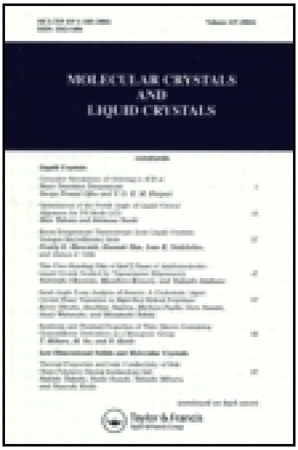

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Holographic Recordings Using Bistable SmC* Structures

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Numerous methods of re-writable optical recordings using nematic mixtures for holographic media have been presented. A new approach to this problem is possible by using surface stabilized ferroelectric liquid crystal structures (SSFLC). This is very promising from the theoretical point of view because the surface stabilized the structure of ferroelectric smectic SmC material inherently consists of a memory effect while driving by external electric field. Moreover, due to the layered structure of the surface stabilized ferroelectric liquid crystal there is a possibility of obtaining high resolution of the written gratings. In the paper, some theoretical basis regarding possibility of optical addressing of SSFCL cells are discussed. Methods of preparation of the optically addressed SSFLC cells in room temperature bistable SmC* structure are presented. Experiments with these cells in simple holographic two-beam set-up (DWTM) are described.*

Keywords: dynamic holography; ferroelectric liquid crystals; OASLM

1. INTRODUCTION

During last 20 years many bistable electrooptical effects utilizing nematic (NLC), chiral nematic (ChLC) as well as ferroelectric (FLC) and antiferroelectric (AFLC) [1,2] liquid crystal have been proposed [3–9]. Simultaneously an increasing interest towards dynamic

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holographic imaging was observed due to its prospective application in optical devices [10–12]. Among the others, a very interesting candidate for the photo addressable medium seems to be surface stabilized (untwisted) structures of the ferro- (SSFLC) and antiferroelectric liquid crystal (SSAFLC). The effect of the long term memorizing of two states in a SSFLC is due to the two anchoring states possible at two substrate plates [9].

Both memorized states are characterized by different orientations of director, hence the main axis of the optical indicatrix. In both cases, the optical axis of the smectic medium is in-plane oriented.

Typically, in display devices, SSFLC of optical thickness $\Delta nd = \lambda/2$ is used in the birefractive set-up and produces two optical transmission states. One of them is a black state obtained when the long axis of the optical indicatrix of the medium is oriented along one of two polarizers used. The bright state is obtained when the director is reoriented by $2\theta < \pi/2$ angle upon the action of the external electric.

The reorientation of the direction of the optical axis of SSFLC structure by polar ferroelectric coupling with the applied DC field is characterized by the threshold electric field E_{th} value [9,13,14]. The switching times suitable for the video refreshment time are easily achievable. Due to the in-plane switching, the high contrast ratio and large viewing angle are also obtained. The wide display application of the bistable SSFLC is hampered mainly due to the difficulty of the uniform aligning the smectic layers. Moreover, SSFLC structures are mechanically and thermally fragile. The polar switching imposes driving by a DC field, complicating and limiting the acceptable driving schemes. The bistability is also perturbed. Due to the surface polarization, the bistable states have slightly different energies and the device can become metastable or monostable. Finally, the image sticking can occur by the ion adsorption.

In this paper we report the effect of the light induced spatial modulation by the bistable SSFLC structure obtained in a standard cell, where the orienting layer on the one side is doped with the photosensitive dye, hence the boundary conditions become unsymmetrical under the illumination. Using this structure, the effects of periodical modulation of the switching electric field E_{th} are observed, hence upon driving the holographic grating is written. The process of the grating writing and erasing is described. The diffraction efficiency as well as the switching characteristic upon dye concentration in the orienting layer and driving voltage are presented and discussed.

2. EXPERIMENT

2.1. The Cell Preparation

The custom made cells were prepared using optically flat glass plates covered by low resistivity ITO layers ($R = 10\,\Omega/\square$). The orienting layers were spincoated using a basic solution of the commercial polyamide Nylon 6/6 (Fluka) in 2,2,2-Trifluoroethanol. The Nylon concentration in the basic solution was 0.3% by wt. The mixture was prepared by few hours steering of the 2,2,2-Trifluoroethanol with the Nylon balls on the magnetic stirrer for complete dissolving of the polyamide. Afterwards the solution was treated by the ultrasonic agitation for an hour. One of the surfaces of each cell was spincoated by use of a pure basic solution while the other one was spincoated with the admixture of the basic solution with 2%, 5% and 10% by wt. of the antraquinone dye (blue 2590).

Spincoated substrate glasses were dried and baked and after cooling they were uniformly rubbed. Parameters of surface treatment of all glasses; with pure and dye doped orienting layers were the same. Cells were assembled using a rodlike 1.6 μm glass spacers deposited on the surfaces by spraying method and stabilized by the adhesive glue applied. Reference cells with both orienting layers from a pure Nylon solution were also prepared. The cell wiring was attached by ultrasonic soldering. Cells were optically inspected and the space gap between substrate glasses was measured by interference method before. The cell structure is shown on Figure 1.

Before filling with the smectic material cells were heated up in the Instead hot stage to the temperature of 130°C which is higher than the temperature of the isotropization of the smectic material used. Cells were filed with W201 mixture synthesized in the Institute of Chemistry of MUT, which exhibits an antiferroelectric SmC_A^* phase and the tilt angle $\theta = 22.5°$ of at room temperature. The details of material parameters of the mixture were presented elsewhere [15].

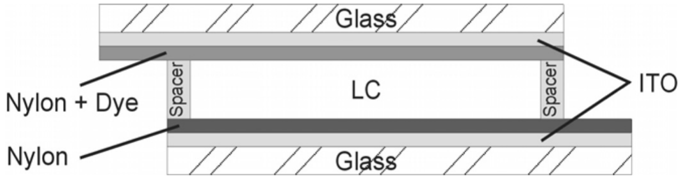

FIGURE 1 Schematic diagram of the LC cell with pure Nylon and dye doped Nylon orienting layers.

The optically uniform structure within the cell was obtained upon a few slow melting-cooling cycles in the hot stage without or with the AC electric field (triangle pulse) applied. The amplitude of the electric field was applied to the cells was $U = 12.5\,V$. The cooling rate was $\Delta t = 0{,}2°C/\text{min}$, the frequency was $f = 14\,\text{Hz}$. The optical uniformity of the SSFLC structure was inspected under Biolar PI (PZO, Poland) polarizing microscope. The observation of the single switching current peak obtained while driving with the triangle switching pulse reveals that the anticlinic antiferroelectric structure is destroyed in favor of the synclinic ferroelectric one due to the surface action of the orienting layers inside the measuring cells. This was confirmed by the microscopic observations.

As reference parameters the spontaneous polarization and the switching time were evaluated for a reference cell with the dopant of the antraquinone dye at the room temperature as well as for the reference cell without the dye. All parameters were measured during observations of the electrooptical switching under a 50 Hz AC pulse. Spontaneous polarization and the time switching of W201 mixture are shown in the Figures 2 and 3. In case of these measurements there were no differences for obtained results for the reference cell and cells with one dye doped orienting layer used.

As to obtain optically uniform structures for the optical writing all cells were treated in the same way. Samples were heated to the

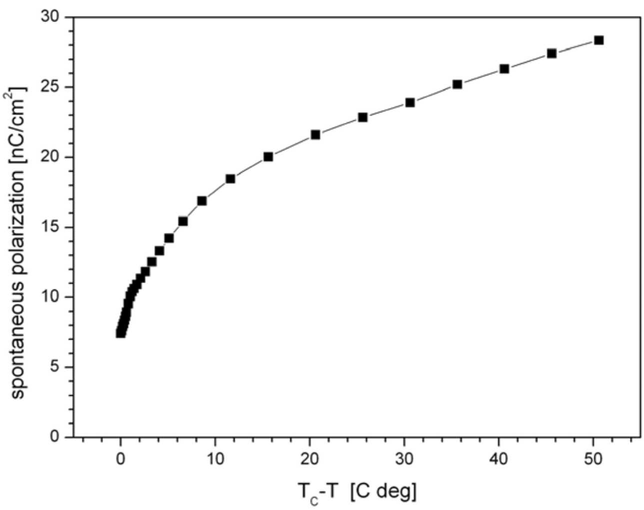

FIGURE 2 Spontaneous polarization vs. reduced temperature for reference cell filled with W201 mixture.

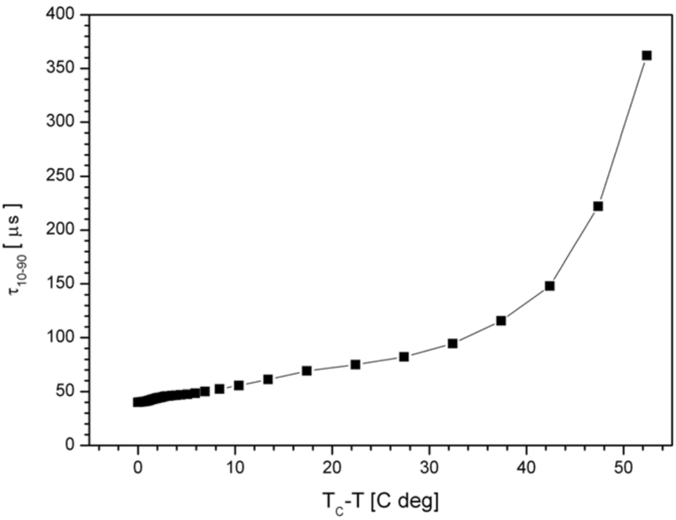

FIGURE 3 Time switching vs. reduced temperature for reference cell filled with W201 mixture.

isotropic stage ($t_{iso} < t_1 = 130°C$) and then slowly cooled at the rate of $\Delta t = 0.5\,K/min$ through transition range ($t_{trans} > t_2 = 78°C$; $\Delta t = 0{,}2\,K/min$) in the vicinity of the alternating electric field. The microphotogram of the sample after this process is shown in the Figure 4.

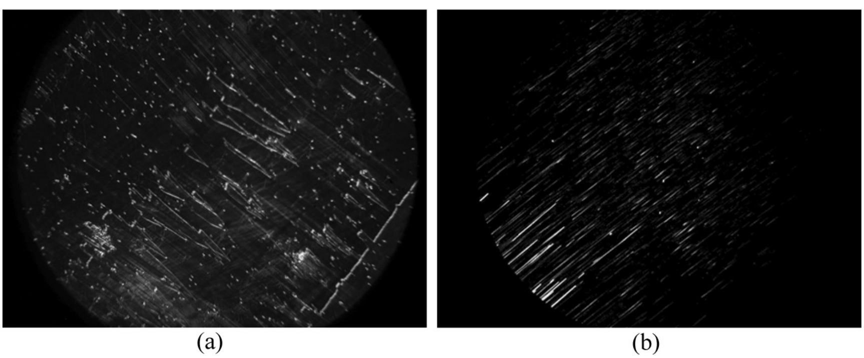

FIGURE 4 Images of the ordered molecules in cells with 10% photosensitive admixture in the layer after thermal arrangement process: (a) – the C2 structure (with some C1 inclusion) obtained upon slow cooling under electric field ($U = 12.5\,V$, $f = 14\,Hz$, triangle), (b) – structure obtained under cooling without electric field.

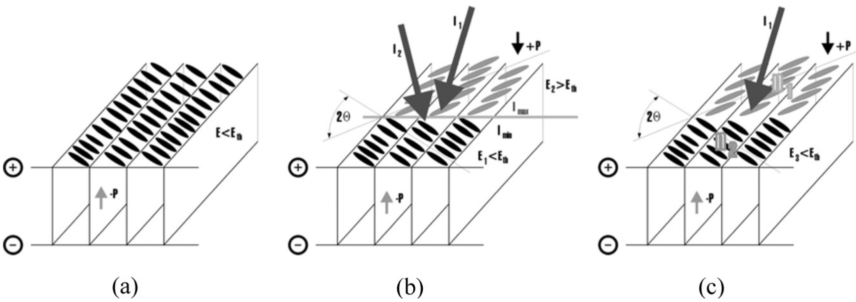

FIGURE 5 Operation of the holographic grating recorded onto SSFLC bistable structure: (a) structure prepared for the recording, (b) grating recorded by the coherent beams interference where within the dye doped layer the electric charge is induced, (c) reconstruction of the grating.

2.2. Holographic Recording Using SmC* Structure

The mechanism of the gratings creation using SmC* bistable layer is suspected to work as explained below (refer to Fig. 5).

The molecular arrangement of the bookshelf structure of the SmC* phase induced within the cell is presented in the Figure 5a. Before the optical writing, the electric field E_1 of the value below the threshold one E_{th}, is applied. At this state, the interfering laser beams are switched on. The presence of interfering beams produces interference grating in plane of SSFLC slab. Within this grating one can distinguish areas where the local increase of the electric field is induced. Where the effective electric field E_2 magnitude exceeds E_{th}, the SSFLC structure is driven to switch locally to the opposite state (Fig. 5b). Between the areas where the director was driven to switch to the opposite state there is the difference of the orientation of the optical axis of the LC medium, hence the phase type holographic grating is recorded. The bistability of the used cell produces stable recording of the grating. The reconstruction of the recorded information can be done by single laser beam. It is important to provide reconstruction beam's parameters not to be able to increase electrical field over the threshold level E_{th}: i.e., properly reduced intensity and/or wavelength differ from dye absorbance wavelength.

2.3. Experimental Set-up

Experimental DTWM (Degenerated Two-Wave Mixing) set-up is shown in the Figure 6. It consists of He-Ne laser and optomechanical unit providing two beams interference field for the grating writing,

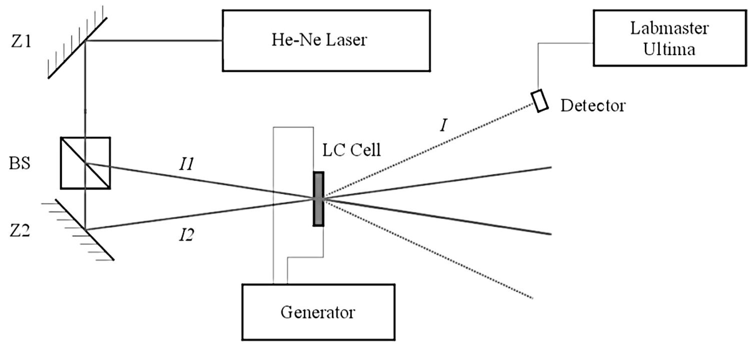

FIGURE 6 Experimental DTWM set-up for interference gratings recordings onto LC cells. Z1, Z2 – mirrors, BS – beam splitter, I1, I2 – laser beams, I – first diffraction order.

function generator for the LC cell driving. The laser power meter is used for the diffraction efficiency measurements obtained by using of the recorded gratings. The power of each interfering writing beam's was $I_{1,2} \approx 7{,}5\,\mathrm{mW}$. The set-up was configured to achieve grating's period of $\Lambda = 21\,\mu\mathrm{m}$. In the experiment the power of the first diffraction order was measured and the number of diffraction order was noticed. [16,17].

3. RESULTS

Optical recording of the holographic grating by using cells with one of two orienting layers doped by antraquinone dye as well as for the reference cell without the dye were donated at similar circumstances described above proved that the obtained grating properties depend on the dye concentration, electric field strength applied upon writing and writing beams light intensity. The wavelength of the used light beam should fit the absorbance bandwidth of the used photosensitive dye. The effects of grating' writings onto LC cells with orientation layer with admixture concentration range from 2% to 10% and dye admixture into LC layer (to the saturation level) are presented in Table 1. For this experiment, the concentration of 5% wt. of the dye in the nylon is the minimum when the writing of the grating is possible onto SmC* SSFLC structure. The influence of the cell treatment in SSFLC bookshelf structure formation seems to play a minor role.

The recording of the hologram can be observed using polarizing microscope. In the Figure 10 the cell is presented in the birefractive set up before writing. The same cell with recorded grating a few

TABLE 1 The Influence of Dye Admixture in the Cell to Optical Grating Recording

LC cell	LC layer ordering	Existence of diffraction grating
W201 + 2590	without electrical field	yes (good)
10%	without electrical field	
	$U_{pp} = 25\,V$, $f = 14\,Hz$, triangle	
5%	without electrical field	yes (poor)
	$U_{pp} = 10\,V$, $f = 14\,Hz$, square	no
2%	without electrical field	

minutes after writing is presented. The observed grating is slowly fading when the recording process ends. It is supposed that this is due to charge flow (leading to progressive equalization between areas corresponding to dark and light grating's fringes) when the optical field disappears. This process is very intensive directly after the end of recording and then is relatively slow – however several cells exhibit the presence of the grating even after few days. Figure 7 show the diffraction maxima obtained in dynamic recording-reconstruction process. Figure 8 show the diffraction efficiency decreasing a few seconds after the cell was reoriented (rotated along axis z) – orders described as I_{mem} are diffracted at the grating which was memorized onto LC cell. However this allow to suspect the bistable SmC* based LC cells can be suitable for static recording.

In the Figure 9 the SSFLC structure of the virgin sample in the birefractive set-up is shown. Numerous zig-zag defects are present. In the Figure 10 the same structure with the recorded hologram obtained by low level electrical drive ($E < E_{th}$) is shown. In the image the measurement scale is imprinted to show regularity and to estimate period of the fringes.

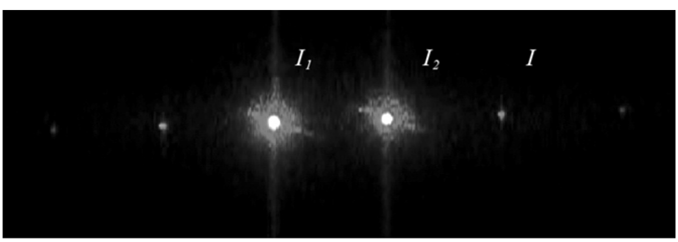

FIGURE 7 Diffraction effect of the dynamic recoding-reconstruction process of the holographic grating recorded onto SSFLC cell.

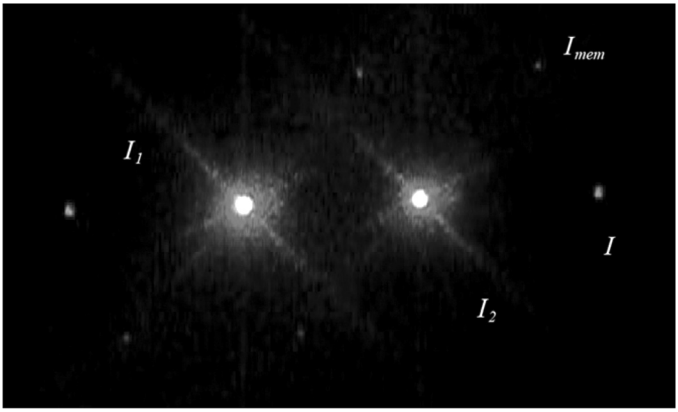

FIGURE 8 Diffraction effect of the memorized holographic grating recorded onto SSFLC cell.

The 1st order diffraction efficiency of the optical holographic recordings versus driving voltage was studied. The diffraction efficiency η was defined as:

$$\eta = \frac{\boldsymbol{I}_{1\text{st}}}{\boldsymbol{I}_{read}} \tag{2}$$

where $I_{1\text{st}}$ – intensity of first diffraction order, I_{read} – intensity of the reading beam.

In the Figures 11 and 12 the diffraction efficiencies for the cells with dye admixture in orientation layer and in LC layer are shown respectively. The sign indicates the polarity of the applied voltage.

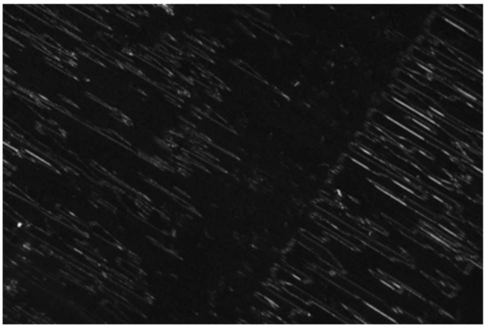

FIGURE 9 Thermally ordered SmC* structure obtained with no electrical field.

FIGURE 10 Image of the holographic grating recorded onto SmC* layer.

For the cell with LC with dye admixture there exist two maxima on the graph. This effect is supposedly caused by the cancelation of the remainder of the helical structure by the low electric field. At the higher value of the electric filed applied the LC layer behaves as a typical ferroelectic phase.

The maximum diffraction efficiency level ($\eta \approx 0{,}35\%$) for the cell with orientation layer with dye admixture (10%) is present when the $U = 1.6$–$1.8\,\mathrm{V}$ is applied. It is worth pointing out that the higher

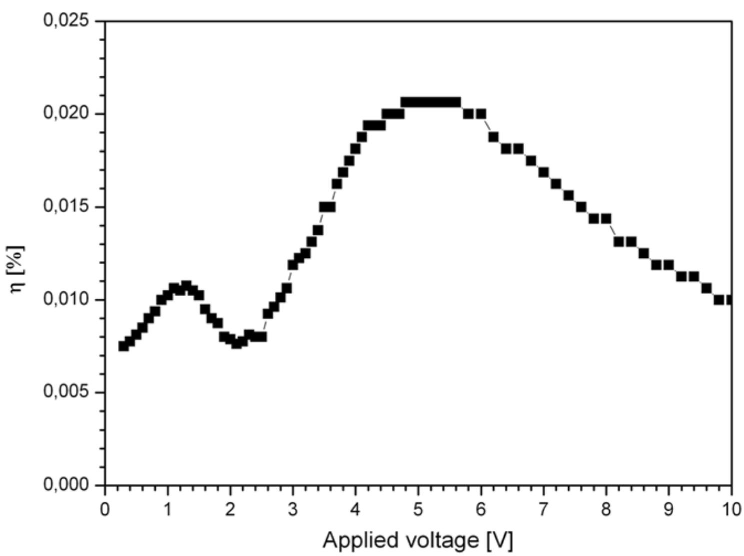

FIGURE 11 1st order diffraction efficiency vs. voltage for the cell with dye admixture (to the saturation level) in the LC layer.

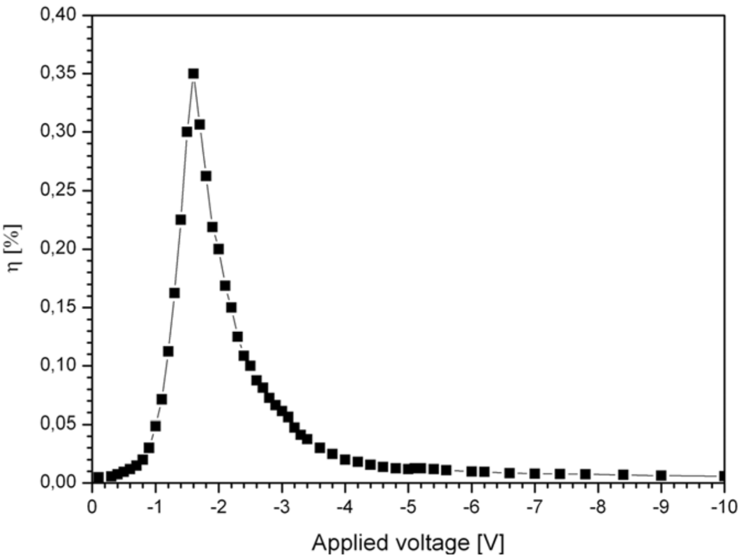

FIGURE 12 1st order diffraction efficiency vs. voltage for the cell with dye admixture (10%) in the orientation layer.

diffraction efficiencies can be obtained at a very narrow voltage range only; from approx. 1.2 V to approx. 2.7 V.

4. CONCLUSIONS

Presented results show that the photosensitive dye affects the electro-optical performance of the SSFLC structure under external electric field. As it has been shown, it can be utilized for the rewritable optical recordings (i.e., holographic gratings). The diffraction efficiency depends on the dye contamination in the orienting layer as well as from the magnitude of the external electric field applied. However, the expected high diffraction efficiency η, promised by the structural properties of the bistable SSFLC, was not achieved at presented study the obtained result $\eta = 0.35\%$ suggest future application of optically addressed SSFLC.

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