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Electrical characteristics of liquid crystal cell 5CB with addition of cobalt ferrite nanoparticles ($CoFe_2O_4$)

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The effect of $CoFe_2O_4$ nanoparticles on the characteristics of a liquid crystal cell based on the nematic composition 4-Cyano-4′-pentylbiphenyl (5CB) under the influence of sinusoidal voltage of different frequencies and amplitudes was studied. At the control signal frequency of 500 kHz, a resonant increase in current with a subsequent decrease occurs in the electric circuit. This indicates the formation of a series oscillatory circuit. The quality factor of the system with nanoparticles does not depend on the amplitude of the controlled voltage. Liquid crystal cells with a constant quality factor can find application in a number of devices and technologies where stable electrical characteristics are required.

Keywords: nematic liquid crystal cell (LC cell), $CoFe_2O_4$ nanoparticles.

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Hybrid systems with nanoparticles with specific physical and chemical characteristics, which have the capacity to alter the response parameters of liquid crystal (LC) cells, introduced into the structure are being studied actively as a means to improve the functional properties of LC materials. Among the promising additives of this kind are nanoparticles of silver and ferrites (such as $CoFe_2O_4$). The introduction of nanoparticles into LC materials has a significant impact on their dielectric and electrical properties. For example, it was found in [1] that silver nanoparticles in a system with 5CB affect the dielectric characteristics of an LC cell, which is associated with a change in its response to external influences. The addition of nanoparticles may also induce changes in the orientation of liquid crystal molecules and, consequently, their electrical and optical behavior. Similar studies [2] have demonstrated that the presence of nanoparticles in LC systems may induce resonance effects due to their influence on the frequency characteristics and conductivity of the material.

The introduction of cobalt ferrite nanoparticles ($CoFe_2O_4$) into a nematic LC also produces significant effects. This material has a number of valuable properties, which include a prominent magnetic anisotropy, mechanical and chemical stability, and pronounced electrical characteristics. The introduction of $CoFe_2O_4$ nanoparticles into the 5CB LC system has the potential to alter significantly its electrical and optical properties, opening up opportunities for production of more sensitive sensors and stable displays with improved performance [3]. In addition, the presence of ferrite nanoparticles may induce local electric and magnetic fields, potentially affecting the orientation and dynamics of LC molecules and modifying both electrical and optical responses of a cell.

The aim of the present study is to analyze the electrical response of an LC cell based on the 5CB (4-Cyano-4′-pentylbiphenyl) nematic composition with introduced $CoFe_2O_4$ nanoparticles to sinusoidal voltage of varying amplitudes and frequencies. Particular attention is paid to the identification of resonance effects, the change in current characteristics of the system, and the formulation of dependences that may serve as a basis for design of new types of devices with controlled frequency characteristics.

Two LC cells based on 5CB were fabricated for experiments. The structure of these cells is shown in Fig. 1.

The LC layer thickness is $10\,\mu$m. ITO layers were exposed at the outer edges of the cell in order to connect them to a control voltage generator. These layers also acted as an orientant, providing S-deformation when an electric field was applied. A 0.1 wt.% solution of $CoFe_2O_4$ was introduced into one of the fabricated cells using the capillary effect.

A Tektronix AFG 3021 B variable voltage generator was used in experiments to supply both cells with a sinusoidal voltage of different amplitudes (1, 5, and 10 V), and changes in the current amplitude were recorded with a Fluke 8846A digital multimeter by measuring the quality factor based on the resonant characteristics. The obtained dependence is shown in Fig. 2.

The quality factors of the systems were calculated in order to examine the changes in more detail. The calculated quality factors corresponding to different control voltage amplitudes for the pure LC cell and the cell with added magnetic nanoparticles are given in the table. Quality factor

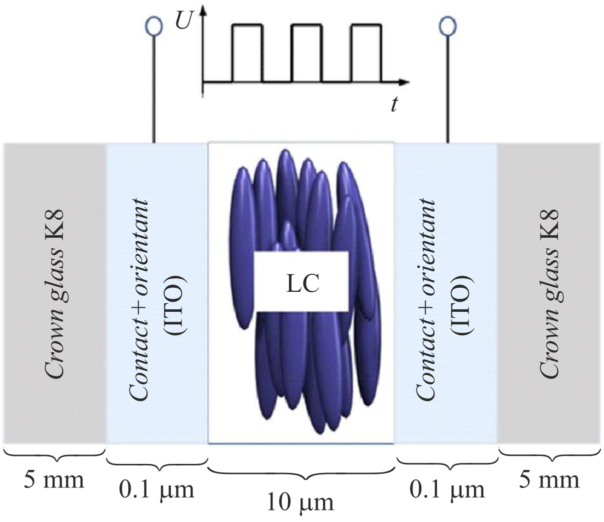

Figure 1. LC cell structure.

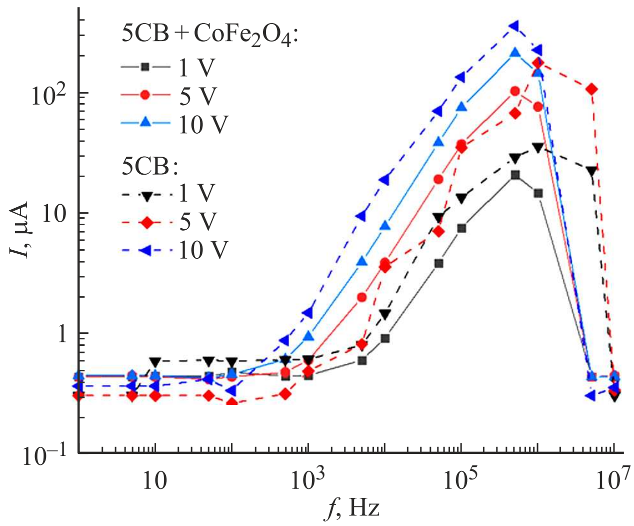

Figure 2. Dependence of the current amplitude on frequency at different amplitudes of the applied sinusoidal voltage.

Q was calculated based on the obtained plots and the following formula:

$$Q = \frac{f_{res}}{\Delta f},$$

where f_{res} is the resonance frequency [Hz] and Δf is the width of the frequency dependence at a current amplitude being $\sqrt{2}$ times lower than the resonance one [Hz].

Having analyzed the frequency dependences of current at different amplitudes of sinusoidal voltage, we arrive at the following conclusions.

(1) Resonance is observed both for the pure 5CB cell and for its version sensitized with $CoFe_2O_4$ nanoparticles, and the resonance frequency of the system measured under the influence of sinusoidal voltage remains unchanged at 500 kHz. Although ferrite nanoparticles have magnetic properties, their concentration and effect on 5CB molecules are limited to local regions. Nanoparticles do not exert any significant influence on the macroscopic inductance of the system that could shift the resonance frequency.

Calculated quality factors of systems at different control voltage amplitudes

System	Control voltage amplitude, V		
	1	5	10
5CB	0.245	0.390	1.17
5CB+$CoFe_2O_4$	0.58	0.59	0.56

(2) In the pure 5CB cell, the quality factor increased with increasing control voltage, since this cell does not contain nanoparticles that could induce local fields and additional magnetic losses. Cobalt ferrite nanoparticles introduced into the cell produce local fields and may interact with liquid crystal molecules, limiting their orientation in a single direction. This leads to additional losses and a reduction of the quality factor (especially at high voltages when the external electric field starts to compete with the local fields of nanoparticles).

(3) The quality factor of the system with nanoparticles does not depend on the control voltage amplitude. $CoFe_2O_4$ nanoparticles may screen partially the external electric field, creating local regions of a strong field around themselves. These local fields stabilize LC molecules and make the system less susceptible to external voltage variations. Thus, regardless of the increase in control voltage (within the studied range), the electrical response of the cell with nanoparticles remains unchanged with a constant quality factor.

Liquid crystal cells with a constant quality factor, including those with added cobalt ferrite nanoparticles, may find application in a number of devices and technologies where stable electrical characteristics are critical. For example, the use of these cells in radio-frequency devices, such as filters, frequency stabilizers, and modulators, may ensure stable operation at different signal power levels. This is especially important in telecommunications, where frequency characteristics need to remain stable regardless of input signal power variations.

Conflict of interest

The authors declare that they have no conflict of interest.

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