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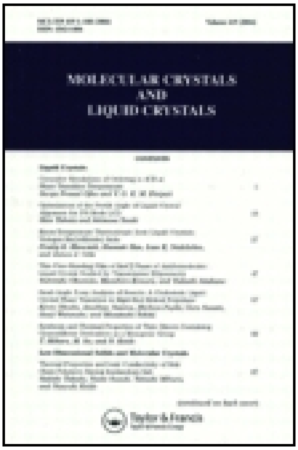

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Influence of Longitudinal Electric Field on Time Characteristics of Freedericksz Transition

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Influence of Longitudinal Electric Field on Time Characteristics of Freedericksz Transition

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Electrooptic properties of liquid crystal cells with semiconductor substrate are studied. A DC electric field has been applied along the semiconductor substrate. It is shown, that presence of such field results both in reduction of Freedericksz threshold and in essential reduction of characteristic reorientation and relaxation times.

For more understanding of the mechanism of current flow through the liquid crystal – semiconductor interface, the Volt-Ampere (V-I) and spectral characteristics of photocurrent for such system have been investigated.

Keywords: Freedericksz transition; liquid crystal; semiconductor

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INTRODUCTION

Semiconductor–liquid crystal interface (SLCI) is a very interesting and promising system both from the scientific and applied points of view, especially since both components of this structure are widely used in various applications. It is very difficult to overestimate the role of semiconductors in modern technologies, since they are basic materials for the majority of components of microelectronics, radioelectronics and optoelectronics. Moreover, investigation of solid-state junctions might lead to significant advances in semiconductor physics and microelectronics.

Practical applications of liquid crystals are also very wide: from the cheap indicators and displays based on the electrooptic effects in liquid crystals, from various sensors up to elements of fast photonic devices. Such a broad use of semiconductors and liquid crystals for technical

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needs is a result of the sensitivity of both materials external influences, such as light radiation and electric field. Moreover, practically all the monitoring of modern techniques is based on the electrical and light signal manipulations.

In view of this introduction, it is very tempting to try using complex properties of both materials in a single structure, which could essentially enrich its functional possibilities. The study of such structures became increasingly important also due to existence of optoelectronic devices based on contact of semiconductors with liquid crystals. These are the optical valves, spatial light modulators, liquid crystal displays and so on. In such devices the role of a thin interface layer formed in the SLCI may be very important. This is confirmed, for instance, by the obtained in [1] enhancement of the giant optical nonlinearity [2], or by occurrence of the anomalous photovoltage effect [3]. One of the most relevant features of interfaces is the fact that in many cases conditions allow formation of thin transition layers, which can be characterized by the two-dimensional electronic conductivity, i.e., such a region where the motion of electrons along one coordinate is limited [4].

Consideration of the problem of various transition layers (both the solid state and those formed on the solid–liquid interface) is very complicated, since the microscopic structure of the transition layer is not exactly known. For the solid-state heterojunctions more or less exact description is possible in the framework of the effective mass approximation, by modeling the transition layer to smoothen the atomic structure. The situation is more complicated for the solid–liquid interface, since the effective mass approximation is unacceptable for the liquid phase. For the semiconductor–electrolyte system a qualitative model was suggested, where an electronic band structure was attributed to the electrolyte [5]. This model breaks down for LC, since for them the electronic states energy spectrum was not considered at all, which was not surprising in view of the complexity of the microscopic structure of these media.

However, one can assume that the motion of charge carriers near this interface takes place in the field with a complicated potential. From one side of the interface the carriers are influenced by the semiconductor crystal field, which is characterized by the three-dimensional translational invariance. This field superimposes with a slightly changed electric field formed near the semiconductor surface as a result of contact with LC and depends on the externally applied voltage. From the other side of the boundary 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 and LC molecules, influences the

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carriers. Apparently, the influence of this interface layer should be affected during the SLCI investigations, where the interface layer parameters could change as a result of special effects by electric fields or light.

EXPERIMENT

To study the electro-optical properties of liquid crystal cells with semiconductor substrate (see Fig. 1) the experimental setup is assembled, Figure 2.

The cell is a thin layer of a nematic liquid crystal (E-48), confined between glass (covered with ITO layer) and semiconductor substrates. High resistance p- or n-type silicon is used as a semiconductor substrate. A thin layer of organic film is applied to both substrates to maintain the planar orientation of liquid crystal molecules. Lasers with 0.63 μm and 0.53 μm wavelengths were used as a light source. The cell was placed between the crossed polarizers (PL, AL). Light reflected from the cell was registered with photodetector on oscilloscope (Fig. 2).

Contacts for the AC voltage application with frequency 1 kHz from function generator were attached to the glass substrate and to rear part of semiconductor to observe the ordinary electrooptic Freedericksz effect.

Beside that, the special additional contacts allowing application of DC electric field have been made on semiconductor substrate. Such cell design allows investigation of orientation and relaxation characteristics of the liquid crystal – semiconductor structure under the influence of AC field, applied between ITO glass and semiconductor, as well under the influence of DC field, applied to semiconductor.

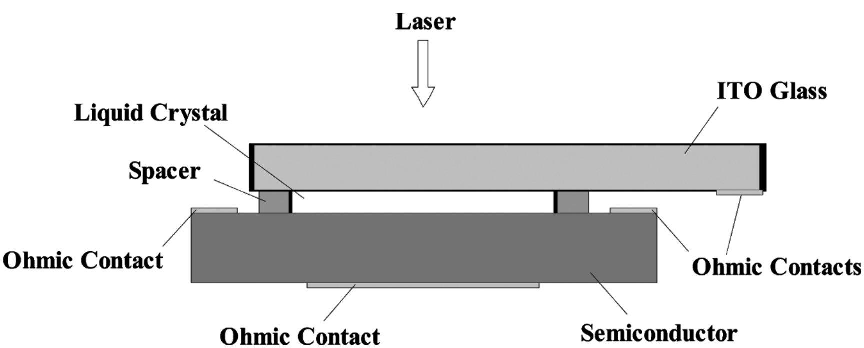

FIGURE 1 Design of liquid crystal-semiconductor cell.

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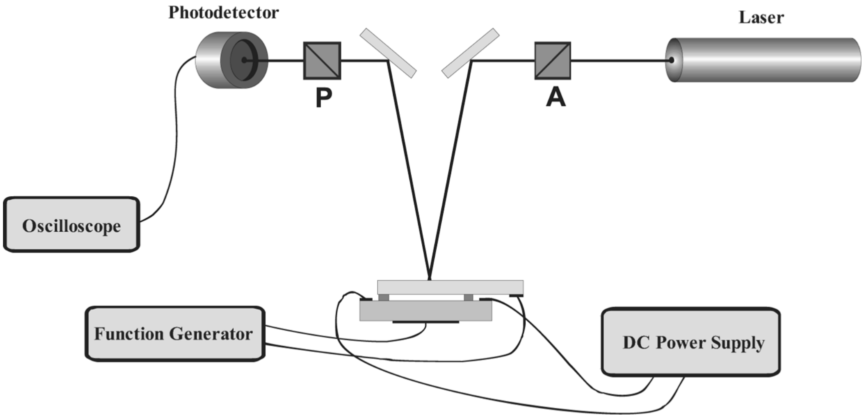

FIGURE 2 Experimental setting for measuring the reorientation and relaxation characteristics of liquid crystal-semiconductor cell.

RESULTS

To find out the role of the semiconductor substrate from the point of view of liquid crystal cells' electro-optical properties we have produced two identical cells: in one of them the liquid crystal has been confined between two glass substrates, and in the second one – one of the glass substrates has been replaced by semiconductor.

Let us note that in both cases typical oscillations due to the Freedericksz transition are observed (Figs. 3, 4 correspondingly). It is easily noticed, however, that in case of the cell with semiconductor substrate the number of oscillations noticeably grows (Fig. 4).

As it is known, semiconductors by their resistivity are on intermediate position between metals and dielectrics. The presence of terminal resistance in semiconductors allows to apply to them electric field in wide enough range. Taking this into consideration, we can investigate electro-optical properties of liquid crystals in the presence of longitudinal electric fields. Here it is necessary to especially note that under the influence of only longitudinal constant (DC) field, applied to semiconductor, orientation oscillations also arise. However, there is an essential difference between such oscillations and the oscillations, caused by the Freedericksz transition.

The dynamics of oscillations caused by DC field applied to semiconductor is presented in Figure 5. It is seen that starting from DC voltage of 4.5 V (threshold value for the given cell), the oscillations arise and with increase of DC field their number noticeably grows. Similar experiments have been carried out for a cell with a different semiconductor substrate.

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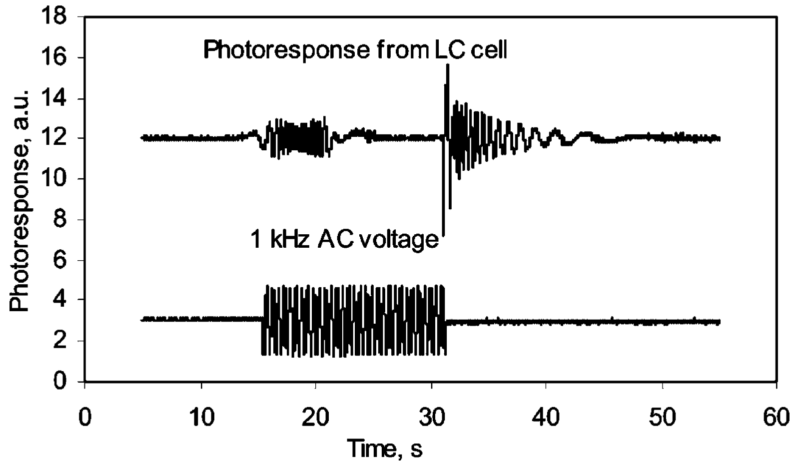

FIGURE 3 Typical reorientation and relaxation oscillations for LC cell with two glass substrates.

For comparison, the dependence of the number of oscillations on the DC field applied to semiconductor is presented in Figure 6. As one would expect, the number of oscillations also depends on the cell's thickness (Fig. 7).

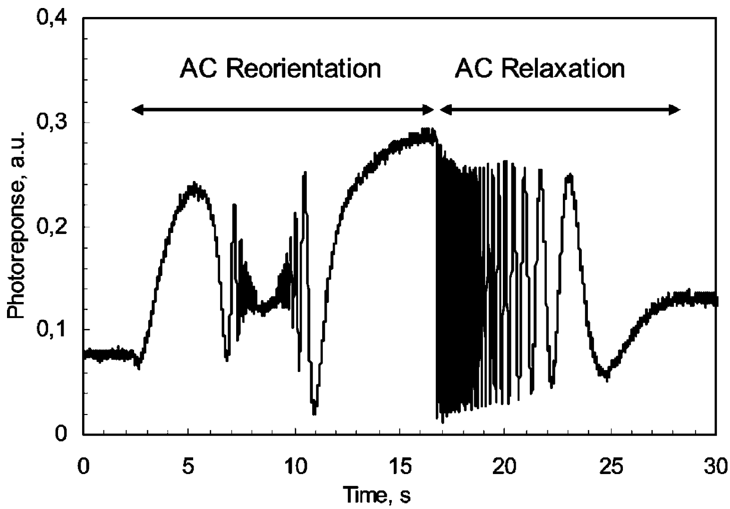

FIGURE 4 Typical reorientation and relaxation oscillations for LC cell with semiconductor substrate.

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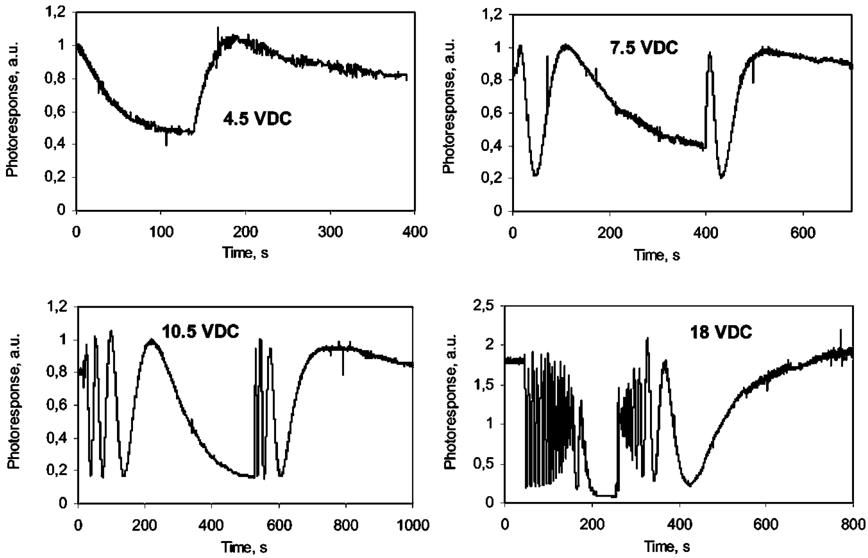

FIGURE 5 Reorientation and relaxation oscillations caused by DC field for LC cell with semiconductor substrate.

The observed phenomena, in our opinion, most likely are caused by the presence of the interface layer formed between semiconductor and liquid crystal. We mentioned the complex character of such layers in the introduction. However, presence of such layer on the semiconductor–liquid crystal boundary implies existence of properties, typical for

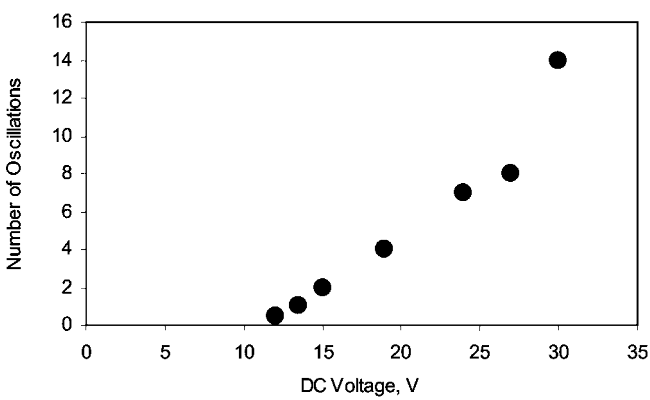

FIGURE 6 The dependence of oscillations' number from the applied to semiconductor DC field value.

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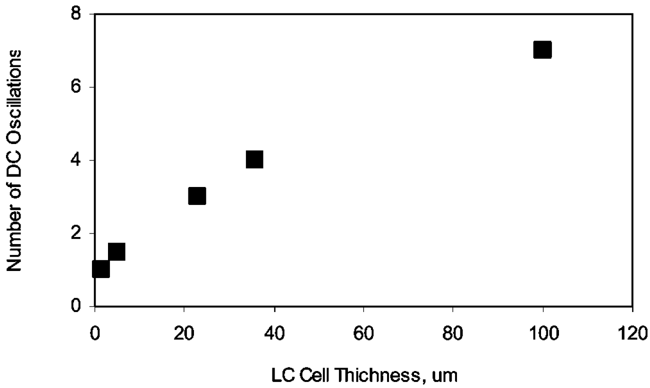

FIGURE 7 The dependence of oscillations' number from the liquid crystal thickness.

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transitive layers: homo-, hetero-transitions, and also inter-phase transitions. First of all, it is the presence of the electric field caused by the processes of electronic exchange on the boundary. It is reasonable to assume that such field should inevitably affect the current flow through the structure.

For more complete understanding of the processes occurring on the liquid crystal – semiconductor boundary, in particular the mechanism of current-passing, the Volt-Ampere (V-I) and spectral characteristics of photocurrent of such system have been investigated (Figs. 8, 9 correspondingly).

As it is seen from the figures, the V-I characteristic of cell is typical for structures with internal built-in fields. Therefore, on a direct branch of V-I characteristic it is necessary to expect increase of photocurrent through the cell. The results of these investigations are given in Figure 10.

In our opinion, more complete understanding of the role and influence of the interface layer on electro-optical properties of liquid crystal cells with semiconductor substrate, undoubtedly, demands additional research. However, it is by now clear that application of longitudinal electric field to one of LC cell substrates results in the expansion of management possibilities of its characteristics. First of all, as it was marked above, it is the occurrence of oscillations when DC field is applied to the semiconductor substrate. Secondly, the presence of semiconductor alone already results in the change of orientation and relaxation characteristics of LC cell caused by Freedericksz transition. It is obvious to expect also interesting results in the mutual influence

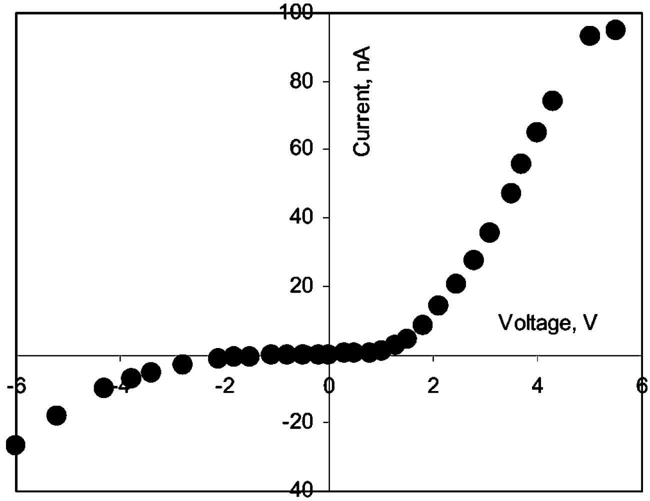

FIGURE 8 The Volt-Ampere characteristics for LC cell with semiconductor substrate.

of longitudinal and transverse fields applied to LC cell. These results are shown in Figures 11–13. On Figure 11 the effect of varying field on DC and AC oscillations number is presented. At small values of AC voltage (up to Freedericksz threshold), the number of DC oscillations

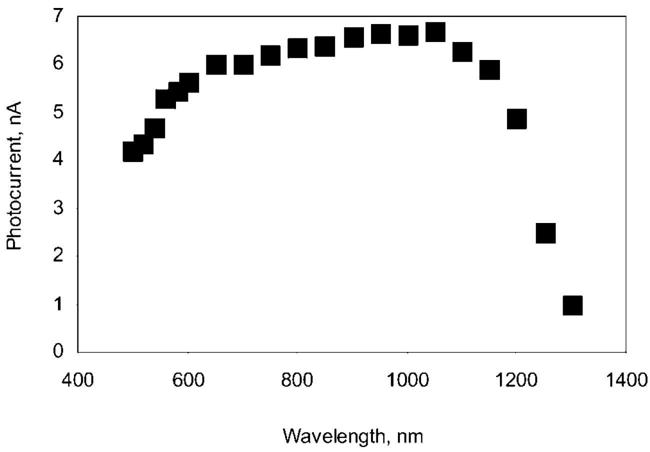

FIGURE 9 The spectral characteristic for LC cell with semiconductor substrate.

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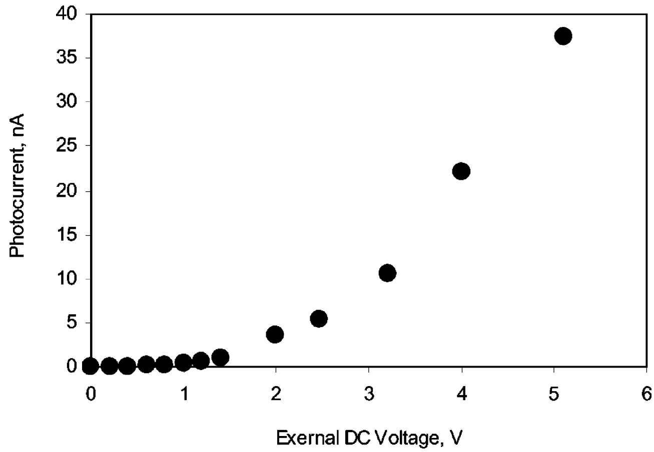

FIGURE 10 Dependence of photocurrent from the external voltage.

practically is constant. AC oscillations are excited as the field grows. In particular, for these voltage values a certain increase of DC oscillations is observed. However, further increase of AC field results in suppression of DC oscillations, while the number of AC oscillations grows.

Actually, presence of the DC field reduces the threshold value of AC field for Freedericksz transition. This can be seen well on Figure 12.

The presence of DC field results not only in the reduction of Freedericksz threshold, but also, as it was mentioned above, in the increase of the number of reorientation and relaxation oscillations,

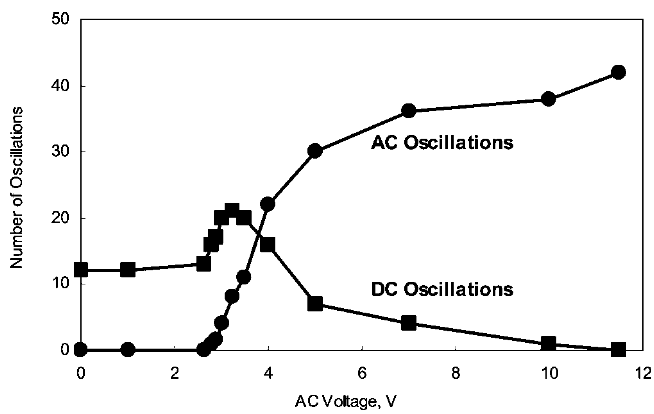

FIGURE 11 Influence of AC field on the number of AC and DC oscillations.

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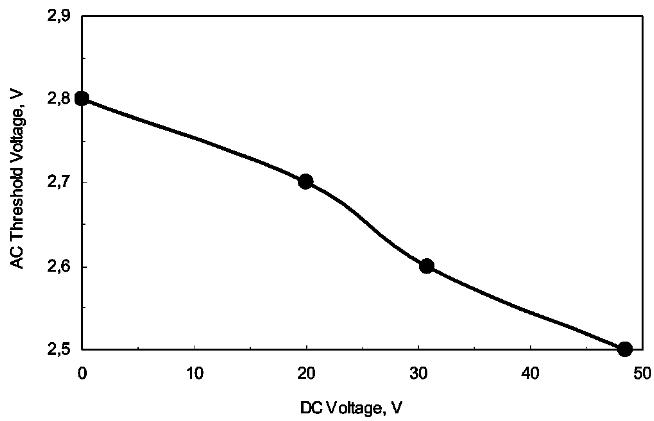

FIGURE 12 Influence of DC field on threshold value of Frederick's transition.

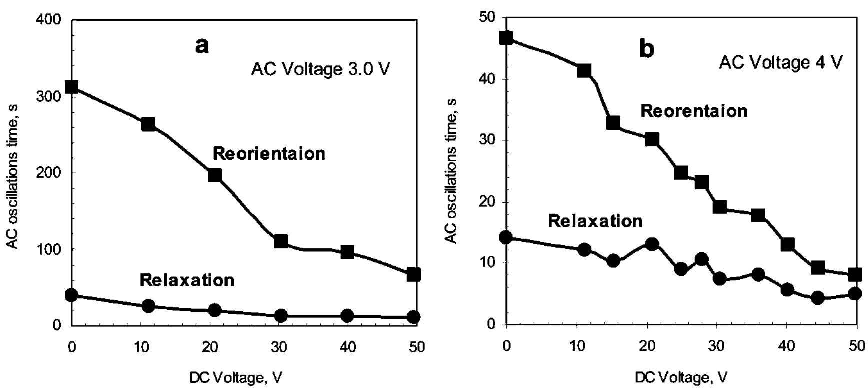

FIGURE 13 Influence of DC field on characteristic times of AC oscillations at different AC voltage.

and, hence, in the reduction of typical reorientation and relaxation times of AC oscillations. The results of such measurements for two different AC field values are given in Figure 13.

CONCLUSIONS

1. Application of longitudinal constant electric field to one of liquid crystal cell substrates results in occurrence of orientation oscillations, differing from oscillations, caused by Freedericksz transition. As the DC field magnitude increases, the number of such oscillations noticeably grows.

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2. The volt-ampere characteristic of the LC cell with semiconductor substrate and dependence of photocurrent on applied voltage are typical for structures with the internal built-in fields.
3. Mutual influence of constant longitudinal and variable transverse electric fields applied to liquid crystal cell is observed.
   - Change of the AC field value results in the change of the number of oscillations caused by the DC field.
   - Presence of the DC field reduces the threshold value of AC field for Freedericksz transition.
   - Presence of the DC field results in reduction of typical reorientation and relaxation oscillations times, caused by Freedericksz transition.

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