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Investigation of Transient Processes in Nematic Liquid Crystal Cells with Semiconductor Substrate, Caused by the Electric Field Applied to Semiconductor

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In the present work the results of detailed researches on characteristics of transient processes, appearing by application of DC field to semiconductor substrate of liquid crystal cell have been carried out. It is shown, that oscillations, caused by longitudinal DC field applied to the semiconductor differ from the oscillations, caused by the Freedericksz transitions. The dependences of character and number of these oscillations on the applied DC field value, the type and thickness of nematic liquid crystal are investigated. The probable mechanisms explaining the observable phenomena are discussed.

Keywords: Freedericksz transition; liquid crystal cell; semiconductor

INTRODUCTION

Last year as a result of rapid development of optoelectronics and photonics the creation and improvement of devices, based on semiconductor-liquid crystal (SC-LC) structure, take on special significance. Some of them are Light Valves (LV) and Spatial Light Modulators (SLM), used in such technological fields like optical data processing, adaptive optics, optical correlation, machine vision, image processing and analysis, beam steering, holographic data storage, and displays.

One of the main parameters of these devices is the response time, conditioned by transient processes in liquid crystal (LC) layer

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due to external influence. Previously we have noted that the application of constant electric field along the semiconductor leads to reduction of characteristic times of Freedericksz transition [1,2]. In the view of practical application this result gives additional possibilities for improvement of SLM and LV time parameters. However, the fundamental understanding of physical bases of the observed phenomenon is necessary, as well as the detection of SC-LC structure parameters, optimal for application of the given effect. In this connection we investigated the processes, taking place in LC cell when applying the longitudinal constant field to semiconductor substrate, and the influence of this field on dynamic of processes, conditioned by Freedericksz transition.

EXPERIMENT

Experimental setup, presented in Figure 1, is assembled to carry out investigations.

The radiation of He–Ne laser, as an optical probe, was directed to the investigated LC cell through polarizer. The light, passing through the LC layer and reflecting from Si substrate, was directed through the second polarizer, crossed with the first, to photodetector, and the measurement results were recorded by oscilloscope.

The investigations are carried out on LC cells, in which one of substrates is glass, covered with the conductive ITO layer, and another one is a semiconductor wafer (single crystal silicon). All investigated cells are planar oriented. For cells preparation there were used nematic liquid crystals E-48 and 5-CB. The special ohmic contacts are put on semiconductor substrate by high vacuum evaporation technique.

Longitudinal DC field has been applied along the semiconductor substrate, and AC field with 5 V amplitude and 1 kHz frequency has been applied across the cell.

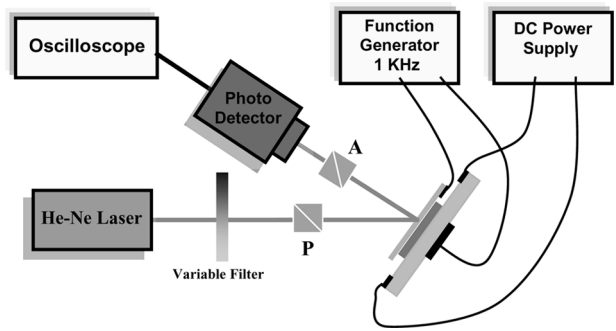

FIGURE 1 Experimental setup.

RESULTS

Earlier it has been shown, that the formation of electric field along the semiconductor substrate surface, contacting with nematic liquid crystals (NLC), leads to reorientation processes of NLC molecules, and correspondingly to appearance of phase incursion [1,2].

It has been noted, that the observable effect has a threshold character, however, the characteristic times of reorientation and relaxation processes differ from similar characteristics, caused by Freedericksz transition.

It is supposed, that the reorientation of NLC molecules under formation of DC field along the semiconductor is conditioned by the processes, taking place at semiconductor-LC interface.

The qualitative analysis of the observable processes is very complicated, in view of the fact that the microscopic structure of the transition layer is not exactly known. If in case with the solid-state heterojunctions more or less exact description is possible in the frameworks of the effective mass approximation, in case of LC the description of energetic spectrum of the electronic states is impossible in view of the complexity of the microscopic structure of these media. Note, that the motion of charge carriers near the semiconductor-LC interface takes place in the field with a complicated potential. From one side the carriers are influenced by the semiconductor crystal field, which is imposed by a slightly changed electric field formed near the semiconductor surface as a result of contact with LC. From the other side the field of LC molecules influences the carriers. Just at the interface the field of the reconstructed layer formed as a result of the interaction between the "dangling bonds" of surface atoms of solid state and LC molecules.

Apparently, the slightest external influence should lead to essential change of the interface layer state.

Taking into account the foresaid, the additional investigations were carried out for clarification of physical bases of the observable phenomenon and determination of parameters, having maximal influence on transient processes, caused by application of constant electric field to semiconductor substrate of LC cell. Dynamic characteristics of the transient process, caused by the application of DC field to the semiconductor, depending on the value of applied voltage, are investigated. LC cells with various semiconductor substrates and also with various thickness of LC layer and various LC type, have been investigated.

Investigations have shown that the application of longitudinal field also leads to NLC molecules reorientation and, accordingly, to phase incursion appearing. The observable effect has threshold character, however, as the value of threshold, as well as the number of oscillations change depending on the parameters of used cell. For all the cases it is possible to conclude that number of oscillations (both reorientation and relaxation), caused by the application of DC

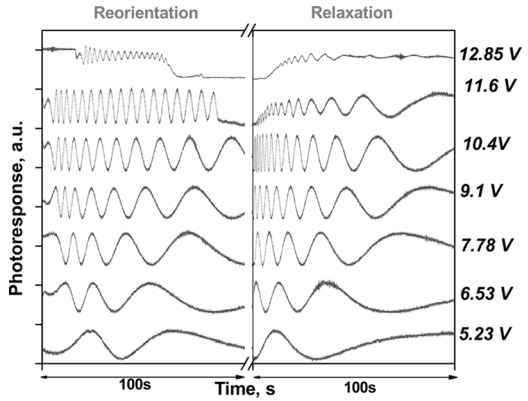

FIGURE 2 Dynamic characteristics of transient processes caused by the applied to semiconductor DC electric field.

longitudinal field to semiconductor (DC oscillations), grows with the increase of the applied voltage. Results of such measurements for one of the investigated cells are presented in Figures 2 and 3.

Dependence of number of oscillations on LC layer thickness has been investigated to LC layer thickness for three various cells made accordingly 23 μm, 36 μm, and 50 μm. All other cells parameters are absolutely identical. The n-type single crystal silicon wafer with 420 μm thickness and 4.5 Ohm·cm resistivity is used in this case as semiconductor substrate. The results of these investigations are presented in Figure 4.

As it is seen from the figure, the number of oscillations increases with the increase of NLC layer thickness.

As it was noted, in the previous works [1,2] the interference of two fields – longitudinal along the semiconductor substrate and

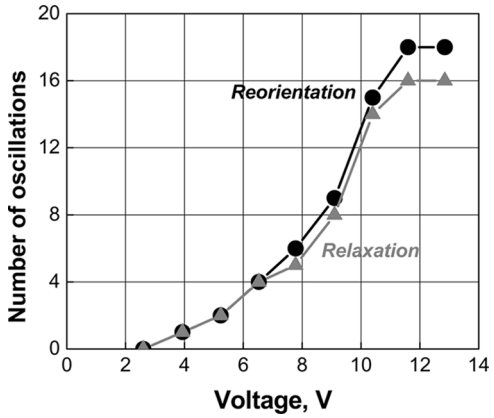

FIGURE 3 Dependence of oscillations number vs. applied to semiconductor DC field.

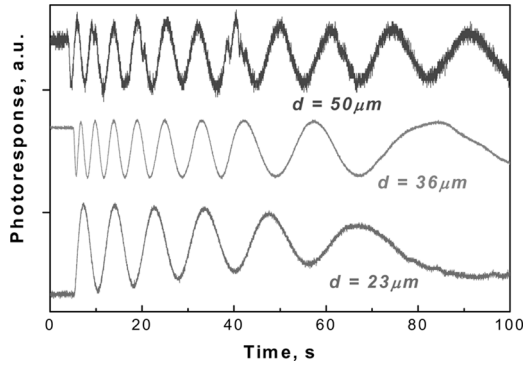

FIGURE 4 Oscillations, generated with NLC reorientation process during the application of DC field, for cells with different LC layer thickness.

transversal along the semiconductor – LC structure, as well as the influence of longitudinal field on characteristic times of Freedericksz transition have been investigated. However, in previous experiments we have observed the mutual influence of these two fields in dynamics. That is, the AC field is switched on when the process of reorientation, caused by the longitudinal DC field influence, has not been completed [2]. Though in this case there is notable reduction of Freedericksz transition times, it is difficult to estimate the influence of DC field, applied to semiconductor, on time characteristics of the structure during such experiment. Moreover, due to complexity of the processes, in this case it is difficult to make qualitative analysis and work out recommendations for practical application of the observed effect.

Reasoning from the aforesaid, we rather changed the experiment conditions. Measurements were conducted at steady state modes. After application of DC voltage to semiconductor substrate, the cell was held certain time (approximately from 100 up to 500 sec. depending on DC field value, cell sizes and geometry, LC type, etc.) before attenuation of all transition processes, induced by DC field. Only then AC field between glass substrate and rear part of the semiconductor was turned on, and the dynamics of Freedericksz transition establishment was recorded. Let's note that in all cases the direction of DC field along semiconductor substrate was in parallel to the director of planar oriented LC cells.

The obtained results for cell, filled with liquid crystal E-48, are presented in Figures 5a and b for reorientation (after turning on AC field) and relaxation (after turning off AC field) processes at various values of DC field applied to semiconductor. For convenience all curves are shifted along vertical scale on equal intervals, on the right the values of DC fields are specified. On the basis of these results, the dependences of Freedericksz transition establishment times vs. DC

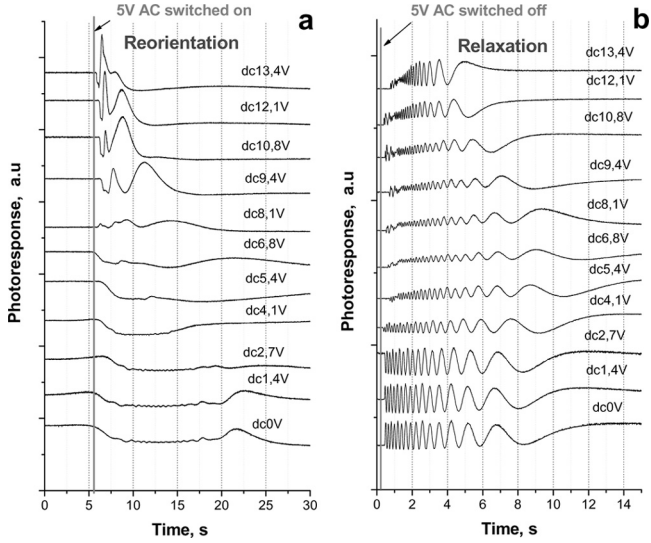

FIGURE 5 Reorientation (a) and relaxation (b) processes in presence of DC field, applied to semiconductor substrate.

field, applied to semiconductor substrate, for reorientation (Fig. 6a) and relaxation (Fig. 6b) processes have been plotted.

From the figures it is seen that noticeable reductions of Freedericksz transition establishment time with the increase of DC field takes place. However, in case of reorientation processes this reduction is much more significant than for relaxation. Similar results have been obtained and on other cells with LC of E-48.

Investigations on cells with LC 5-CB gave similar results (see Figs. 7a, b). The reduction of Freedericksz transition establishment

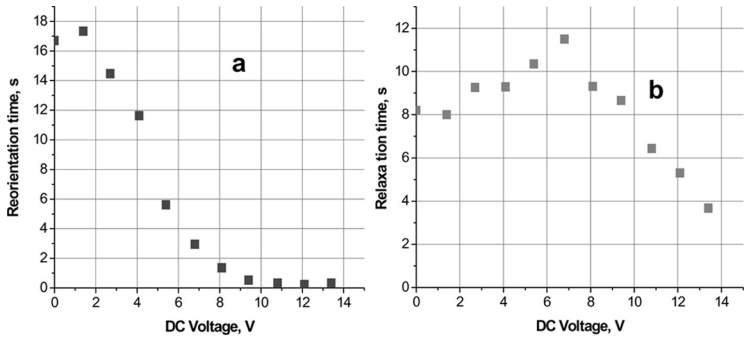

FIGURE 6 Influence of DC field on characteristic times of reorientation (a) and relaxation (b) processes for cell with E-48 LC.

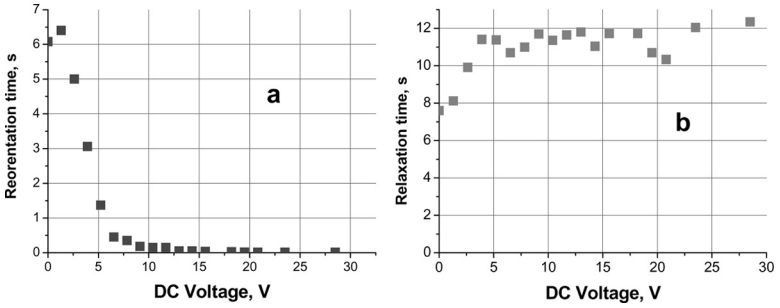

FIGURE 7 Influence of DC field on characteristic times of reorientation (a) and relaxation (b) processes for LC cell with E-48 LC.

times is again observed with the increase of DC field for reorientation processes, at that stronger than in case with cell filled with LC E-48.

DISCUSSION

Thus, the experiments have shown that the orientation processes, characteristics of which depend on the applied voltage value, cell parameters and LC properties, appear when applying DC electric field along the semiconductor substrate of LC cell. Particularly, number and amplitude of oscillations, caused by LC molecules reorientation process, grow with increase of DC voltage and LC layer thickness. Investigations have shown that such influence on the semiconductor-LC structure leads not only to appearance of transient orientation processes, but after their establishment (attenuation of reorientation oscillations) the system turns into a new qualitative state. Observation of Freedericksz effect for the system in this state shows that the characteristic times for reorientation process noticeably reduce. We suppose that, apparently, such behavior may be conditioned by formation of semiconductor-liquid crystal interface layer and processes, taking place in this layer under the external influence.

The evidencing fact is that the characteristic times for relaxation processes, conditioned by Freedericksz transition, are not essentially changed under the external influence. It is reasonable as the relaxation process is conditioned by viscoelastic properties of LC.

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