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Light-radiation-induced non-volatile change in the liquid crystal orientation in the vicinity of its contact with a conductor

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The study has shown experimentally that, when the contact between the conductor (Cu) and liquid crystal (nematic 5CB) is exposed to light radiation (from an incandescent lamp or low-power He−Ne laser with $\lambda = 0.63\,\mu$m), a change in the initial orientation of liquid crystal molecules takes place in the vicinity of the meniscus. It has been established that reorientation of molecules is non-stationary in character with pronounced time periods of increase and relaxation in the size of the liquid crystal deformation region. The characteristic time corresponding to the maximum deformation ranges within several seconds. We assume that the observed meniscus change with which we associate the reorientation of molecules is caused by variation in the liquid crystal surface tension due to electron photoemission into the liquid crystal from the conductor during its irradiation.

Keywords: conductor−liquid crystal contact, surface tension, electrowetting, electron photoemission.

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Due to significant anisotropy of their refractive index, liquid crystals (LC) help successfully solve the problems associated with modulation of light-wave parameters (phase, polarization, amplitude). At present, modulation of light in all liquid-crystal devices (displays, light modulators, etc.) occurs due to LC molecule reorientation induced by electric field applied to the anisotropic medium [1]. Advances in technology will apparently require for non-volatile light-modulating liquid crystal devices that may be located at places with a limited or, subsequently, absolutely absent access. From this point of view, effects induced by light irradiation of liquid-crystal materials and caused, e.g. by the photorefractive effect [2], photoisomerization of light-absorbing dopants [3] or adsorption of photoexcited molecules [4] remain promising for solving such tasks. However, at present there exist serious obstacles for using them in non-volatile light modulating devices. Realization of these effects still needs significant powers of light radiation from coherent light sources [5]. In particular, it appears impossible to completely eliminate the necessity of exposure to electric field [6]. The published studies show that experiments devoted to investigating the interaction between light wave and LC are aimed mainly at improving the diffraction efficiency, while, e.g., fiber-optic devices need such interaction effects that would involve continuous control of the light wave phase. Operating wavelengths still belong mainly to the short— and midwave optical spectrum ranges [7], which is incompatible with up-to-date systems for information transmission and processing.

There exists a well known effect of electrowetting (see, e.g. [8–10]) which implies that the contact wetting angle of a liquid varies with varying ion concentration at the liquid−solid interface. This effect is studied not only experimentally; attempts are also made at creating theoretical constructions aimed at quantitative prediction of the influence of this effect on the interphase processes. At the same time, it should be noted that this effect has already found practical application in controllable liquid lenses, prisms and microfluidic devices [11,12]. However, the electrowetting control remains volatile, and the applied voltage equals tens of volts.

The goal of this study was to experimentally confirm the possibility of changing the LC molecule orientation and, hence, the possibility of modulating the light wave front parameters in the process of changing the conductor surface electrowetting by liquid crystal under light irradiation without using electric field sources.

Fig. 1 schematically illustrates the experimental conditions. Nematic LC 4-n-pentyl-4′-cyanobiphenyl (5CB) (Merck) having the phase transition temperature of 35°C was placed on a glass substrate shaped as a plane-parallel plate 1.3 mm thick which was put on the stage of polarizing microscope Micromed POLAR 3. The substrateś horizontal position ensured the symmetry of gravity effect on the LC meniscus. The plate surface was thoroughly treated with organic solvents (dimethylformamide, ethyl alcohol). The conductor in the form of a cylindrical copper column was pressed against the glass surface. Being partially immersed in the glass layer, it created a contact with LC (Fig. 1, *a*). The effect was observed using crossed polarizers in the transmission mode. The images were fixed by video-camera BR-5101LC-UF (2592 × 1944 pixels) driven by code ScopePhoto 3.1. Time intervals were measured based on the fixed imagesdata accurately to 0.1 s. The

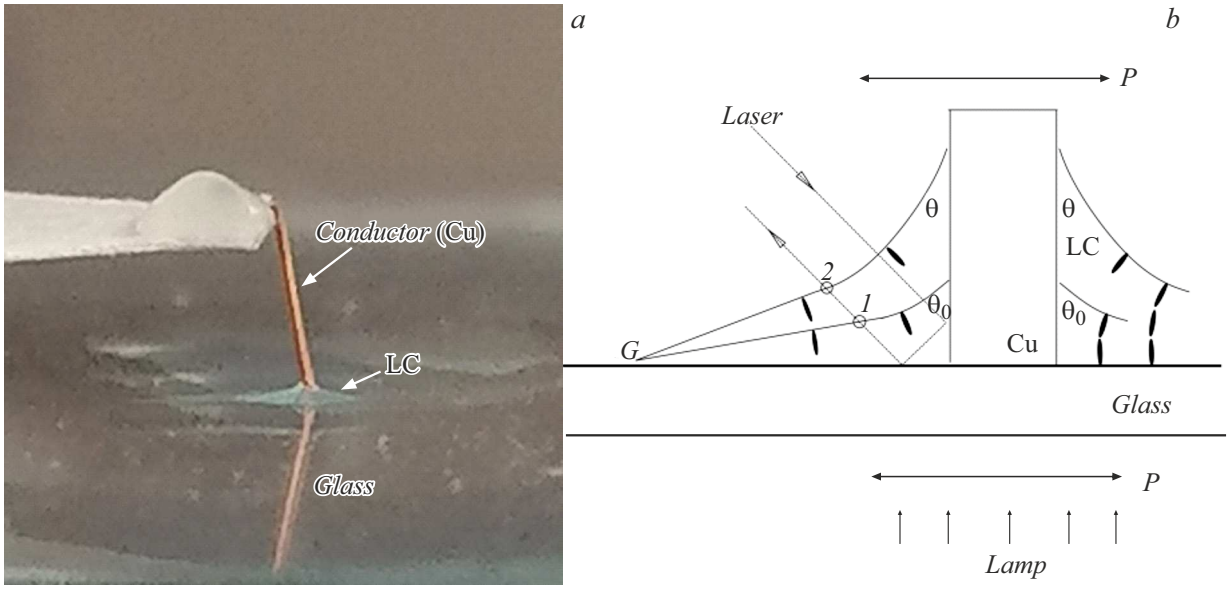

Figure 1. Experimental details: *a* — general view of the conductor–liquid crystal contact. *b* — experimental scheme elements. LC — liquid crystal, *P* — polarizer, *G* — glass–LC interface. *1* and *2* — any laser beam exit points on LC surface at two meniscus positions. Cu — cylindrical conductor 0.2 mm in diameter and 3 mm in height. θ_0 and θ — initial and minimal edge wetting angles, respectively.

contact location was chosen so as to ensure at that point homeotropic LC orientation prior to the moment when the conductor came in contact with the LC and glass surface. With such an initial orientation of the LC molecules, deformation of the initial director field was accompanied by brightening of the microscope field of view; when the phase delay between the ordinary and extraordinary beams exceeded a certain threshold, it was accompanied by its coloring due to the polarized light interference. Two light sources were used: the microscope illumination lamp and focused radiation of He–Ne-laser LGN-208B ($\lambda = 0.63\,\mu$m, output power of 1.5 mW). Light from the lamp fell onto the conductor–LC contact without changing the geometry of the microscope illumination scheme. Both light sources were switched on in advance in order to prevent induced voltage at the conductor at the switch-on moment. The relevant light flow directed towards the contact was opened using mechanical shutters.

Figs. 2, *a*, *b* demonstrate polarization images of the LC surface fragment in the vicinity of the conductor–LC contact when the light flow from the microscope incandescent lamp is turned on. Fig. 2, *a* corresponds to the moment 0.1 s after opening the shutter of the microscope illumination lamp. At this moment, the dark field of LC homeotropic orientation that is almost the same as the initial one is clearly seen in the vicinity of the contact over the entire field of view. There are observed a slight brightening of the microscope field of view and interference ring around the conductor. Taking into account that cyanobiphenyl molecules are oriented normally to the free LC surface, we can relate the mentioned brightening and interference ring to the liquid crystal surface warping in the vicinity of the meniscus and, hence, with deformation of the initial (homeotropic) field of director. Over time, the further expansion of the LC deformation bright region around the conductor and appearance of new, also expanding interference rings were observed (Fig. 2, *b*). After reaching the maximum dimensions, that LC deformation region turns to the stage of relaxation to certain stationary dimensions. Fig. 3 illustrates the dynamics of variations in size *R* of the deformed LC region. When the conductor–LC contact is illuminated with the laser (Fig. 2, *c*), dynamics of variation in the deformed LC region size is similar to that in the case of illumination with the incandescent lamp. The only difference is the deformation region size. In the case of laser irradiation, this region becomes wider, and the number of interference rings increases (Fig. 2, *c*). Each interference ring (beginning from the LC deformation region periphery) represents the phase shift by 2π. A sufficient phase shift in the relevant LC regions, as well as the length of the period of maximal LC deformation, which is about several seconds (Fig. 3), demonstrate the possibility of using this LC reorientation method in practical applications.

The contact location was chosen immediately at the LC boundary in order to reveal the character of the meniscus displacement under irradiation. Since the glass–LC interface (*G*) does not shift when the light is turned on (and this fact is visually recordable), the meniscus displacement is to be accompanied by variation in the LC surface slope. Then, the character of variation in the LC surface slope may be judged from the visual displacement of bright points in the horizontal plane on the LC surface (see inset in Fig. 2, *c*) at the moment of turning on the laser radiation. Each of these bright points corresponds to a place on the

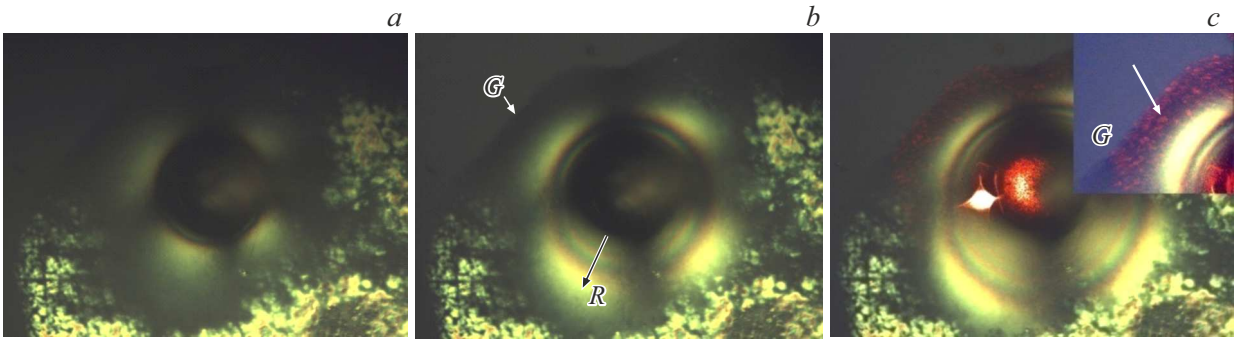

Figure 2. Polarization images of an LC layer fragment in the vicinity of the conductor–LC contact. Time intervals after opening the incandescent lamp shutter were 0.1 (*a*) and 8 s (*b*). *c* — LC deformation in the vicinity of the conductor–LC contact irradiated with laser radiation (jointly with the incandescent lamp radiation). In the inset, the arrow indicates bright points of the laser beams intersection with the LC surface.

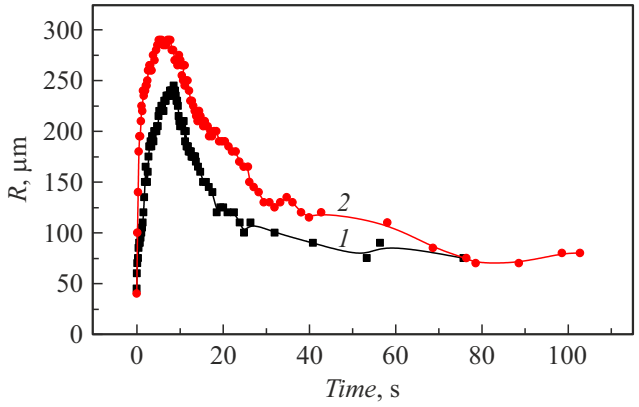

Figure 3. Size R of the LC deformation region versus the time of exposure to light. *1* — illumination of the contact with the incandescent lamp, *2* — illumination of the contact with the laser jointly with the incandescent lamp.

LC surface where a certain diffracted laser beam leaves the LC layer after reflecting from the surfaces of the conductor and plane-parallel glass plate (Fig. 1, *b*). The experiment reveals that, in the period from the irradiation onset till reaching the maximum size of deformed LC region, bright points move from the conductor towards the glass–LC interface (G). This displacement of bright points means that, during this time interval, the slope angle of the LC surface plane increases and, hence, the meniscus rises along the conductor. Fig. 1, *b* schematically illustrates the bright point displacement during the specified time interval with an example of points *1* and *2*. Thus, at the moment of maximum LC deformation, the edge wetting angle takes the minimum value θ (Fig. 1, *b*). While the LC deformation region decreases, bright points shift in the opposite direction, from G towards the conductor. This means that, during the specified time period, the slope angle of the LC surface plane decreases, meniscus lowers down, and edge wetting angle increases.

The observed modification of the LC surface and resulting actual change in the initial LC molecule orientation may be explained by the process of electrowetting which changes when the conductor is illuminated. The increase in ion concentration is known to promote a decrease in the liquid surface tension. In this study we can attribute the decrease in the LC surface tension to formation of extra ions in the conductorś nearelectrode region arising due to electron photoemission into LC from the illuminated conductor. Relaxation of the deformed LC region may be explained by two processes: first, by restriction of the electron photoemission into LC because of generation of stopping potential on the conductor surface and, second, by screening the ions photogenerated in LC by opposite-sign intrinsic ions. These processes promote partial recovery of surface tension to previous values, due to which the edge wetting angles also returns to initial values.

In conclusion, note that the change in the LC orientation occurs in the case of illuminating the copper conductor whose electron work function exceeds the energy of a photon with $\lambda = 0.63\,\mu$m, and, hence, the classical photoeffect is impossible for such a conductor. Therefore, it is possible to assume that the potential barrier for the photoelectron transition through the conductor–LC interface is reduced and, hence, there may occur a further shift (towards higher values) of the light wavelength at which LC reorientation takes place.

Conflict of interests

The authors declare that they have no conflict of interests.

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