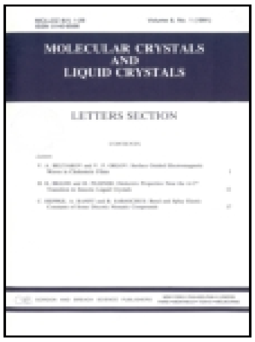

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Optical Response Features of LC Cells Doped with CdSe/ZnS Quantum Dots

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We investigated the optical response times of the LC cells with a nematic liquid crystal with positive dielectric anisotropy doped with 3.5 nm semiconductor quantum dots CdSe/ZnS. We observed that the optical response times of LC cells doped with 1 and 2 mg/ml QDs decreased significantly after one month in comparison with initial. The turn-on time at a wavelength of 1.55 μm of the twist cell with a thickness of 8 μm, filled with the suspension of the LC and 1 mg/ml QDs was about 200 μs. It is shown that using a unipolar square wave voltage decreasing response time of the liquid crystal cell.

Keywords Nematic liquid crystals; semiconductor quantum dots; response time

Introduction

Doping the liquid crystal (LC) is a flexible way to modify their properties for development of new photonic devices and metamaterials. Properties of the LC, doped with nanoparticles depend on their nature, size, shape and concentration. One of the fundamental problems in the study of liquid crystals doped with nanoparticles is to explain the influence of nanoparticles on the dynamics of the molecules reorientation and optical response time of LC devices. Studies in this field are interesting for the development of LC devices and contributes to the next level of LC devices technology [1, 2].

Ways of speeding up photonic switching LC devices are based on the laws of their operation, of which the most commonly used are: increasing the applied voltage or decreasing the thickness of the liquid crystal layer. Creating high-speed LC photonic devices remains relevant and development of technology doping liquid crystal with nanoparticles can facilitate that.

One of the well-studied classes of nanoparticles is semiconductor quantum dots (QDs) [3]. The study of 5CB doped with CdSe/ZnS nanoparticles showed that it is possible not only to reduce the threshold voltage on 25%, but also to improve the response time. However, slow LC director relaxation depending on the size and concentration of the nanoparticles was observed [4]. A decrease in the threshold voltage U_{th} in result of adding CdSe/ZnS QDs in a nematic liquid crystal with a positive dielectric anisotropy experimentally demonstrated

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[5]. The threshold of Freedericksz effect for splay deformation depends on the elasticity coefficient K_{11} and dielectric anisotropy $\Delta\varepsilon$ of the LC $U_{th} = \pi\sqrt{K_{11}}\big/\sqrt{\varepsilon_{\Delta}\varepsilon}$. Changing the coefficient of elasticity and dielectric anisotropy depends on the orientation order parameter, which decreases with increasing concentration of nanoparticles. The response time changes according to formula τ_{on}:

$$\tau_{on} = \frac{4\pi\gamma_1}{\Delta\varepsilon(f)}\frac{d^2}{(U^2 - U_{th}^2)} \tag{1}$$

where d is a cell thickness and $\gamma_1$the rotational viscosity.

Lowering of $\Delta\varepsilon$ with increasing the concentration of QDs should cause an increase of the LC optical response time in accordance with formula (1). While lowering of U_{th} should facilitate to decrease τ_{on}.

In this work, we investigated the dynamics of the nematic liquid crystal optical response with positive dielectric anisotropy, doped with CdSe / ZnS quantum dots and influence of the electric field pulse shape applied to the LC cell on the optical response.

Experimental Details

The experiments were performed on plane-parallel electrically controlled LC cells with homogeneous orientation made-up of two glass substrates with a diameter of 35 mm coated with transparent conducting layers of indium tin oxide and alignment polyimide layers. The nematic LC of ZhK-1282 type (NIOPIK, Moscow) with positive dielectric anisotropy was used. The colloidal semiconductor QDs CdSe/ZnS of the core/shell type with a diameter of ∼3.5 nm were used in this work. Each QD comprised a CdSe core passivated by ZnS and covered by a layer of trioctylphosphine oxide molecules. The QDs were synthesized at the Institute for Physicochemical Problems (Minsk) using a method described in [6]. The concentration of CdSe/ZnS nanoparticles doped to LC were 1 and 2 mg/ml. We blended the suspensions of QDs in nematic phase LC using an ultrasonic bath for 1.5 hour prior to filling the cells.

Measuring electrooptical properties of LC cells was performed using a known method. LC cell were mounted between the polarizer and analyzer so that the angle between the polarization vector of the incident radiation and the LC director was 45$^{\text{o}}$ to maximize transmittance in the absence of an electric field. The transmitted light with a wavelength of 0.65 μm was measured by an oscilloscope from photo detector signal. The optical response of HTN cells, as well as the turn-on and turn-off times, was studied with an LTR34 based multicomponent control system making it possible to flexibly vary the electric field parameters. This modular multichannel computerized system is designed for automated analog and digital data input/output and processing and also for controlling the response of LC devices. It comprises a basic unit of modules, demountable task specific modular units (DAC, amplifier, etc.), and a computer. With this control system, one can vary the electric field parameters, namely, oscillation mode; duration, repetition rate, amplitude, polarity, and number of signals; time intervals between signals; and DC and AC voltage application sequencing. The system was controlled with a dedicated computer program that allows simulation of the parameters of an electrical signal applied to an LC device and provides coupling of the modules with the basic unit, computer, and each other [7]. All experimental measurements were performed at room temperature.

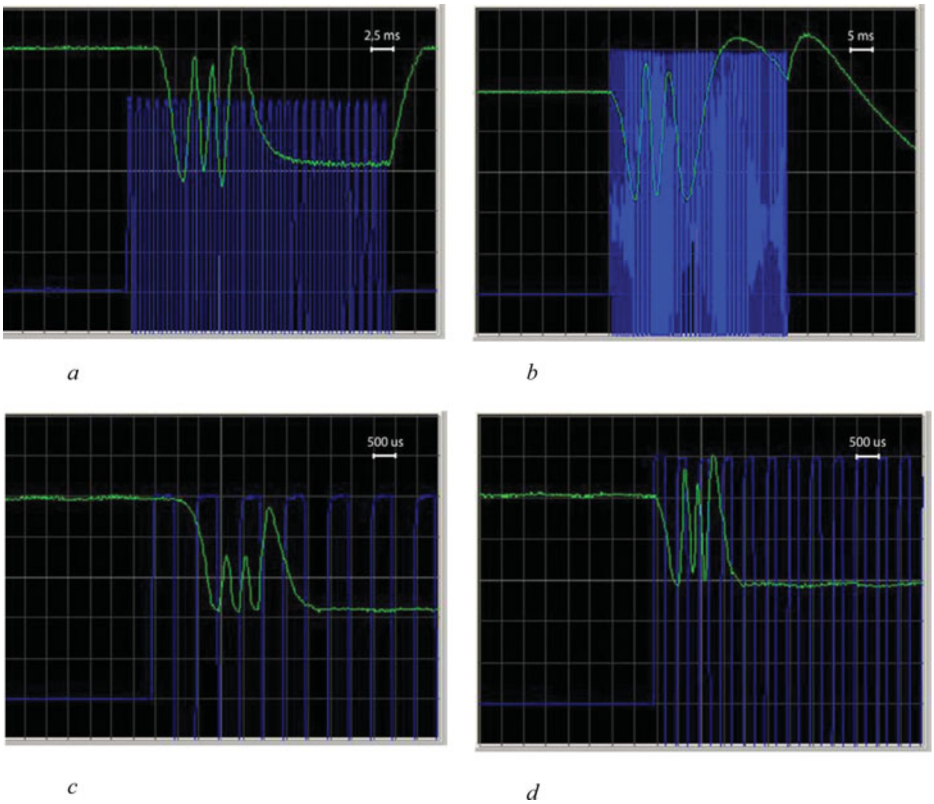

Figure 1. The optical responses at a wavelength of 0.65 microns of filled with a suspension of LC cells with CdSe/ZnS QDs with concentration of 1 mg/ml, 14.4 μm thickness (a) and 2 mg/ml with a thickness 13.4 μm (b) the initial and after 1,5 months (c) and (d) correspondingly. A bipolar square wave alternating electric field with 1 kHz frequency with operating voltage of 50 V was applied to the cells.

Oscillograms of the optical responses of two cells orientated homogeneously with the LC suspensions with concentration of 1 mg/ml (a) and 2 mg/ml (b) QDs in the result of splay deformation obtained at once after manufacturing of the LC cells and after 1,5 months (c) and (d) are shown in Figure 1. Oscillogram of the twist cell optical response at a wavelength of 1.55 μm, filled with the suspension of LC and CdSe/ZnS QDs with a concentration 1 mg/ml obtained by applying a bipolar square wave alternating voltage 60 V with 1 kHz is shown on Figure 2. Comparison of optical response waveforms at the wavelength 0.65 μm for LC cell with 1 mg/ml QDs in the result of applying an alternating electric field in the form of unipolar and bipolar square waves illustrates Figure 3.

Result and Discussion

Slowing optical response more than two times can be observed on oscillograms with increasing QDs concentration from 1 mg/ml (*a*) to 2 mg/ml (*b*) (Figure 1). This may be caused by decreasing of the LC orientation order parameter, as well as lowering the dielectric anisotropy of the medium with CdSe/ZnS QDs [5]. A significant decrease in the optical response time of LC cells was observed a half months later in repeated measurements, as

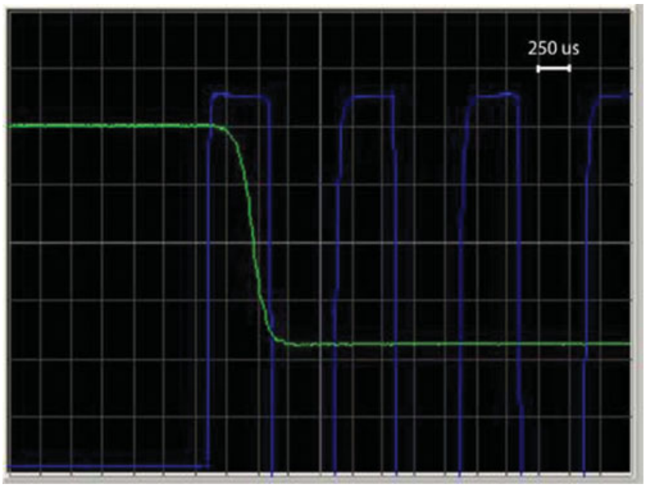

Figure 2. Oscillogram of the twist cell optical response at a wavelength of 1.55 μm, filled with the suspension of LC and CdSe/ZnS QDs with a concentration 1 mg/ml obtained by applying a bipolar square wave alternating voltage of 60 V and 1 kHz.

can be seen in the oscillograms (*c* and *d*) on Figure 1. This may be caused by decreasing of the screening effect of the liquid crystal resulted from ions capturing contained in the liquid crystal layer by the surface states of the quantum dots.

The ions separation process under the influence of an external electric field leads to the formation of space charge at the interface between the liquid crystal and orienting LC layer, which causes the fall of the applied voltage.

Insulating nanoparticles added to a nematic liquid crystal reduces the moving - ion density and the effect of shielding the applied voltage thus contributes to a reduction of

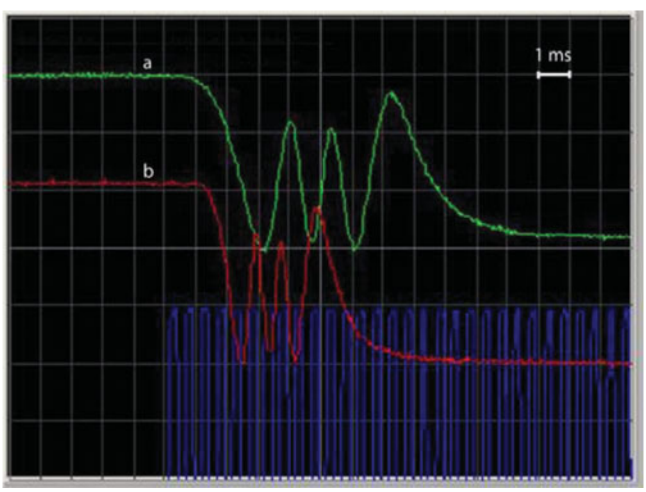

Figure 3. LC cell optical response doped with semiconductor CdSe/ZnS QDs with a concentration 2 mg/ml obtained by applying an alternating electric field in the form of bipolar square wave of 30 V and 1 kHz (a) and unipolar square wave of 30 V and 9 kHz (b).

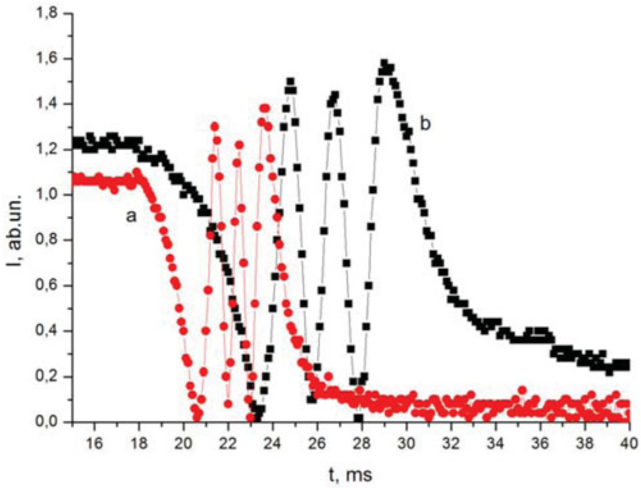

Figure 4. Optical response time obtained by applying an alternating electric field in the form of unipolar square wave of 30 V and 9 kHz (a) and bipolar square wave of 30 V and 9 kHz.

the threshold voltage [9–10]. Reducing the number of ions in the LC helps to reduce the screening effect of the applied voltage and to accelerate the reorientation process of the molecules.

As for LC cell without QDs we performed the same experiments but within a few weeks, no change was observed in the electrooptical response. The average response time for 2π phase modulation was about 2 ms.

Optical response at a wavelength of 1.55 μm of the twist cell with a thickness of 8 μm, filled with the suspension of the LC with 1 mg/ml quantum dots shown in Figure 2. The turn-on time of the cell was about 200 μs. This result indicates that the nematic liquid crystals doped with QDs can be used as a medium for optical device, for example, for modulating signal in components of telecommunications systems.

We compared the optical responses at the wavelength 0.65 microns for LC cell containing 1 mg/ml QDs in dependence from a waveform of an alternating electric field. An unipolar and a bipolar square waves were used for this. Figure 3 illustrates the acceleration of optical response if unipolar square wave was applied to the LC cell.

The polarity at the substrates boundaries of LC cell is changed in accordance with the pulse repetition frequency of a bipolar square wave AC voltage. While in the case of unipolar waveform, a polarity sign remains constants on substrates of the LC cell. Comparison dynamic of optical response for LC cell with QDs showed that if the polarity is not changed, the response time is reduced, as in the primary and repeated measurements. Impact AC field of unipolar square wave is equivalent to the action of constant potential.

Distortion of optical response was observed in the case by unipolar meander. That related with back flow in LCs when the voltage equal to zero and a reversion of the LC director take place in these periods. Increasing the frequency of the alternating electric field up to the 6–9 kHz allowed to exclude visible distortions of optical response and did not affect on the response time appreciably.

Comparison of the optical response time if bi- or unipolar square wave electric field with the frequency of 9 kHz were applied to the LC cell is shown in Figure 4.

Conclusion

We investigated the optical response times of the LC cells with a nematic liquid crystal with positive dielectric anisotropy doped with 3.5 nm semiconductor quantum dots CdSe/ZnS. We observed that the optical response times of LC cells doped with 1 and 2 mg/ml QDs decreased significantly after one month in comparison with initial. Explanation for this may be reducing the screening effect of the liquid crystal layer due to presence of QDs as ions traps. The turn-on time at a wavelength of 1.55 μm of the twist cell with a thickness of 8 μm, filled with the suspension of the LC with of 1 mg/ml QDs was about 200 μs. Influence of a waveform of applied voltage to the LC cells on a response time was studied. Effectiveness of unipolar square waveform AC voltage was shown. Applying to the liquid crystal cell of a unipolar AC voltage contributes to decreasing response time of the LC cells.

Research results show that adding the semiconductor QDs CdSe/ZnS in a nematic liquid crystal change optical response dynamics in dependence on the concentration of QDs and can reduce the optical response time. Optimizing the concentration of semiconductor QDs added to the nematic liquid crystal and improving controlling electrical signal opens up new possibilities for the development of LC device technology and improving the performance of optical response.

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