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Properties of different LC cells with high optical anisotropy as a dynamic holographic media

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Dynamic optical data storage and other applications in the field of optical data processing would be possible due to development of suitable nonlinear optical materials. The experimental investigations of the orientation photorefractive effect in nematic liquid crystals have been presented. The investigations showed that the orientational optical sensitivity of liquid crystals can be greatly enhanced by an external electric and optical applied field. The photorefractive volume space charge field in the LC cell is the result of charge generation in the bright regions of interference pattern and charge transportation.

Keywords: photorefractive liquid crystals, dynamic holography.

1. Introduction

The aim of this work is an attempt to write dynamic holographic gratings in multi-component liquid crystal (LC) mixtures. In our previous investigations, the liquid crystal mixtures were chosen among isothiocyanate mixtures, for which the obtained diffraction efficiency results were relatively good [1]. The obtained results gave possibility to optimise examined liquid crystals taking into consideration the chemical composition and physical parameters. According to the theory, one of the important elements of LC mixture, which can give the increase in diffraction efficiency, is an optical anisotropy. In this experiment, the diffraction gratings were written in LC cells containing LC mixtures with different optical anisotropies Δn = 0.35–0.6 at 25°C.

Because little absorption in the visible range is connected with "the charge transfer" effect, the examined mixtures allowed recording of diffraction gratings without of the photosensitive dyes [2]. The record of diffraction gratings in such material, in spite of the little writing beam energy (about 100 W/m) [3], should be compensated by the characteristic of material optical properties [4]. From application point of view, the development of technology concerning the record of diffraction efficiency in liquid crystals, it became essential to examine the influence of chemical composition changes in LC mixtures on diffraction efficiency [5].

2. Experiment

The main components of examined mixtures were the same (in chemical composition tests) – all three tested mixtures were obtained from 1294-1b mixture. The 1294-1b mixture is a mixture with Δn = 0.35. The last phase was to check the influence of induced (under the impact of illumination) temperature changes (local changes) in the capacity of LC cell on the ordering of liquid crystal structure and at the same time the influence on grating recording. The thickness of the liquid crystal layer was 6 and 9 µm. Every mixture coming from 1294-1b was examined in degenerated two wave mixing (DTWM) [6]) setup (Fig. 1). The source of reading/writing beam was a laser (He-Ne 40 mW, "S" polarisation). The angle between writing beams was chosen to meet the requirements of Raman-Nath regime (Λ = *l*/*sin* = 12 µm) [3]. The main beam and diffracted light beam intensities were measured using two-head laser power meter (Labmaster Ultima – Coherent).

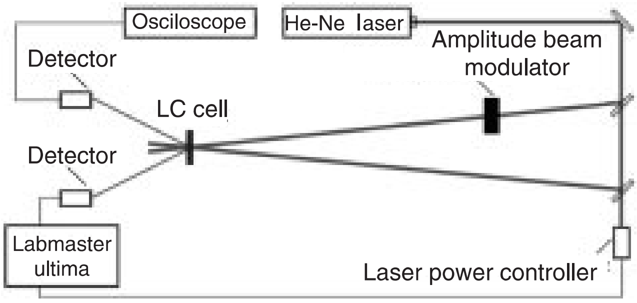

Fig. 1. DTWM setup used in experiments.

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The diffraction efficiency in characteristic nematic range temperatures was measured in DTWM built inside a temperature chamber. That chamber allowed the environmental temperature range to be changed from –20°C to 90°C (for example in the nematic range). The tested mixtures had the clearing point when their temperature is above 22°C, but we tested the mixture in the whole range of temperatures attainable in the chamber. Every experiment started from room temperature, which is about 20°C. Slow heating of the chamber makes possible observation of three interesting aspects: the transition temperature, the moment when the diffraction spot appeared, and the entire grating diffraction process until its end. To get rid of the influence of temperature on the silicon detectors, we placed them beyond the chamber. Only the diffracted beam was taken out from the chamber.

The 1294-1b liquid crystal used consists of a mixture of fourteen components [6]. The mixture had nematic range from 3°C to 155°C and the optical anisotropy $\Delta n = 0.35$ in 25°C. The mixture 1294-1b as a holographic medium was discussed in Ref. 1. The mixture was then divided into three parts (1294-1-2, nematic range from 47.2°C to 230°C, optical anisotropy $\Delta n = 0.30$; 1294-1-3, nematic range from 26°C to 220°C, optical anisotropy $\Delta n = 0.28$; 1294-1-1, nematic range from 22°C to 160°C, optical anisotropy $\Delta n = 0.2$).

3. Results and discussion

The first tested mixture was 1294-1-2 and first measurements started from 20°C. After the temperature transformation phase, we observed that the solid crystal scattering was ended. At that place the diffraction efficiency beam appeared (20 μW). The temperature was slowly increasing and we have noticed that the diffraction beam falls down, as shown in Fig. 2. Later on, we increased the temperature to the maximum (80–90°C) and we measured how the diffraction fallen. An interesting process was observed, when we wanted to change the cell with a liquid crystal, we had to decrease the temperature inside the chamber. The chamber was equipped with a cooling system based on dry ice (frozen CO_2 sunk in alcohol). That type of cooling makes it possible to reduce the temperature inside the chamber in a short time. We could decrease the temperature down to –10°C in a few seconds. That type of decrease evidently supports the diffraction efficiency effect (overfrozen). The diffraction efficiency rises up between –10 and 10°C. That effect was very unstable. The time of existence of the high-energy diffraction beam was very short and appeared only when the gradient of the temperature was observed in the chamber (Fig. 3).

The same experiments were done for 1294-1-2 mixture. Characteristic shapes of the diffraction efficiency were similar to the 1294-1-3, but diffraction efficiency was less then 50%. The characteristic shapes are shown in Figs. 2 and 3. The worst parameters of our experimental mixtures has the 1294-1-1, even through that mixture nematic range starts at 22°C. We did not observe the diffraction efficiency in all reasonable temperatures.

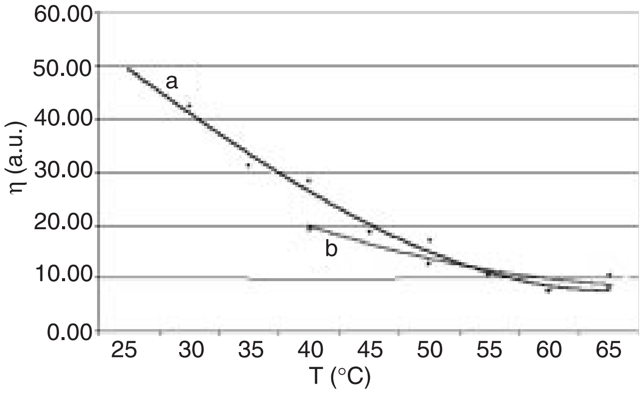

Fig. 2. Dependence of the diffraction efficiency vs. temperature, (a) mixture 1294-1-3 and (b) mixture 1294-1-2.

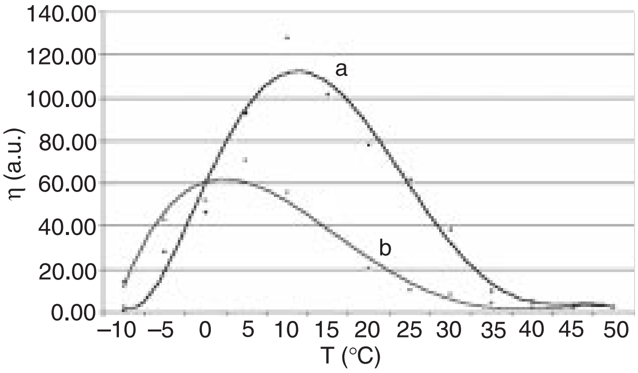

Fig. 3. Dependence of the diffraction efficiency vs. temperature, (a) mixture 1294-1-3 and (b) mixture 1294-1-2.

At the beginning of the high Δn experiments, LC cell was put in constant two interfered beams and the diffraction efficiency was measured for different DC applied voltage. As it was previously expected, the mixture with the highest Δn was the most efficiently in our experiment. Maximum diffraction efficiency obtained for each mixture is shown in Fig. 4.

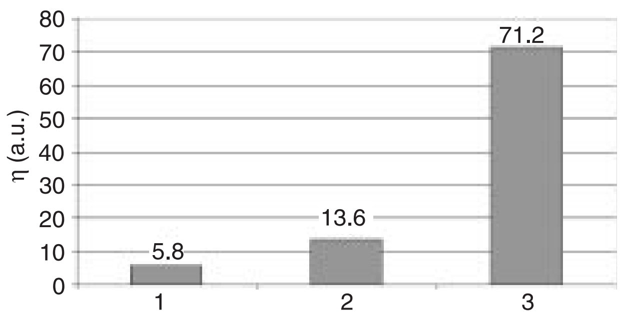

Fig. 4. Diffraction efficiency for LC cells containing mixtures with different optical anisotropy, 1 – $\Delta n = 0.35$, 2 – $\Delta n = 0.4$, and 3 – $\Delta n = 0.6$.

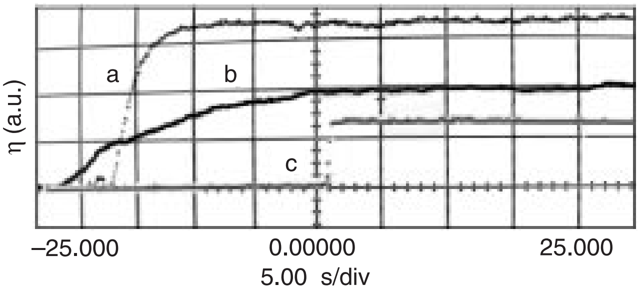

Fig. 5. The grating writing characteristics, LC mixtures: (a) $\Delta n = 0.6$, (b) $\Delta n = 0.4$, and (c) $\Delta n = 0.35$.

The measured dynamic characteristics were divided into two important groups. Very essential for applications is the grating building time. As it is shown in Fig. 5, the most effective dynamic diffraction efficiency was obtained for the same mixture as in the static experiments. The same diagram shown that the writing time is the fastest for the mixture with $\Delta n = 0.35$ and 0.6. The weak properties of the writing time have the mixture with $\Delta n = 0.4$. The same situation can be observed for erasing time (Fig. 6). The worst dynamic parameters were observed for the mixture with $\Delta n = 0.4$. We should choose which kind of crystal is needed fast or effective.

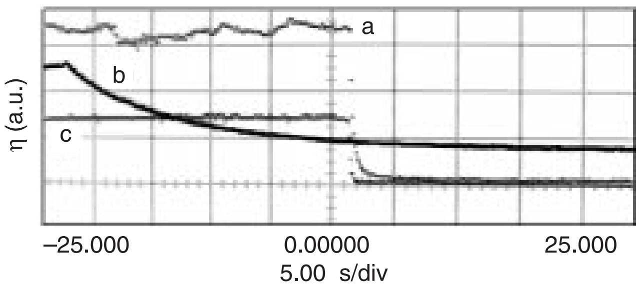

Fig. 6. The grating erasing characteristics, LC mixtures: (a) $\Delta n = 0.6$, (b) $\Delta n = 0.4$, and (c) $\Delta n = 0.35$.

The dynamical properties of the mixture with $\Delta n = 0.4$ were not satisfactory but long erasing times can greatly exchange a value of the mixture. After writing sequence the grating inside the cell, it decreased very slowly for more than 10 minutes. That suggested the way to obtain permanently written grating inside the cell.

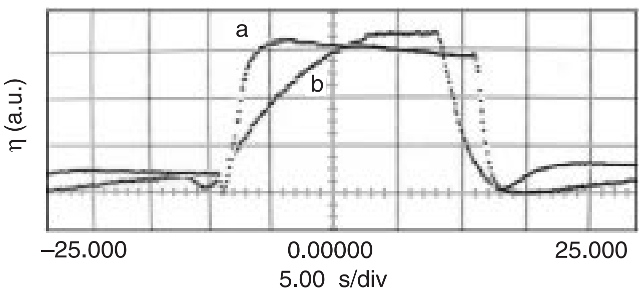

Fig. 7. Diagram of the dynamic diffraction efficiency response for LC cells with $\Delta n = 0.35$, (a) cell with photosensitive layer and (b) cell without photosensitive layer.

Dynamical properties of LC cells with photosensitive layer were also tested. An example of the obtained results for LC cell with the mixture 1294-1b ($\Delta n = 0.35$) is shown in Fig. 7. As diagram shows, photosensitive layer decreases the writing/erasing times. Written gratings are also much similar to the rectangular shape of the writing beam.

4. Conclusions

The components which are added to 1294-1-2 (to obtain 1294-1-3) decreases viscosity and optical anisotropy. In this case, decrease in the viscosity probably has positive influence on the diffraction efficiency what was expected.

As it was theoretically predicted, refractive optical index of liquid crystal mixture extremely increases diffraction efficiency. The tested cells with LC mixtures and with high refractive optical index shown also that time of the response times of the liquid crystals for external optical field do not correspond with optical anisotropy. Our experiments showed two different means of applications depending on liquid crystals properties.

In one case, fast and efficiency liquid crystals can be used in dynamic holography movies where the writing and reading times should be the shortest as possible. Our experiments shown also that photosensitive layer can decrease the writing/erasing times for LC mixtures.

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