

EXTERNAL ELECTRIC FIELDS ACTION ON LIQUID CRYSTALLINE LAYERS, MODIFYING THEIR DEGREE OF ORDER

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*Two mesogens were considered in this study; a thermotropic one, named *N*-(*p*'-methoxy-benziliden)-*p*-*n*'-butyl aniline and a lyotropic liquid crystal, poly (phenyl-meth-acrylic) ester of cetylxybenzoic acid in tetra chloromethane. Their birefringence was measured with a Rayleigh interferometer in absence and in presence of an electrostatic field with variable intensity. The results were transformed in continuous functions in order to be used to simulate the transmission factor for Wood multistage filter. The results for simulation of Wood filters based on *N*-(*p*'-methoxy-benziliden)-*p*-*n*'-butyl aniline are given in this paper.*

Keywords: MBBA, PPMAECOBA in TCM, linear birefringence, Wood multistage tunable polarization interferential filter

1. Introduction

Liquid crystals (mesophases) are intermediate phases between the anisotropic crystals and isotropic liquids [1-3]. The compounds which under suitable conditions give rise to mesophases are named mesogens. Liquid crystals were classified by Friedel in thermotropic (with order determined by temperature) and lyotropic (ordered in given conditions of mesogen concentration in a liquid).

Thermotropic liquid crystals can be Nematics, Cholesterics or Smectics [1, 2]. The anisotropy of liquid crystals is given by the orientational (or orientational and positional) order of the component particles (elongated molecules or molecular aggregates) [3], while their fluidity is assured by tridimensional mobility including translations or rotation motion around the mesogen long axis.

Due to their high sensitivity to external factors (temperature, pressure and mechanic, electric or magnetic fields), liquid crystals have multiple applications in medicine, in optoelectronics, in environmental measurements.

Liquid crystals are of the great importance in display applications [4] due to their ready response to external electric fields. In the past 50 years the industry of displays was in continuous progress. In order to develop other applications, the knowledge about the influence of various external factors on the anisotropy of

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liquid crystals is needed. In this way, our research [5-8] has been contributed to obtain information about the order degree in some nematic liquid crystals (MBBA and PPMAECOBA in TCM) reflected in their birefringence, an optical parameter very important in controlling the polarization state of light propagating through. Because the director versor of nematic liquid crystals can be controlled by external electric fields with small intensity, they are unique as controllable birefringent media.

Liquid crystals are kept in special cells with internal walls covered by orientation layers, or with conducting transparent layers when the cell must support an external electric field (acting perpendicular) on the walls.

In order to describe the anisotropic properties of liquid crystalline layers, a parameter, p , named order parameter was defined as being the percent of particles oriented along the preferential direction [3]:

$$p = \frac{1}{3} [3 \cos^2 \theta + 1] \quad (1)$$

In (1), θ is the angle between the long axis of one molecule and the preferential direction given by the liquid crystal director \vec{n} .

The higher the degree of order, the higher is the liquid crystal anisotropy.

Our study refers to uniax anisotropic layers of mesomorphic particles (nematic liquid crystals). The optical anisotropy of such layers is given by linear birefringence Δn [9];

$$\Delta n = n_e - n_0 \quad (2)$$

In (2) n_e and n_0 are the refractive indices of liquid crystal, named extraordinary (e) and ordinary (o) indices and measured with linear polarized radiations having their electric field intensity parallel, respectively perpendicular on the director \vec{n} [5,9].

Optical linear birefringence Δn is material - dependent and a dispersive parameter of nematic liquid crystal.

The ideal equilibrium configuration of nematic mesophase is indicated by its high transparency. In perturbed phase, the aspect of nematic liquid crystal is diffusive as the emulsions, due to high diffusion on disordered components.

The aim of this paper is to illustrate dependence of the optical birefringence of nematic liquid crystalline layers on the intensity of an external electrostatic field applied between the walls of the cell containing anisotropic layer.

An application of the birefringence dependence on the external electrostatic field is also described.

2. Experimental

Two mesogens were considered in our study: N-(p'-methoxy-benziliden)-p-n'-butyl aniline (MBBA) and poly (phenyl-meth-acrylic) ester of cetoxybenzoic acid (PPMAECOBA) in tetra chloromethane (TCM) with chemical structures given in Fig. 1.

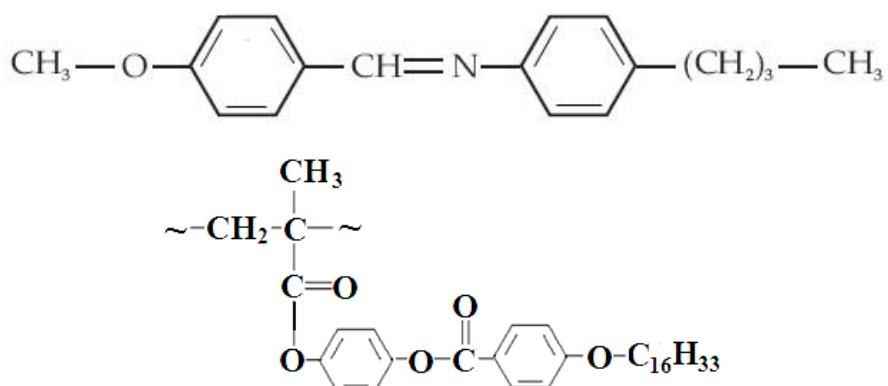


Fig. 1 Chemical structures of: a) MBBA and b) PPMAECOBA

Both mesogens show nematic liquid crystalline properties; MBBA [8] is a thermotropic liquid crystal, while PPMAECOBA in TCM is a lyotropic liquid crystal [5,10,11].

The nematic phase of the two mesogenes is carried out at room temperature [8], in the interval 20-40 degrees C.

A special cell (fig.2) with the interior walls covered by a transparent conducting layer (SnO_2) was used to keep the mesogens. Connected to a battery, an electrostatic electric field acts perpendicular on the transparent walls of the cell [5-7].

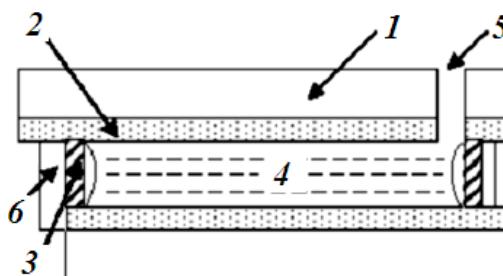


Fig. 2 Schematic representation of the cell containing liquid crystal: 1-glass plates; 2-conducting layer; 3 – spacers; 4 – liquid crystal; 5 – filling aperture; 6- epoxy resin.

The initial molecular alignment was assured [12-14] by slowly moving a filter paper in the same direction on the internal walls of the glass plates; this operation was repeated by about 100 times [8].

The measurements were made in the absence and in the presence of the electrostatic field [5-7]. The cell was introduced in the measure beam of the Rayleigh interferometer (Fig.3). One isotropic glass plate (IL) with its refractive index between the values of the main refractive indices of liquid crystalline layer was introduced in the compensatory beam of the interferometer, in order to keep the central fringe in the visual field and to compensate the losses by reflections at the separation surfaces (for obtaining null minima).

Identical polarizers were introduced in both beams of the interferometer [8, 14-16]. The linearly polarized radiations are at normal incidence on the cell walls. The measurements were made when the light electric field intensity in the measure beam was parallel, respectively perpendicular on the optical axis (given by the versor \vec{n} parallel to the preferential direction) of the liquid crystalline layer.

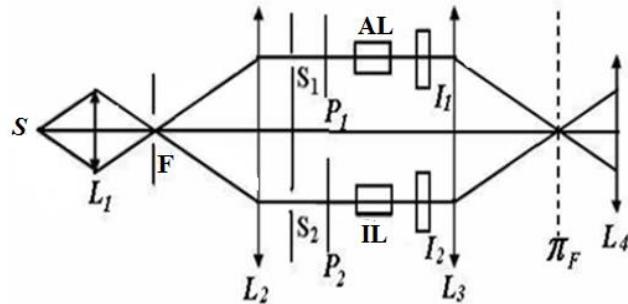


Fig. 3 Schematic representation of Rayleigh interferometer: S-light source; L_j , $j=1-4$ - lenses; F screen with entrance slit; S_1 and S_2 - diffraction slits; P_1 and P_2 - light polarizers; AL - anisotropic layer; IL - isotropic layer; l_1 and l_2 - compensatory plates.

The main refractive indices of liquid crystalline layer are computed using the formula [8]:

$$n_i = n_g = \frac{k_i \lambda}{h}; i = e, o \quad (3)$$

Notations in (3) have following significance: n_i $i = e, o$ – extraordinary, respectively, ordinary refractive indices; n_g – refractive index of isotropic glass layer, IL; λ – light wavelength; h – thickness of anisotropic layer, AL; k_i $i = e, o$ – interference order of the fringe from the mobile system of fringes which is superposed on the zero fringe of the fix system of fringes. The indices e and o correspond to the extraordinary and to the ordinary rays.

The potential difference between the cell walls was in the range [0, 2]V and the thickness of the anisotropic layer, $h = 14 \mu\text{m}$, was limited by the cell spacers (Fig. 2).

The extraordinary and ordinary indices of the liquid crystalline layer were measured in the absence and in the presence of the electrostatic field, acting between the interior walls of the cell.

3. Results and discussions

In nematic liquids crystals, the molecules are ordered with their long axes in parallel and having their mass centers chaotically distributed. The preferential arrangement of the molecular long axes can be obtained either when the thermal fluctuations and all exterior interactions are negligible, or in an electric field of certain intensity, or due to the interactions with the surfaces of the precinct walls [16,17].

Using the experimental results for n_e and n_o [17,18], the birefringence given by relation (2) was computed for the radiations used to illuminate Rayleigh interferometer.

Cauchy dependence of the birefringence on the light wavelength, of the type [9, 16,17];

$$\Delta n = A_1 + \frac{A_2}{\lambda^2} + \frac{A_3}{\lambda^4} \quad (4)$$

was used and an approximate linear dependence of coefficients A_j $j=1,2,3$ on the electrostatic field intensity is considered.

$$A_j(E) = A_j(o) + \alpha_j E \quad j=1,2,3 \quad (5)$$

The established dependences of the birefringence on the electrostatic field intensity are the following.

For MBBA:

$$\begin{aligned} \Delta n_{MBBA} = & (0.0958 + 8,6929 \cdot 10^{-9} E) + (5.0536 \cdot 10^{-15} + 9.3874 \cdot 10^{-21} E) \frac{1}{\lambda^2} + \\ & +(5.5847 \cdot 10^{-28} - 3.8285 \cdot 10^{-34} E) \frac{1}{\lambda^4} \end{aligned} \quad (6)$$

and for PPMAECOBA in TCM:

$$\begin{aligned} \Delta n_{PPMAECOBA} = & (-0.0299 + 4,7321 \cdot 10^{-7} E) + (7.4284 \cdot 10^{-14} - 3.1184 \cdot 10^{-20} E) \frac{1}{\lambda^2} + \\ & + (-6.4850 \cdot 10^{-27} + 2.6190 \cdot 10^{-33} E) \frac{1}{\lambda^4} \end{aligned} \quad (7)$$

Relations (6) and (7) can be used to obtain the birefringence of the liquid crystalline layers of the studied mesogens for each visible radiation in the range $[0, 1.43 \cdot 10^5 \text{ V/m}]$.

Making the derivatives of relations (6) and (7), one obtains the speed of variation of the birefringence with electric field intensity. This parameter of nematic liquid crystal depends on the light wavelength as it follows:

For MBBA:

$$\frac{\partial n}{\partial E_{MBBA}} = 8.6929 \cdot 10^{-9} + 9.3974 \cdot 10^{-21} \frac{1}{\lambda^2} - 3.8285 \cdot 10^{-34} \frac{1}{\lambda^4} \quad (8)$$

For PPMAECOBA in TCM:

$$\frac{\partial n}{\partial E_{PPMAECOBA}} = 4.7321 \cdot 10^{-7} - 3.1184 \cdot 10^{-20} \frac{1}{\lambda^2} + 2.6190 \cdot 10^{-33} \frac{1}{\lambda^4} \quad (9)$$

The formulae (6-9) are important when optical retarders or various polarization filters are designed for various visible ranges.

The results obtained by using Rayleigh interferometer are in good accordance with those obtained based on channels spectra [5,8] polarizing microscope [16] or by interferometric method in conoscopic illumination [19].

4. Simulation of Wood Filter with MBBA

The basic structure of the tuneable Wood polarisation interferential filters made of liquid crystals is shown in Figs.4 a) and b). An important disadvantage of a Wood interferential filter with a single element (Fig. 4a) is the equality of the bandwidth of the bands corresponding to the transmission maxima and the width of the channels. Consequently, the Wood interferential filter with a single stage has a modest selectivity and its use in defining and transmission of some spectral channels of reduced width (for example in data communication by optical fibers) is non-performing [20,21].

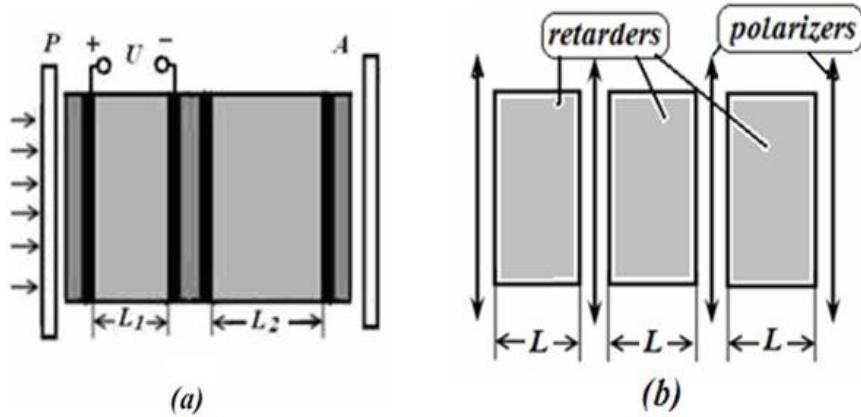


Fig. 4: a) Single-stage Liquid Crystal Transmission Filter (LCTF) system b) Three stages Wood polarizing interference filter

In order to improve their performances a multi-layer geometry is adopted here. This kind of filters is achieved by more identical layers (Fig. 4 b).

Let us considering a device achieved from m identical elements so the transmission direction of the entrance polarizer in each element to be parallel to the transmission direction of the exit polarizer from the precedent layer. The one from the above mentioned polarizer can be eliminated.

The transmission factor of the device becomes [17,21];

$$T = \frac{1}{2} \sin^{2m} \left(\frac{\pi(L_1 \Delta n_1(\lambda, E) \pm L_2 \Delta n_2(\lambda))}{\lambda} \right) m = 2, 3, 4, \dots \quad (10)$$

where m is the number of the identical elements of the multi-layers filter.

The wavelengths corresponding to the maxima and to the minima of transmission for a Wood interferential filter with a single stage are:

$$\begin{cases} \lambda_{k,Max} = \frac{2(L_1 \Delta n_1 \pm L_2 \Delta n_2)}{4k \pm 1}, & (k \in \mathbb{Z}) \\ \lambda_{k,min} = \frac{L_1 \Delta n_1 \pm L_2 \Delta n_2}{k}, & (k \in \mathbb{Z}, k \neq 0) \end{cases} \quad (11)$$

The spectral bandwidth corresponding to the maxim at the wavelength $\lambda_{k,Max}$ is:

$$\Delta\lambda = |\lambda_{k,Max} - \lambda_{k,Min}| = \frac{\lambda_{k,Max}}{k} \cong \frac{\lambda_{k,Max}^2}{2(L_1 \Delta n_1 \pm L_2 \Delta n_2)} \quad (12)$$

Relation (12) permits the estimation of the retardation $(L_1 \Delta n_1 \pm L_2 \Delta n_2)$ necessary to eliminate one from the two neighbouring lines separated by the spectral interval $\Delta\lambda$.

The wavelengths corresponding to the maxims and minims of transmission and the number of the transmitted bands in the considered spectral range are the same with those obtained with a filter achieved by one element.

The transmission spectral bandwidth neighbouring the maxim of k order is modified, (one decreases). It is given by relation [17,21]:

$$\Delta\lambda_{(m)} = \frac{4\pi(L_1 \Delta n_1(\lambda, E) \pm L_2 \Delta n_2(\lambda)) \arcsin \frac{1}{2^m}}{(2k+1)^2 \pi^2 - 4 \left(\arcsin \frac{1}{2^m} \right)^2} \quad (13)$$

The relations (10) - (13) are the equations of the model used for simulation the Wood tunable LC-PIF-s with transmission factor shown in Fig.5.

The transmission factor of Wood Liquid Crystal Polarization Interferential Filters (Wood-LC-PIF) as it resulted for simulation based on MBBA anisotropic liquid

crystal for one stage and for multiple stages ($m=2-5$) is represented in Fig. 5. In Fig. 5 two cases were considered:

Case I when the anisotropic layers in Fig. 4a have optical axes in parallel;
 Case II when the anisotropic layers in Fig. 4a have perpendicular optical axes

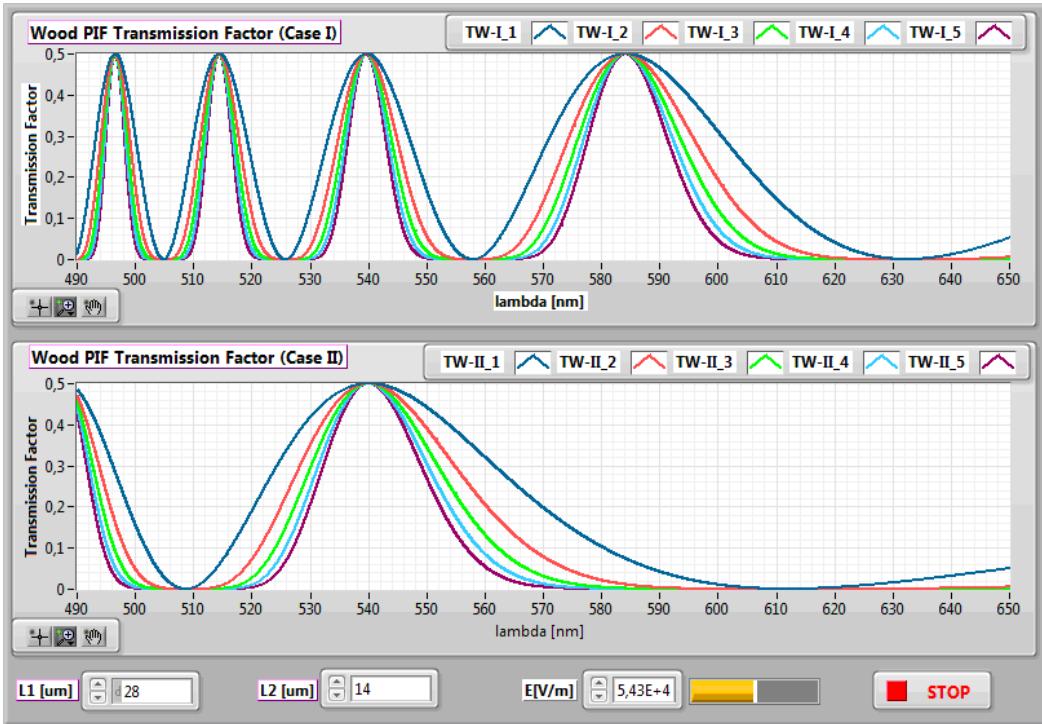


Fig. 5 Transmission factor of Wood LC-PIF- with MMBA for one stage ($m=1$) and for $m=2,3,4,5$ stages.

From Fig.5 it results that half-pass band in the case I is smaller than for the case II. This fact suggests that the orientation corresponding to parallel optical axes of anisotropic layers in devices described in Fig. 4 is more efficient for filtering the optical radiations around the wavelength corresponding to the maximum ($\lambda = 540\text{nm}$).

Using several elements mounted in a cascade [17], one obtains increasingly narrow transmission bands, but the transmission intensity decreases, concomitantly with the increase of the filter complexity.

Polarization interferometric filters with continuous control are fit for applications that do not need high resolution.

5. Conclusions

The values of the main refractive indices and the corresponding linear birefringence depend on the wavelength of the radiation for which they were determined, decreasing with the wavelength increasing. The two studied liquid crystals show a normal dispersion.

The values of the linear dispersion of the studied liquid crystals are dependent on the intensity of the external electrostatic field applied, increasing with the electrostatic field intensity. A saturation of the phenomenon was emphasized when the applied electrostatic voltage was near 2V. The very small values of the voltage needed for liquid crystal molecules orientation is an important advantage in using these substances for displays.

The element of Wood filter, consisting from two anisotropic layers must have optical axes in parallel in order to assure an efficient filtering of light.

The increase in the number of the stages in Wood filter determines a higher filtering effect.

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