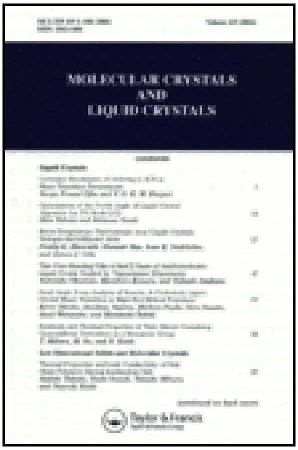

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LIQUID CRYSTAL PHOTOSENSITIVE CELLS AS A MEDIUM FOR REAL-TIME DIGITAL PROJECTED HOLOGRAMS

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The possibility of diffraction pattern generation in pure and dye-doped LC (Liquid Crystal) cells as a media was proven. Newly developed projection method of optoelectronic reconstruction of holograms expands possible applications of liquid crystals in dynamic holography. The presented works goal is to check the physical and optical parameters of isothiocyanate nematic liquid crystal mixtures and cell construction in reference to projection set-up of hologram presentation. The experimental results of holographic image registration are discussed. Sample reconstructions of synthetic holograms are shown.

Keywords: liquid crystal photorefractivity; real time holography

INTRODUCTION

In optoelectronic holographic imaging more popular media is AMLCD (*Active Matrix Liquid Crystal Display*) now. The disadvantages of these devices for this application are: very large pixel size, low fill factor (i.e. existance of the crossed patterns of masked areas) and low resolution

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(up to 1.5 milllions of pixels). Possible increase of resolution and fill factor could be performed by replacing AMLCD by optically addressed LC cell [1]. However the optically addressing method is more complicated but offer more possibilities.

Holographic gratings formed by interfered He–Ne laser beams in pure nematic liquid crystal and dye-doped nematic liquid crystal cells under DC voltage were described in [2,3]. In this case physical mechanism of pattern generation is detailed and could be describled as a volume photoconductivity inside the LC cell supported by charge transfer mechanism under external electric field [4]. Main application of the optical holograms registration/reconstruction are OASLM (*Opically Adressed Spatial Light Modulators*) [5,6].

Our investigations were focused on proving the usefulness of LC cells for the holographic imaging. In this experiment as a addressing unit the DLP (*Digital Light Processing*) projector was taken [7,8]. Holograms with different fringe periods (Λ) and fringe contrast (C) were incoherently projected on LC cell and simultaneously read by a laser beam [9]. Alternatively two laser sources as a reading beam were used. In LC cells we have examined pure nematic mixture with high optical anisotropy and doped with three different antraquinone and azo dyes. We tried to understand and explain the mechanism of writing grating in the nematic LC cell used in this setup.

THE HOLOGRAPHIC GRATING EXPERIMENT

Now our investigations are concentrated on synthetically computed holographic gratings generated by computer and projected by DLP projector based on DMD (*Digital Micromirrors Device*) with different color filters on a LC cell.

The basic concept of DHS (*Digital Holographic System*) relies on digital recording of microinterferogram (hologram) which contains information about the object [4].

There are also two methods of creation of microinterferogram: optically and by computer synthesis (Fig. 1). A computer generated hologram is created by numerical simulation of interference between an object and reference beams, while the optical one is given by physical interference of these two beams and recording of the interference field by high resolution CCD camera.

First as a simple holograms written by projected methods in the cells were black and white lines (gratings) with different width and contrast. The next real object holographic gratings onto LC cells were projected. The holograms had been read by laser beams. As a grating reading source

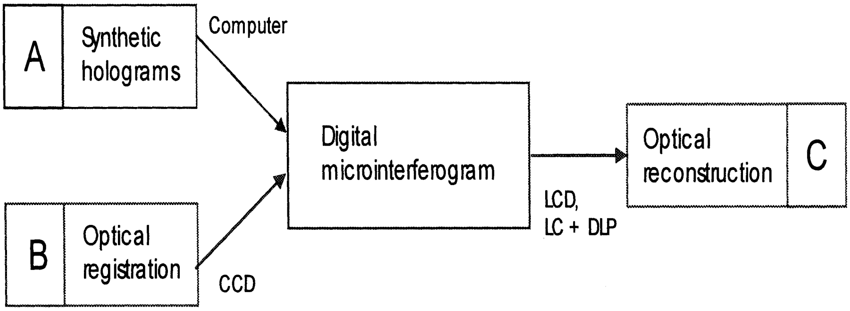


FIGURE 1 Methods of holographic registration and reconstruction of an amplitude-phase information: A – numerical generation of holograms, B – optical registration of holograms, C – optoelectronic reconstruction by means of AMLCD or LC cell and DLP projector.

in our experiments a few mW lasers: HeNe, HeCd and YAG (sec. harm.) were used.

There are two general methods of optical reconstruction of digital microinterferograms. The simplest way is to display the digital data directly at the LCD and reconstruct the hologram by illuminating it by a laser beam [5,6,7]. The alternative method uses optically addressed LC cell working as an optical valve. The microinterferogram is written at the LC cell by illuminating it with a DLP projector based on the DMD (*Digital Micromirrors Device*) [8]. The created microinterferogram is illuminated by a coherent beam and the hologram is reconstructed.

The brightness of reconstructed images is dependent on the diffraction efficiency (η) of the system. Resolving power of the media is responsible for detail reproduction and beam separation (angle between 0th and diffracted orders). It is needed for each angular position of the fringes due to ability of reconstruction of details at the objects. Good quality holographic images needs to have the system with high diffraction efficiency, independent from the period and orientation of the fringes.

For testing the multimedia application of the examined units we also have prepared some computer generated holograms (CGH) for reconstruction onto new type LC cells by projection method [4]. In this case the digital projector (DMD based DLP projector) was replaced by analog device (photographic slide projector with halogen light source). The digitally stored microinterferograms were exposed on the silver-halide high-resolution photographic film (135 type) and processed in contrast developer. The projection optics has transferred images in the way to achieve dimensions at the cells plane 1.5×1 mm what corresponds with the pixel size in digitally stored hologram $\Delta \approx 15\,\mu$m. Color filter in writing beam was used for adjust the wavelength of the beam. The holograms were written by optical way (incoherent projection) onto LC cell and simultaneously reconstructed by laser beam polarized in accordance of the direction of rubbing. The experimental set-up is shown in Figure 2.

The behavior of thin (5 – 20 μm) cells with pure isothiocyanate nematic liquid crystal with high optical anisotropy ($\Delta n > 0.35$), antraquinone doped was investigated. The above mentioned LC mixtures in cells with different photoconductive layers were tested. Our experiments were aimed at optimization of various cell construction parameters, LC mixtures and photosensitive admixtures in respect to demand the highest diffraction efficiency and shortest write/erasing times.

The typical paralelly oriented cells containing pure and dye-doped liquid crystal mixture were used [5,9]. The cell was powered by DC voltage. DC field reorient the director of LC molecules from homogenous to homeotropic state (value of this DC field was modified accordingly to requirement within the range 4–25 V). When DC is applied, the LC director in the cell have homeotropic orientation. The writing beam is incoherent, unpolarized and impignes perpendiculary to the cell [4,10]. The grating existing as a graphic bitmap file in the computer memory is transferred to DMD chip and is imaged at the LC cell plane by dedicated optical system. The color filter allow us to control writing beam wavelength. The projection method enables precise focusing and magnification of images. At the LC cell, holograms with rectangular apertures were written with smallest pixel size of approximately $\Lambda = 13\,\mu m$. The reading beam is polarized and also perpendicular to the cell (Fig. 3, 4). Reading beam was applied at the aperture of hologram only. The color filter placed behind the cell in the experimental set-up is used for blocking writing beam - useless in measurements. Introduction experiments have shown a strange behaviour of LC mixtures. All of

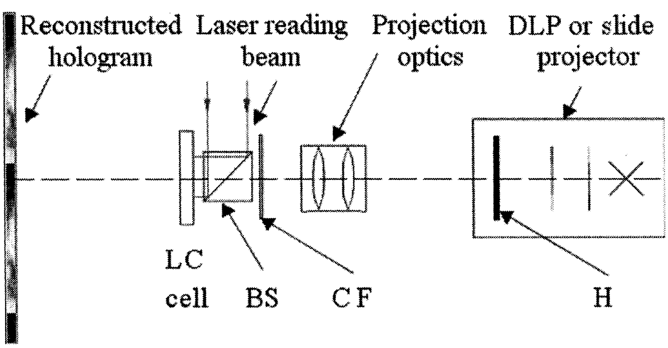


FIGURE 2 Experimental set-up for optical hologram reconstruction method of CGH, BS – beamsplitter, CF – color filter, H – holographic grating.

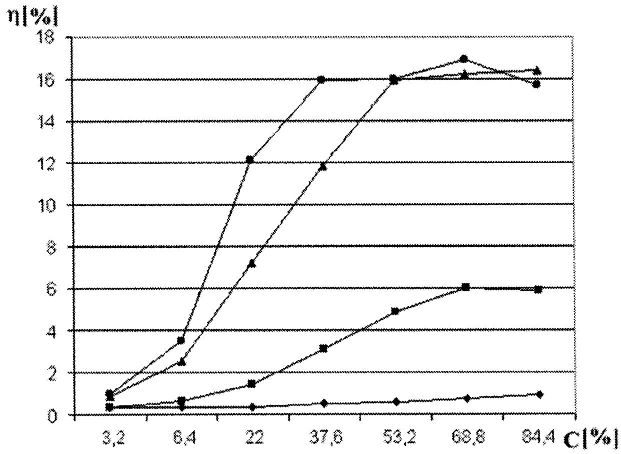


FIGURE 3 Diffraction efficiency for cell with blue dye as a function of fringe contrast and diffrend periods (HeNe laser reading beam, blue filter in writing beam). Grating period Λ: —◆—13,6 μm, —■—27,2 μm, —▲—40,8 μm, —●—54,4 μm.

the investigated LC cells worked most effectively with the blue filter in the writing beam. It can be explained as a interaction of pure liquid cristal with the light. We observed that irradiated pure LC mixture after some period of

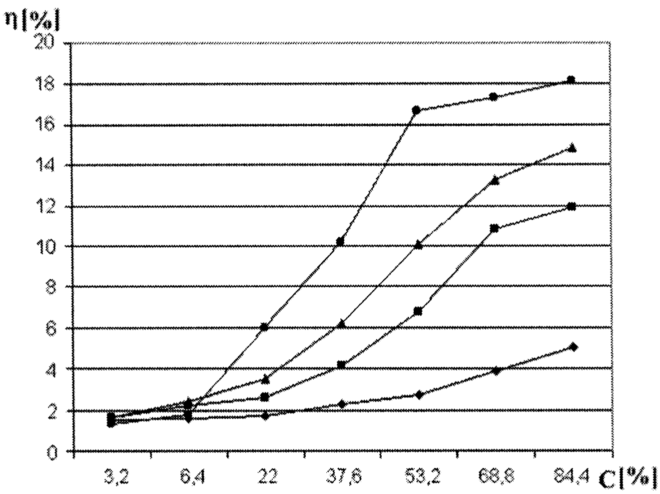


FIGURE 4 Diffraction efficiency for cell with blue dye as a function of fringe contrast and diffrend periods (HeCd laser reading beam, blue filter in writing beam). Grating period Λ: —◆—13,6 μm, —■—27,2 μm, —▲—40,8 μm, —●—54,4 μm.

time seems to start take a yellow colour–that means that have absorption band better interacted with blue light.

RESULTS AND DISCUSSION

The diffraction efficiency was measured for different periods of gratings and modulation depth (contrast). The results of investigations are shown in Figures 3–6.

The curves in Figure 3 show diffraction efficiency as a function of the contrast of the image written in LC cell containing mixture with blue dye (max. absorption 630 nm) in different grating periods. In this case reading beam was a He–Ne ($\lambda = 632{,}8$ nm) laser. The highest diffraction is observed for the maximum period ($\Lambda = 54{,}4\,\mu m$) and is decreasing as the period is smaller. We suppose that decrasing of the contrast in the function of the resolution in projection optical system occurs. Therefore we suppose the results achieved with higher resolution ($\Lambda < 40{,}8\,\mu m$) could be not exactly connected with the reality.

The diffraction efficiency is better when the fringe contrast increases. Maximum contrast probably gives more effective refraction index inside the cell and there we can search for a natural explanation (increase of photorefractive index) of our investigations. That means high intensity of projected beams make high local electrical field decrease inside the cell (photorefractive effect) and reorientation of the molecules. Similar situation is observed for the other reading beam–laser He–Cd ($\lambda = 442$ nm) (Fig. 4).

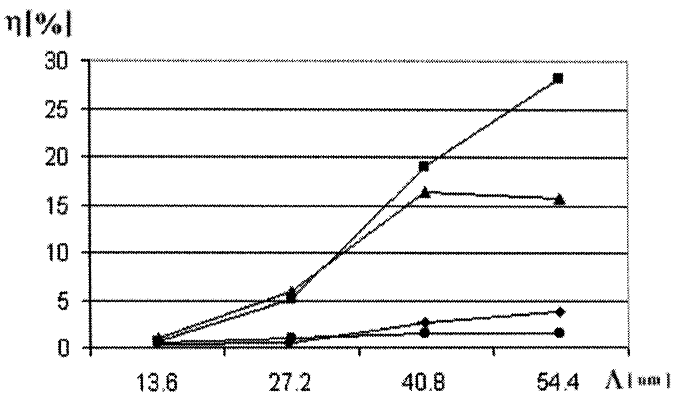


FIGURE 5 Diffraction efficiency for cells with different dyes as a function of gratings period (HeNe laser reading beam, blue filter in writing beam). Dye: —◆— red, —●—yellow, —▲—blue, —■— pure mixture.

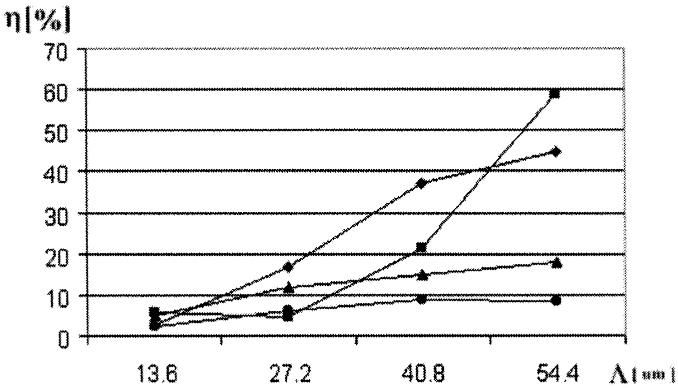


FIGURE 6 Diffraction efficiency for cells with different dyes as a function of gratings period (HeCd laser reading beam). Dye: —●—red, —◆—yellow, —▲—blue, —■—pure mixture.

We also tested other LC mixtures with different dyes ($\lambda_{max} = 445$ and $\lambda_{max} = 495\,nm$). The results are shown in Fig. 5. We can observe that different dyes gave unexpected results. In both arrangements pure LC mixture gives the highest efficiency, while the theoretical consideration leads to the conclusion that the mixtures with addition of dye with maximum absorption near writing beam wavelength should provide the maximum η.

But mixture with the blue dye gives better efficiency in He–Ne reading beam than the red and yellow ones. The yellow one gives better efficiency in He–Cd reading beam. That means some kind of dependance of diffraction efficiency from the reading beam wavelegth. Probably we can explain it as a reduction of electric field (interaction dye-reading beam) inside the cell which helps in construction of the grating.

We observed that cells containing liquid crystal mixtures with different dyes have different diffraction efficiency (the maximum value about 20%) and depend on the modulation deep of projected gratings. Strong diffraction efficiency dependence on the projected grating period was observed [3]. Few millisecond writing/erasing times was obtained (Fig. 7).

The influence of the angular orientation of the projected gratings in the relation to rubbing direction in the cell is low. The diffraction efficiencies at 0 and 90 deg reach similar values (for the cell with blue dye and He–Ne laser reading: $\eta_0 = 3.54\%$, $\eta_{90} = 3.55\%$). Much more important is the direction of polarization of reconstruction beam which has to be perpendicular to the rubbing direction. When it is oriented opposite diffraction efficiency falls close to the zero level.

Finally the synthetic holograms of the simple objects (i.e. letters Z, T, O and little figures) were applied to check possibility of optoelectronic

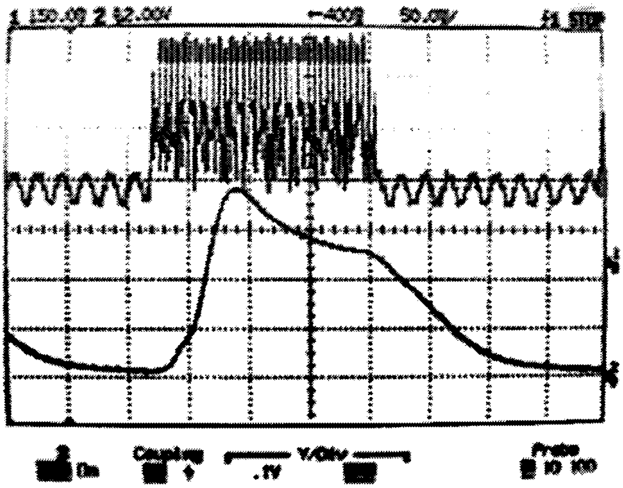


FIGURE 7 Dyamic properties of LC cell with pure nematic LC under periodic illumination.

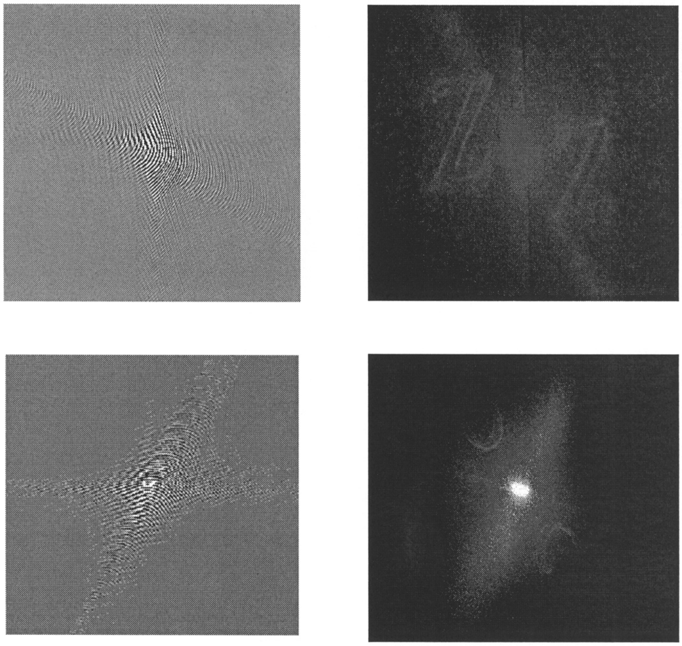
reconstruction. Sample projected grating (numerically calculated CGH) and obtained spectrum (reconstruction) of Z and O letters are shown in Figure 8. The quality is relatively good and proves the usefulness of these LC samples in multimedia holographic systems.

CONCLUSIONS

Obtained results were relatively good from application point of view. Employing of better optics for projection, use of different mixtures or cell arrangements should lead to improvements of the reconstruction quality.

Diffraction efficiencies of the LC cells are in wide range approximately linearly dependant on the modulation depth of the fingers (Fig. 3, 4). Diffraction efficiency of the LC cells strongly depends on the period of the grating. The smallest dependance is shown by cells with the doping with blue and red dye in the case of He–Ne laser, and yellow dye in the case of He–Cd laser (Fig. 5, 6). Unfortunately, these cells are characterized by low η in these conditions (maximum diffraction efficiency was $\eta \approx 20\%$).

Some inaccuracy at the higher values are caused by the limitations of the projection optics. However parameters of the examined LC cells are not fully satisfactory in respect to the DHS–*Dynamic Holographic System* requirements. It is expected that changes of dyes, LC mixtures, rubbing arrangement or construction of the cells will give better quality effect of



(a)

(b)

FIGURE 8 (a) The synthetic grating and (b) obtained hologram reconstruction of Z and O letters.

holographic reconstruction. Investigated LC cells fulfilled isothiocyanate LC mixture with very high refractive index seem to be very promising media for optoelectronic dynamic image reconstruction and real-time holograms.

The digital projected hologram registration can be also used as a method of LC cell parameters investigation like resolution contrast and other spatial parameters [12].

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