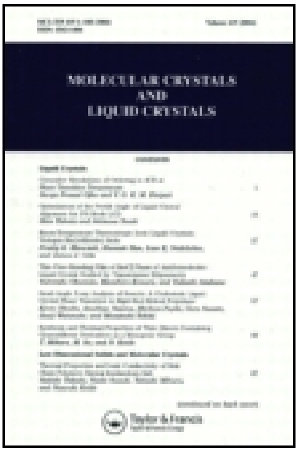

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The Study of Liquid Crystal Membrane by a Sensitive Interference Method

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Here we have expounded the method and results of a detailed study on the reflection from a liquid crystal membrane's beam. The membrane was embedded into Fabri-Perot's interferometer and was under the influence of an external electric field. We have learned that by interferential rings, one can define the alteration of the path difference of the reflected beam of an interferometer accurate to 0.1Å.

Keywords Liquid crystal; membrane; laser; interferometer

In 1984, in the Department of Optics under my direction, a thesis, which researched the model of biomembrane based on a lyotropic liquid crystal (LC) under the influence of an electric field, was considered. The membrane has been placed in a cell with parallel sides and the interferential annular picture in the reflected beam was. The theoretical interpretation has been represented as the formation of Newton rings via membrane's flexural deformation. The work had not yet been published. The latest repetition of these measurements was in 2011 and invalidated this approach and the necessity for treatment of a used cell, of a Fabri-Perot's interferometer (FPI), with an embedded membrane.

To date, there are various methods for investigating transparent and semitransparent physical objects' via external influence, particularly for biomembranes [1]. Previously, methods for the investigation of multiple-beam pictures in reflected FPI light has been put forward for measuring the forms of laser resonator's mirrors [2]. Our work suggests that the method for investigation of an interferential image–reflected from the membrane, based on lyotropic LCs, embedded into FPI. We have used the aqueous solution of LC pentadetsilsulfonate of natrium, doped on aperture via diameter 0.6mm in Teflon septum, embedded between the mirrors of an interferometer (Fig. 1).

Figure 1 shows the setup for the experiment. The radiation of semiconductor laser (1) with a wavelength of $\lambda = 0.53$ μm and a power of 4 mW power focused by a lens (3) with focal length 80 mm, on the aperture in Teflon septum with LC (6), placed between mirrors (4) and (5), forming the FPI. As an interferometer can use a usual glass cell with perfectly parallel sides, perpendicular to laser's beam, and unlike usual FPI, without any cover. The cell with electrodes filled with distilled water or electrolytes hasn't been made deliberately—it was arising by solution small amount of LC via membrane making. In our experiments, the Teflon with membrane was removable, which has allowed the measurement of the characteristics of separate compartments of cell. It was measured that

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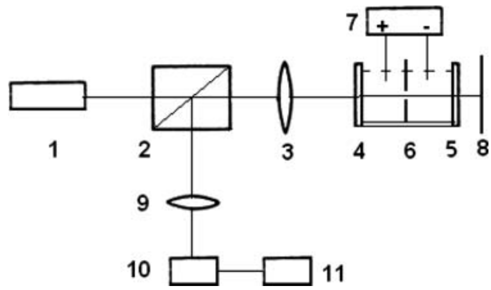


Figure 1. Experimental setup, 1—laser, $\lambda = 0.53$ μm, 2—prism, 3 and 9—the lenses, 4 and 5—cell-Fabry-Perot interferometer, 6—Teflon septum, 7—power source, 8—mirror for adjustment, 10—videocamera or photo transistor, 11—display.

the volt-ampere characteristics of each compartment of cell are all linear and related with the amount of LC dissolved in water and with the intrinsic resistance of membrane (Fig. 2).

For measurements of the parameters of a membrane, the reflected beam by means of a prism (2) and a short-focus lens (9) with focal length 5 mm was used. Registration was made by means of a video camera or the phototransistor (10), with an exit on the display (11), depending on character of a task in view. On the display the interferential ring picture was observed (Fig. 3).

Complexities of the experiment consisted in the reception of an interferential picture in the reflected bunch. For the exact adjustment of a bunch, the flat mirror (8) temporarily used was put closely to an output window. Depending on the voltage registered by the electrodes from the power source (7) voltage electric on the electrodes, the radius of rings changed, either increasing or decreasing. In cases when the membrane was in area beam waist of lenses (3) or out of, opposite pictures were observed–rings divergent or converged. A slight hydrostatic pressure change in water level, also led to a change in the number of rings.

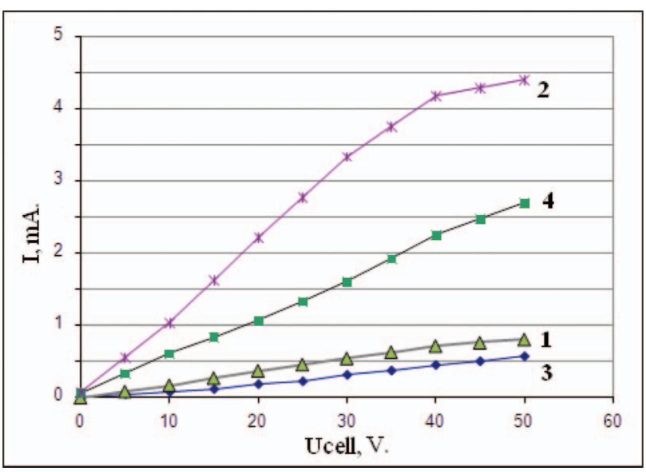


Figure 2. Volt-ampere characteristics of the used cell, 1—with distilled water without a Teflon septum; 2—with the addition of very small amount of LC; 3—with distilled water and Teflon septum; 4—with the addition of very small amount of liquid crystal.

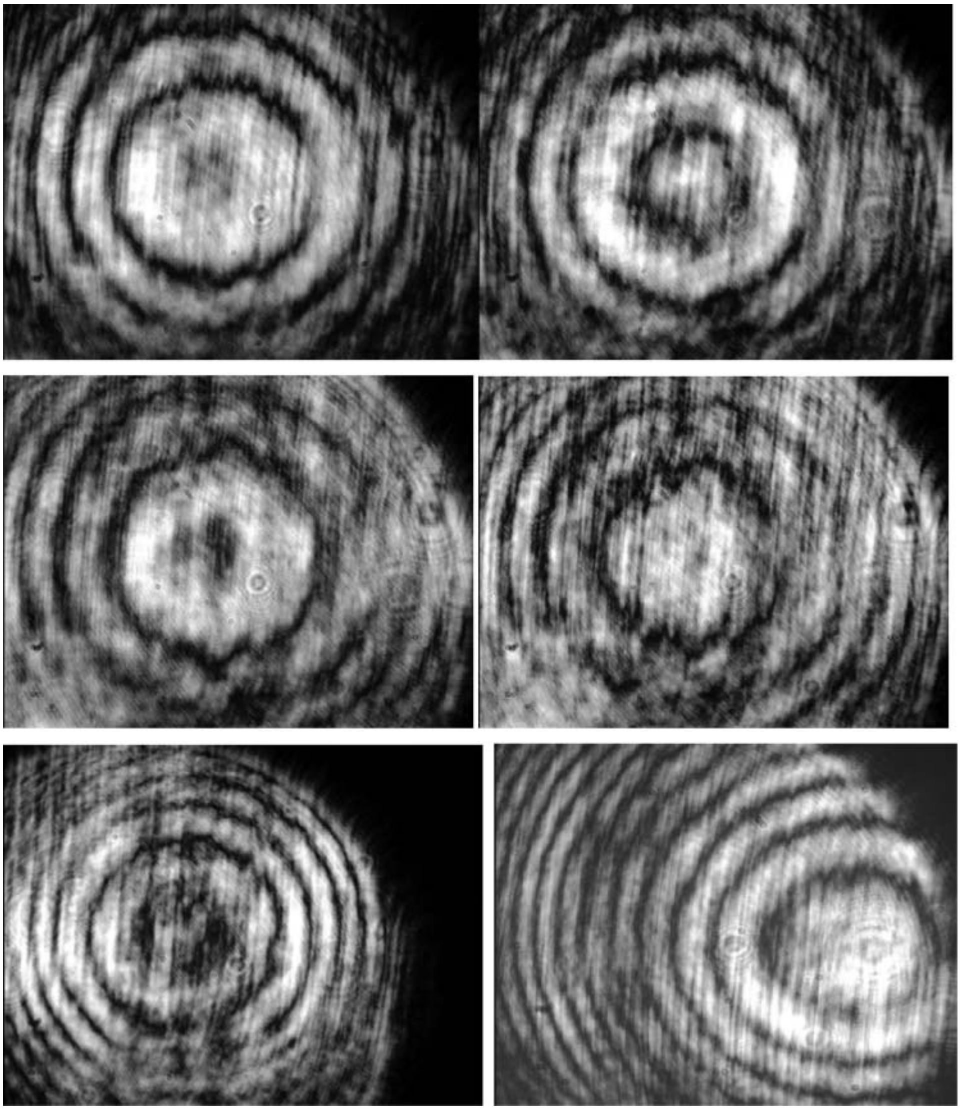
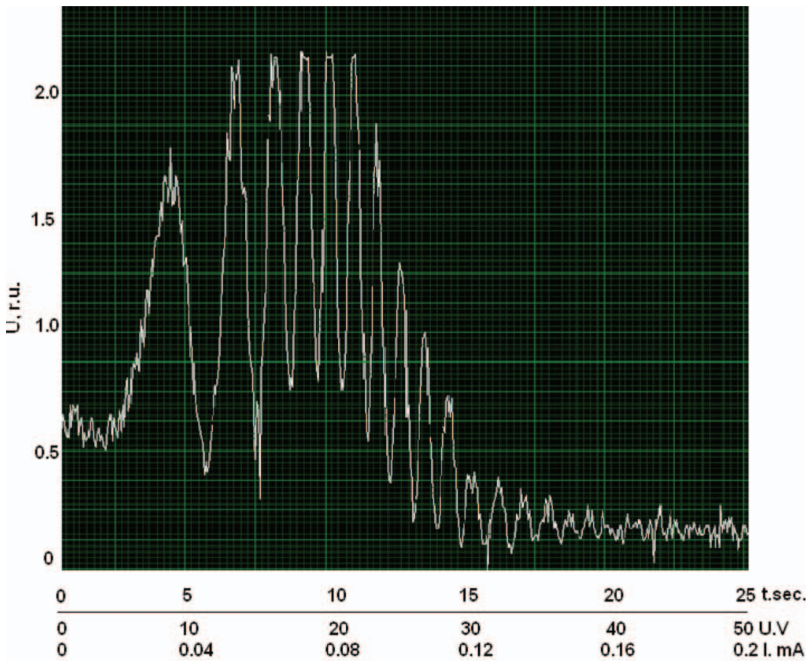


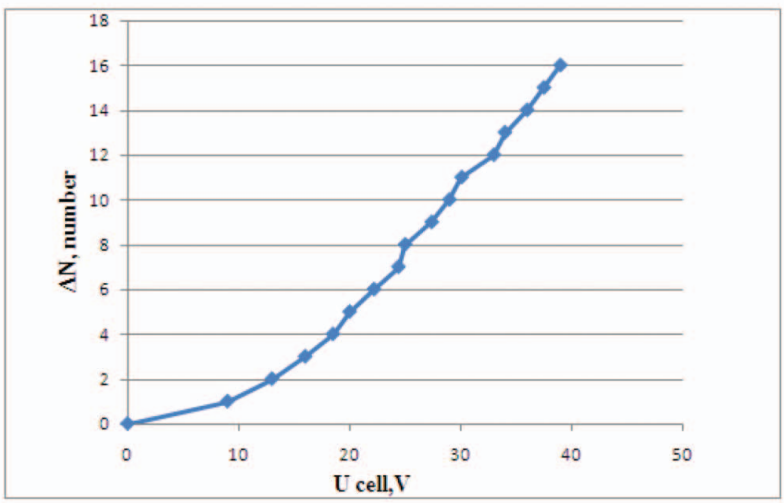
Figure 3. Picture of interference fringes on the screen. The change of the number of rings depends on the applied voltage.

To study the dynamics, the program Lab View was used on the cell which was under the influence of slowly increasing ramp voltage with a period of 25 sec, the maximum voltage and current −0.2 mA and 50 V. The reflected signal was detected with a phototransistor output on a virtual oscilloscope for Lab View. Figure 4 shows the results of these measurements and shows the number of rings passing through the center of the picture.

Calibration measurements were conducted as follows: as in a normal FPI, when changing the pump current of the laser, the number of interference rings also changed due to slight changes in the emission wavelength. For currents above the threshold, lasing from 180 to 250 mA, the wavelength happened to change approximately of 1Å, the transition from one longitudinal mode to another. This was measured in an independent experiment [3].



(a)



(b)

Figure 4. Result of changing the number of rings or of a phase shift $2\pi N$ by applying 50 V (0.2mA, 25 sec.) saw tooth amplitude on the cell; On the vertical axis **a**—value of the output voltage of the phototransistor in arbitrary units; **b**—change of the number of rings.

According to these results, an assessment of the path difference changes when the current passing through the membrane and the measured distance between the peaks of the rings change, in Fig. 4, which is equivalent to the thickness of the rings of Fig. 5.

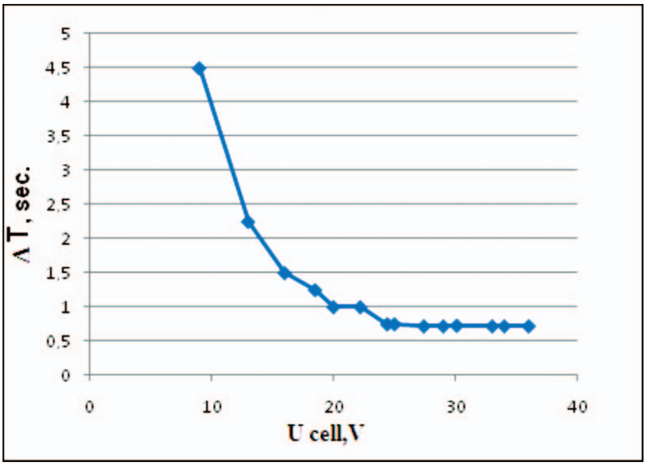


Figure 5. Change of the temporary distance between the peaks of the interference pattern (the proportional thickness of the rings), depending on the applied voltage to the membrane.

From this, it follows that a change in one ring corresponds to a change in the optical path difference that is equal to 1 Å, and the phase difference in 2 π (phase shift) with an accuracy up to 0.1 the distance between the rings, i.e. can measure the change in path difference of up to 0.1Å.

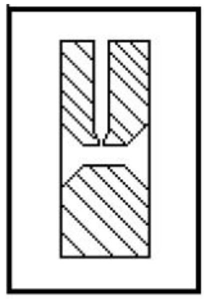
For example, a maximum constant thickness of 1 μm corresponds to the refractive index change at 10^{-4}, with double pass through the membrane. If this thickness is less, the index reaches 10^{-3}. From Fig. 4, it follows that at a voltage of 40 V, the number of rings reaches 16, i.e., phase shift equal $2\pi N$ reaches 32π, and the path difference of the 16Å and the refractive index change equal to $2{\cdot}10^{-3}$ at a constant thickness. In a real experiment, the thickness of the membrane is changing. The change in the flexural deformation is possible with a change in the thickness and the orientation of the LC molecules [4].

In these experiments, for the first time the vertical side hole in the Teflon septum with a diameter of 0.6 mm was used, amounting to the main hole (Fig. 6a). Thus allowing the introduction of a LC, optic fiber or an additional electrode in the membrane. Figure 6b gives a qualitative explanation of creation of bilayer membranes.

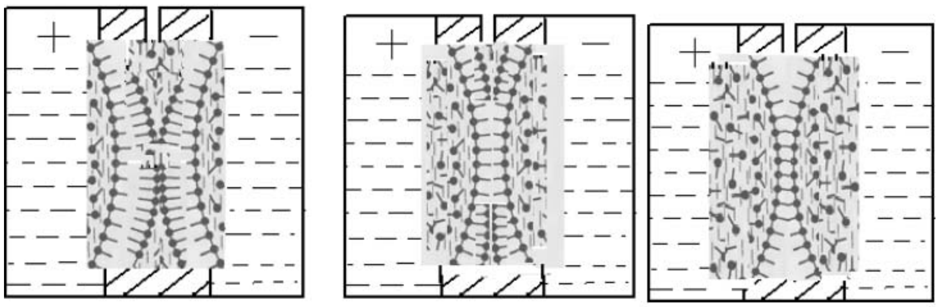
It is important to note that the experiment showed that we are dealing with nanoscale bilayer membrane thickness because the reflected radiation in the microscope can be seen in the center of full dark. All this corresponds to a black membrane in reflected light.

With a further increase in current from 2 mA, the effect of chaotic destabilization of membranes, "stress" to the breakdown of the membrane, occurs. At low current, with some delay, this effect is restored again (Fig. 7). These measurements were carried out by the phototransistor, set in the center of the ring pattern supplied by saw tooth voltage. In this mode, there are strong random fluctuations in all directions.

From Fig. 7, we can estimate the average period of fluctuation, which was determined to be 0.25 sec from preliminary measurements, has a frequency reaching 4 Hz. After achieving the bilayer membrane, the current increase leads to the appearance of pores, which are penetrated by water, and an increase in thickness. This increase in current leads to a new compression and so on with successive appearance of pores. Thus, our measurements of these statistics will determine the appearance of pores.



(a)



(b)

Figure 6. (a) Teflon septum with vertical channel. (b) A gradual transition from multilayer to bilayer "black" membrane is shown when the current is increased through the cell. Some quantities of LC molecules were dissolved in water.

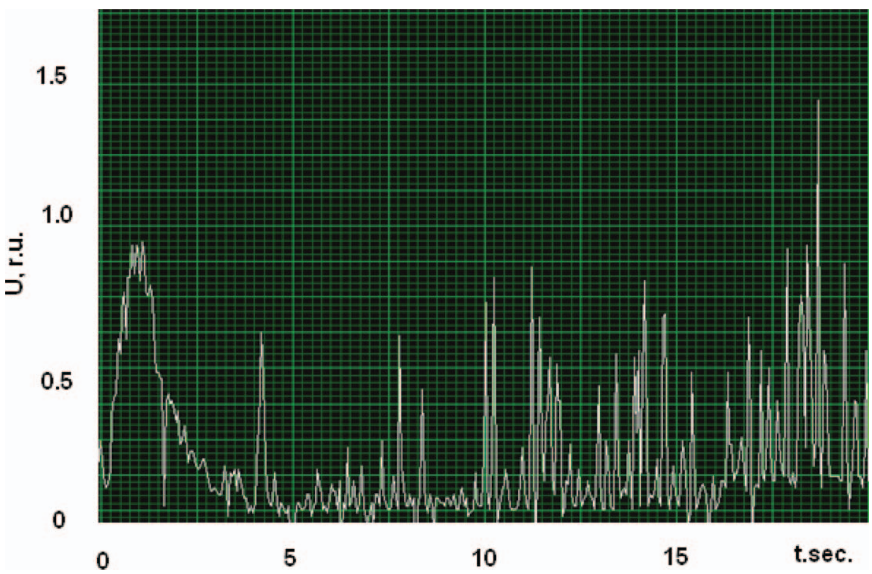


Figure 7. The observed chaotic "stress" of the membrane.

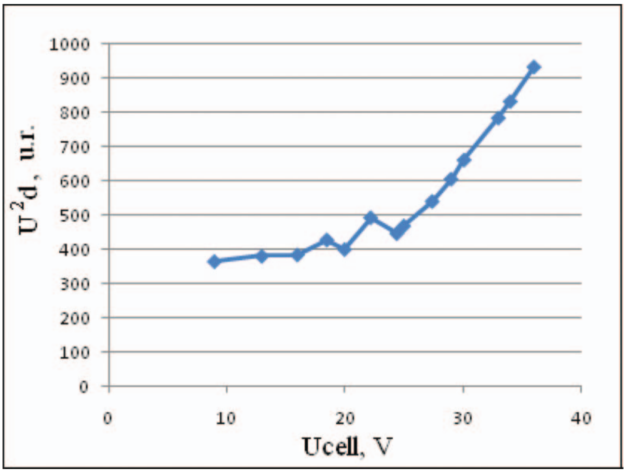


Figure 8. Dependence $U^2d = E^2d^3$ [4] on an applied voltage. In the low voltage region, there is a decrease in the thickness of the rings (Fig. 5), but the change of value U^2d is not significant, that is U^2 is inversely proportional to d (Fig. 6), but then the thickness does not change.

In [6], a similar phenomenon is theoretically examined. Further studies will discuss this effect in more detail.

The value of the flexoelectric coefficient $e_1 + e_3$ can be determine using the path difference formula $\Delta\ell$ [4,5] (there is no data for lyotropic LCs, therefore the data for a nematic liquid crystal was used)

$$\Delta\ell = \frac{1}{12}\left(\frac{e_1 + e_3}{K_3}\right)^2 (n_e - n_o)E^2d^3, \qquad (1)$$

where K_3 is elastic Frank's constant ($K_3 = 7.5 \cdot 10^{-7}$ CGS), n_e, n_o - refractive indexes ($n_e = 1.754$, $n_o = 1.544$), $E = U/d$ is the tension of the electric field, and ***d*** is the membrane thickness (d $\approx$ 50 μm).

Using Fig. 4 for the phase shift and Fig. 8's constant region of $E^2d^3 = U^2d$, we obtain a numerical value of $|e_1 + e_3| = 1.7 \cdot 10^{-5}$ CGS, which roughly coincides with the results of other studies for nematic LCs [5].

Acknowledgment

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