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Mechanisms of Re-writable Hologram Recordings in NLC Cells

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During investigations concerning application of LC cells as a media for dynamic holographic recordings, unwanted permanent recordings were observed on NLC cells with photosensitive layer (i.e., PVK – polivinylocarbazol). Applications of optically addressed NLC based cells with photosensitive layer as a re-writable media for holographic recording have been noticed. However, recent work has proved that in these cells optical addressing can produce permanent, quasi-permanent and erasable holographic gratings, the mechanism of these phenomena was not explained. In this paper, conditions of the optical recordings in NLC cells are presented. Some basic discussion regarding physical phenomena of permanency are discussed.

Keywords: holography; optical data storage; photorefractive liquid crystals

1. INTRODUCTION

LC cells filled with nematic liquid crystals can be used as a media for different optical applications [1,2]. In previous investigations, the diffraction efficiency for cells filled with different nematic isothiocyanate mixtures with or without dyes doped used as a media in

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holographic setups were determined [3]. A very effective way to improve the optical parameters of the cells (i.e., diffraction efficiency and dynamic properties) is to apply an additional photosensitive layer in the cells construction (i.e., PVK – as in our case). Experimental results were very promising, the possibility of dynamic reconstruction of digitally stored holograms by the liquid crystals devices was proved [4]. The schematic diagram of the cell with this additional layer is shown on Figure 1.

During experimental work with the cells modified as described, of memory effect was observed [5]. In some of the experimental LC cells permanent (long lasting) writing was realized and in other ones – quasi-permanent (spontaneously disappearing). This behavior was observed only when in LC cells construction an additional photosensitive layer was present. However, this phenomena is harmful from dynamic holography application point of view, these LC cells would be very useful as re-usable media for static holographic recordings where multiple use medias are needed (possible applications: imaging holography, optical correlators, holographic memories etc.).

Some of the results and theoretical discussion regarding possibilities of long lasting optical recordings in LC cells and methods of erasing were presented in papers [6–8]. For present experiments with the goal of complex explanation of physical mechanism of permanent optical recordings and its erasing methods, two types of cells were chosen and prepared. In the paper respective marks will be used for different types of the cells, as follows:

1. TD type – NLC in the cell has homogenous orientation,
2. TR type – NLC in the cell has homogenous-homeotropic orientation (homogenous on PVK and homeotropic on polymide layer).

Previously the memory effect in optical addressed LC cells was observed in these two specific types of the LC cells' construction.

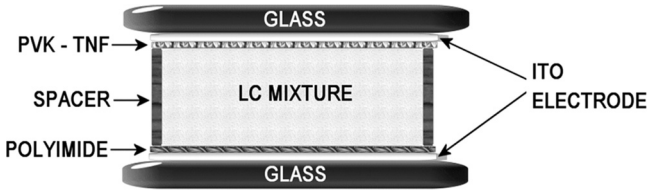

FIGURE 1 The LC cell structure.

2. MEMORY EFFECT IN OPTICALLY ADDRESSED LC CELLS

As mentioned above only the cells with photosensitive layer can be considered when the memory effect is under examination. However, pure PVK layer is insufficiently sensitive for visible range of spectrum, the addition of C_{60} or TNF dissolvent is commonly used to obtain higher sensitivity in visible range. The memory effect was observed when either of these dissolvent was used (PVK-C_{60} or PVK-TNF layers in the cell's construction) [5,6]. It can be supposed that neither of these two dissolvents has influence on the permanent writing phenomena.

Based on previous observation two types of permanency can be named: light, when recorded gratings vanished after few hours (quasi-permanent writing), and strong, when recordings do not disappear even when the cell was left for some weeks without any external electrical nor optical field (permanent writing). We supposed that such an effect is caused by some kind of charge trapping nearby orientation layer. Such trapping can be explained as an accumulation of the ions (charges) near the layer (or layers' border) as an effect of the external field [6]. After some investigations it was assumed that recording time can depend on applied fields.

In experiments, two sources of fields were applied: electrical (power supply) and optical (He-Ne laser). Electrical field has to, firstly, orient the LC structure, then writing process is continued using optically generated field. A major role (as information medium) in writing process plays light. It was possible that time or power (or both) of the illumination is responsible for the sort of memory type (permanent or quasi-permanent). In another case it is interesting what the influence of the writing parameters on erasing possibilities is. If ion trapping (as a result of exposition) is not strong enough, it should be possible to release these ions and erase the hologram. Experimental results with low-power laser beams recordings have denied the influence of the exposure time on the permanent grating creation. On the other hand, there is a kind of threshold level of power density which can produce permanent recording in LC cells [7,8]. Thus in further examination of permanency physics it is reasonable to use power densities higher than the threshold level.

At the moment three methods of erasing were proposed. Firstly, electrical drive higher than Freederiksz level and next thermal heating was used. Both stimulations give no satisfying effect – voltage has no influence on permanent writing. High temperature heating has removed the recording but the cell was useless for another writing (destroyed) [5]. In next stage, the UV light for erasing was used with a

much better effect – the possibilities of re-writable properties in optically addressed LC cells were proven [6].

3. EXPERIMENT

The basic writing and reading parameters for examined LC cells were tested in the DTWM setup. The DTWM setup is realizing simple holographic recording (shown on Fig. 2) and consists of two crossed He-Ne laser beams (wavelength $\lambda = 632{,}8\,\text{nm}$, beams power $P_{1,2} = 3{,}5\,\text{mW}$, single beam aperture diameter $A = 4\,\text{mm}$, thus power density $S \approx 140\,\text{W/m}^2$). Additional components were in use, i.e., function generator, oscilloscope and light sensitive detectors. LC cells (configuration is shown on Fig. 1) were filled with pure nematic liquid crystal mixtures with high optical anisotropy ($\Delta n = 0{,}35$). Thicknesses of the cells differ from 5 to 7 μm. Cells with two orientations were used: homogenous and combined (homogenous–homeotropic). The experimental setup was determined to fulfill the Raman-Nath regime. The TNF admixture were chosen and added to PVK. As a polyimids the SE130 and PI1211 from Nissan Chemicals Industries Ltd. was used.

To assume which process plays the main role in writing permanent (or erasable) gratings, some of experiments were prepared and performed. In recent experiments differences between obtained holograms (its permanency) according to writing process were observed. We supposed that one of the main role in that effect plays externally applied voltage (electrical LC cell pre-formation, applied voltage polarization). As a pre-formation we understand DC voltage appliance

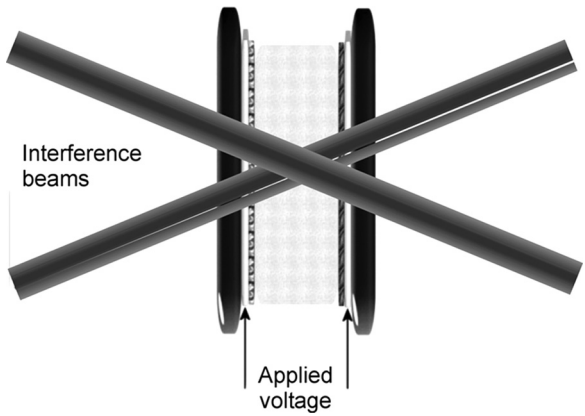

FIGURE 2 Beam interference on LC cell.

TABLE 1 Parameters of Writing Conditions for LC Cells with Parallel Layer Orientation (Illumination Incidence – Thru PVK or Polyimide Layers During 30 min; Beams Polarization Parallel to the Orientation Order)

Cell	Exposed layer	30 V DC polarization on PVK layer	Pre-formation
TD1	PVK	+	no
TD2	polyimide		
TD3		–	
TD4	PVK	+	30 minutes
TD5			
TD6		–	30 minutes

without any optical illumination. In other case we observe that permanency does depend on time of the illumination (writing beam) when the intensity of the illumination is higher than threshold level [7,8].

In recent experiment it was tried to resolve re-writable media problem using different setups (exposure time, applied voltage). According to recent observations we suppose that in permanency of the hologram recording pre-formation process and voltage polarization of the cell are important. The LC cells were prepared (with mentioned above two different layer configurations), placed in a holder and then writing process was applied with parameters shown in tables below (Tables 1 and 2). As an illumination incidence the exposed layer is understood (it makes determination of the layer which is directed to the source which the beams are coming from).

Simultaneously two parallel cells (TD type) were selected for the experiment where photo induced current was measured according to pre-formation configuration. Experimental assumptions are listed in Table 3.

TABLE 2 Parameters of Writing Conditions for LC Cells with Mixed Orientation Layer (Illumination Incidence – Thru PVK or Polyimide Layers During 30 min; Beams Polarization Parallel to the Orientation Order)

Cell	Exposed layer	30 V DC polarization on PVK layer	Pre-formation
TR1	PVK	–	no
TR2	polyimide		
TR3	PVK	+	
TR4	polyimide		30 minutes
TR5	PVK	+	
TR6		–	30 minutes

TABLE 3 Photo Current Measurement Conditions for Pre-formatted LC Cells without Illumination

Cell	Applied pre-formation voltage
TD7-PC	30 Volts (+ on PVK layer)
TD8-PC	30 Volts (− on PVK layer)

3. RESULTS

After writing process all LC cells were left for a long period (two weeks) at room temperature without any illumination or electric field. After that time, the reconstruction of the grating was checked.

TABLE 4 Results of the Observations After 2 Weeks for Cells with Parallel Orientation Layers

Cell	Diffraction on the recorded grating	Comments
TD1	Observed	Diffraction orders were observed with and without electric field
TD2		Diffraction orders were observed without electric field but after reorientation of the cell (90° rotation − reading beam is perpendicular to orientation of the incidence layer). Grating vanished after DC voltage appliance.
TD3	Not observed	−
TD4	Observed	Diffraction orders were observed without electric field but after reorientation of the cell (90° rotation − reading beam is perpendicular to orientation of the incidence layer). Diffraction observed with DC voltage too.
TD5		Diffraction orders were observed without electric field but after reorientation of the cell (90° rotation − reading beam is perpendicular to orientation of the incidence layer). Grating vanished after DC voltage appliance.
TD6	Not observed	−

Diffraction efficiency was not measured precisely, only the presence or absence of the writing was verified. As permanently written, it can define holographic reconstruction with $\eta \geq 1\%$ diffraction efficiency (it can be understood as minimum diffraction efficiency enable for observation). Table 4 presents the results of the observations and conclusions which were expressed during the experiment. Reading setup was prepared similarly to the one shown on Figure 2 with one beam

TABLE 5 Results of the Observations After 2 Weeks for Cells with Mixed Orientation Layers

Cell name	Diffraction on the recorded grating	Comments
TR1	Observed	Diffraction orders were observed but after reorientation of the cell (90° rotation – reading beam is perpendicular to orientation of the incidence layer). Diffraction was observed with DC applied voltage too.
TR2	Not observed	–
TR3	Observed	Diffraction orders were observed. After reorientation of the cell (90° rotation – reading beam is perpendicular to orientation of the incidence layer) η increases. Diffraction was observed with and without DC voltage.
TR4		Diffraction orders were observed without electric field but after reorientation of the cell (90° rotation – reading beam is perpendicular to orientation of the incidence layer). Grating vanished after DC voltage appliance.
TR5	Not observed	–
TR6	Observed	Diffraction orders were observed but after reorientation of the cell (90° rotation – reading beam is perpendicular to orientation of the incidence layer). Diffraction was observed only with DC voltage.

cut. To reconstruct the holographic recording from LC cell under DC voltage, U = 15 V was set. This value was chosen before (as much equal) after experiments with similar LC cells. DC polarization was set accordingly to the polarization used in writing process. Laser beam polarization was the same as in the writing process too.

Next step was to define erasing conditions. For those cells which had permanently written gratings it was tried to set proper procedure to erase it. According to recent experiments, we decide to use UV light [6]. As a light source, a UV lamp unit with total power consumption of 600 W was used. Single erasing period was set as 20 minutes UV exposure and applied in repeats. Before each consecutive repeat, the presence of diffraction orders was checked. The esults of the erasing experiments are presented in Table 6.

As it was assumed, re-writable media should allow to write a new hologram again after erasing process is performed. Two cells (TD4, TR1) which have been successfully erased were placed into writing setup again. The aim of this stage was to write hologram in the same place using identical writing conditions as presented in Tables 1 and 2.

When the exposition was finished, both LC cells were left in room temperature for other two weeks. Table below shows the results of the re-writing process. Re-written holograms characterized similar observation properties as during the first recording.

Now it is time to report the results of experiment regarding photo induced current measured on pre-formatted cells. Regarding the results shown in tables above (Tables 4–7) it can be concluded that

TABLE 6 Erasing Properties of the LC Cells

Cell	UV exposure periods	Results/Comments
TD1	4 repeats	Grating not vanished even after 4 UV illumination periods. Grating was visible until LC cell destruction. Destructed LC cell has no behavior of the isotropic structure.
TD2	4 repeats	Grating not vanished even after 4 UV illumination periods.
TD4	2 repeats	Grating vanished.
TD5	4 repeats	Grating not vanished even after 4 UV illumination periods.
TR1	2 repeats	Grating vanished.
TR3	4 repeats	Grating not vanished even after 4 UV illumination periods.
TR4		
TR6		

TABLE 7 Results of the Re-writing Process

Cell	Diffraction on the recorded grating	Comments
TD4	Observed	Diffraction orders were observed without electric field but after reorientation of the cell (90° rotation – reading beam was perpendicular to orientation of the incidence layer). Diffraction was observed with DC voltage too.
TR1		Diffraction orders were observed but after reorientation of the cell (90° rotation – reading beam is perpendicular to orientation of the incidence layer). Diffraction was observed only with DC voltage applied.

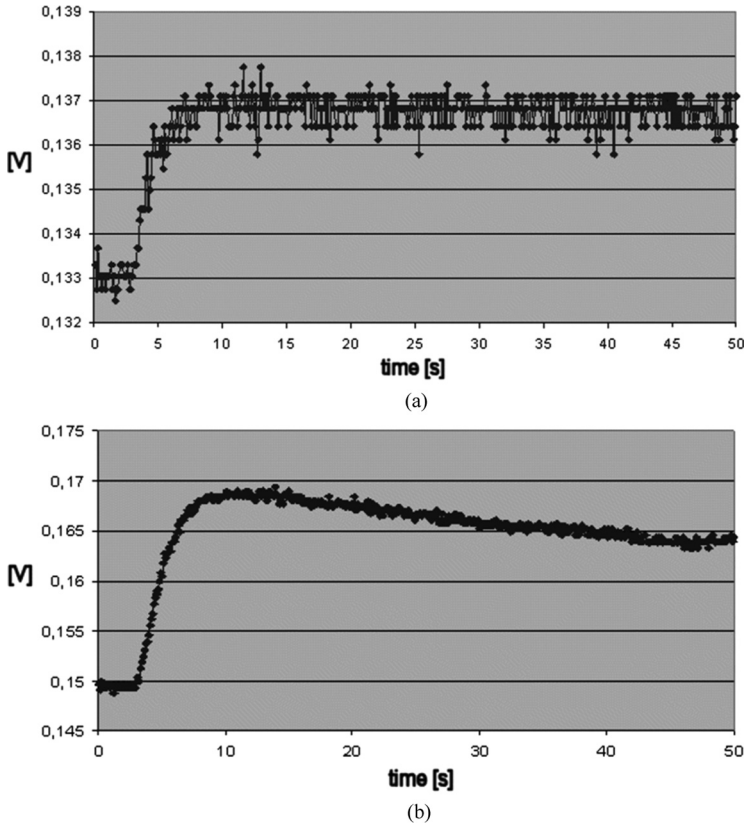

FIGURE 3 Photo induced current in LC cell measured as a voltage change on 560 kΩ resistor: (a) –TD7-PC, (b) –TD8-PC.

applied voltage polarization during pre-formation process (and during exposure) takes one of the major roles in hologram's recording permanency. Figure 3 shows difference in photo induced current in two differently pre-formatted LC cells.

Photo generated current was determined using the results of measurements of DC voltage changes (in time) on 560 kΩ resistor. LC cell was polarized by DC voltage U = 15 V. Applied voltage were polarized as in pre-formation process. Figure 3 shows the differences between LC cells with different pre-formation conditions. It is clearly visible the photo current, measured on the cell which was driven with positive pole applied on PVK, is much higher than when to apply the negative pole. It can be supposed than some kind of semi conductivity on the layers' border is created (p-n junction between PVK and LC layers) and thus if it is polarized in barrier direction free ions (and/or charges) travelling inside liquid crystal layer cannot be trapped by PVK layer. These free ions can play the major role when the re-writable recordings are under consideration. On the other hand, when the junction would be polarized in conductive direction these ions can be trapped deeply inside PVK layer. This produces very stable quantum distribution at the PVK layers plane. When the grating is recorded with this condition, it is not possible to remove it by any method of charges relaxation.

4. CONCLUSIONS

Properly prepared and driven NLC based optically addressed cells are suitable for holographic application as a recording medias with re-writable properties. Non symmetrical layers configuration is needed to perform writing which can be successfully erased later by UV exposure. Re-writable properties of these NLC cells are determined by external (optical and electrical) fields. The main role in re-writable properties takes applied external DC voltage, which (as we suppose) are responsible for permanent ion deposition in LC cell.

Photo induced current observations, after different LC cell preformation with applied voltage, suggest that one of the construction layer traps free ions from the LC cell. Using according applied DC voltage polarization we can choose what type of hologram permanency (erasable when negative polarization on the PVK layer is applied or permanent when positive) can be written.

When configuration of the cell and cell's drive for permanent recording is done, light exposition will build strong ions structure inside cells' construction. When this is performed, ions trapping (as we suppose) is very deep and erasing of the recording is impossible without

destroying the medium. Riddance of the trapped ions is not possible even by high UV illumination or thermal heating. Influence of long time UV illumination or high temperature, in most cases, causes LC cell destruction.

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