase and an isotropic medium. In the selective reflection band, when illuminated at normal incidence, the interface creates a coupling between the located dielectric reflection and the spread selective reflection. This coupling enables experimental measurement of the standing electric field orientation inside the liquid crystal.

Along the z direction of the screw axis of a twisted liquid crystal two vibration modes exist in the incident light sense: each mode is associated with a different wavevector. The two modes are plane, elliptically polarized waves; both keep constant polarization states, not in the laboratory frame but in a mobile frame which rotates with the twisted structure. The two modes are called favoured modes; their polarization states of electric, E, and magnetic, H, fields and their dispersion laws are different [1, 2].

The present work is restricted to the so-called selective reflection band narrow spectral domain (< 300 Å); here, wavelengths in the medium are close to the helicoidal pitch p (wavelength in vacuum $\lambda \sim np$ where n is the average refractive index of the mesophase). In a right handed cholesteric phase (N_r^*) the electrically favoured extraordinary mode is left handed, nearly circular [3] and propagates with a real index n' close to $2n$. The ordinary mode electric field E'' is rectilinear; its wavevector and its refractive index are strictly imaginary. E'' is an evanescent oscillation which vanishes according to $(-\exp 2\pi n''e/\lambda)$. In the medium, the orientation of the electric field E'' makes an angle ϕ with the director: this angle [4] varies from $-90°$ to $0°$ when λ scans the selective reflection band $(n_0p,\ n_ep)$.

The formation mechanism of the favoured rectilinear mode is described in [5]. It shows another peculiar aspect of the selective reflection (adding to the well-known absence of polarization sense of reflection from a cholesteric): the whole bulk contributes to the selective reflection of a birefringent helicoidal mesophase. As a consequence, the interface between a twisted birefringent mesophase (N^*, S_C^* . . .) and a transparent isotropic medium is expected to have original optical properties in the selective reflection band. When the mesophase average refractive index and the isotropic refractive index are different, a combination may occur between the selective reflection (distributed in the mesophase) and the dielectric reflection (confined at the interface).

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The favoured E' and E'' vibration modes in the mesophase enable us to study easily the reflected and transmitted vibrations by the interface between a twisted mesophase and an isotropic medium, at normal incidence: the polarization states of these vibrations depend on the incident light polarization state and the sense of interface crossing. Among the cases studied [4, 6], three require particular attention. When the incident light travels from the isotropic medium to the mesophase: (1) The reflection is complete for a particular elliptical incident vibration, right handed if the mesophase is right handed. Its great axis coincides with the rectilinear E'' field direction at the interface. The ellipticity angle η of that vibration satisfies tg $\eta = n/n_i$ where n is the average refractive index of the mesophase and n_i is the isotropic refractive index. (2) If an isotropic–N_r^* interface is illuminated with a right handed circularly polarized vibration, the reflected vibration is a right handed elliptical one, in the same sense as the incident. Its great axis coincides with the E'' field direction at the interface. The third case appears when the incident light propagates from mesophase to isotropic medium. (3) The circularly polarized favoured extraordinary mode propagates without any deformation in the mesophase: at an interface it gives rise to an elliptically polarized transmitted vibration into the isotropic medium. Its ellipticity angle η, given by the same relation tg $\eta = n/n_i$ as for case (1), is constant. Its great axis is perpendicular to the direction of the rectilinear field E'' at the interface.

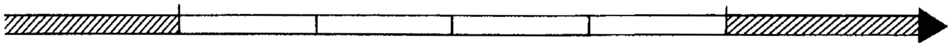
The three cases described show that the evanescent electric field E'' direction in the mesophase can be obtained at the interface; it is given by the great axis of an elliptical vibration. The weaker the ellipticity of the vibration, the easier is the measurement; this is obtained when the n and n_i refractive indexes are very different. If the director is known at the interface, the dispersion law of the angle between the field E'' orientation and the mesophase director can be studied.

Only the experimental proof of the third case is reported here [7]. The measurements have been performed with a polarizing microscope, illuminated with a dye laser to scan the selective reflection band. A cholesteric preparation deposited on a glass slide and covered with a ZnSe slide (the isotropic medium of the experiment) is placed on the rotating stage of the microscope: both slides are rubbed to know the director orientation at the interfaces (given by the rubbing direction). The slides form a small wedge (of angle 0·2°) and the preparation exhibits the well-known Cano line defects [8]: such a structure is the criterion for a homogeneous twist through the whole sample thickness. The laser light first crosses a circular polarizer (left or right handed according to the mesophase): the resulting vibration, at normal incidence, crosses the glass–mesophase interface without any change (owing to the refractive index adaptation between glass and mesophase). This incident wave reaches the cholesteric–ZnSe interface. The isotropic index is very high (2·7) and the transmitted wave has an ellipticity angle η of 31°. This vibration crosses the ZnSe and ZnSe–air interface without change at normal incidence. The outside vibration is observed through an elliptical analyser with a four plages system [9]; the preparation is rotated so that the angle between the preparation and the analyser is equal to the ϕ orientation calculated for the incident wavelength. The quarter-wave plate of the elliptical analyser is rotated to obtain the best extinction; this rotation gives the vibration ellipticity angle. A slight rotation of the preparation then enables us to improve the adjustment. The angle between the analyser and the preparation gives the great axis direction of the vibration studied; the orientation of the field E'' at the interface is then calculated by rotation of $-90°$.

Transmitted vibrations by an interface cholesteric mesophase–isotropic medium, in the selective reflection band. Comparison, at the wavelengths indicated, betweeen the calculated and measured values of the ellipticity angle and the great axis orientation with the director. Chart 1. The cholesteric mixture is composed of 46 per cent (by weight) of a ternary eutectic mixture of phenylcyclohexanes (1083 mixture, E. Merck, Darmstadt, F.R. Germany) and 54 per cent of a cholesterol ester mixture (pelargonate 75 per cent, myristate 25 per cent). Chart 2. The cholesteric mixture is composed of 70 per cent (by weight) of a nematic mixture (EBBA, 4-ethoxybenzylidene-4′-*n*-butylaniline 40 per cent; MBBA 4-methoxybenzylidene-4′-*n*-butylaniline 60 per cent) and 30 per cent of a cholesterol ester mixture (propionate 50 per cent, butyrate 50 per cent).

Chart 1.

5935 Å Selective reflection band 6235 Å λ



	5935 Å	6010 Å	6085 Å	6160 Å	6235 Å
Calculated ellipticity	31°	31°	31°	31°	31°
Measured ellipticity	38° ± 5°	32° ± 3°	32° ± 2°	33° ± 3°	40° ± 5°
Calculated orientation	0°	30°	45°	60°	90°
Measured orientation	−2° ± 8°	−27° ± 4°	47° ± 3°	62° ± 3°	88° ± 9°

Chart 2.

5800 Å Selective reflection band 6328 Å λ

	5800 Å	5930 Å	6060 Å	6200 Å	6328 Å
Calculated ellipticity	31°	31°	31°	31°	31°
Measured ellipticity	40° ± 5°	33° ± 3°	33° ± 2°	34° ± 2°	42° ± 4°
Calculated orientation	0°	30°	45°	60°	90°
Measured orientation	−3° ± 7°	29° ± 4°	46° ± 3°	59° ± 2°	89° ± 8°

Charts 1 and 2 gather the results obtained with two different cholesteric mixtures (both are left handed). A set of measurements is given for some wavelengths inside the selective reflection band of each mixture. Agreement with theoretical predictions is good: the vibration transmitted through the interface keeps a constant ellipticity angle while its great axis rotates 90° when the incident wavelength scans the whole selective reflection band.

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