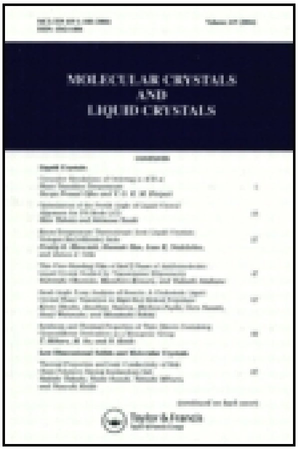

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Interface effects on semiconductor-liquid crystal structure

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INTERFACE EFFECTS ON SEMICONDUCTOR-LIQUID CRYSTAL STRUCTURE

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We study orientational processes due to externally controlled interaction between surface atoms of a semiconductor and the interfacial molecules of liquid crystals (LC). Two different types of LC reorientation is observed: one due to an electric field acting along the interface between the semiconductor and the LC; and the conventional volume reorientation caused by the electric field acting between the LC substrates. The time characteristic and the threshold value of one type of reorientation depend on the degree of development of the other type of orientation.

Keywords: interface; liquid crystal; semiconductor; "surface" orientation

INTRODUCTION

The investigations of semiconductor-liquid crystal interface (SLCI) are very promising from the practical viewpoint. Both constituents of SLCI are widely used, due to their high sensitivity to external influences, specifically, to light beams and electric fields. Using semiconductor and liquid crystal materials in a unified structure may lead to essential enrichment of functional capabilities of opto-electronic technologies. Such structures have already been used in liquid crystal displays with active matrix, i.e. substrate coated by amorphous α-Si and as spatial light modulators (SLM). However, the sluggishness remains one of the major shortcomings for LC displays with active matrix, as well as for SLM. Thus, investigation of

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possibilities to influence on dynamic characteristics of the LC orientation by external electric and optical signals is very important.

Below we present the results of further investigations of the interaction of the recently observed "surface" orientation effect [1] that occurs upon application of an electric field along the semiconductor electrode surface with the conventional electrooptic effect.

EXPERIMENT

The nematic LC E48 was used in these studies planarly oriented in three different thicknesses (10 μm, 23 μm and 36 μm), at that most of measurements were fulfilled by using thick cells. One of the substrates of the cells was glass with ITO coating, whereas the second substrate was made of a semiconductor Si. To apply the surface DC field along the interface between the semiconductor and the LC, electro-conductive contact layers were sputtered along the edges of the semiconductor substrate, in areas not in contact with the LC. An additional contact was coated on the back surface of the semiconductor substrate for application of an AC field across the LC cell.

Two different types of external bias voltages were applied to the cells. The first type is a 1 kHz AC field as it is usually applied across LC cells leading to the well-known Fredericsz effect. The second type is a DC voltage applied along the semiconductor, although the application of AC field along the semiconductor does not result in any effect. As we have reported before in [1], a new type of orientational effect takes place upon application of a constant electric field along the interface. The interaction of these two orientational processes is studied in details in the present paper.

The investigation of dynamic characteristics of the reorientation effects was implemented through measurement of the variation in the polarization of a test laser beam reflected from the semiconductor substrate. The number of oscillations in this laser beam at the output of the polarizer corresponds to the phase shift of the beam, which is a measure of the magnitude of reorientation of the LC. We used two types of lasers with wavelengths 628 nm and 530 nm and maximum powers ~20 mW. AC fields of various strengths were applied across the LC cell simultaneously with the fixed DC field (up to 47 Volt) along the surface, and the influence of this field on the threshold and dynamic characteristics of the Fredericsz effect was investigated.

RESULTS AND DISCUSSION

Figure 1 demonstrates a typical dynamic characteristic of the reorientation process obtained in the following circumstances.

First the longitudinal surface field is turned on, and a relatively slow process of surface reorientation starts taking place. Then, at a certain moment (m = 3 indicates the number of oscillations induced in the test laser beam due to application of the DC field), an AC field across the LC cell is turned on, leading to a conventional effect reorientation. In contrast to the surface reorientation, the conventional effect occurs much faster and is finished long before the surface effect reaches stationary state. After the conventional process of reorientation is reaching steady state, both the surface DC field and the AC fields are turned off. In this mode (Fig. 1), the relaxation of the conventional effect occurs against the relaxation of the surface effect and proceeds faster. Moreover, during the occurrence of the surface effect, it is possible to observe the relaxation of the conventional effect as the AC field is turned-off (Figure 2).

The most interesting effect in our observations is the fact that, after each following turn-on and turn-off of the conventional effect versus the continuous surface reorientation effect, the characteristic times of the conventional orientation and relaxation process essentially decrease. In other words, the speed of reorientation and relaxation of the NLC director induced by an AC electric field across the cell (conventional effect of Freedericksz transition) is decreasing at the presence of the DC electric

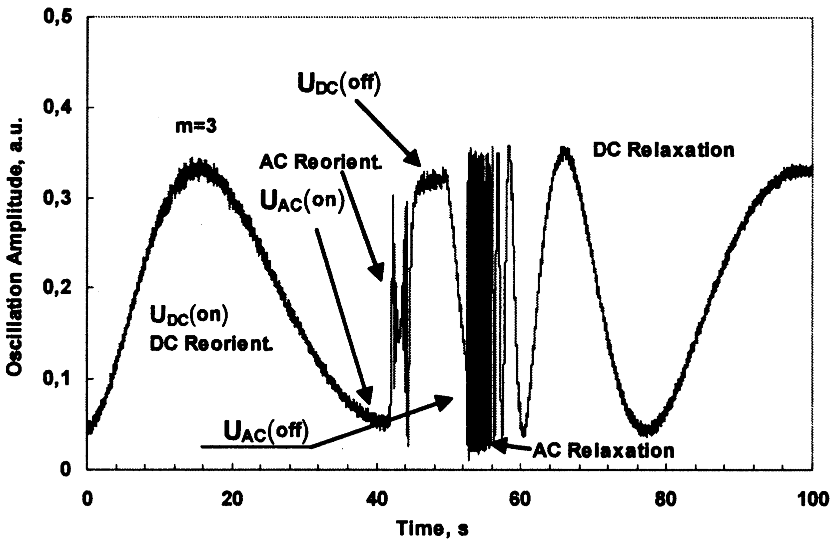

FIGURE 1 Dynamics of LC reorientation induced by electric fields applied along the interface between the semiconductor and LC (surface field) and normal to the cell.

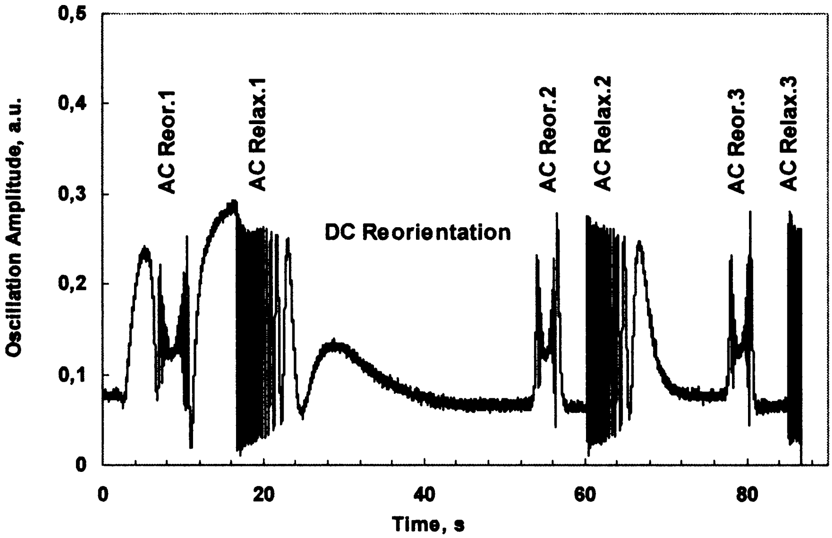

FIGURE 2 Dynamics of LC reorientations induced by the normal AC field repeatedly switched on and off at different stages of the surface field induced reorientation.

field applied along the semiconductor substrate. By that, the switching times are shorter the longer the semiconductor substrate is subject to the DC field.

The switching times of the conventional effect of AC reorientation increase upon turning-off the DC field. By that, the switching times increase gradually with relaxation of the surface effect orientation. The dependences of the characteristic times of the conventional orientation, observed at various stages of the surface orientation, are shown in Figure 3. The data in Figure 3a are obtained at application of the DC field. Figure 3b shows the increase in the switching times when switching off the DC field.

The conventional reorientation times can be further decreased by increasing the DC surface fields (Fig. 4). The effect for cells of different thickness is shown in Figure 5.

Below we presented the results of comparison of the numbers of oscillation of both types of orientation effects depending on the strength of the AC voltage at a fixed DC field (47 Volt). The number of DC oscillations is practically constant at the pre-threshold values of the AC-field and increases substantially near the threshold of AC-field induced reorientation (Fig. 6). Strong AC fields that saturate the reorientation result in decreasing and complete disappearance of the effect of the surface DC field.

To further study the interference between these two orientational processes, the strength of the DC field was gradually increased while applying

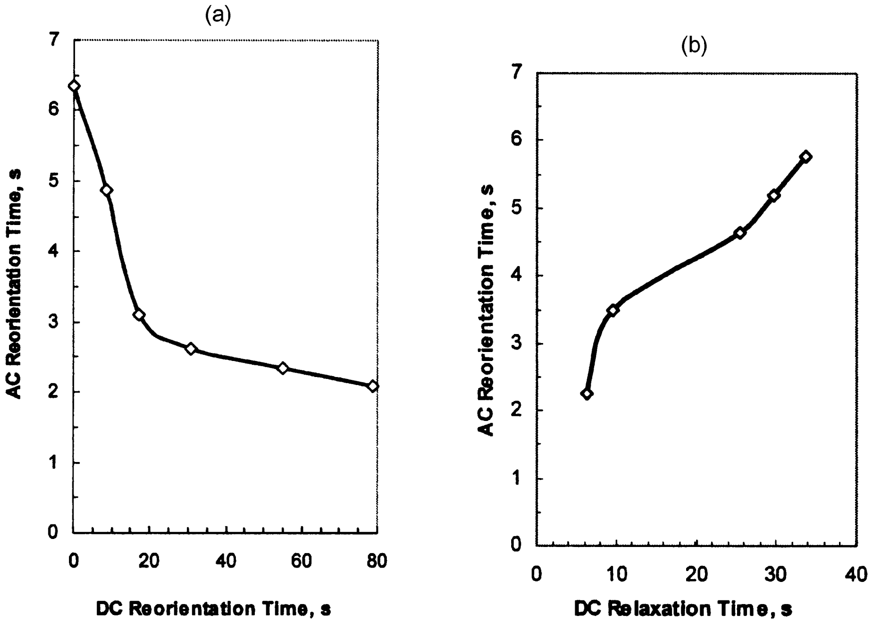

FIGURE 3 Characteristic times of the conventional reorientation for different stages of surface reorientation: a) surface DC field is on; b) surface DC field is off.

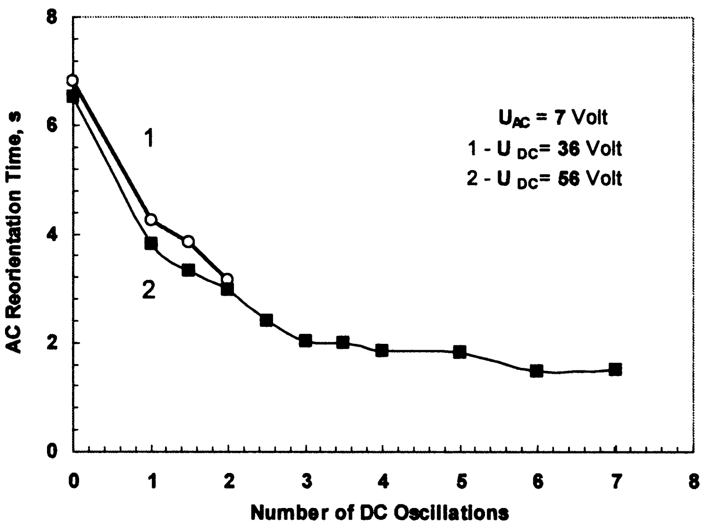

FIGURE 4 The characteristic time of LC reorientation induced by an AC electric field as a function of strength of the surface orientation.

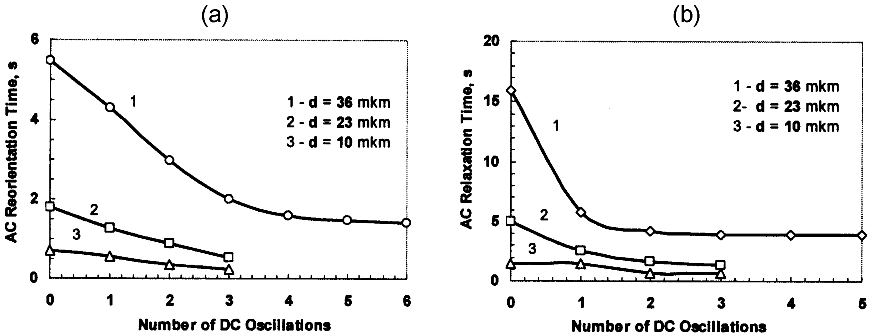

FIGURE 5 Dependences of the conventional reorientation: a) and relaxation; b) characteristic times on the stage of surface reorientation for cells of various thicknesses.

a constant AC field to the cell. While the AC field-induced reorientation process with no surface field applied starts at 2.8 V, application of a DC voltage of 47 V reduces the threshold voltage of the AC field to 2.5 V (Fig. 7). Thus, the threshold of AC field-induced reorientation process

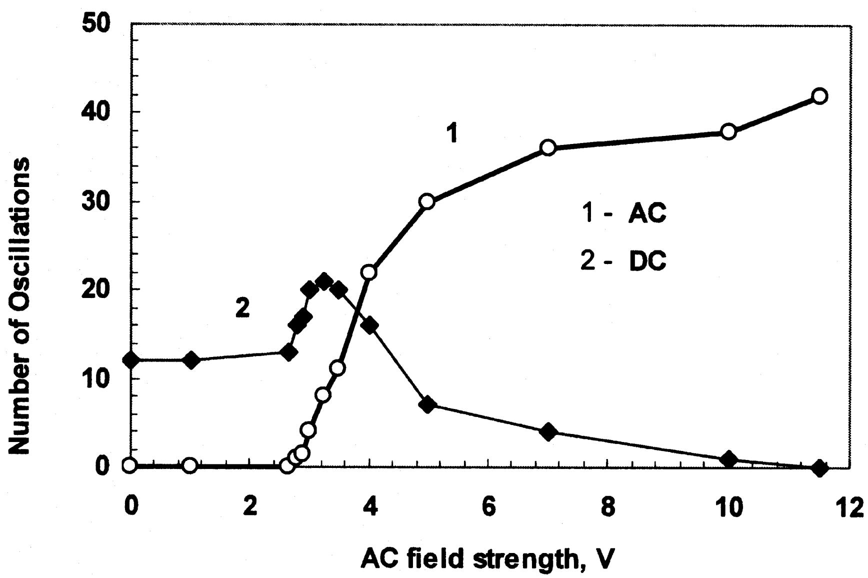

FIGURE 6 The number of oscillation for both conventional and "surface" effects depending on AC voltage at 47 V DC voltage.

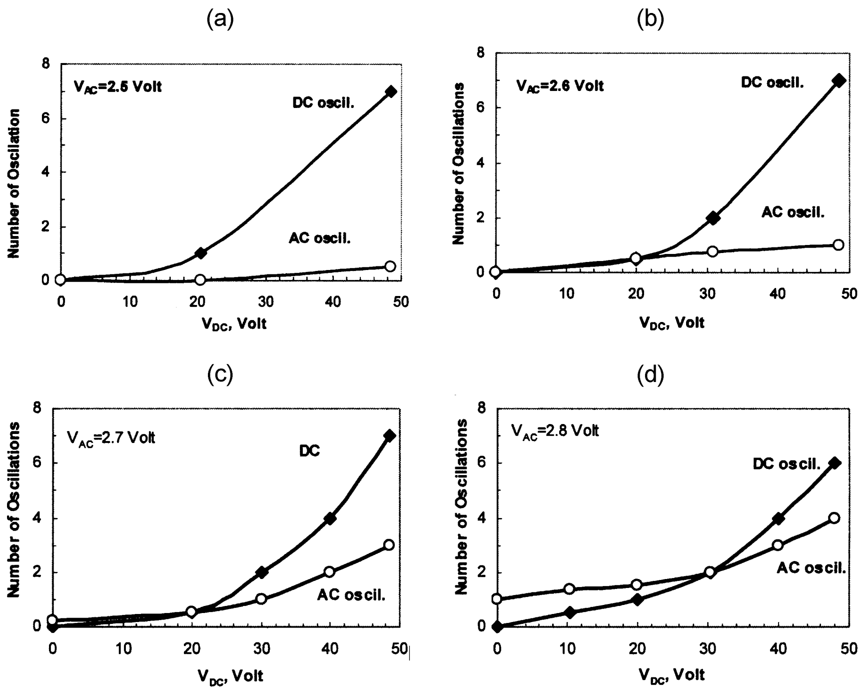

FIGURE 7 The comparison of number of oscillations for both "surface" and conventional "bulk" reorientation effects, depending the values of DC field and at the different fixed values of alternating field: a) 2.5 V; b) 2.6 V; c) 2.7 V; d) 2.8 V.

decreases with increasing surface field (Fig. 8). Moreover, the number of the AC oscillations increases with increasing DC field (Fig. 9a). The dependence on the strength of the DC voltage is becoming negligible at increasing values of the AC field (Fig. 9b,c).

These results suggest that both phenomena have similar nature corresponding to reorientation of LC director. Their origins are, however, essentially different: the conventional effect starts by reorientation of the LC in the bulk of the cell whereas the surface is stimulated first at the boundaries of the cell at the semiconductor substrate.

It is important to emphasize that, in spite of that at the sufficiently great supraliminal behavior the obtained AC oscillations are conditioned as a rule by the bulk effect, nevertheless the influence of DC "surface" field becomes apparent unambiguously at the dynamic characteristics consideration. Really it is obvious from Figure 10, where the reorientation and relaxation times of bulk effect are presented at different stages of "surface" effect and for AC threshold, intermediate and supraliminal behavior.

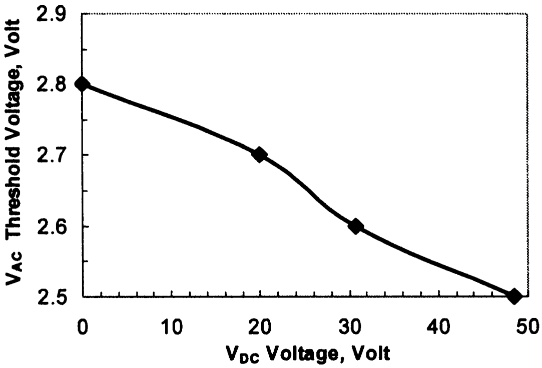

FIGURE 8 The threshold of conventional effect beginning, depending on value of applied "surface" field.

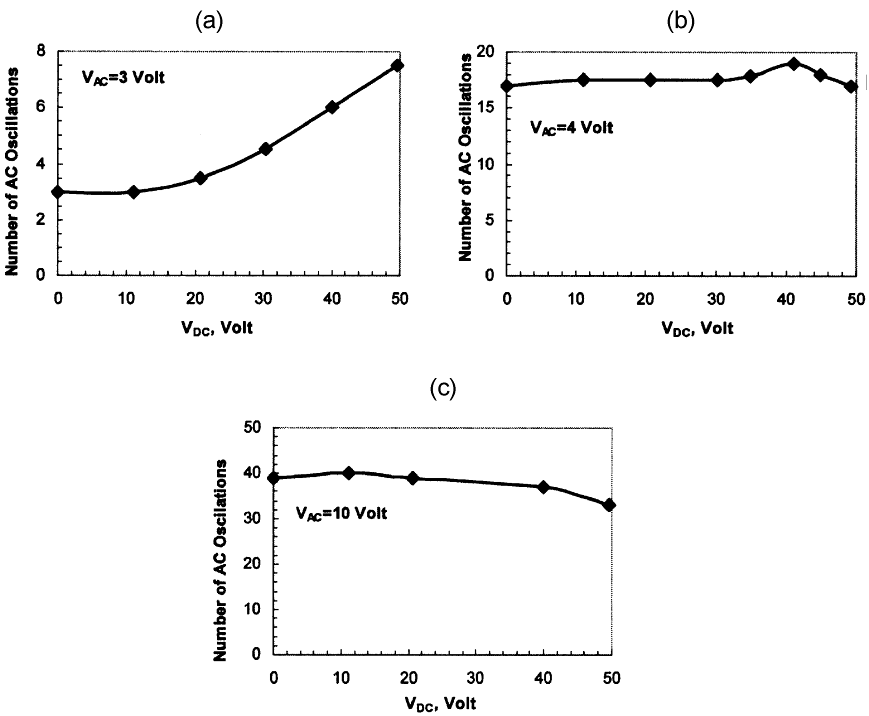

FIGURE 9 The number of AC oscillation depending on DC voltage for a) near-threshold; b) intermediate and c) supraliminal effects.

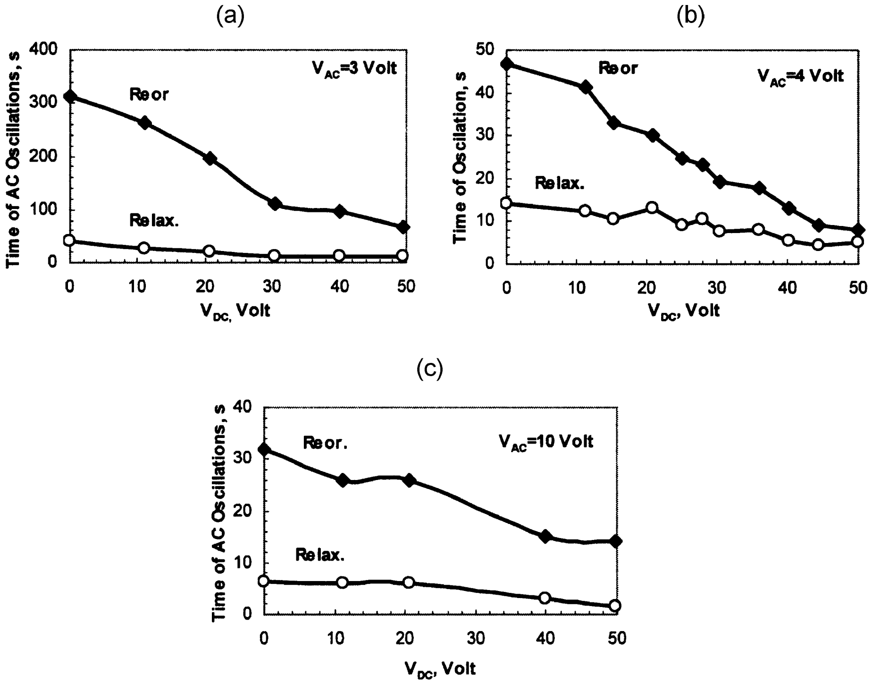

FIGURE 10 The reorientation and relaxation times of AC field-induced reorientation at different stages of surface effect: a) $V_{AC} = 3\,V$; b) $V_{AC} = 4\,V$ and c) $V_{AC} = 10\,V$.

It was suggested in [1] that the phenomenon of reorientation, observed upon application of a DC field along the interface between the semiconductor and the LC, was conditioned by the influence of the surface. It is plausible that the main factor influencing the dynamic characteristic of the observed orientational processes is the change in the anchoring conditions of LC molecules on the semiconductor substrate induced by the DC field.

CONCLUSION

These results confirm the importance of a thin surface layer formed at the SLCI on processes taking place at various external excitations. Unfortunately, the exact quantitative analysis is very difficult here due to the complexity of the microscopic structure of the transition layer [2]. These results provide new possibilities for controlling electrooptic processes at the SLCI and can be used to increase the operating speed of SLM, LC displays and other LC-based electro-optical devices. We hope that the observed increase in the speed of reorientation of over 5–6 times is not a final result and it may be enhanced further using different types of semiconductors, treatment of the surfaces, and variation of liquid crystal parameters.

As another interface-controlled effect may be mentioned the phenomenon of light induced recharging of the electronic states formed on SLCI as a result of LC molecules bonding with the semiconductor surface atoms. Indeed, light induced recharging on the interface leads to change of LC anchoring conditions, and finally results in some peculiarities of electro-optic phenomena passage. For instance, one can mention the increasing in phase incursion, obtained, when the effect of giant optical nonlinearity was investigated at the SLCI [3]. Note, that only this effect allows designing and creation of a relatively sensitive device for laser beam intensity real time measuring [4].

Thus, various external influences can essentially affect the SLCI characteristics, and consequently the use of additional possibilities of electrooptical processes regulation by both electrical and optical signals, of course, leading to the enhancement of corresponding devices functions.

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