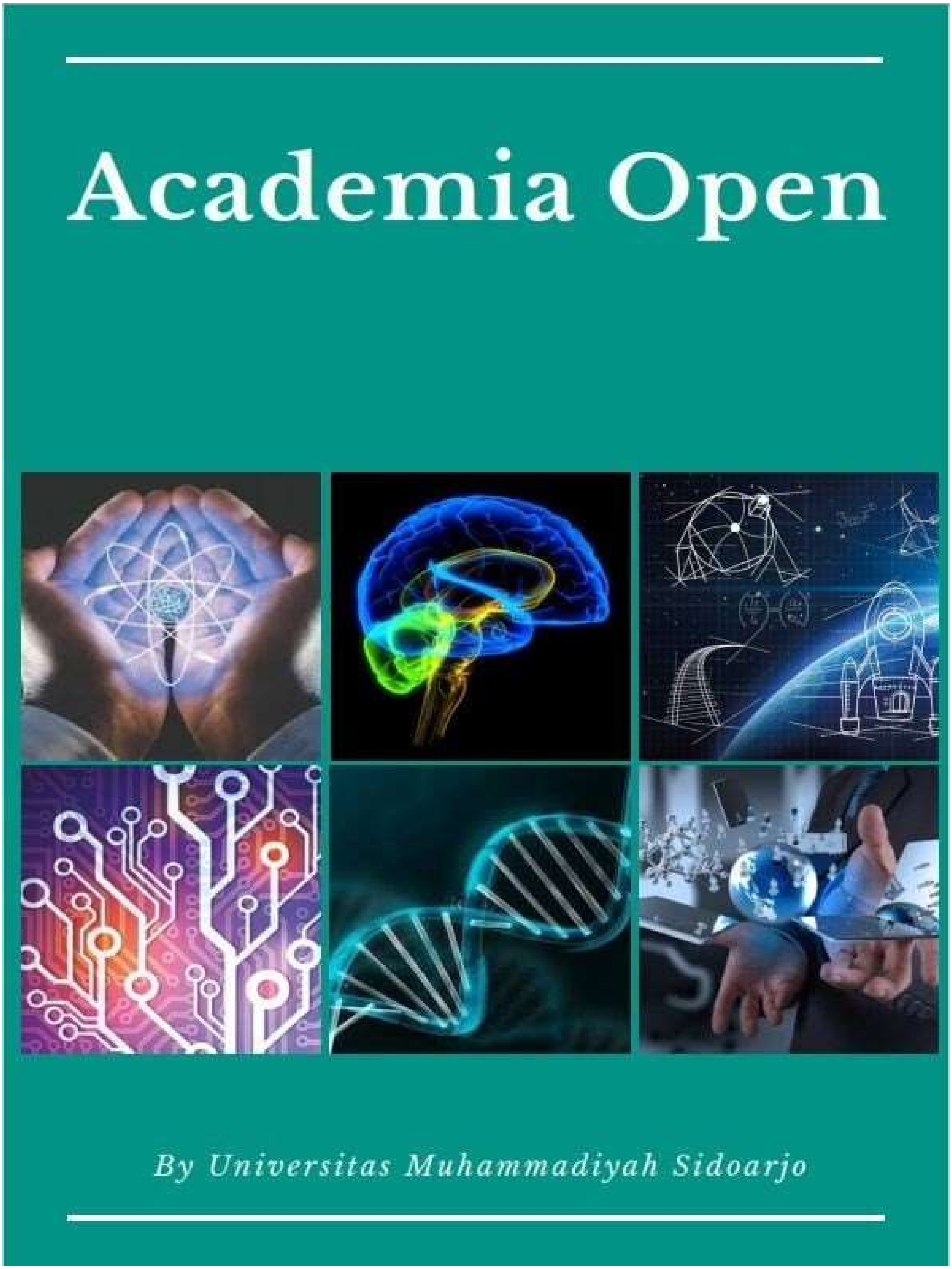
Academia Open
Vol. 11 No. 1 (2026): June
DOI: 10.21070/acopen.11.2026.13308



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DOI: 10.21070/acopen.11.2026.13308

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Academia Open
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Academia Open
Vol. 11 No. 1 (2026): June
DOI: 10.21070/acopen.11.2026.13308

Stationary And Non-Stationary Photocurrent in a Symmetric Nematic Cell with Methyl Red

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Abstract

General Background: Teaching text structure is a central component of native language education aimed at developing coherent oral and written communication. **Specific Background:** Methodological and linguistic studies emphasize diverse approaches and principles guiding the extraction of theoretical knowledge, skill formation, and error prevention in text construction. **Knowledge Gap:** Despite extensive literature, a systematized synthesis of core approaches and principles for teaching text structure remains insufficiently articulated. **Aims:** This article aims to identify and classify fundamental approaches and principles underlying the teaching of text structure and the development of stable text-building skills. **Results:** The study delineates key linguistic, cognitive, communicative, modular, and competency-based principles, highlighting their roles in organizing theoretical content and designing effective exercises. **Novelty:** The article integrates these approaches into a coherent methodological framework grounded in existing theoretical and methodological sources. **Implications:** The findings support more systematic and principle-based instruction of text structure, contributing to improved communicative competence and speech culture in native language education.

Keywords : Text Structure Teaching, Linguistic Pedagogical Approaches, Textual Error Correction, Native Language Instruction, Communicative Competence Development

Highlight :

- Modular learning technology divides text structure concepts into independent modules for systematic knowledge acquisition.
- Textual errors include logical, compositional, and grammatical mistakes requiring targeted instructional intervention strategies.
- Linguistic phenomena demonstrate communicative essence through connected speech requiring integrated systematic native language education.

Published date: 2026-01-21

Introduction

Liquid crystal photovoltaics and photoelectric phenomena have been of great scientific interest because of their many applications in optoelectronic sensing, light energy conversion, and functional soft matter systems. This latter class of materials is particularly attractive because photoactive dyes can be incorporated into nematic liquid crystals featuring anisotropic molecular ordering combined with light induced charge generation and transport. Methyl Red, as an organic dye, has the characteristics of good visible light absorption capacity and fast photoionization and electron transfer ability, making it a good candidate for the study of photocurrent generating mechanisms in symmetric nematic cells.

The dynamic formation of photocurrent in dye doped nematic cells is determined by the interconnect theory of photoelectric effect on transparent electrodes, electric double layer, ion generation, and thermally activated charge transport by photoexcited dye molecules. Previous studies have shown that illumination in the liquid crystal induces microsecond order transient and long-lived currents dependent on the properties of the electrodes, the light absorption distribution, and the ordering of the molecular species in the liquid crystal medium. Nevertheless, all prior works have either only qualitatively described the photovoltaic effect or have only studied limited thickness ranges, missing an adequate resolution of the systematic role of cell thickness and temperature dependent activation processes.

In the present work we fill this gap and in particular we explore stationary and non-stationary photocurrents in symmetric nematic liquid crystal cells doped with methyl red over a wide range of thickness and temperatures. Time resolved photocurrent measurements for peak amplitudes, steady state currents (and their dependences on inverse thickness and temperature) are performed using controlled white light illumination with spectral filtering. A quantitative analysis of charge carrier transport mechanisms in the nematic medium is made possible by extracting activation energies from Arrhenius type analyses.

This appears to be due to an initial increase in steady state current as light absorption is enhanced with increasing thickness, counteracting the decrease in non-stationary photocurrent peaks associated with the increase in capacitance that accompanies the thickening of the cell. Results validate these expectations and show an unambiguous increase in activation energy with decreasing thickness, suggesting enhanced molecular ordering in the vicinity of confining surfaces. This work gives further understanding on charge transport and photovoltaic properties in dye doped liquid crystals, as well as considerations for low voltage optoelectronic devices, light sensors, and advanced functional liquid crystal-based energy systems.

1. Methodology

The approach of this work is to use a controlled experimental study of stationary and non-stationary photocurrents in symmetric nematic liquid crystal cells with methyl red doping, according to the arrangement and procedures of the article attached below. To ensure that the dye absorbs a sunburning amount of light to undergo efficient photoexcitation, we mixed nematic liquid crystal 5CB with methyl red (~1 percent by weight, i.e., close to maximum solubility) 7. The planar aligned liquid crystal cells were then manufactured with transparent ITO coated glass electrodes, to form symmetric cells with highly controllable thicknesses starting on the micrometer scale. One electrode was grounded and the other was connected to a low noise amplifier and an oscilloscope for current measurements in the time domain. White LED source was used for illumination and a ZhS 16 optical filter was applied to narrow the spectrum and keep excitation conditions uniform. Photocurrent signals were measured right after the light source was turned on in transient (peak currents) and in steady state in prolonged illumination experiments. For the study of thickness effects, measurements were repeated for differently thick cells, while keeping the same optical and electrical conditions. To perform temperature dependent measurements, we slowly heat and cool the cells in a controlled manner, recording the steady state photocurrent at each temperature step. We analyzed the logarithmic dependence of the photocurrent on inverse temperature to obtain activation energies related to charge carrier transport. Identical measurement environmental conditions were used for all measurements to minimize external effects so that differences in both the magnitude of photocurrent and temporal response of activation as a function of cell thickness can be compared.

Result and Discussion

The experimental setup consists of an LC cell with an electrolyte (5CB+MR). The concentration of methyl red in the nematic was about 1% by weight, which corresponds to almost the maximum value during its dissolution. White light LED source (W–LED). Light filter. The measuring electrode of the LC cell (1) is connected to the oscilloscope via an amplifier, which is indicated in the figure by numbers (Figure 1) [1], [2].

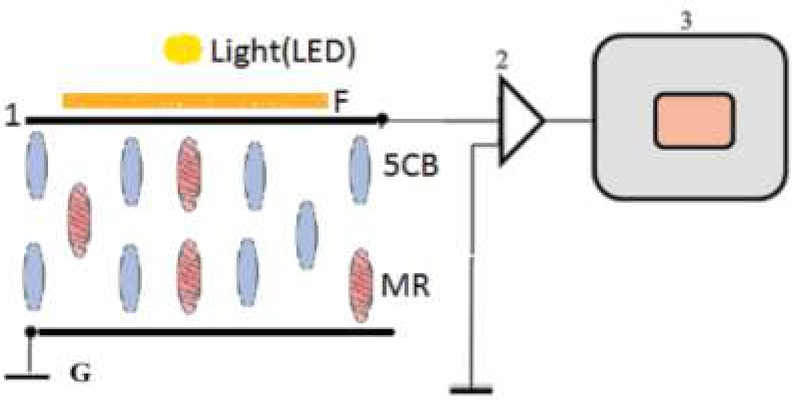

Figure 1. Experimental setup diagram. 1 – Measuring electrode of the LC cell. 2 – Amplifier. 3 – Oscilloscope. G – Grounded electrode. F – Light filter.

When the white light source (W-LED) is switched on, the photoelectric effect occurs first in the ITO electrodes. As a result of the photoelectric effect, the collecting electrode becomes positively charged. Photoelectrons entering the dense layer of the double electric layer change its capacity and, accordingly, the capacity of the entire nematic cell [3]. Simultaneously with the photoelectric effect, the mechanism of electron transfers from excited MC molecules to the electrodes (collecting and grounded) is switched on [4]. Due to the absorption of light in the nematic layer with dye molecules, we assume that ions of both signs are formed throughout the volume of the liquid crystal layer due to the dissociation of some impurity molecules AB by the mechanism $MR^{*}+AB \rightarrow MR + A^{+} + B^{-}$, where MR^{*} are photo excited methyl red molecules, A^{+} and B^{-} are ions [5], [6], [7]. The distribution of the ion concentration corresponds to the absorption of light; the electron transfer to the grounded electrode is less than to the collecting one. Therefore, the resulting electron current in the external circuit flows from the collecting one to the grounded one (Figure 2) [8], [9], [10], [11].

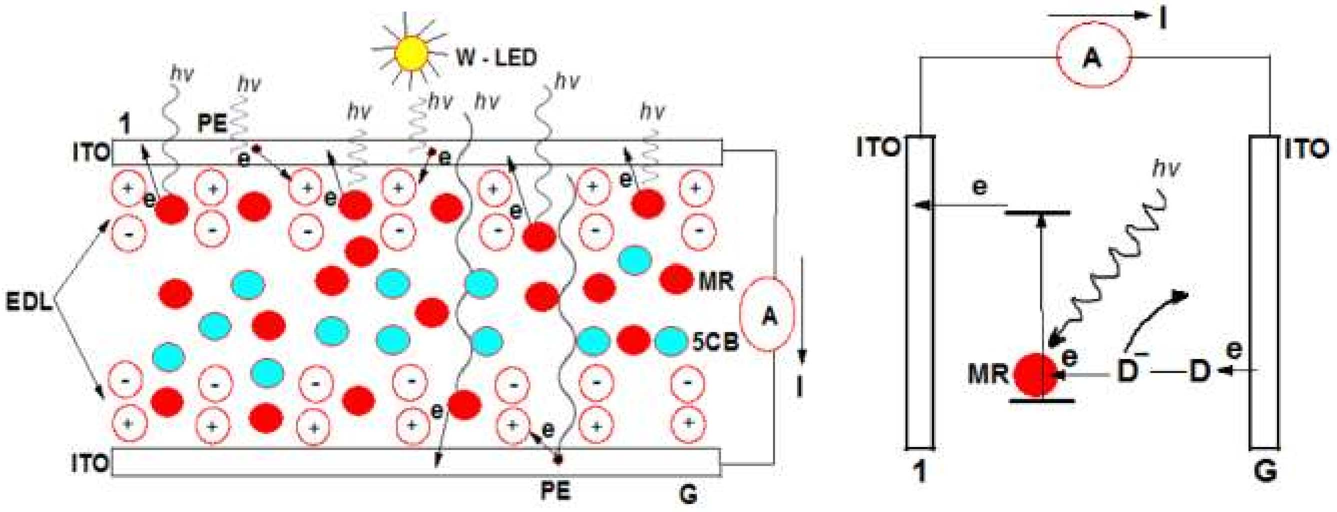

Figure 2. On the mechanism of the photovoltaic effect in a nematic cell with methyl red (MR), 1 – ITO collecting electrode, G – grounded ITO electrode, PE – photoelectric effect in the ITO electrode, D – electron donor, EDL – electric double layer.

Experiment

To obtain the dependence of the photocurrent on time in cells of different thicknesses, it was within the range of 5 – 100 μm at room temperature with a ZhS-16 light filter, the graphs are shown in Figure. 3.

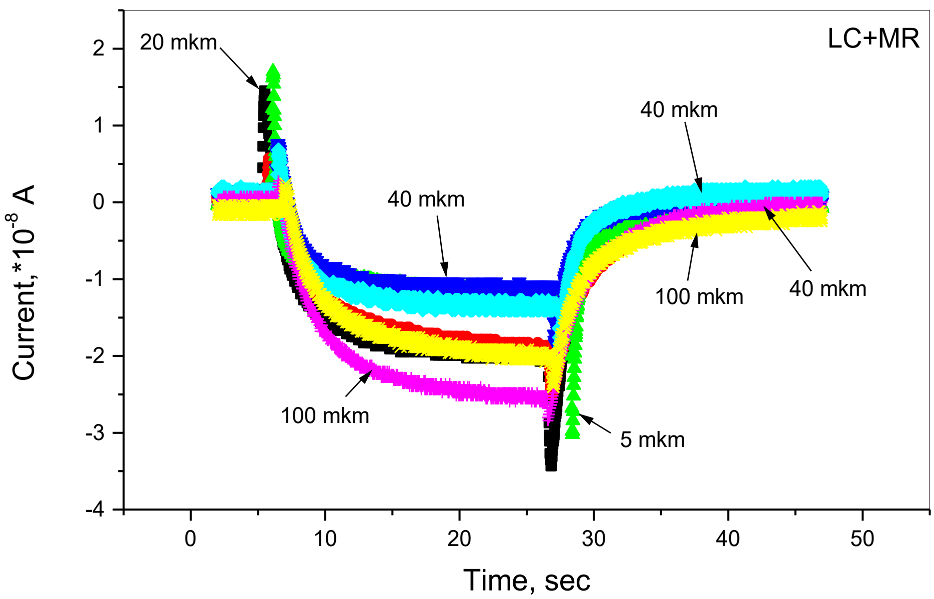

Figure 3. Dependence of photocurrent on time in 5 μm, 20 μm, 40 μm and 100 μm cells with a ZhS-16 light filter.

From Figure 3 it is clear that with different cells within 5 – 100 μm with a light filter (ZhS-16) at room temperature, when we turn on the white light source (W-LED), it is clear that the light falls in the cell and the liquid crystal with the dye absorbs the light well due to the fact that the dye molecules absorb the light and are excited [12]. Let's select the left part of this graph and display it separately in Figure 4.

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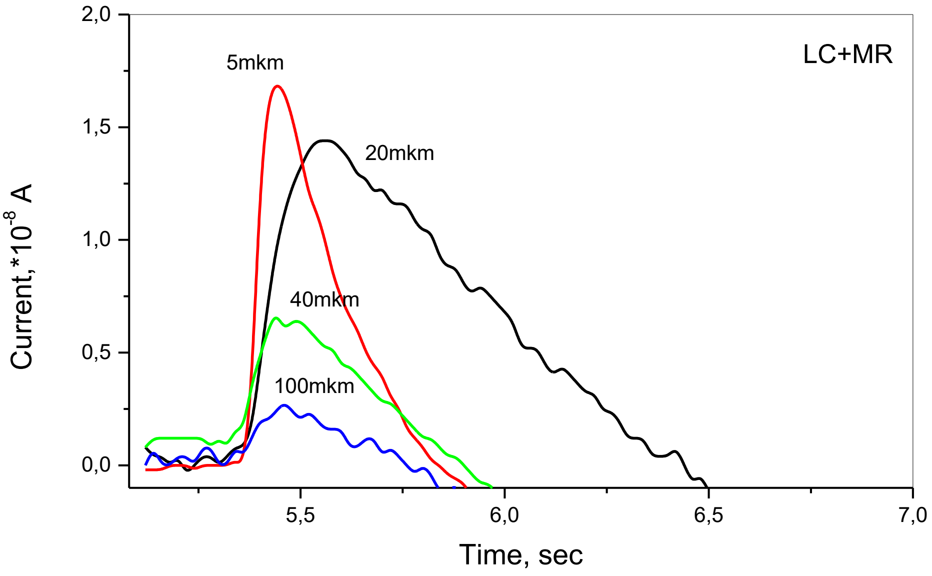

Figure 4 First peak of photocurrent in LC with dye. Effect of LC cell thickness d with ZhS-16 light filter.

From Figure 4 we obtain for each cell the peaks of the photocurrent and then through Table 1 we draw a Figure 5 between the peaks of the photocurrents and the inverse thickness (1/d).

Table 1;

Таблица.1

Толщина(d) ячейка	1/d	Пик фототока
5 мкм	0,2	$1{,}714.10^{-8}$ A
20 мкм	0,05	$1{,}406.\ 10^{-8}$ A
40 мкм	0,025	$0{,}516.\ 10^{-8}$ A
100 мкм	0,01	$0{,}235.\ 10^{-8}$ A

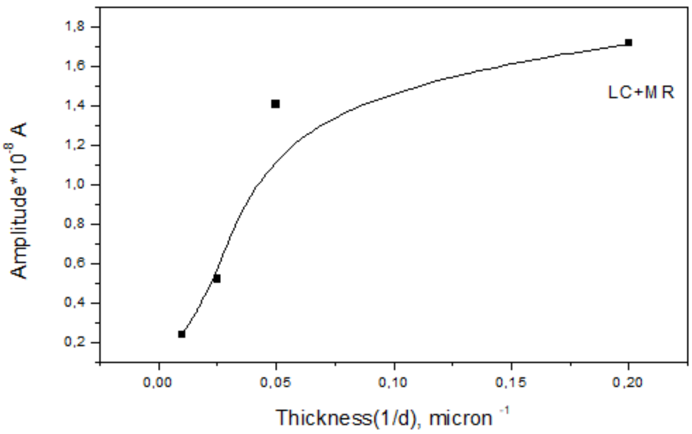

Figure 5. Dependence of the amplitude of the photocurrent peak when the illumination is turned on the inverse thickness (1/d) for different cells with the ZhS-16 light filter.

Below in Table. 2 we obtained the values for the current (I) at room temperature for different cells lay within the range of $5 - 100\ \mu m$ with the ZhS-16 light filter in Figure 6.

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Table 2;

Таблица. 2

Толщина(d)	Ток ЖС – 16
5 мкм	$1{,}22.10^{-8}$ A
20 мкм	2.10^{-8} A
40 мкм	$1{,}917.10^{-8}$ A
100 мкм	$2{,}557.10^{-8}$ A

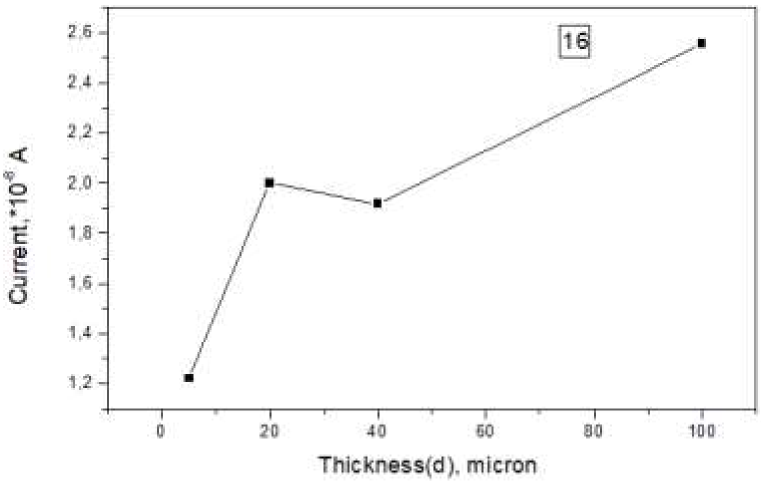

Figure 6 Dependence of photocurrent on the cell thickness with a ZhS-16 light filter.

Temperature dependence of photocurrent Let's do an experiment with a 1 μm thick nematic liquid crystal cell with a dye when irradiated through a light filter (ZhS-16). When we turn on the white light source (W-LED), we can see that the light falls into the cell. The liquid crystal with the dye absorbs light well because the dye molecules absorb light and are excited [13]. Each time, the temperature was measured with an increase of 1 C^0. The temperature changed during heating from 21$C^0$to 40$C^0$and back during cooling, while decreasing the temperature each time by 1C^0o when measuring starting from 40$C^0$to 24C^0. In this experiment, we obtained the results and from these results we plotted the graph in Figure 7a, as well as the graph of (LnI) and $(1/T)$, which is shown in Figure 7b. The temperature is given in degrees Kelvin $(T = 273 + tC^0)$. In this experiment, the activation energy of the photocurrent was found from the slope of the linear dependence, the value of which was $\Delta E = 0.87\ eV$. Then we continue the experiment with a cell of a nematic liquid crystal with a dye with a thickness of 5 μm in Figure 8a and b, 20 μm in Figure 9a and b, 40 μm in Figure 10a and b and 100 μm in Figure 11a and b with a light filter (LC – 16) [14]. In this experiment, the activation energy was found from the slope of the linear dependence, the value of which was $\Delta E = 0.225\ eV, \Delta E = 0.237\ eV, \Delta E = 0.157\ eV$ and $\Delta E = 0.0805\ eV$.

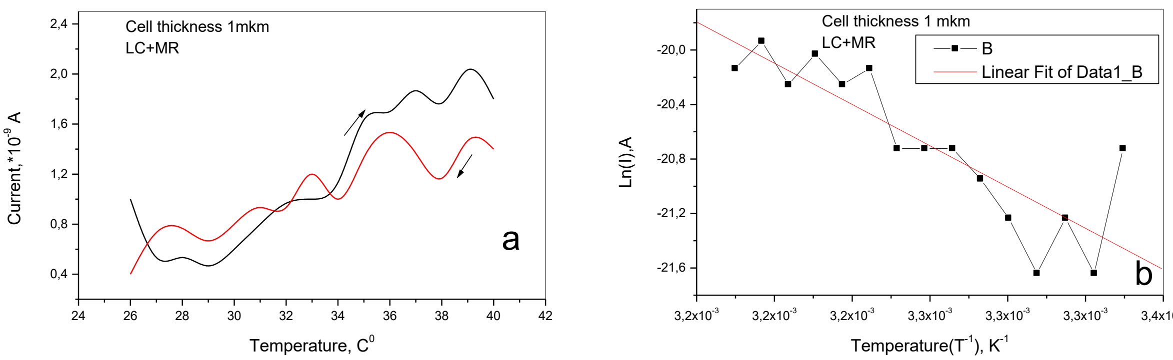

Figure 7. a – Temperature dependence of photocurrent during photovoltaic effect in LC with dye in 1 μm cell. **b** – Dependence of photocurrent logarithm on inverse temperature. Heating. ZhS–16 light filter.

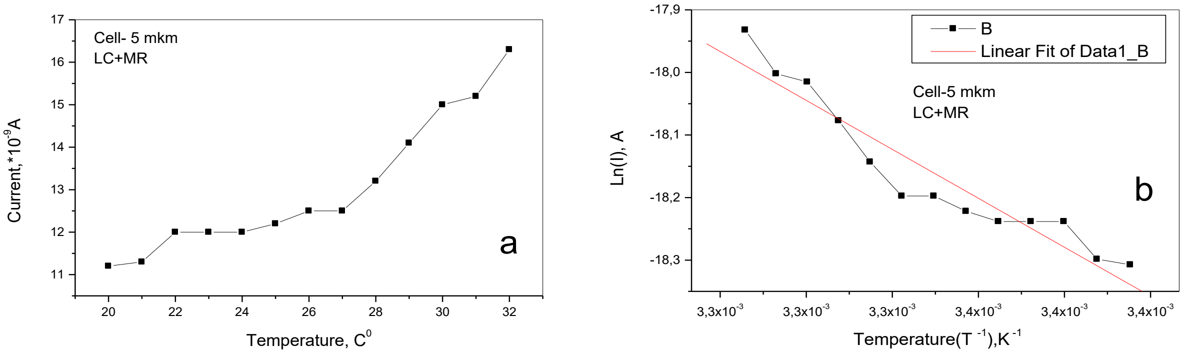

Figure 8. a – Temperature dependence of photocurrent during photovoltaic effect in LC with dye in 5 μm cell. **b** – Dependence of photocurrent logarithm on inverse temperature. Heating. ZhS–16 light filter.

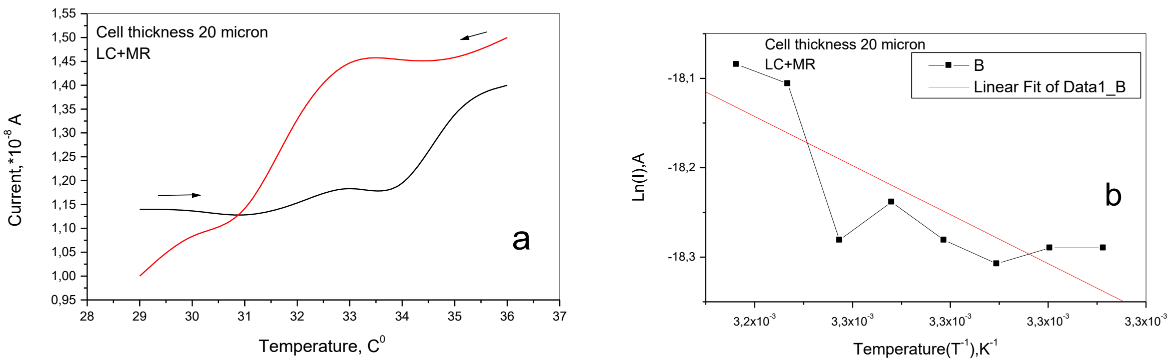

Figure 9. a – Temperature dependence of photocurrent during photovoltaic effect in LC with dye in 20 μm cell. **b** – Dependence of photocurrent logarithm on inverse temperature. Heating. ZhS–16 light filter.

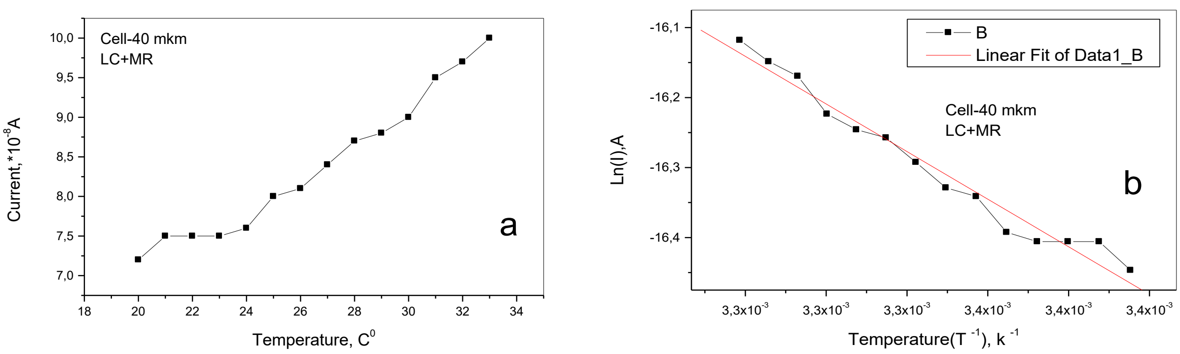

Figure 10. a – Temperature dependence of photocurrent during photovoltaic effect in LC with dye in 40 μm cell. **b** – Dependence of photocurrent logarithm on inverse temperature. Heating. ZhS–16 light filter.

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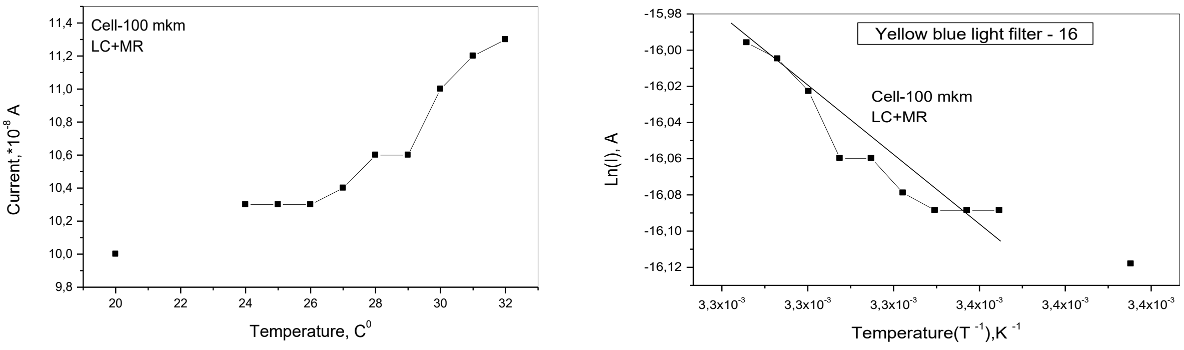

Figure 11. a – Temperature dependence of photocurrent during photovoltaic effect in LC with dye in 100 µm cell. **b** – Dependence of photocurrent logarithm on inverse temperature. Heating. ZhS-16 light filter.

Figure 12 shows temperature dependences of steady-state photocurrent in cells of different thickness with dye. It is evident that good linear approximation of experimental data takes place in the axes shown in the graph [15]. This may indicate an activation mechanism of charge transfer in the steady-state photocurrent I mode in LC cells with MC. The increase in activation energy shown in Table 3 and Figure. 13 can be associated with an increase in the order parameter of the liquid crystal medium imposed by the surface.

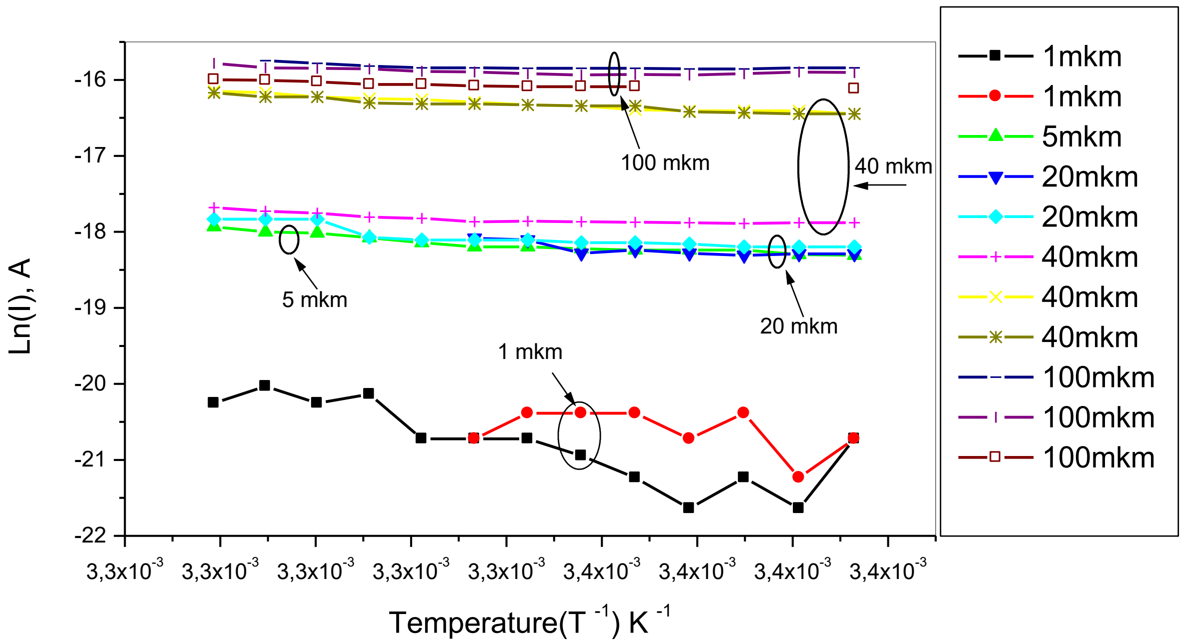

Figure. 12. Dependence of the logarithm of the photocurrent I in nematic cells of 1 µm, 5 µm, 20 µm, 40 µm and 100 µm with MK on the reciprocal value of the temperature with the ZhS-16 light filter.

Table 3;

Таблица.3

Ячейка	ΔE
1мкм	0,87 эв
5мкм	0,225 эв
20мкм	0,237 эв
40мкм	0,157 эв
100мкм	0,0805 эв

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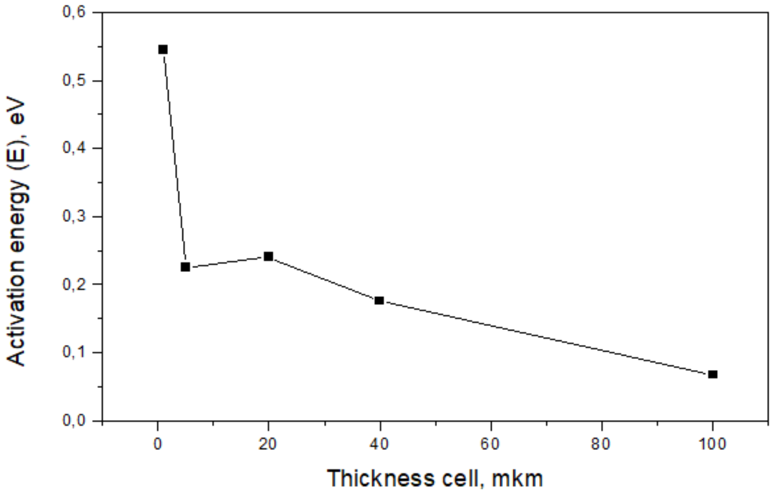

Figure 13. Dependence of the activation energy on the thickness of the nematic cell.

Conclusion

The steady-state photocurrent in a symmetric nematic cell with methyl red is caused by photoionization of dye molecules and electron transfer to the electrodes. Due to the absorption of light in the nematic with a dye, the electron current in the less illuminated electrode is always lower. The non-stationary photocurrent of the nematic cell with methyl red when light irradiation is turned on is caused by the charging current of double electric layers at the LCD/ITO interface due to the photoelectric effect in ITO. The temperature dependences of the steady-state photocurrent during the photovoltaic effect in the nematic with a dye obey the Arrhenius equation with an activation energy in the range from $0.05\ eV\ to\ 0.5\ eV$. An increase in the activation energy with a decrease in the thickness of the LCD layer is associated with an increase in the ordering of the LCD medium due to the influence of the walls.

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