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Optical data storage in LC cells

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Liquid crystal devices as a medium for holograms storage have been investigated. Long term memory effects in LC cells have been observed. Experiments proved that certain combination of insulating alignment layers has a major influence on the long term memory effect. Optimal liquid crystal cell construction allows us to achieve sufficient diffraction efficiency to record holographic patterns and to develop a re-writable holographic medium. The configuration of PVK and polyimide layers in LC cell construction with specific LC mixture was tested. The method of permanent and re-writable recording of optical data (holographic pattern) onto LC cells was achieved. However, the method of erasing recorded data was realized but mechanisms of this phenomenon are not clearly understood yet.

Keywords: photorefractive liquid crystals, holography, optical data storage.

1. Introduction

Nematic liquid crystals (NLCs) can be used as media for different optical applications [1–3]. In our previous investigations, liquid crystal cells filled with properly chosen isothiocyanate mixtures were used. Diffraction efficiency of these units was relatively good. Large dielectric and optical anisotropies have made nematic liquid crystals very attractive class of materials for a wide range of applications [4]. One possible method is the rewritable (erasable) medium for holographic recordings. In our recent experiments, concerning dynamical properties of the LC cells, a kind of memory effect was affirmed. That effect was maleficent from the dynamic holography point of view but it can be used in rewritable holography. Our recent experiments are concentrated on this type of application.

Early results have been obtained with the cells without addition of photosensitive layers, classic homeotropic or twisted configuration [5]. Different optical properties (in static and dynamic mode) were observed. Although these cells were sufficient for many static applications, our requirements for the dynamic configuration were not fulfilled. To improve optical properties (to increase the diffraction efficiency and to shorten the reaction time), the photosensitive layer was added. One of many possible methods was to use PVK layer in a cell construction (Fig. 1). However, pure PVK layer is not sensitive enough for visible light, but PVK doped with TNF dissolvent, to obtain the higher sensitivity in visible range, was used. It was observed during the experiments that some cells with PVK-TNF layers had influence on writing time shortening and some of them can store written gratings. PVK layer also changes the liquid crystal orientation in cells. In previous experiments, it was observed that the direction of reading beam polarization is very important for diffraction efficiency [5]. The aim of the work was to resolve the re-writable effect phenomena. It was observed that written grating does not disappear even when the cell was left for some weeks without any external electrical field, i.e., permanent data storage was achieved.

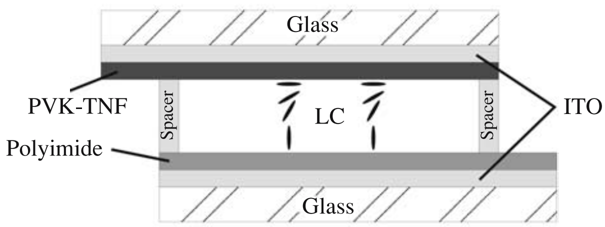

Fig. 1. LC cell structure.

2. Experiment

In experiments, three problems listed below were considered to which we were trying to find solutions:

- find a method to obtain durable recording of holographic gratings onto liquid crystal cells,
- find a method for erasing written holograms to allow the cell to be re-used,
- suggest a physical basis of memory effect in liquid crystal cells.

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It can be supposed that solution for these problems can be found among the results of observation of diffraction efficiency and durability of permanent gratings.

LC cells were filled with pure nematic liquid crystal mixtures with a high optical anisotropy $\Delta n = 0.35$, detailed specification of the LC mixture 1294 can be found in Ref. 7. The thicknesses of the cells differ from 6 to 9 μm. The experimental set-up was determined to fulfil the Raman-Nath regime, thus the period of the grating was defined and set to $\Lambda = 12.7$ μm. In this case, the reading/writing beams power was set to $P_{1,2} = 3.5$ mW. The basic writing and reading parameters of LC cells were tested in the DWTM set-up [2]. The DWTM set-up consisted of 632.8 nm He-Ne laser, laser power meter, and digital oscilloscope shown in Fig. 2.

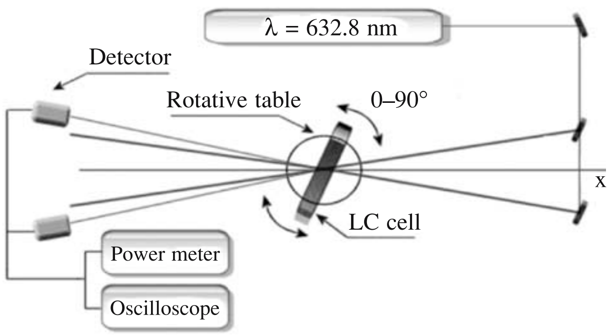

Fig. 2. Experimental set-up.

LC cell was mounted in a holder which enabled us XYZ rotations. It makes possible to measure the dependence between the orientation of the liquid crystal molecules and polarization of the writing/reading beams. Using that simple set-up, static and dynamic measurements of the LC cells were executed. The attention was paid to the memory effects, to obtain stable and erasable medium for holographic recordings. In the previous printed results, described in Ref. 1, we shown dependence between reading beam polarization and orientation of the polyimide. Orientation of the polyimide should be parallel to polarization of the reading beam. According to previously done experiments, we set the reading beam polarization parallel to the first orientation layer [5]. As the first layer we understand orientation layer through the reading beam entering the cell (see Fig. 3).

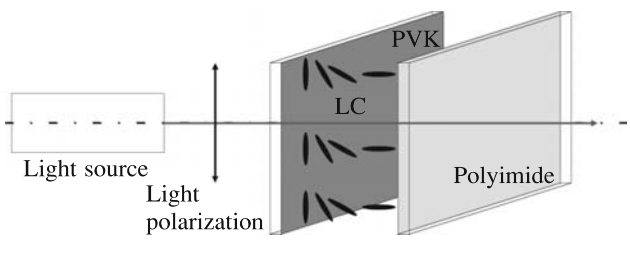

Fig. 3. Orientation of the rubbing direction to the beam polarization.

3. Results

At the beginning of every stage of investigations, optimal input parameters for all the cells were determined. To do this, the optimal voltage was applied and the cells orientation was changed to obtain maximum diffraction efficiency. The defined parameters of the optical set-up were constant for the measurements of every cell. Two He-Ne laser beams ($\lambda = 632.8$ nm) with the polarization stages parallel to the LC cell layers orientation were applied. The holographic grating, created in this set-up, was written on the medium (LC cell) at the exposure time of approx. 1 hour. Then, the cells have been left for 10 minutes for relaxation. A kind of memory effect (written permanently hologram) can be observed in some situations, as shown in Fig. 4. The goal was to choose the LC cell with the longest possible off-switching time or semi-permanent writing which can be erased.

Let us suppose that the holograms written on PVK side may be observed using the opposite (polyimide) side [1]. That is another very interesting observation that written holograms are selective for polarization of the reading beam. It can also be confirmed that there is the dependence between diffraction efficiency and the applied voltage for dynamically and permanently written holograms. During the experiments, a problem appeared which was analyzed in Ref. 5, i.e., the dependence between the parameters of applied voltage (shape, amplitude, frequency) and the diffraction efficiency. Sinusoidal voltage could increase diffraction efficiency of the written hologram. It can be supposed that it is caused by the influence of dynamical properties of the LC mixtures under AC voltage [5]. Low frequency AC voltage in specific circumstances can compensate influence of the orientation layers on the LC molecules. In this case, the external optical field takes the main part in the reorientation process of the LC molecules.

The cells with the longest observed vanishing time (more than a week) were chosen to the last stage of our experiments. This last stage was focused on erasing the written holograms.

We observed that a cell construction, shown in Fig. 1, is very sensitive to the applied voltage polarization. In previously done experiments, we focused on maximum diffraction efficiency results [1]. In dynamically changed hologram, the permanent writing is impossible because of short frame duration. We also observe that a major part in hologram reconstruction takes the polarization of the applied voltage. In dynamically written holograms, that was not an important part of the results. In permanent writing, as we observe, the polarization of the applied voltage plays a major role. We supposed that a liquid crystal cell can be replaced as a kind of semiconductor junction, from the electrical point of view. We can polarize that junction in the way we need. That type of conclusion directed us to other our experiments. In liquid crystal cells, in which we observe permanent writing, we tried to erase holograms using different methods. One was illumination with high inten-

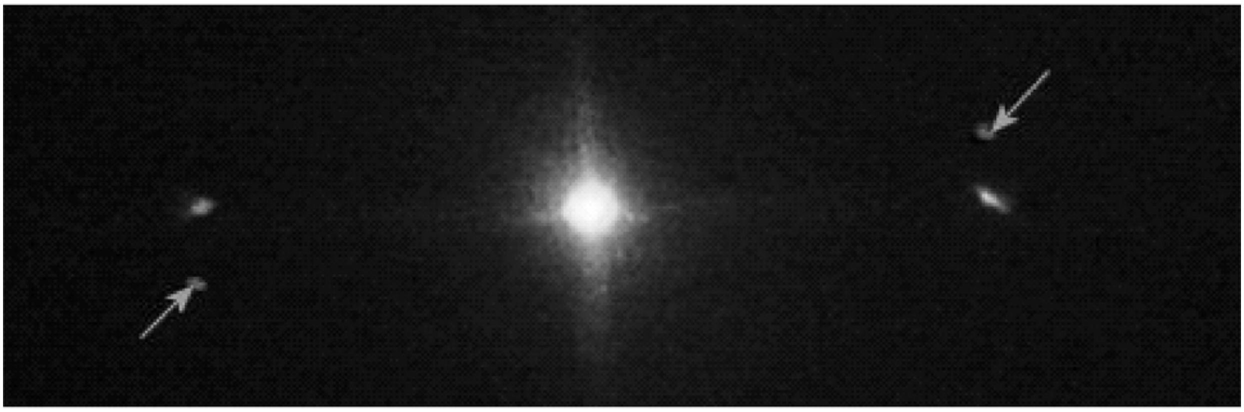

Fig. 4. Observed hologram. Arrows show reconstruction of the stored hologram.

sity UV light (200 W UV-lamp). It was observed that using this method some of the holograms can be erased completely and some of them not. Thus, we suppose that the main factor on which the possibility of re-writing depends is a polarization of the junction. When negative polarization was applied on the PVK side (Fig. 1), the erasing process was possible. When positive polarization was applied on the PVK, the writing was permanent (not erasable). We supposed that electrical charges inside LC cells are trapped in the construction layers. These charges are accumulated near the border between polyimide (orientation layer) and liquid crystal layer.

4. Conclusions

Re-writable properties of the LC cells strongly depend on the cell construction layers [4]. Some of the cells configuration allow us to use the LC cell as a re-writable medium, i.e., used in our experiment.

Re-writable properties of the LC cells strongly depend on the cell construction layers. An amplifier, like PVK layer, increases diffraction efficiency for dynamic and rewritable holographic recordings. We suppose that the border between the PVK layer and liquid crystal creates a semiconductive junction. The direction of the junction determines a type of the written hologram. When the junction is polarized in a reverse direction, the holograms can be written and then erased by UV light. When the junction is under conductive polarization, we suppose the exposure of light produces non-removable charges accumulation near polyimide-PVK layer's border. Thus, to understand the described process, the next experimental work has to be done with a selected above construction of LC cells.

The addition of PVK layer has a noticeable improvement in the diffraction efficiency, quite larger than simple admixtures of dyes to the LC mixture [6].

Written holograms can be effectively read only using a beam polarized in parallel to the rubbing direction, as shown in Fig. 3. That means holograms written on one side of the cell could be read when the cell is reoriented to the opposite side, provided that mentioned above polarization restrictions are fulfilled. Moreover, using different light polarization, various holograms can be reconstructed.

The orientation of the writing beams polarization has no effect on the holograms writing process. That enables us to write simultaneously multi-exposure holograms onto liquid crystal cell.

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