Investigations of the diffraction efficiency in dye-doped LC cells under low frequency AC voltage

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In this paper, relation between the diffraction efficiency in LC dye doped cell in two wave mixing system and the applied voltage parameters had been described. The goal of this work was increase in diffraction efficiency using low frequency AC voltage. The LC cells used in the experiments were filled with pure and dye-doped liquid crystal mixtures. In this system, we obtained diffraction efficiency increasing about five to eight times.

Keywords: liquid crystals, dynamic holographic gratings.

1. Introduction

The dynamic holography systems are now very rapidly inquired by most laboratories in the word, because there can be such the way in the new spatial light modulators [1–3]. The dynamic gratings formation on multi-wave mixing in dye-doped nematic liquid crystal (LC) can be supported by applied AC modulated voltage (square-wave form) as was explained and photorefractive effects in LC as was explained by Agashkov *et al.* [4] and Zhang *et al.* [5]. Our previous work proposed projection method setup that contains mixtures and the cells chosen before [6,7]. The first step to the dynamic holography based on liquid crystal optically addressed (using projection method) spatial light modulator is to test the mixture and cell parameters in two wave mixing system [8–10], where the holographic gratings are formed by two interfered He-Ne laser beams. The main method in our dynamic holography system is projected method (method uses coherent illumination to address spatial light modulator), where the stored holograms can be projected very fast. That situation requires suitable fast, sensitive and effective mixtures.

In this paper, we try to explain our experiments and results which are focused on the relation between diffraction efficiency, the current in LC cell during dynamic processes of writing holographic gratings and AC alternate and non-alternate voltage in frequency regime from f = 0 Hz to f = 25 Hz.

Typical LC cells (thickness d = 6–10 μm) with polyimide orientation layer and degenerate two wave mixing (DTWM) system for writing holograms were used. The diffraction efficiency in cells was tested and observations show that it is respectively good. Holographic gratings formed by interfered He-Ne laser beams in cells with pure liquid crystal and dye-doped liquid crystal were described [3]. The possibility of diffraction pattern generation in LC cells as a media was proven. Newly developed projection method of optoelectronic reconstruction of holograms expands possible applications of LCs in holography [4]. The presented works goal is to check the physical and optical parameters of LC mixtures in reference to set-up mentioned above. The DTWM systems were used here only to test the cells that were then used in system with projected method. Our investigations were focused on proving the usefulness of LC cells for the holographic imaging.

All the previous measurements were done using the DC voltage. Those experiments suggested that the DC voltage (field) was more suitable in LC mixtures (ion separation) and cells where mixtures were used. Apart from that, the DC voltage both supports grating formations inside the cell (more stability) and increases influence of the light on the director. All previous experiments described the diffraction

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efficiency η as a function of voltage applied. After all the previous experiments the unexpected thing was observed. When the applied voltage was immediately decreased, diffraction efficiency was observed as a very strong impulse. Another experiment was needed in which the cells with AC field were tested.

2. Experimental assumptions

The holograms were written and read by the He-Ne ($\lambda = 632.8$ nm) laser beam in conventional two-wave mixing technique using linearly s-polarised input light [3]. In experiments the nematic mixture with high optical anisotropy (isothiocyanates compound, $\Delta n = 0.35$) were used. The pure mixtures and mixture with antraquinone ($\lambda_{max} = 620$ nm) were also tested [4]. The measurements were performed in a 90° twisted nematic LC cell. The laser beam was split into two beams crossed each other in the LC cell section (Fig. 1).

Such a light intensity pattern generates an index of refraction grating in the cell (the case of Raman-Nath regime – grating spacing $\Lambda = \lambda/sin\theta = 12$ µm). The measurement setup allowed to observe the dynamic processes connected with the cell (the current I, applied voltage character V, diffraction efficiency η). Diffraction efficiency was calculated from intensity values measured by power laser beam (Coherent Labmaster) device.

3. Results

In the first experiments the sinusoidal voltage was applied to the cell (in our experiments connected with manual decreasing of voltage – where the maximum of the diffraction efficiency was observed) with very low frequency ($f = 0.1$–1 Hz). Obtained results inform that diffraction efficiency increases up to 500% this was the correct way. Although many cells were tested, it turned out that they gave the same results. That gives information that the carrier and

the ion transport inside the cell allow to obtain short while when fields disposition inside the cell are most profitable for light–LC mixture interaction what can was observed as an diffraction efficiency impulses. Increase in frequency gives no effect, on the contrary diffraction decreases. Consequently, the support of the diffraction needs more voltage. Given shapes of the diffraction efficiency was observed as an impulses on the sinusoid slope. Probably unsymmetrical character of the cell or unsymmetrical disposition of the carriers which were in-build inside the polyimide layer gives unsymmetrical impulses on the slopes (Figs. 2 and 3).
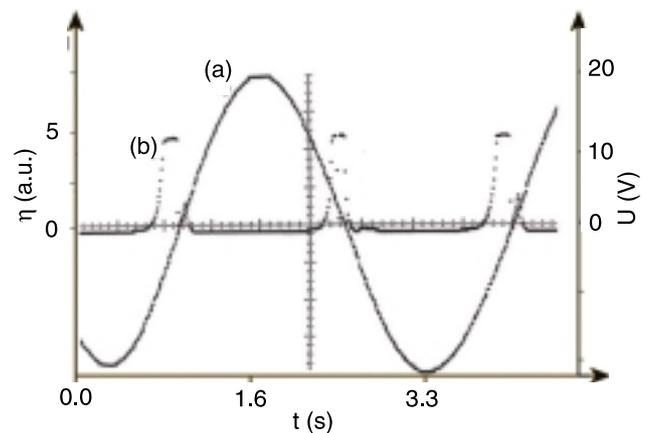
Fig. 2. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 0.3$ Hz, $U = 20$ VPP (a), diffraction efficiency (b).

The results presented above suggested to investigations about situation where applied voltage was DC and was set about the maximum diffraction efficiency level then modulated. The obtained situation was the same as situation when the offset voltage was used – to always have alternative voltage above zero. The investigations were concentrated about the measurements of the cell behaviour when offset voltage was increased from zero to maximum dif-
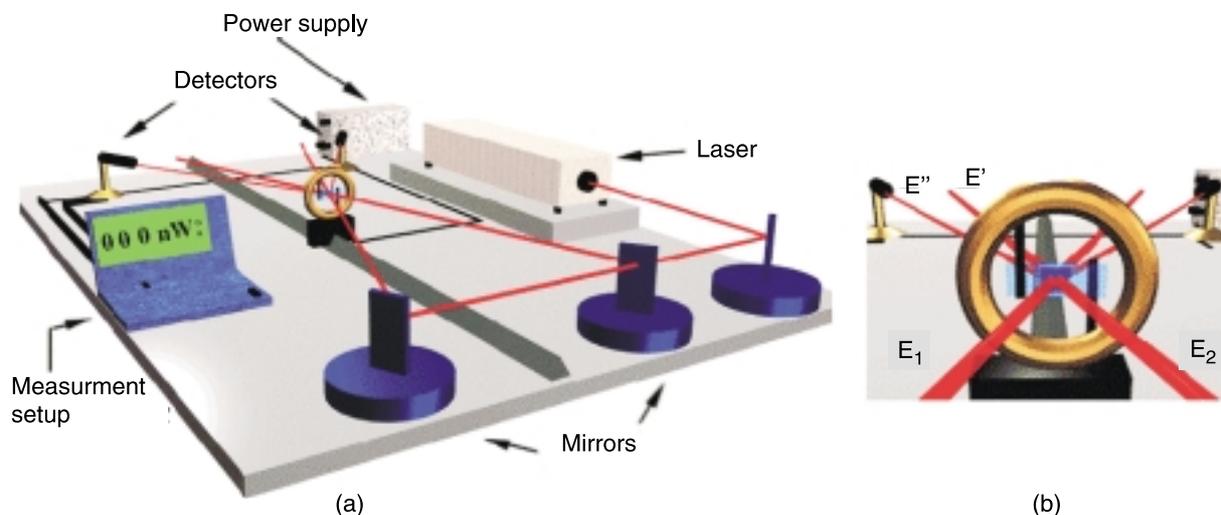
Fig. 1. Experimental setup (a), LC cell in the holder (b). E_1, E_2 are the incident beams; E', E'' are the diffracted beams.
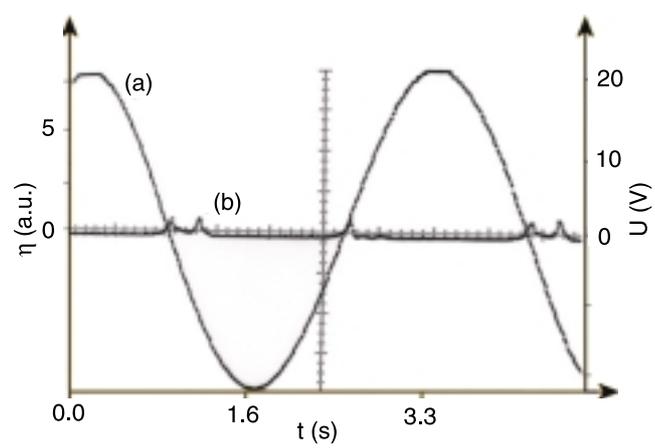
Fig. 3. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 3$ Hz, $U = 20$ VPP (a), diffraction efficiency (b).

fraction voltage level (Figs. 4 and 5). Other shapes and voltage characters were also tested. The most interesting was the square shape. The filling factor of the square gives
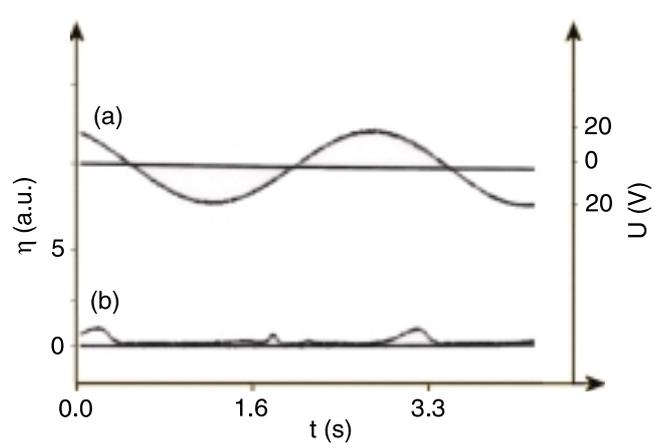
Fig. 4. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 0.3$ Hz, $U = 20$ VPP, offset voltage $U_{off} = 0$ V (a), diffraction efficiency (b).
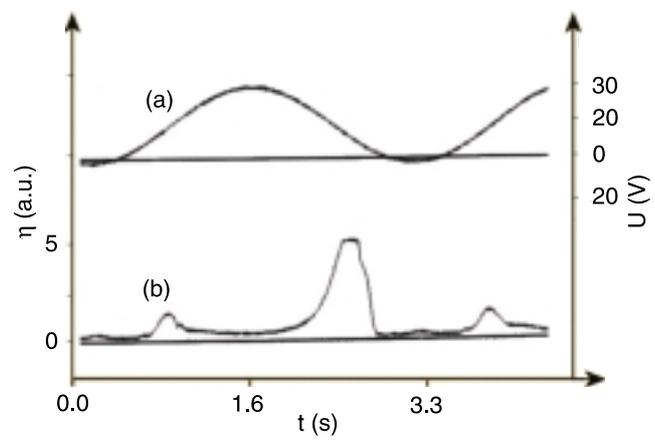
Fig. 5. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 0.3$ Hz, $U = 20$ VPP, offset voltage $U_{off} = 10$ V (a), diffraction efficiency (b).
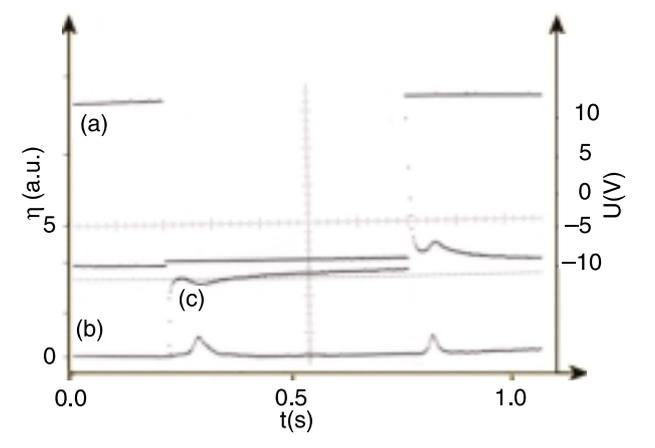
Fig. 6. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 1$ Hz, $U = 10$ VPP, offset voltage $U_{off} = 3$ V (a), diffraction efficiency (b) and the current (c).
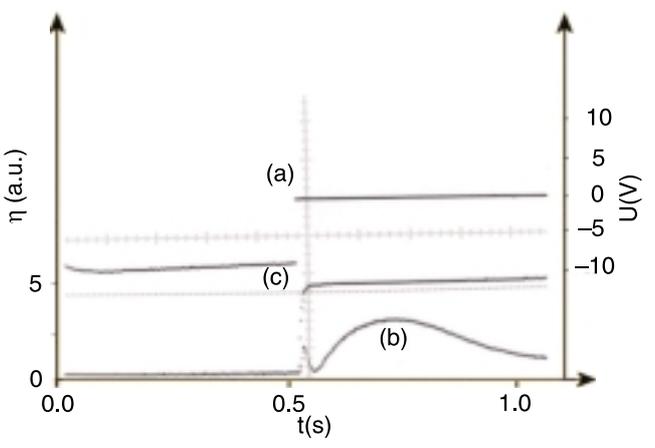
Fig. 7. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 1$ Hz, $U = 10$ VPP, offset voltage $U_{off} = 8$ V (a), diffraction efficiency (b) and the current (c).

more flexibility – more parameters to be changed (Figs. 6 and 7).

The disappearance of the diffraction efficiency after a very short voltage impulse was a long process in the time
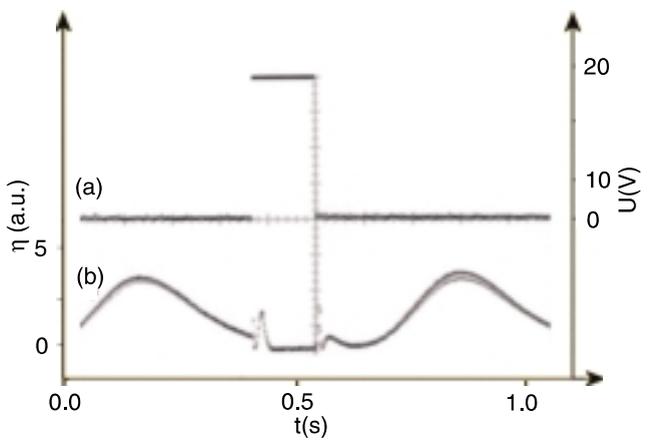
Fig. 8. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 1.5$ Hz, $U = 12$ VPP, offset voltage $U_{off} = 6$ V, duty $d = 20\%$; voltage (a), diffraction efficiency (b).
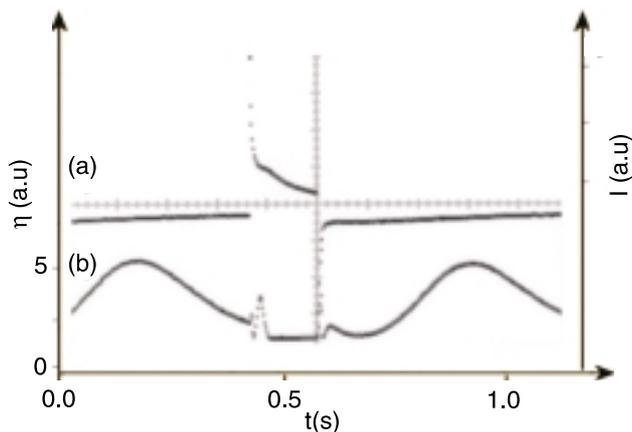
Fig. 9. Oscillogram of the applied AC voltage, $f = 1.5$ Hz, $V = 12$ VPP, offset voltage $U_{off} = 6$ V, duty $d = 20\%$; the current (a), diffraction efficiency (b).

Fig. 11. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 10$ Hz, $U = 12$ VPP, offset voltage $U_{off} = 6$ V, duty $d = 80\%$; voltage (a), diffraction efficiency (b), diffraction efficiency for AC voltage, $f = 1.5$ Hz, $V = 12$ VPP, offset voltage $U_{off} = 6$ V, duty $d = 20\%$; voltage (c).

domain. After that various filling factors were tested. That gave the possibility of having stability of the diffraction index when the frequency is increased (Figs. 8 and 9).

The diffraction efficiency was measured also for higher frequencies (projected method requirements). The offset voltage and filling factor were suitably changed. That gave a very interesting effect. In low frequency ($f = 0.1$–5 Hz) the diffraction efficiency increases with the filling factor as shown in figures above (Figs. 8 and 9). The filling factor means percent of the width of the upper part of the square. When the frequency increased about $f = 10$ Hz another setup was needed. The filling factor had to be increased above 50% as shown below (Figs. 10 and 11). That suggested us that the applied voltage has to be suitably changed, proportionally to the requirements, and that diffraction efficiency can be hold on this same level for different frequencies.

It is interesting to observe that the shape of diffraction efficiency (observed on oscilloscope in time domain) has a different character to the shape of voltage impulses and is

probably not connected with the fast current changes in the cell.

The shapes of the current curves suggested that at least two different kinds of charges take part in dynamic field changes inside the cell [6,7]. These charges were probably accumulated near or inside the layers that have direct contact with LC mixture and were responsible for the fields disposition. For very low frequency, about 1 Hz or less, square shape of connected voltage, the current curve has similar character as the observed curve of the impulse that supplies the cell (the current maximum changes were observed on edges of the square) but the current changes were very fast. That situation not means that all charges from the cell were changed their places as an oscillogram suggested. The slower part of the charges can have the same value as the carriers observed on the square edge but they are accumulated in long time. That effect was observed when the diffraction efficiency decreasing. The most effective diffraction was obtained for the sinusoidal voltage supply. In this situation, the current has a different shape to the square voltage impulses, and different to the diffraction efficiency impulses. The diffraction efficiency was observed as impulses on the slopes of the sinusoid (the voltage). Latest experiments proved that square voltage with suitable offset voltage and filling factor can be used as a holographic medium in high frequency systems ($f = 20$–25 Hz).

4. Conclusions

- Suitably applied voltage parameters can increase the diffraction efficiency, specify in frequencies more than 25 Hz which are required in the systems using projected method or fast optical correlator. In the DC voltage, only writing light beam took part in gratings fingers reconstruction inside the cell. That was a very slow process, specify clearing the written gratings. Those experiments proved that the AC voltage could support fast changes inside the cell.

Fig. 10. Oscillogram of the diffraction efficiency. The applied AC voltage frequency $f = 10$ Hz, $U = 12$ VPP, offset voltage $U_{off} = 6$ V, duty $d = 20\%$; voltage (a), diffraction efficiency (b).

- The current changes were much faster then the diffraction efficiency changes. We didn't find direct correlation between the current diagrams and diffraction efficiency curves. All the processes connected with the current were done (in time domain) before the diffraction efficiency was observed. Interesting was the fact that new filled cell should stay in DC field for some time to start work (the diffraction efficiency observations). These processes are probably linked with a charge accumulation process in the cell. The diffraction efficiency was also changed (increased about 500%) in time domain, when the cell was worked in AC field.
- For different shapes of applied voltage the different diffraction efficiency was observed. The diffraction efficiency was observed as impulses in different places of applied shapes of the voltage.
- Observations of the diffraction efficiency obtained in AC voltage suggested that LC cells could be used in the fast correlation and holographic systems [8].
- The recent experiments not prove the connection between the current and the diffraction efficiency.
- Obtained results was similar to the others explanations of the cells behaviour under AC voltage [4,6].

Acknowledgements

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