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Features of the Optical Response and Relaxation of the Nematic LC Doped with CdSe/ZnS Quantum Dots

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Dynamics of the electro-optical response and relaxation time of nematic liquid crystal (NLC) cells doped with CdSe/ZnS semiconductor quantum dots (QDs) and homogeneously oriented by rubbed polyimide were investigated. The influence of nanoparticles' concentration as well as parameters of alternating electric field were shown. The optical response time decreased 1.5 time by increasing concentration of QDs up to 1.5 mg/mL as it was compared with the pure LC. Applying unipolar square wave electric field to the LC cell reduces optical response time twice comparing to bipolar meander. However, we observed slowdown of the relaxation process both in case of doping NLC by nanoparticles and in case of applying unipolar square wave pulses.

Keywords: Nematic liquid crystal; quantum dots; optical response; relaxation; response time

PACS: 42.70Df; 4279.Kr; 83.80.Xz; 83.60.Np

1. Introduction

Improving response time of devices based on the liquid crystal (LC) technology is important for development of modern display devices, and optical information processing. This is caused due to the need of accelerating of communication processes in optical systems and improving of image quality. Some methods based on the laws of change in time characteristics of LC devices are well-known. Response speed of LC devices raises with increasing of electric field voltage and decreasing of liquid crystal layer thickness. Significantly improving performance of LC devices can be achieved using dual-frequency nematic liquid crystal (NLC) due to the sign inversion of the dielectric anisotropy according with frequency of voltage applied to a device. This allows to control over the relaxation process using high-frequency electric field [1].

Another way to improve performance of LC devices is adding nanoparticles in the NLC. This reduces the order parameter, and should cause a change in the dielectric anisotropy, Frank elasticity coefficients, corresponding changes in threshold voltage of the Fredericks effect and dynamics of liquid crystal molecules reorientation. Doping semiconductor quantum dots reduces the threshold voltage of nematic liquid crystal [2–5]. Also doping NLC by

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CdSe/ZnS nanoparticles with average size of 3,5 nm and concentrations of 1 and 2 mg/mL resulted in decrease in optical response time, but at the same time in slowing down of relaxation process. This has been explained by monotonic variation of order parameter [2] the dielectric anisotropy with increasing concentrations of QDs [3], decrease in the coefficient of elasticity of LC [6], influence of the screening effect and [7] increase in viscosity because of self-organization of nanoparticles. However, addition of nanoparticles in the LC leads to variations in initial tilt of the director and may cause changes in the orientation [8]. Increasing of the director pretilt angle is another important factor of LC response time reduction [9].

Parameters of electric field applied to a device are another important factor affecting LC devices response speed. The highest impact on the dynamics of reorientation of LC molecules has application to the LC cell a short pulse of constant electric field [10]. Nevertheless, it can form space charge near the electrodes [11]. Accumulation of space charge adversely affects on slowing relaxation after switching off electric field. Therefore, to control switching of LC devices are used alternating electric field in the form of sinusoidal oscillations or bipolar rectangular pulses. Changing sign on the electrodes of LC device when used AC voltage prevents formation of internal electric fields. However, application of alternating electric field less affects reorientation dynamics of LC molecules, as compared with constant electric field. Efficiency action of sinusoidal, bipolar, and unipolar meanders with different frequencies and polarities have been compared. We showed that using unipolar meander promotes substantial acceleration of LC optical response [12].

In this paper, we present investigation of features of the optical response and relaxation of the NLC with positive dielectric anisotropy, doped with CdSe/ZnS semiconductor quantum dots and effect of alternating electric field in form of unipolar square pulses on the dynamic characteristics of the LC cells.

2. Experimental Setup and Materials

All studies were conducted on plain LC cells composed of two glass substrates, the inner surface of which is coated with transparent conductive electrode of indium tin oxides. Alignment layers of rubbed polyimide were used to create homogeneous orientation of the NLC. Thicknesses of the LC layer were monitored by measuring the capacitance of an empty cell. We used the LC-1282 (NIOPIK, Moscow) with optical anisotropy $\Delta \mathrm{n} = 0.17$ at 632.8 nm wavelength, phase transition temperature 62ºC and $\Delta\varepsilon = 9.9$ at frequency of 1 kHz.

Semiconductor CdSe/ZnS QDs core-shell type and size of 3.5 nm core were used for doping NLC. Suspensions were prepared by adding dry batches of QDs in the nematic mesophase. Suspension with LC and QDs mixed in an ultrasonic bath for about 1 hour before filling the cells. We used suspensions containing 0.5, 1, 1.5 and 2 mg/mL CdSe/ZnS. The orientation of liquid crystal cells with suspensions was homogenous and controlled using a polarizing microscope.

Dynamic characteristics of the LC cells were measured using classical electro-optical circuit. LC cell was placed between two crossed polarizer's. Semiconductor laser diode with a wavelength of 0.65 μm was used as the light source. Light passed through the cell incident on the photodiode, whose signal was fed to the oscilloscope. Parameters of electric field, such as waveform, duration, frequency of filling, amplitude, polarity of signals and time interval between alternating voltage signals applied to the cell was varied by using a multi-component system based on LTR34. Measurements of the LC cells dynamics were

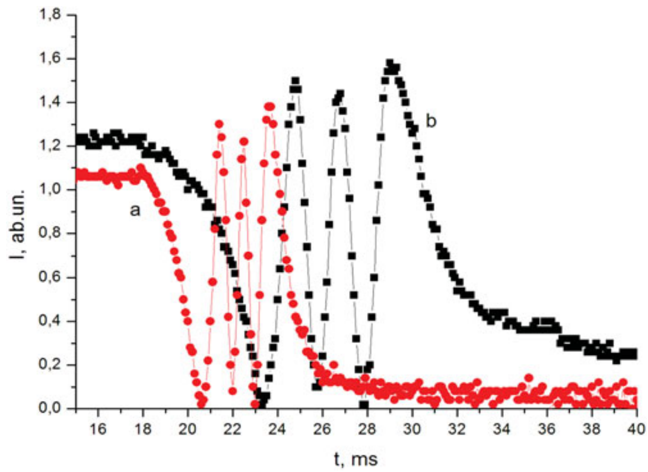

Figure 1. Oscillograms of the NLC cell optical response time obtained by applying alternating electric field in the form of unipolar (a) and bipolar square waves under voltage of 30 V at frequency of 9 kHz.

conducted upon application of alternating electric field in the form of bipolar or unipolar rectangular pulses. Intensity of modulated optical signal as a function of applied voltage, and time dependence of the optical response and relaxation were recorded using a computer program for testing LC cells. All measurements were performed at room temperature.

3. Results and Discussion

Figure 1 shows a comparison of the optical response oscillograms under application of unipolar and bipolar meander to the LC cell with thickness of 11.6 μm and QDs concentration of 2 mg/mL. It is evident that using unipolar square wave pulses (Fig.1a) accelerating optical response of the LC cells as against using bipolar pulses (Fig.1b).

Figure 2 illustrates decrease of the optical response time of the NLC cells depending on concentration of QDs in result of applying unipolar (a) or bipolar (b) electric field. Thickness of investigated cells was about 13 μm. Optical response time was measured for 2π phase transition.

The optical response time decreased 1.5 time with increasing concentration of QDs from 0.5 to 1.5 mg/mL as it was compared with the pure NLC. At the same time application of unipolar pulses reduced it twice comparing with bipolar square wave electric field. Adding nanoparticles to the NLC led to a change in order parameter, which decreased with increasing of nanoparicles' concentration. Therefore changing of order parameter can increase director's angle and decrease threshold voltage, which should help to speed up reorientation of LC molecules in electric field.

The feature of unipolar square wave is absence of electric field in the second half-period and the sign of applied potential on electrodes of a LC cell is not changed like in case of application of constant electric field pulse. This may lead to formation of space charge near the electrodes from ions, forming in the result of dissociation of the NLC individual components or admixtures. The process of dissociation and recombination of ions in liquid crystal is in equilibrium. Density of positive and negative charges in the NLC is constant [13]. Ions move between the electrodes in accordance with their charge sign and frequency

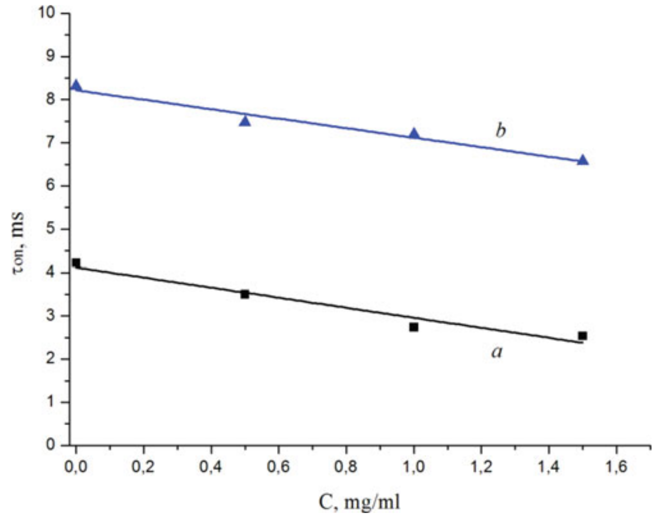

Figure 2. Dependences of the LC cells optical response on CdSe/ZnS QDs concentration for unipolar (a) and bipolar square waves (b) electric field form at frequency of 1 kHz.

of alternating electric field applied to LC cells. The slowdown of relaxation process under application of unipolar pulses to the cell with pure NLC and thickness about 7.6 μm is illustrated in Fig. 3. Oscillograms of the relaxation process after application of bi-(*a*) and unipolar square waves (*b*) were obtained in the result of application of 30 V amplitude voltage at frequency of 1 kHz and 50 ms duration.

Natural relaxation process was slower if alternating electric field was applied in the form of unipolar square wave. Slow relaxation can be caused by accumulation of space charge at the interface. The process of space charge runoff depends on the dielectric

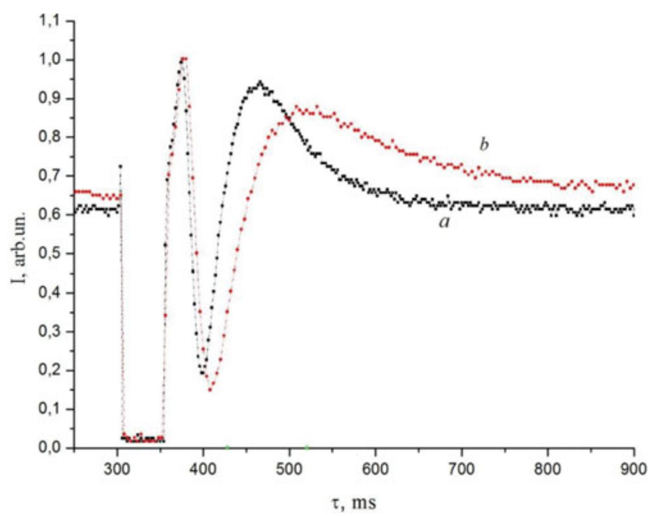

Figure 3. Oscillograms of the LC cell relaxation process after application of bipolar (a) and unipolar (b) pulses with 30 V amplitude at frequency of 1 kHz and 50 ms duration.

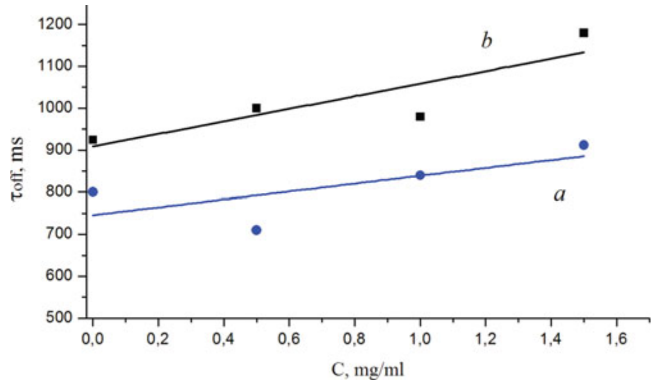

Figure 4. Dependence of the relaxation time of the LC cells on concentration of CdSe/ZnS QDs after application of bipolar (a) and unipolar meanders (b).

properties and thickness of an alignment layer and can be accelerated by optimizing of these properties.

Figure 4 shows dependence of the relaxation time in the NLC cells on the concentration of QDs upon application of bipolar (a) and unipolar pulses (b). Adding ODs to the NLC slows relaxation process, regardless to the form of voltage applied to the cells. Obtained result can be caused by decrease in the coefficient of elasticity due to the change of order parameter and viscosity of the suspension. Further studies of the NLC properties changing in the result of doping QDs will provide a more complete explanation of changes in dynamic characteristics of cells.

4. Summary

We conducted experimental studies of the cells characteristics with homogeneously oriented nematic liquid crystal by rubbed polyimide and doped with semiconductor quantum dots CdSe/ZnS. Influence of QDs concentration, as well as pulse shape of alternating electric field on the optical response and relaxation were studied. The advantage and features of unipolar square wave electric field were shown. We observed decrease of optical response time in 1.5 time with increasing QDs concentration up to 1.5 mg/mL and twice in case of applying unipolar rectangular pulses as it was compared with bipolar electric field. Slowing down of the relaxation process was observed with increasing of QDs concentration. Slowdown of the relaxation process in case of applying unipolar square wave electric field caused by accumulation of space charge and runoff near the interface boundaries, as the sign on the electrodes does not change during the action of electric field and can be eliminated by optimizing properties of an alignment layer

Reducing of relaxation time can be achieved by optimizing frequency of applied voltage, properties of alignment layer and using dual frequency NLC. Optimizing concentration of semiconductor QDs added to the nematic liquid crystal and improving parameters of electrical signal opens up new possibilities for development of the LC device technology and improving performance of optical response.

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