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HIGH VOLTAGE MEMORY OF LC CELLS

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We observed "bleaching" of liquid crystal cells with zero pretilt angle placed between crossed polarizers and subjected to electric field. The pronounced effect is observed, when the strength of the applied field is one order of magnitude higher then the Frederiks threshold. On the microscopic level, the "bleaching" is caused by numerous surface walls. Possible applications of the observed effect are discussed.

Keywords: liquid crystal; memory; orientation defects

INTRODUCTION

Over recent years, memory effects in liquid crystal (LC) cells have been widely discussed. They are interesting from the point of view of academic research, as well as for improvement of known and development of new LCD modes. These effects can be divided in several groups. One group includes surface memory effects, which usually refer to imprinting the order of LC phases on the solid substrates exposed to contact with LC [1]. These effects are usually explained by interfacial LC-substrate coupling that leads to a modified surface bearing the imprint. This means that LC molecules are actually anchored to a memory-imprinted surface, not to the bare surface of the substrate.

The other group includes memory effects associated with application of external fields. The classical effect of this type is keeping of LC orientation caused by electric field after the field is removed [2,3]. The interpretation of these effects is also based on the concept of memory-imprinted surface, which may memorize field induced orientation of LCs.

There are also other effects, which reflect reaction of LC cells on the field previously applied. These effects memorize field application and, in

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this sense, can be referred to the effects of the LC cell's memory. One example of these effects is switching of LC alignment on the bistable surface [4,5]. The other example is image retention or image sticking [6,7], which consists in residual image of LCD after the configuration of the controlling signal is changed. The reason of this phenomenon is considered to be a residual electric potential generated by the adsorbed ions on the alignment layer surfaces. The electric field created with these ions modifies orientation of LC molecules.

In the present paper we describe one more effect related to memorization of the electric field action. It consists in substantial bleaching of LC cells viewed in the crossed polarizers due to appearance of numerous orientational defects. This bleaching may substantially influence electro-optic contrast of LC cells. The experimental conditions of new effect are investigated.

EXPERIMENTAL

Samples

The LC cells consisted of two glass slides with patterned ITO electrodes coated with PI layers (PI 2555, Dupont). To generate uniform planar or tilted alignment of LC, the PI coatings were obliquely treated with plasma beam. As is described in Reference [8], this method provides two alignment modes; (1) with the easy axis in the incident plane of plasma beam; (2) with the easy axis perpendicular to the plane of incidence. The mode 1 provides tilted alignment with the pretilt angle controlled by changing the parameters of irradiation. The mode 2 is characterized by zero pretilt angle (planar alignment). We realized both of these modes to obtain samples with zero and non-zero pretilt angle. Alternatively, PI coatings were unidirectionally rubbed. To obtain a uniform director orientation across the LC cell, the cells were assembled in an antiparallel fashion. The cell gap was kept with spacers of 15 μm in diameter. The cells were filled with the nematic LC K15 (5CB) purchased from Merck.

Methods

For electro-optic measurements we used a homemade computer conjugated system earlier described in Reference [9]. The cell was set between the crossed polarizer and analyzer in such a way that the alignment direction of LC corresponded to polarizer axis. The cells were powered with a sin-like voltage of the frequency of 1 kHz. The transmittance voltage curve (T-V) as well as the transmittance kinetic curves (T-t) for the step-wise voltage on and voltage off processes were measured. The pretilt angle in the cells was measured with the crystal rotation method [10]. The photographs of LC cells in crossed polarizers were taken by CCD camera. Also, LC samples were viewed in polarizing microscope POLAM L-213M (LOMO, Russia). The microscopic images were taken by CCD camera conjugated with this microscope.

RESULTS AND DISCUSSION

Figure 1 shows typical T-V curve of the studied samples. On the microscopic level, this curve describes transition from planar to homeotropic alignment under the applied voltage. As can be seen from Figure 1, homeotropic alignment in the bulk of LC is reached at 8–10 V. This value is several time higher then Frederiks threshold ($\approx$2 V). Figure 2 presents a set of kinetic curves (on and off switching) for the LC cells aligned by plasma method. Here (a) and (b) correspond to the cells with pretilt angle $\theta = 3.5^\circ$ and $\theta = 0^\circ$, respectively. Both cells, at U < 40 V, behave similarly; sample transmittance demonstrates non-essential and reversible changes with applied voltage. However, after application and removal of the voltage U > 50 V (one order of magnitude higher then the Frederiks threshold), the residual transmittance of the LC cell with zero pretilt angle dramatically increases (Fig. 2b). Usually, the induced change in T relaxes over several minutes as is shown in Figure 2b. However, in some cells, relaxation time is substantially longer (several hours). The cell observation between crossed polarizers shows "bleaching" of the area exposed to the electric field. This bleaching gradually decreases with the time after field appli-

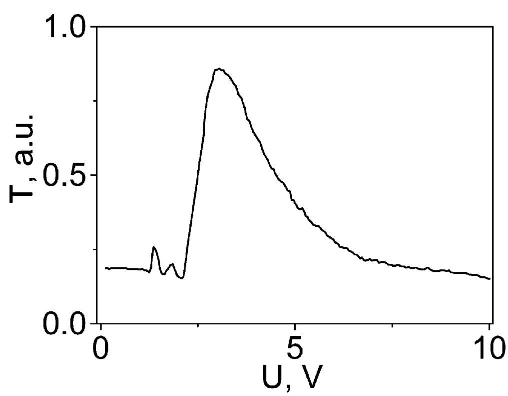
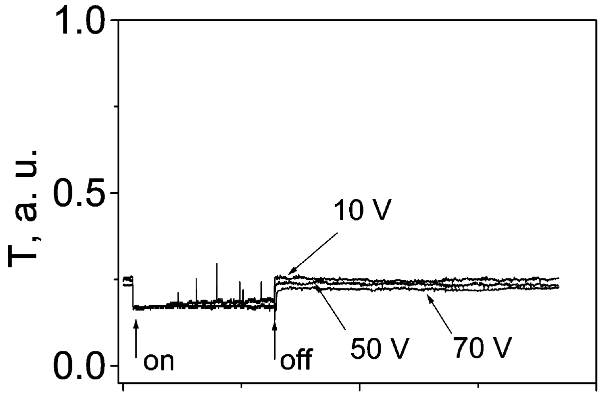
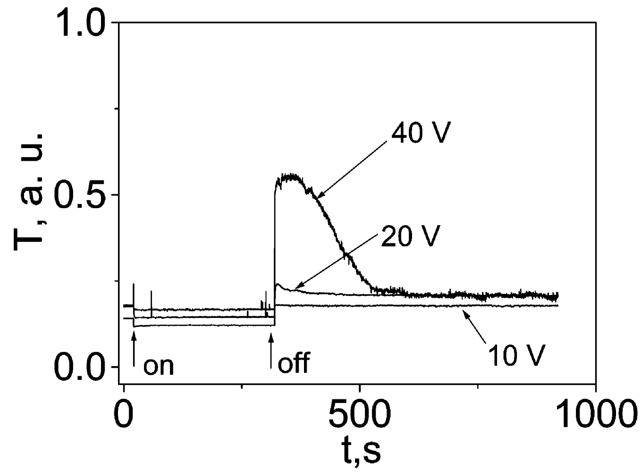


FIGURE 1 Transmittance-voltage curve of LC cell based on plasma treated PI substrates providing zero pretilt angle. Cell gap is 15 μm. The cell is subjected to alternative voltage (f = 1 kHz).



(a)



(b)

FIGURE 2 Switching on and switching off characteristics of LC cells for different applied voltages (f = 1 kHz). (a) cell with $\theta = 3.5°$, (b) cell with $\theta = 0°$.

cation. The cell photographs before, during and after the field application are presented in Figure 3. Surprisingly, the described behavior is not observed in the samples with non-zero pretilt angle (neither in plasma aligned, nor in rubbing aligned samples). This implies important role of LC alignment at the bounding substrate in the origin of new memory phenomenon. The observation of the "bleached" parts of samples in polarizing microscope reveals numerous orientation defects, which are known as surface walls [11]. The typical micrographs of the "bleached" area

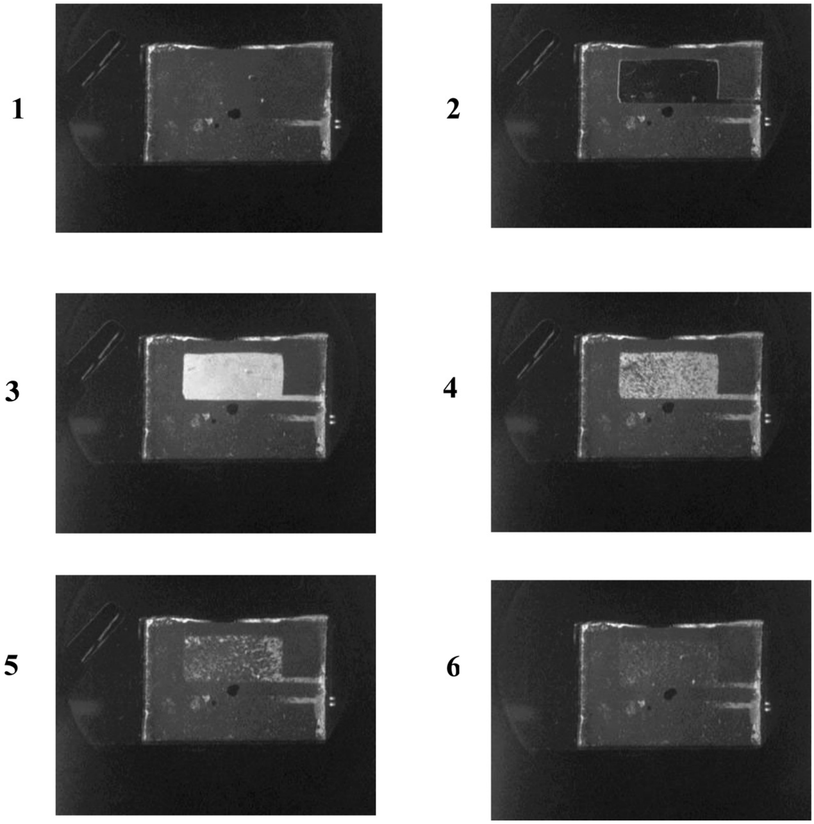


FIGURE 3 "Bleaching" effect in the cell with zero pretilt. The photographs 1–6 demonstrate different stages of the same cell. (1) before voltage application, (2) under the voltage of 50 V, (3)–(6), respectively, 5 s, 1 min, 3 min, and 5 min after the field application. The electric field is applied only across the rectangular area in a center of the cell.

are shown in Figure 4. An averaged width of the walls is about 1.5–2.0 μm. This value can be used to estimate azimuthal anchoring coefficient W_a according to formula $W_a = 2dK/w^2$ [12], where K is elastic constant and w is a width of surface wall. By setting $K = 10^{-11}\,N$, $d = 15\,\mu m$ and $w = 2\,\mu m$ one can obtain $W_a \approx 10^{-4}\,J/m^2$. This value is in good agreement with that for the 2nd mode alignment obtained by other methods [8].

Note again that "bleaching" appears after the applied field one order of magnitude stronger then the Frederiks threshold of the cell. For this reason we call the observed phenomenon "high voltage memory". To clear the role of the field strength, we calculated distribution of LC director

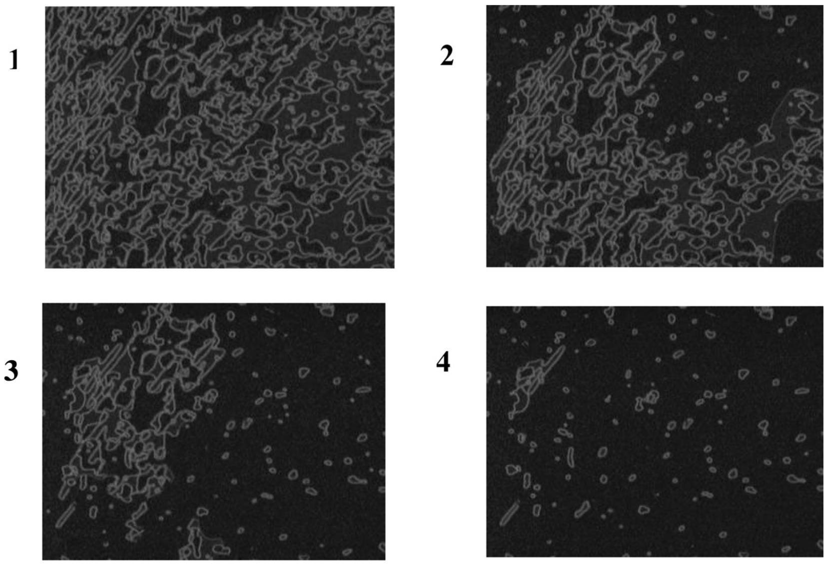


FIGURE 4 Micrographs of the "bleached" area corresponding to (1) 5 s, (2) 1 min, (3) 3 min, and (4) 5 min after the field application.

across the LC cell using the software "Twist Cell Optics 6.0" (Prof. J. Kelly, Liquid Crystal Institute, Kent State University, USA) for different applied voltages. These results are presented in Figure 5. One can conclude that applied voltages corresponding to effective "bleaching" cause homeotropic reorientation of LC director near the aligning substrates. This seems to be important condition for appearance of surface walls in our experiments. The process initiated by field application can be described as follow. After the field is off, the homeotropically oriented director tends to rotate in order to reach planar alignment. Because of zero pretilt angle, the rotation direction is double degenerated. This causes generation of LC domains separated by surface walls. The detailed description of mechanisms as well as topology of surface walls can be found elsewhere [11,12].

The described memory effect was also observed in the cells with double degenerated pretilt angle. To realize this case, we used aligning layers of poly(vinyl 4-fluorocinnamate) irradiated with polarized UV light at normal incidence, assuming that this irradiation procedure provides uniform alignment with double degenerated pretilt angle [13]. As result, we observed surface walls. However, in contrast to experiments with zero pretilt angle cells, the walls separated LC domains with tilted alignment having different sign of pretilt angle.

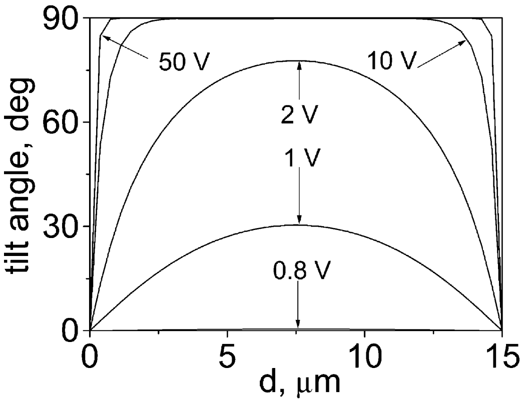


FIGURE 5 The calculated director distributions across LC cell with $\theta = 0°$, corresponding to different applied voltages; (1) 0.8 V, (2) 1 V, (3) 2 V, (4) 10 V, (5) 50 V.

The observed phenomenon is important for technology, since it brings parasitic effects in the performance of LCD. On the other hand, several applications of this phenomenon can be proposed. First of all, it can be used for express analyses of pretilt angle in LC cells. Indeed, as is shown above, the states with zero pretilt angle and non-zero pretilt angle can be easily distinguished. For demonstration, in Figure 6 we show degradation of LC pretilt angle in the plasma aligned cell (PI substrates, 1st alignment mode) monitored with crystal rotation method. In parallel, we show cell photographs taken immediately after the voltage switching off, in the beginning and in the end of the degradation process. As can be seen, degradation of pretilt angle is accompanied with appearance of high voltage memory.

Based on the observed effect new LCD mode can be developed. Presumably, this defects associated mode will be characterized by improved viewing angle. Besides, because of possible pulse driving, power consumption can be reduced. The new mode may successively combine birefringent and scattering properties of LC.

CONCLUSION

We observed “bleaching” of LC cells with zero pretilt angle placed between crossed polarizers and subjected to electric field with the intensity one order of magnitude higher then the Frederiks threshold. This bleaching is caused by numerous orientation defects (surface walls) appearing at the field strength, which is sufficiently high to cause reorientation of LC

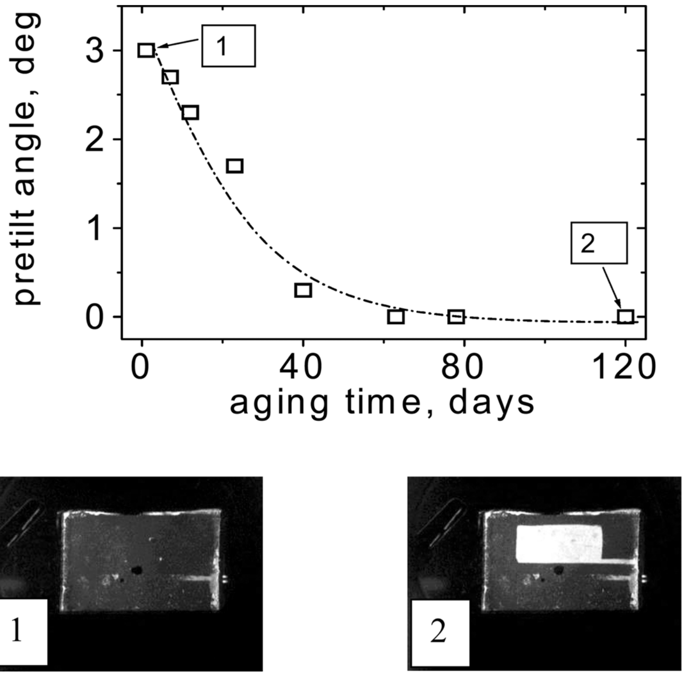


FIGURE 6 Pretilt angle aging in LC cell based on PI substrates treated with plasma (1st alignment mode). The data of pretilt angle θ are measured with crystal rotation method. The inserted photographs demonstrate high voltage memory on the different stages of θ degradation.

director near the aligning substrates. The observed phenomenon may be applied for express test of pretilt angle as well as for development of new LCD mode.

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