Study of the Dynamics of Transmission Gratings Growth on Holographic Polymer-Dispersed Liquid Crystals

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Introduction

In optical holography, among photopolymerizing materials, which are used as registering media, the holographic polymer-dispersed liquid crystals (H-PDLC) controlled by the external electric field, form a special direction [1]. These composite materials are developed to produce displays and photonic crystals, 3D holographic optical memory [2 – 5]. The recent technologies for H-PDLC applications suggest the recording of several transmission or reflection gratings within one material to increase the functional abilities of the material. The technology of superimposed grating formation (multiplexing) in the H-PDLC was initially developed for the reflective displays. One method was the angular multiplexing, which is based on the configuring two or more pairs of laser beams interfering at various angles onto the same volume of the photopolymerizing composition confined into a special cell, wherein the H-PDLC structure is formed. Later, the angular multiplexing, both simultaneous and sequential (temporal) has been used to form superimposed transmission Bragg gratings in a thin layer of the photopolymerizing composition containing nematic liquid crystal [4].

The preparatory stage of the recording of the multiplexed gratings involves an independent recording of the various-period gratings, purposed to study the dynamics of their formations. The aim of the work at this stage is to adjust such recording conditions to get the gratings of different period with similar and maximally high diffraction efficiency (DE) in the first order. The results of these investigations will enable to optimize the recording conditions (exposure time and power density) for each grating and to reduce their possible mutual influence during the multiplexing.

Experimental results and discussion

The dependence of the formed gratings DE on the exposure time during the recording has been studied. The gratings of the periods of 1.3 – 3 µm were recorded with the p-polarized interfering beams of a semiconductor diode (λ=658 nm). The power density in the recording plane was 3 – 6 mW/cm². The initial pre-polymer composition includes a multifunctional monomer – dipentaeritrol penta/hexa acrylate, a nematic liquid crystal (NLC) – the commercial mixture BL038 (Δn=0.27, n0=1.527, Δε=16.4) and a photo-initiating system (methylene blue, triethanolamine, N-vinylpyrrolidone). The preparation of experimental cells with the pre-polymer composition and basic recording scheme are described in [6 – 7].

The measurements of angular dependences of light transmission have been performed using laboratory experimental setup [6]. The light source was the semiconductor diode with the wavelength λ=658 nm. A half-wave plate and polarizer were placed before the cell with the recorded grating to set the polarization of the reading beam. The measurements were made at strictly fulfilled Bragg conditions. From the angular dependences we could estimate the grating period, the first-order DE (the ratio between the diffracted beam intensity and the incident s- or p-polarized beam intensity \( η_1s \) or \( η_1p \)). The polarization contrast was determined as the diffraction efficiencies ratio \( η_1s/η_1p \).

The amplitude of the refractive-index modulation between the alternating planes, enriched with the polymer or with the NLC, which form the H-PDLC structure, is the parameter controlling the DE of the H-PDLC-gratings operating in the Bragg diffraction mode. This parameter is important for the recording of both separate gratings and multiplexed gratings. It determines not only the DE and its external field modulation range, but also the possible number of gratings that can be recorded in the photopolymerizing material [4]. In turn, the amplitude of the refractive-index modulation
in the recorded grating depends on the “balance” between the diffusion processes, photopolymerization, and phase separation of the NLC and polymer during its formation, and also on the orientation of the NLC-droplets in corresponding planes of the grating.

Let us consider the influence of two main factors – the period (i.e. the distance determining the diffusion processes) and power density during the recording (i.e. the photopolymerization rate) on the formed gratings DE.

As is seen from Figure 1, the dependencies of the gratings DE on the exposure time have two domains with different curve slopes at two polarizations of the reading beam for the periods under consideration: DE growth and saturation. Since the transmission H-PDLC-gratings are polarization dependent, it is more preferable to define the domain of DE growth from the dependencies of the DE polarization contrast on the exposure time (Fig. 2). It is seen from Figure 2 that the maximum of the polarization contrast shifts toward lower exposures as the period increases at the same power density. The domain of DE growth reduces from 2 to 1.5 minutes for the periods of 2 and 3 µm, correspondingly. As the grating period is reduced to 1.3 µm, the domain of DE growth hardly changes comparing to the 2 µm grating. Hence, the growth conditions of the gratings of 2 and 1.3 µm, the power density being of 3 mW/cm² are close to each other. The value of the polarization contrast reduces for the period of 1.3 µm owing to the amplifying DE as the gratings read by p-polarized beam (Fig. 1) as compared to the long-periods gratings.

Let us now consider the simultaneous influence of the period and power density on the gratings DE (Fig. 3). As the power density rises from 3 to 6 mW/cm², the domain of DE growth reduces from 2 to 1 minute for the 1.3 µm grating, and the value of the polarization contrast increases. As the period rises from 1.3 to 2 µm at the power density of 6 mW/cm², the domain of DE growth reduces from 1 minute to 30 seconds (Fig. 3). Thus, for the 1.3 µm gratings, in the NLC-enriched planes, the NLC volume fraction increases at the final stage of the formation, the photopolymerization rate rises. The increasing photopolymerization rate (6 mW/cm²) and period (up to 2 µm) result in the reducing polymerization contrast due to DE growth for the case of the p-polarization of the reading beam and insignificant DE reduction for the s-polarization. For this period, the grating quality worsens.

Fig. 1. Dependencies of the DE on the exposure time at the power density of 3 mW/cm²

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The obtained experimental results permit to optimize the exposure and power density during the multiplexing for each grating. In the studied system, at the sequential multiplexing, it is more preferable first to record the long-period grating, to allow the formation of the second one. The exposure time is a critical parameter for the first grating [4]. It is supposed first to record the 2 µm grating, the power density being of 3 mW/cm². The time of the first grating recording reduces comparing to the measured characteristic time of the separate grating recording, since it still forms during the second grating recording. To keep the obtained value of DE of the second 1.3 µm grating, it is suggested to increase the power density up to 6 mW/cm². Using the simultaneous multiplexing, the recording conditions also depend on the power density for each grating.

Fig. 2. Dependencies of the DE polarization contrast on the exposure time for the various-period gratings at the power density of 3 mW/cm².

Fig. 3. Dependencies of the DE polarization contrast on the exposure time at the power density of 6 mW/cm².
Conclusions

The dependence of the diffraction efficiency of transmission Bragg gratings on the exposure time and beam power density during the recording has been investigated. The obtained results enable to predict the recording conditions for each grating at the multiplexing. Using the sequential multiplexing technology, it is suggested to record first the long-period grating, and second – the grating with the shorter period, regarding the diffusion processes, to obtain the gratings with maximally high DE. In this case, the exposure time is critical parameters for the first grating. At the second grating recording, the beam power density should be increased comparing to the value of the first grating. At the simultaneous multiplexing, the beam power density is also a main factor for each grating formation.

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REFERENCES