

The Influence of Electric Field on Special Anisotropic Plates Realized by Poly-(pheny-methacrylic)-ester of Cetyloxybenzoic-acid (PPMAECOBA) in Tetrachloromethane (TCM)

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Liquid crystals have anisotropic optical properties controlled by an applied external electric field. An important application of them is to achieve the special electrically controlled anisotropic plates. A design pattern of quarter and half wave plates from PPMAECOBA liquid crystal in TCM ($c = 10.2 \text{ g/cm}^3$, $M = 10^7$, $L = 14 \mu\text{m}$) is proposed in this paper.

Keywords: quarter and half wave plates, PPMAECOBA, birefringence

Liquid crystals [1] represent an intermediate state between liquid and solid crystal, characteristic only for certain organic materials. A liquid crystal is composed of molecules oriented on the long distance as in an usual crystal and manifests fluid properties. The molecules in the liquid crystals can move easily as the molecules in a liquid. However, all the molecules in the liquid crystal tend to orientate themselves corresponding to the arrangement of molecules in solid crystals.

Liquid crystals are materials widely used in technics and preserve both partial ordering features and characteristics of the liquid phase [2].

PPMAECOBA in TCM is a lyotropic liquid crystal. PPMAECOBA structural formula is shown in figure 1.

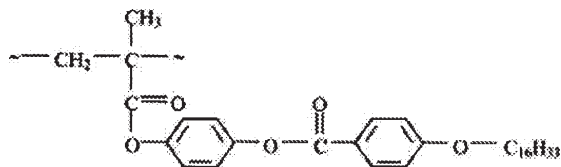


Fig. 1. PPMAECOBA structural formula

The liquid crystal structure of PPMAECOBA solution in a weak solvent as TCM is explained by the lateral chains interactions which contain groups able to build up mesomorphic phase.

The main chain of the polymer is wrapped up by a thermodynamic weak solvent, the intermolecular orientation degree in the lateral chains increases as a result of the solvent – polymer interaction in competition with the interaction of the lateral chains from the polymer internal molecules. The system consisting of PPMAECOBA in TCM is a lyotropic liquid crystal with a high degree orientation of the side chains direction. TCM dissolves only the polymer long lateral chains, which are ordered by a dipolar effect [3, 4].

Liquid crystals have anisotropic optical properties which can be controlled using external electric fields and used in the design applications of the anisotropic plates. Quarter wave plates are important because they turn a circular or elliptical polarized radiation into a linearly polarized radiation. They are used in the analysis of polarization state of the monochromatic radiation and in the study of the circular dichroism. The half wave plates stand at the basis

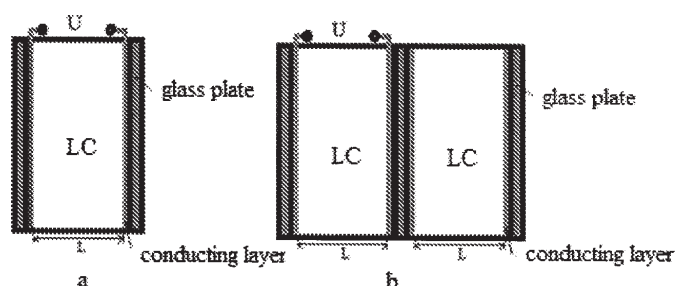


Fig.2. Device made by: a) a liquid crystal single plate with the birefringence electrically controlled (D_1); b) two liquid crystal plates with the same thickness, of which one has the birefringence electrically controlled (D_2)

of half-light analyzer manufacturing used in the Laurent polarimeters.

Let's consider a device made by a liquid crystal single plate under the action of an external electrostatic field (D_1 , fig. 2.a.) and a device with two plates of liquid crystal (D_2 , fig. 2.b.), of which only one is submitted to the action of an external electrostatic field in order to control its birefringence. Anisotropic optical axes of the plates may be perpendicular or parallel to each other.

The birefringence and the optical path difference are given by the formulae (1) and (2) :

$$\Delta n(\lambda, E) = A_1(E) + \frac{A_2(E)}{\lambda^2} + \frac{A_3(E)}{\lambda^4} \quad (1)$$

$$\Delta = \Delta n(\lambda, E) L \quad (2)$$

The electric voltage applied to obtain a quarter wave layer respectively a half wave layer is determined by the condition [5]:

$$\Delta = (2m + 1) \frac{\lambda}{4} \quad (3)$$

$$\Delta = (2m + 1) \frac{\lambda}{2} \quad (4)$$

where $m = 0, 1, 2 \dots$ represents the order of the plate.

Values of the electric voltage for the quarter wave layer and half wave layer can be determined by the relations: -for the device D_1 ;

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$$U_{\frac{\lambda}{4}} = \frac{(2m+1)\frac{\lambda}{4} - L\left(A_{10} + \frac{A_{20}}{\lambda^2} + \frac{A_{30}}{\lambda^4}\right)}{\alpha_1 + \frac{\alpha_2}{\lambda^2} + \frac{\alpha_3}{\lambda^4}} \quad (5)$$

$$U_{\frac{\lambda}{2}} = \frac{(2m+1)\frac{\lambda}{2} - L\left(A_{10} + \frac{A_{20}}{\lambda^2} + \frac{A_{30}}{\lambda^4}\right)}{\alpha_1 + \frac{\alpha_2}{\lambda^2} + \frac{\alpha_3}{\lambda^4}} \quad (6)$$

-for the device D_o , there are two cases considered: when the optical axes of the crystals are perpendicular (7, 8) and parallel (9, 10):

$$U_{\frac{\lambda}{4}} = \frac{(2m+1)\frac{\lambda}{4}}{\alpha_1 + \frac{\alpha_2}{\lambda^2} + \frac{\alpha_3}{\lambda^4}} \quad (7)$$

$$U_{\frac{\lambda}{2}} = \frac{(2m+1)\frac{\lambda}{2}}{\alpha_1 + \frac{\alpha_2}{\lambda^2} + \frac{\alpha_3}{\lambda^4}} \quad (8)$$

$$U_{\frac{\lambda}{4}} = \frac{(2m+1)\frac{\lambda}{4} - 2L\left(A_{10} + \frac{A_{20}}{\lambda^2} + \frac{A_{30}}{\lambda^4}\right)}{\alpha_1 + \frac{\alpha_2}{\lambda^2} + \frac{\alpha_3}{\lambda^4}} \quad (9)$$

$$U_{\frac{\lambda}{2}} = \frac{(2m+1)\frac{\lambda}{2} - 2L\left(A_{10} + \frac{A_{20}}{\lambda^2} + \frac{A_{30}}{\lambda^4}\right)}{\alpha_1 + \frac{\alpha_2}{\lambda^2} + \frac{\alpha_3}{\lambda^4}} \quad (10)$$

At a very high voltages, over threshold voltage [6], most of the liquid crystal molecules are aligned along the electric field direction, except the molecules in the close vicinity of the liquid crystal cell walls [7].

Experimental part

Experimental data used for modelling the birefringence dispersion and the birefringence in the simulations were obtained from [8].

The Cauchy fitting coefficients for the birefringence of PPMAECOBAl liquid crystal in TCM (table 1) have been calculated using the relations:

$$A_{i0} = A_{ie}(0) - A_{io}(0) \quad (11)$$

$$\alpha_i = \alpha_{ie} - \alpha_{io} \quad (12)$$

Table 1
VALUES OF CAUCHY FITTING COEFFICIENTS FOR THE BIREFRINGENCE OF PPMAECOBAl IN TCM

i	A_{i0}	α_i
1	-0.0299	$4.7321 \cdot 10^{-7}$
2	$7.4284 \cdot 10^{-14}$	$-3.1184 \cdot 10^{-20}$
3	$-6.485 \cdot 10^{-27}$	$2.619 \cdot 10^{-33}$

For a 14 μ m thickness of the LC layer of PPMAECOBAl in TCM the maximum admitted voltage for adjustment is $U_{\max} = E_{\max} \cdot L = 140 \text{ kV/m} \cdot 14 \mu\text{m} = 1.96 \text{ V}$. Electric adjustment possibilities of the quarter and half layer characteristics are relatively limited and correspond to the parts of the graphic comprised between -2V and +2V. The experimental data show that the birefringence of PPMAECOBAl in TCM increases with the application of the external electrostatic field, regardless of the polarity of the voltage applied to the two electrodes for electrical conductors of the liquid crystal cell.

Results and discussions

Device (D_o), consisting of a single layer of PPMAECOBAl liquid crystal with $L = 14 \mu\text{m}$.

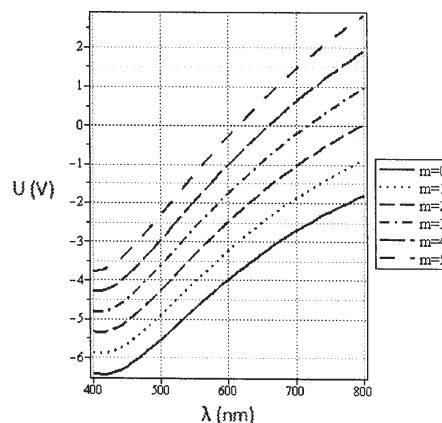


Fig.3. The dependence of the voltage with the wavelength for the quarter wave layer of PPMAECOBAl LC ($L = 14 \mu\text{m}$)

Quarter wave plates simple layer can be made and electrically controlled on the subintervals of the visible range (for 0 order on a narrow domain between 782-800nm, for $m = 1$ between 694-800nm, for $m = 2$ between 634-800nm, for 3 order approximately between 588-800nm, for $m = 4$ between 550-800nm and between 518-735nm for the order 5).

In figure 4 one can see that for half wave length there are subintervals in the visible spectral range for which these can be made and electrically controlled (for $m = 1$ approximately between 609-800nm).

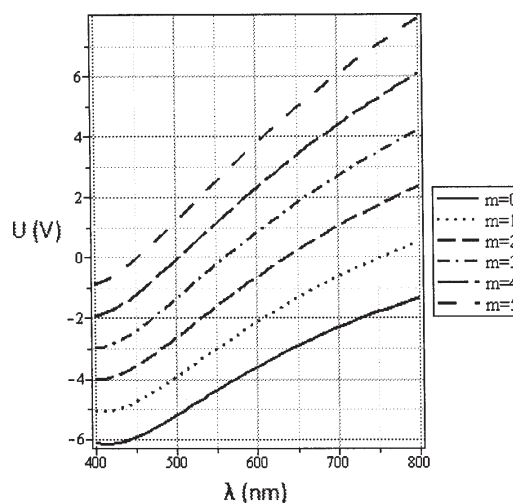


Fig.4. The dependence of the voltage with the light wavelength for the half wave layer of PPMAECOBAl LC ($L = 14 \mu\text{m}$)

Device (D_2) consisting of two layers of PPMAECOBAl liquid crystal with the same thickness ($L=14\mu\text{m}$) having their optical axes parallel respectively perpendicular

The voltage dependence on the light wavelength for the half and quarter wave plates double layer having the orders of $m = 0, 1, 2, 3, 4$ and 5 and equal thickness ($L_1 = L_2 = L = 14\mu\text{m}$) is presented in figures 5 and 6, when the optical axes of the liquid crystal layers are perpendicular.

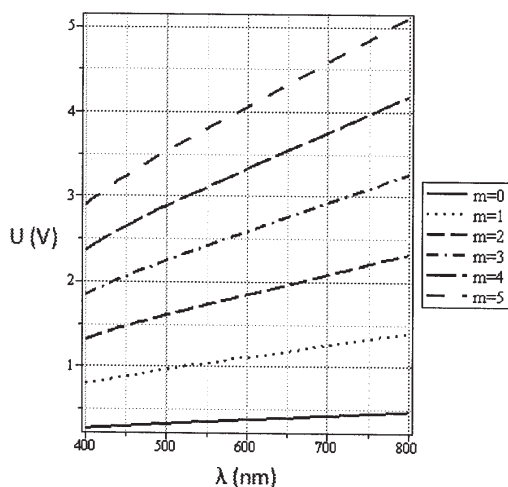


Fig. 5. The dependence of the voltage with the light wavelength for quarter wave plates double layer of PPMAECOBAl LC (optical axes are perpendicular)

One can conclude (fig. 5) that the quarter wave plates double layer with orders 0 and 1 can be electrically controlled on the visible spectral range. A quarter wave plates double layer with order $m = 2$ can be electrically controlled only on subdomain between 400 and 652nm. The layer with $m = 3$ order can be electrically controlled only on a small subdomain (400-427nm). For quarter wave plates double layer having the orders 4 and 5 the adjustment voltage should be exceed by those compatible on the experimental data obtained for PPMAECOBAl in TCM.

Only the half wave plate double layer with 0 order can be electrically controlled for the whole visible range (fig. 6). For the half wave plates double layer with the orders $m \geq 3$ the voltages adjustment are bigger than 1.96 V.

If the optical axes of the liquid crystals are parallel, in the device D_2 using formulas 9 and 10 one obtains figures 7 and 8.

The quarter wave plates having the liquid crystal layers with their optical axes parallel can be electrically controlled

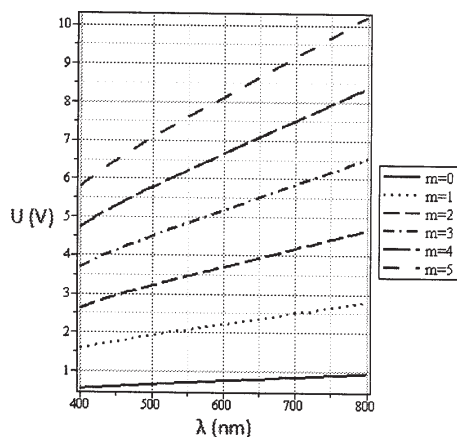


Fig. 6. The dependence of voltage with the light wavelength for half wave plates double layer of PPMAECOBAl LC (optical axes are perpendicular)

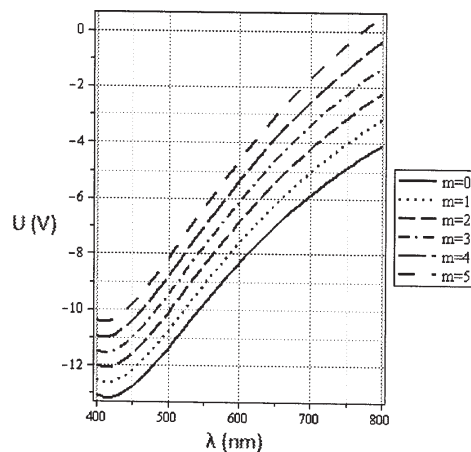


Fig. 7. The dependence of voltage with the light wavelength for quarter wave plates double layer of PPMAECOBAl LC (optical axes are parallel)

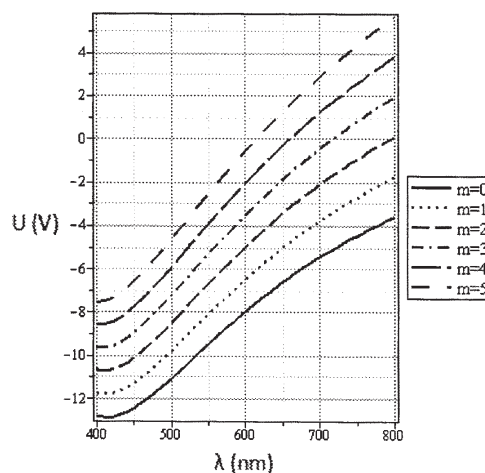


Fig. 8. The dependence of voltage with the light wavelength for half wave plates double layer of PPMAECOBAl LC (optical axes are parallel)

on a narrow subdomain from the visible range when the layer order is $m \geq 3$ (fig. 7).

There are subdomains in the visible range for which the half wave plates with the order $m \geq 1$ can be electrically controlled (fig. 8).

Conclusions

Anisotropic half and quarter wave plates simple layer with PPMAECOBAl liquid crystal in TCM ($L = 14\mu\text{m}$) can be produced and electrically controlled on different subintervals from the visible range.

The half wave plate with two layers of PPMAECOBAl liquid crystal with the same thickness ($L = 14\mu\text{m}$) and with optical axes perpendicular having 0 order and the quarter wave plate double layers (the optical axes are perpendicular) having the orders from 0 to 1 can be controlled in the whole visible range.

For the device D_2 , when the two layers of liquid crystal have their optical axes parallel the quarter wave plates can be electrically controlled on subdomains from the visible range for $m \geq 3$ order and the half wave plates for $m \geq 1$ order.

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