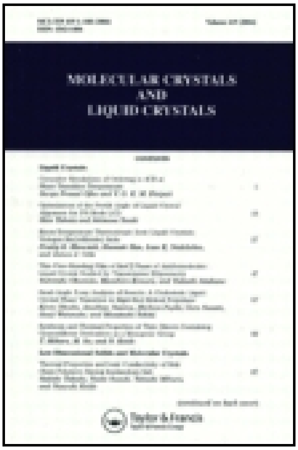

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Ions Influence on Electrooptical Characteristics of NLC

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Ions Influence on Electrooptical Characteristics of NLC

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The results of experimental observations of a carrier charge transfer and influence them on electrooptical response NLC with $\Delta\epsilon > 0$ are given. Main investigations have been carried out with samples with distance between electrodes 3000 and 260 μm. Ions with known parameters (copper Cu^+) were injected. It has been shown that the presence of the ions increases the electrooptical response due to hydrodynamic component. The technique developed gives a possibility of measurements of ions mobility, microviscosity, elastic and diffusion coefficients.

Keywords: injected carriers; mobility; electrooptical responce; stiking

INTRODUCTION

The problem of parasitic storage of previous frames is very urgent for LCD's. Many groups are involved in this problem[1-3]. Up to now there is no doubt that this phenomenon is stipulated by charges, which are stored during operation of the switching pulses and have no time to relax during the interval between them.

The investigations are generally carried out with cells similar to those (in construction and thicknesses) which are utilized in practice. The aligning layers are commonly used. The main drawback of the current experimental approach is that the real chemical composition of generated ions and their parameters are completely unknown. Besides, it is implicitly supposed, that aligning layers are microporeless solid isolators, through which charge carriers can not be injected into the bulk of LC. Therefore all the earlier obtained experimental data have, generally, no common nature and are fair only for a particularly used LC material and for a particular type of an aligning layer.

The last statement can be confirmed by results reported in [3]. Here photopolymerized polymer layers were used as aligning boundary surfaces. The prepolymer on one substrate was subjected to full polymerization, and that on the second one was polymerized partially. The noticeable difference in bulk concentrations of charge carries was obtained dependent upon which of the two differently treated surfaces were used as anode of the cell. This can be accounted for the different amounts of micropores generated for the completely and partially polymerized polymer layers that resulted in different amounts of injected carriers through the last two, respectively.

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We have developed an experimental technique which enables us to introduce into any LC material ions of the same type and of controllable parameters such as ionic radiuses, molecular weights, values of ion charge, mobility , and so on. With knowing these parameters in advance, it is possible reliably to study the effects exerted by the ions on electrooptical behavior of LC's.

Experimental

Experiments were carried out on nematic LC's with a positive dielectric anisotropy ($\Delta\varepsilon>0$).There were used two geometries.

In the first one the LC sample has been tested in a cell of a 8mm high,3mm wide,0.9mm thick parallelepiped shaped size.

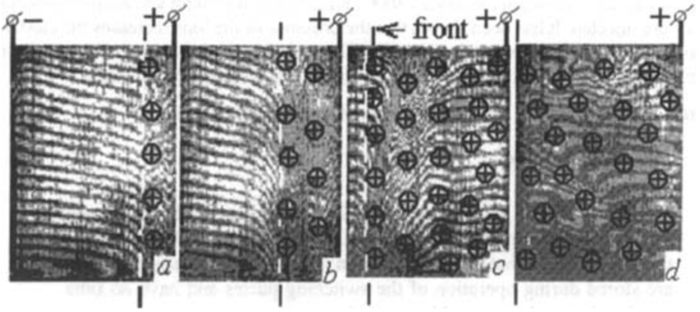

FIGURE 1. Seccessive frames of propagaton of a wave of fringe distorsion

The lateral faces were prepared for the homeotropic orientation, the others were rubbed horizontally. The homeotropic orientation was provided by the copper layer which was vacuum deposited and slightly chemically polished. In this geometry, at the crossed polarizes one can see a system of horizontal interference bands. When the cross direct electric field (50-60V) is applied to the lateral walls, there occur a bending wave moving from the positive electrode inside the sample. Some phases of the motion are presented on photos (FIGURE 1a,b,c,d) for intervals 2,3,8 and 30 min, respectively, after the field is switched on. The bending bands continuously chaotically stir while the field is on. When it is switched off in any phase the stir and the bending wave motion are interrupted. After 1.5-2 hours (!) the initial picture of the horizontal bands is restored (the optical relaxation is completed).But the electrical relaxation is not completed. Thus when the alternative electric field (50V 20-50Hz) is applied to the sample, the response is different in two areas. In the first area, through which the bending wave has passed the interference bands are bent and stirred .

In the second area the bands remain straight as the bending wave has not passed through it yet. If the frequency of the alternative field is high (more than 1 kHz) there is no difference in the response between the areas. After 10-12hours (!) the response is the same at the high and low frequency. The electrical relaxation is finished. The above-mentioned processes may take place unlimited number of times.

In the second cell geometry the same LC material was used and the same initial homeotropic LC alignment was provided. The thickness of the cell was of 260 μm. The cell was divided into two half parts (right and left in FIGURE 2). Control and driving voltages were applied to the right half part, while the left half part of the cell was used as a reference one. Here was used the longitudinal field.

In initial state at crossed polarizes, after a.c. voltage of any frequency applied to the both half parts of the cell, we observe a black field pattern (full extinction) for the both parts of the cell (FIGURE 2a, 2b). When the direct electric field (15V) is applied to the right half part of the cell, the initial dark pattern is getting brighter, and i.e. the intensity of light passing through the cell is increased. In 1.5-2 min after voltage switched on, passing light intensity reaches its maximum value and doesn't change from now on (FIGURE 2c). The cell has became translucent because the initial homeotropic orientation of LC medium has been disturbed

After d.c. voltage switched off, the passing light intensity through the right half part of the cell is decreased and reaches its initial minimum value in 15-20 seconds. Thus, during this time the initial homeotropic LC alignment of the right part is being restored and relaxation of LC optical characteristics(optical relaxation) is finishing. However, electric state of the right and left half parts of the cell are different by now.

The effect is displayed with applying to both parts a.c. voltage of different frequencies. If a.c. voltage of 50V 250Hz (high frequency) is applied, the both parts of the cell remain dark at crossed polarizes (FIGURE 2d). But if a.c. voltage of low frequency (50V 25Hz) is applied, the right half part (previously subjected to the action of d.c. voltage) is getting translucent (FIGURE 2e). The difference in behavior of the right and left half parts is decreased with time and completely disappears in ~8-10 minutes after d.c. voltage is removed from the cell . This characteristic time duration can be considered as an electric relaxation .The successive frames of the process are shown in FIGURES 2f, 2g, 2h, and 2i.

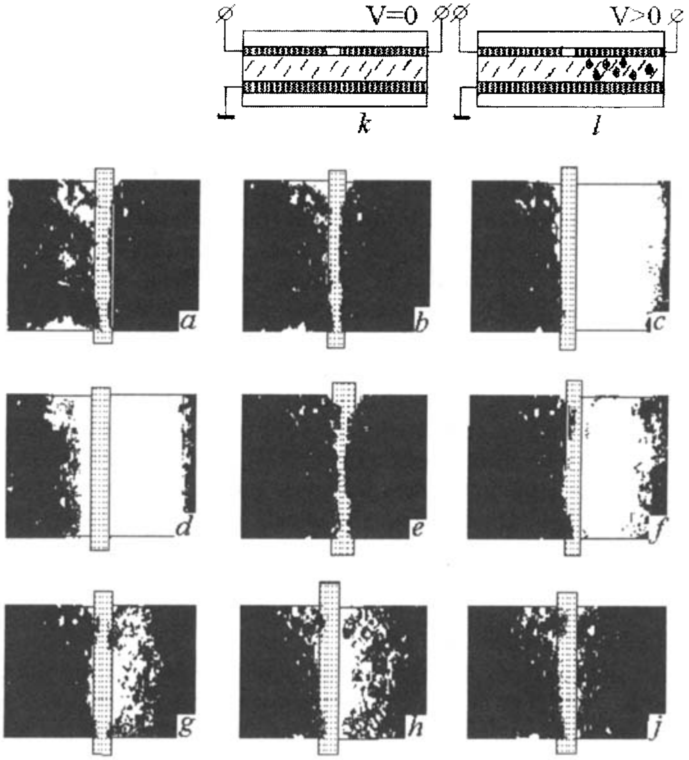

FIGURE 2. Photopatterns of LC textures for the second cell geometry taken at crossed polarizes: a/c. voltage of 50V and different frequencies 25Hz (a), 250Hz (b) is applied to the both half parts of the cell; (c) d.c. voltage of 15V is applied to the right half part of the sample for 2 minutes, and no voltage applied to the left half part; (d) a.c. voltage of 50V 25Hz is applied to the both half parts of the cell in 10 seconds after d.c. voltage switched off; (e) - a.c. voltage of 50V 250Hz is applied to the both half parts of the cell in 15 seconds after d.c. voltage switched off, (f,g,h,j) - a.c. voltage of 50V 25Hz is applied to the both half parts of the cell in 1min, 2min, 3min, 5 min, respectively, after d.c. voltage switched off,(k,l)- the cell construction.

Discussion

In principle, applying an a.c. electric field to a cell with homeotropically aligned LC with $\Delta\varepsilon>0$ has not to result in any electrooptic response. It is the case, we observe in our experiments when an a.c. electric field is applied to the cell not subjected to any influence before. However, as it is seen from the above, the electrooptic cell behavior is essentially changed, if the cell was previously exposed to d.c. electric field.

We can explain the observed processes as follows.

1. When the direct field is applied a positive ions Cu^+ generates on the positive electrode. They move towards the negative electrode. Here the LC medium can be considered as a weak electrolyte. Behind the front of the moved ions there is the LC which possesses a surplus positive volumetric charge. The latter interacts with the applied field and distorts its. The locally distorted field orients the molecules NLC and arises a picture of the bending bands. The moving charges arise a electrohydrodynamical (EHD) instability which looks like the chaotically stirring bands. If the electric field is switched off the EHD instability and the caused stirring bands interrupt instantaneously while the static bending of the bands remain in the course of 1.5-2 hours. Naturally, the above processes are not observed in that part of sample through which the front of ions is not passed yet. The neutral and volumetrically charged parts of the sample have different response on the applied alternative electric field of the low frequency. The charges oscillate with the field's frequency. By the low one a runs of the charges are enough large in order to arise a local field. The latter distort a external field. As a result the LC is disorientating and the bands are bending in this part of the sample. In the neutral part of the sample there are no charges at all. The external field is not distorted and the bands are not bending. When the frequency is high the charge's runs are not enough in order to distort the external field noticeably. Consequently the response is equivalent for the neutral and volumetrically charged parts of the sample.

2. Thus, with no doubt it is possible to assert that the volume charge of injected ions traveling through the bulk of a LC cell increasing electrooptical response at the expense of electrohydrodynamic components. To confirm this thought, we will cite experimental observations made by one of the author still in 1974 [5].

Electrooptic response of a twisted LC structure was studied under applying of rectangular unipolar pulses of 6 V amplitude and 5 ms duration and of different frequency sequences. 90°-twisted LC structure was obtained by rubbing clean ITO-covered substrates (without any aligning dielectric layers). Under applying voltage of a single unipolar pulse shape or a pulse sequence shape of frequency no more than 4 Hz, the electrooptical response was practically absent (FIGURE 3a, oscillogram 1).At constant impulse amplitude the growth of pulse sequence frequency gives rise to an increasing the electrooptic response(oscillograms 2, 3). At the pulse sequence

frequency of 10 Hz electrooptic response reaches its maximum value (oscillogram 4) with rise and fall front duration of ~20 and ~40 ms, respectively. Note, that driving impulse duration (during which dielectric torque, untwisting the initial twisted structure, exists) is just of 5 ms that is much less than front duration of electrooptical signal observed. With further increasing the pulse sequence frequency, the electrooptic response shape does not change. Since pulse sequence frequency of ~16-18 Hz, LC medium is not in time to relax optically within the time interval between the two successive driving pulses. The process of storage of the electrooptic response signal is starting from now on (oscillogram 5). An amplified current oscillogram corresponding to the electrooptical response is shown in FIGURE 3b.
Explanations to the observed processes can be the following. During the operation of a square driving pulse the charged ions are generated near the electrode and/or in bulk of the sample. In this geometry their parameters are unknown.

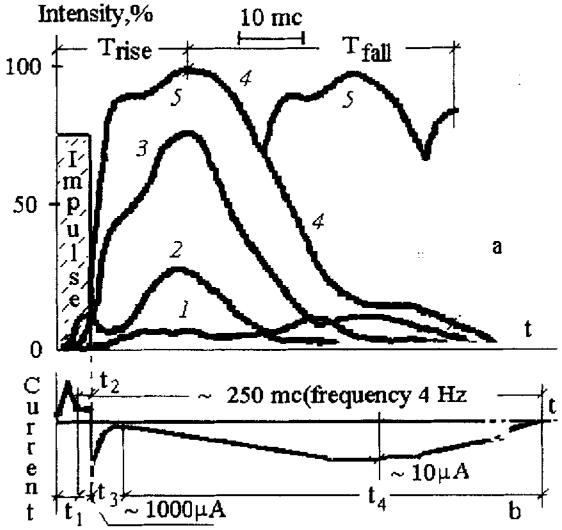

FIGURE 3. Time dependence of transmitted light intensity through the cell at parallel polarizes, under applying of pulsed voltage of 6 V in amplitude and time duration of 5 ms for the different frequencies (a):1- up to 4 Hz, 2 - 5 Hz, 3 - 6,6 Hz, 4 - 10 Hz, and 5 - 40 Hz; (b):simplified shape of the corresponding current across the cell.

Under such unipolar voltage pulse, charged ions are in time to drift a certain distance from the electrode surface and by the end of the pulse operation an excess volume charge into LC bulk is formed. During the time interval between two successive driving pulses the excess bulk charge is being relaxed. If the pulse sequence frequency is sufficient for the excess bulk charge to relax completely within the two-successive-single-pulses interval, electrooptic response of LC on each of the sequent driving pulses is the same and minimal in value (FIGURE 3a, oscillogram 1, $f < 4$ Hz). At higher pulse sequence frequency the excess bulk charge is not in time to relax within the successive-pulses interval and a residual charge is left into LC bulk by the beginning of the following driving pulse. Under these conditions the following driving pulse exerts an influence on LC media not only by means of dielectric torque also by moving the residual charge. Moveable residual charge involves neighboring LC molecules into movement and twisted LC media comes untwisted additionally. The electrooptic response is increased (oscillograms 2, 3). When concentration of residual ion charge riches a sufficient value, by combined operations of dielectric and flow-hydrodinamic torque, the initial twisted structure is a seccess to come untwisted much more and to give maximum electrooptic signal (oscillograms 4, 5).

It is seen from this experiment, that untwisting LC layer hydrodynamic component of electrooptic signal is compared to or even exceeds the component caused by dielectric torque action. It is worth noting that the rise front of the electrooptic signal is being formed long after the driving pulse operation (i.e, its formation is occurred by an inertia).

A simplified current oscillogram was restored from the electrooptic response signal (FIGURE 3b) with peak values of current: 500 μA (t1); 1000 μA (t2); and 10-15 μA (t3) for different time instants, respectively. As it is seen from the oscillogram 3b, during long time after driving pulse stops operating, the back flow current is presented into the bulk of LC. It is obviously due to the movement of the residual bulk charge. An application of driving pulse to the cell while current of relaxed ions is still going on, result in a larger value of the electrooptic signal in our experiments (compared with that if there is no any back flow of residual ions), i.e. stick effect to be occurred in real operation of LCD's. Thus, the said above reasons on processes occurring in LC layer is supposed to be quite argued.

3.These experimental data are referred to the particular LC, particular orienting surfaces and particular thickness of LC cell at constant temperature. Apparently, from the data on optical relaxation times of the same LC at different temperatures and from studying the electrooptical behavior for the different LC layer thicknesses (for example, in a wedge-shaped cell), it is possible to determine anchoring energy of orienting surfaces and LC elastic constants.

4. Knowing the rate of the movement of the ions flow front, one can calculate the Cu^+ ion mobility for given LC. According to our measurements it equals $2,7x10^{-6}$ cm^{-2} V^{-1} s^{-1}.
5. With the developed technique it is possible to measure the mobility of Cu^+ ions for different LC materials as well as microviscoity for any given LC material provided that alignment coatings made of different metals of known ion parameters would be used.
Using commercial LC materials and alignment coatings utilized in real devices, one can study the influence current carries in particular hardware products.

Conclusion

1. It has been shown that the bulk charge, specially injected or by any way originated in LC medium, gives an essential contribution to electrooptical response, increasing the last. This contribution can be attributed to electrohydrodynamic nature of the observed phenomena. It is possible to assert that this contribution does not depend on the type of LC used and can be observed for other LC phases (smectics, cholesterics not necessarily for nematics only) either.
2. The technique (of wide capabilities) for studying an influence of charged ion carriers on the electrooptical characteristics of LC's is developed.
3. The experimental technique for measuring a number of LC parameters, in particular, microviscosity and mobility of injected ions is suggested. Modifying the technique, it is possible to measure elastic constants, anchoring energy and diffusion constants of LC's.

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