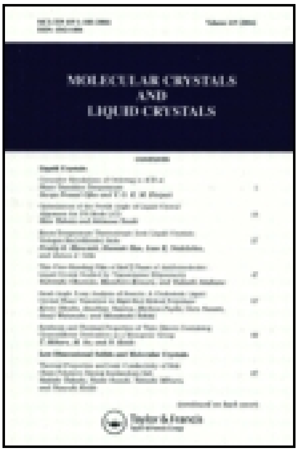

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Optimizing of Control Signal Shape for Improving of Time Characteristics of Liquid Crystal Based Devices

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The dynamics of reorientation processes of planar oriented nematic liquid crystals can be controlled and improved by 1 kHz continuous, as well as pulsed, auxiliary electric fields. A device and a special software for forming a control signal of complex shape are created. We show that using a four-step control signal for optical switching allows fivefold reduction of switching time compared to conventional two-step signal.

Keywords Electro-optical response; light valve; liquid crystal; transient nematic effect

Introduction

The operating speed is one of the main parameters of devices based on liquid crystals (LC)–displays, spatial light modulators, light valves, phase retarders, etc.). It is known that for improvement of operating speed the thickness of LC is reduced, special types of orienting coatings and liquid crystals are used, the control is carried out by pulse voltage. For example, the use of obliquely deposited orienting coatings reduces the orientation time, but the relaxation time increases in this case [1]. The increase in operating speed for both orientation processes is observed for the so-called π-cells, when obliquely deposited orienting coatings are placed opposite each other anti-parallel [2,3]. In this case, the transient processes take place in the presence of hydrodynamic flow, which contributes to operating speed. There are double-frequency liquid crystals, which change the sign of dielectric anisotropy at different frequencies of the control voltage [4,5]. Some studies are dedicated to the synthesis of quick-response LC or LC sensitization by means of nano-particles (fullerenes, nanotubes, ferroelectric particles, etc.) [6]. Recently polymer-stabilized LC found an application, in which the operating speed is provided with LC ordering not only by orientation at the boundaries, but also by LC stabilization in the volume between the long polymer molecules [7].

It is known that the degree of liquid crystal order is characterized by the order parameter S, which depends on the initial state of LC orientation, as well as on the external influences (temperature, electric and magnetic fields, etc.) [8]. When contacting of LC with specially treated surface of the substrate the order is changed: a near-surface polarity and short-range

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order translation into volume appear [8,9]. The change of the order parameter due to the influence of the surface is described by the theory of Landau-de Gennes [10] according to which, the value of Sparameter in the near-surface region is greater than in the bulk of liquid crystal. One can assume that under the certain conditions (in this case the shape and parameters of the control electric signal are meant) the external exposure can result in penetration of high order surface layer into the volume, and thus affect the dynamics of reorientation processes. This paper deals with optimization of control signal shape taking into account the input of the highly ordered surface layer in the dynamics of reorientation processes.

Statement of Problem

When the laser beam propagates through LC cell placed between crossed polarizers so that the direction of the polarization of the incident beam makes a 45° angle with the LC director (Fig. 1), and under the influence of external electric field the typical oscillations due to the reorientation of LC are observed.

Let's consider the orientation processes of LC molecules under the influence of 1 kHz AC voltage with the amplitude varying with rate of 30 mV/s (Fig. 2). In this case, the orientation and relaxation oscillations occur identically. Slow change in voltage provides an adequate response of the molecules, despite the inertia of the liquid crystal. By that, the central layers of LC cell are first reoriented with increasing voltage. In this case the LC order during the reorientation processes does not change.

A different picture is observed in case of sudden impact of the external voltage with a sufficiently large amplitude. The electro-optical response of LC on the impact of a bipolar pulse with a duration of several milliseconds and a frequency of 0.1–10 Hz is considered (Fig. 3). The duration and repetition rate is chosen in such a way as to ensure a sharp reorientation and complete relaxation of the LC molecules.

In this case, the nature of reorientation and relaxation oscillations is different. At the beginning of the pulse a sharp reorientation oscillation is observed, and then the oscillations fade away and by the end of the pulse seek to restoration. Upon the termination of the pulse (relaxation) the nature of the oscillations is the same as in previous case (slow variation of voltage).

At the initial moment of the pulse action (sharp reorientation oscillation, Fig. 3) the system tends to keep its original ordered state. Here, perhaps the translation of highly

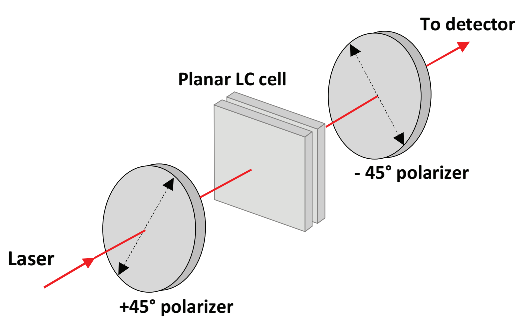

Figure 1. Scheme of experiment.

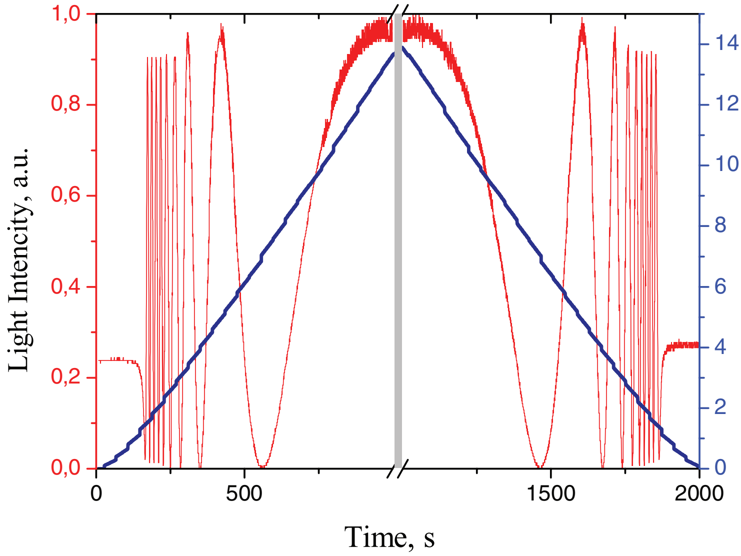

Figure 2. The electro-optical response under influence of slowly varying control voltage.

ordered surface layer into the LC bulk occurs under the action of elastic forces. Then the ordering in the bulk is broken because of unmatched response of LC molecules to sharp forced impact of electric field and appearance of nonviscous flows (the oscillations fade away due to the strong light scattering). By the end of pulse action the system tends to the order restoration (restoration of reorientation oscillations). After the end of pulse action the relaxation process takes place only under the influence of molecular forces of elasticity,

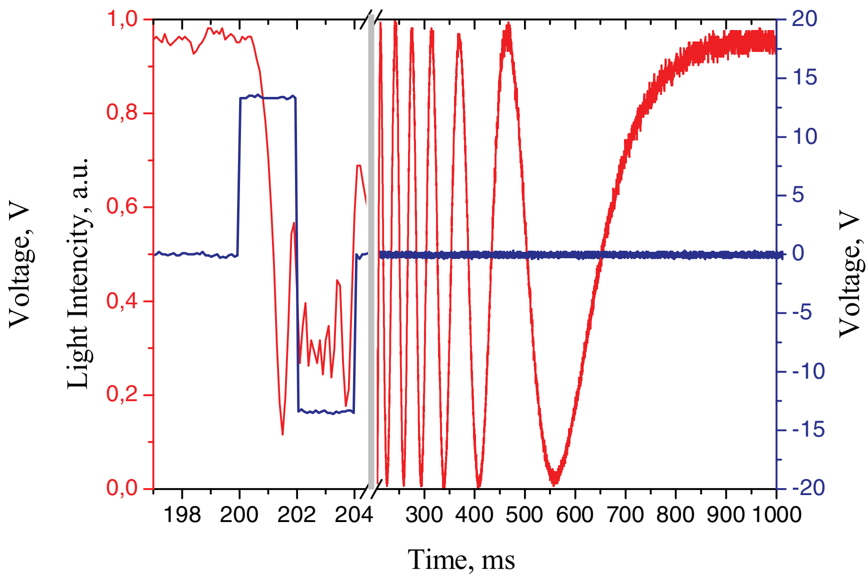

Figure 3. The electro-optical response under the influence of pulse voltage.

and the system returns to its original oriented state, similar to relaxation after influence of alternating electric field.

The above mentioned feature of the reorientation process under the influence of pulse, namely, more ordered reorientation of LC at the initial moment of its action, can be used in forming the control signal to improve the operating speed of LC based devices

Experimental Results and Discussion

A planar oriented cell filled with 6CHBT nematic liquid crystal ($\Delta n = 0.15$) with a thickness of 5 μm was made and investigated. The orientation of LC molecules on the substrates was carried out by photo-alignment–deposition of ROLIC linearly photo-polymerized polymer ROP-103/2CP on the substrate and subsequent irradiation with linearly polarized radiation of He-Cd laser at 325 nm wavelength.

Such a LC cell, located between crossed polarizers, so that the angle between the direction of polarization of the incident beam and LC director is 45°, can operate as an electrically controlled light valve (LV), where the intensity of transmitted light is changed from minimum to maximum and back again within π phase shift. To achieve maximum performance it is necessary to select the proper range of control voltage using the calibration curve (Fig. 4a).

The prepared LC cell as a light valve can operate in two modes (Fig. 4b):

– fast switching (high-voltage range $V >> V_{th}$)
– slow switching (the voltages close to the threshold $V < 5V_{th}$).

In the fast switching mode under the influence of strong electric field both bulk and boundary layers of LC are involved in reorientation process, which reduces the relaxation time due to

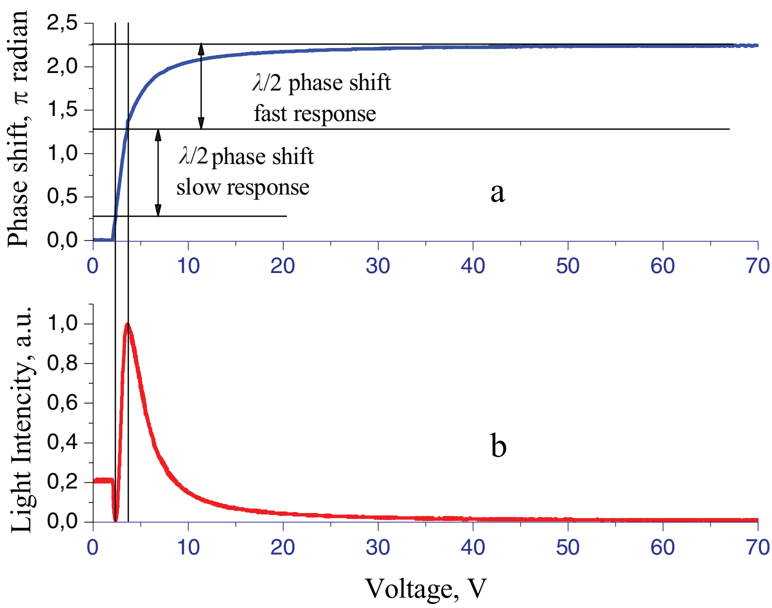

Figure 4. Calibration curve of phase shift (a) and intensity of the transmitted light vs. applied voltage (b) for LC cell (6CHBT, Δ n = 0.15) with a thickness of 5 μm.

the binding energy of the LC molecules with the surface of the substrate. Working in this mode, despite the maximum performance, there are undesirable back flows, making it less acceptable.

In the slow switching mode reorientation occurs in the bulk of LC. In this case, operation time is essentially larger than in previous mode, due to its dependency only on the rotational viscosity and elasticity of LC. However, in this case it is possible to achieve high performance by applying the control voltage of a special shape, which is based on the transition nematic effect (TNE), when a step change in voltage leads to the switching between the quasi-steady states of LC.

Figure 5 shows the time characteristics of light valve in the slow switching mode during control by TNE signals of different shapes (two-, three-and four- step signal).

In the case of control by a two-step signal the switching within π phase shift is achieved by varying the voltage from 2.4 V (holding voltage 1) to 3.8 V (holding voltage 2) and vice versa. In the case of a three-step signal at the achieving π phase shift the holding voltage 2 is turned off completely for a short time and then a holding voltage 1 is reapplied. In this case, as it is seen in Fig. 5a, the relaxation time is reduced by 3 times compared with the previous case.

To reduce the reorientation time the control signal is formed subject to the above described features of reorientation process under the influence of electric pulse on LC cell. Namely, before application of holding voltage 2 a short pulse with amplitude 12.6 V is applied to a cell, ensuring sharp and ordered LC reorientation. The reorientation time as

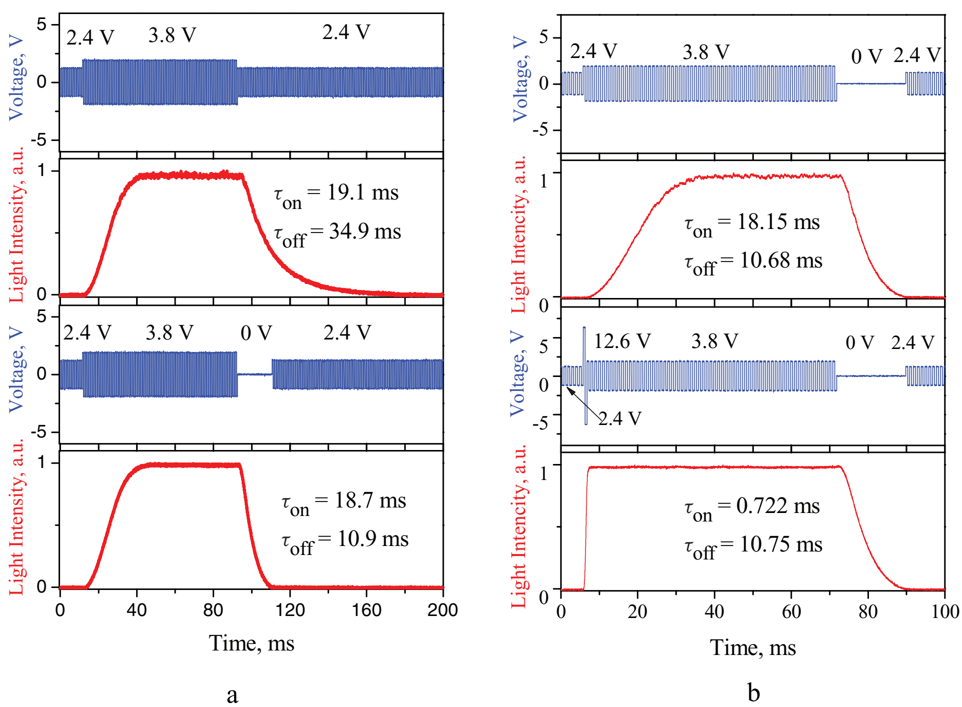

Figure 5. Time response of LC light valve in slow switching mode: a–comparison of switching at control by two- and three-step TNE signals, b–comparison of switching at control by threeand four-step TNE signals.

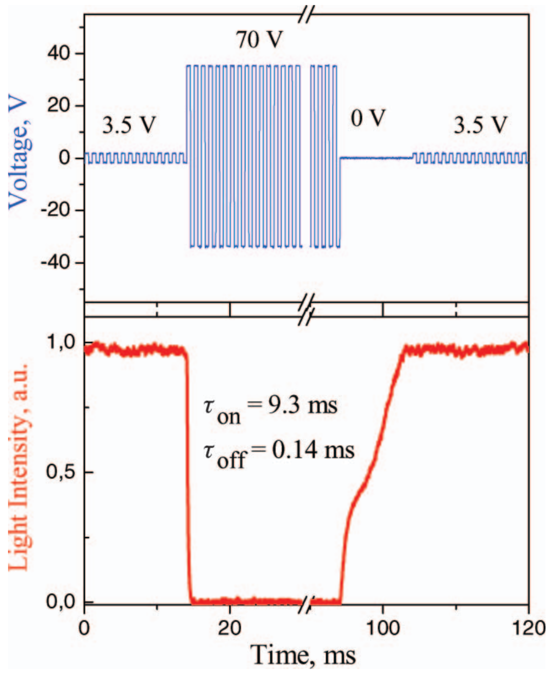

Figure 6. Time response of LC light valve in fast switching mode.

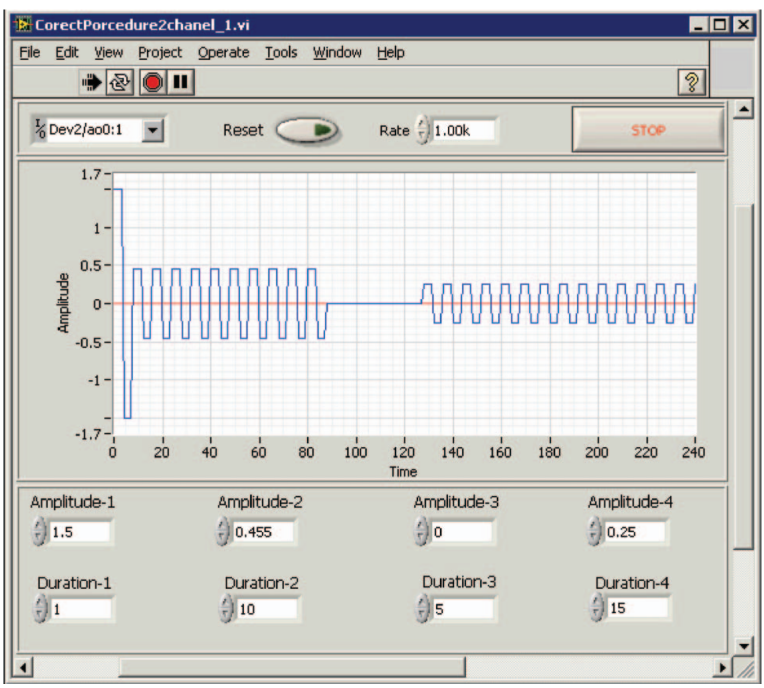

Figure 7. Interface of developed LC driver for forming a control signal with complex shape.

compared with a three-step control is reduced about 25 times, and the total switching time – 5 times.

The switching dynamics of investigated light valve in the fast switching mode is shown in Fig. 6. In this case reorientation and relaxation times are 140 μs and 9.3 ms correspondingly.

From comparison of the given mode with the four-step control in the slow switching mode can conclude that the switching times for both modes are almost identical. That is, the usage of control signal of special shape in slow switching mode make possible the obtaining of switching times characteristic for fast switching, i.e. at the application of high voltages. One should also pay attention to the break in time dependence of the light intensity curve in the fast switching mode, conditioned by presence of back flows. During the four step control (Fig. 5b) no break is observed.

For the experiment in LabVIEW media we have created a device, by means of which it is possible to form a control signal with complex shape. The interface of device is shown in Fig. 7.

Conclusion

As a result of experimental studies it is shown that the switching dynamics of the planar-oriented cell filled with nematic liquid crystal also depends on the shape of control signal. To improve the operating speed it is proposed to control by a four-step signal, providing the reduction of both reorientation and relaxation times. Such control by application of voltages close to the threshold allows achieving performance characteristic for a range of high voltages, and thus avoiding all unwanted effects caused by their action.

The proposed method can be used in conjunction with other methods of improving in operating speed of devices based on nematic liquid crystals, in order to obtaining an additional reduction of switching times.

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