

Methods for improvement of surface relief hologram diffraction parameters

M. REINFELDE*, J. MIKELSONE, J. TETERIS

Institute of Solid State Physics, University of Latvia, Riga, 8 Kengaraga Street, Latvia

In this work the methods for improvement of recording parameters of surface relief holograms are studied using $\approx 3 \mu\text{m}$ thick azo-epoxy AAB: BADGE films. Our interest was pointed towards the possibility of experimentally checking the conditions which are more favourable for increasing the diffraction efficiency of surface relief holograms by self-enhancement and by assisting light illumination so contributing to a decrease of recording light exposure dose and recording time for initial grating. The first step of the experiment was to choose the appropriate polarization relationship for the light beams involved in the process. Subsequently, we studied the grating behaviour in light exposure with one of the recording beam when second one is closed, i.e. self-enhancement, was tested. The influence of assisting light during recording and self-enhancement was examined.

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1. Introduction

Holographic self-enhancement (SE) is well known process that takes place for the holograms (HG) recorded under intensity modulated light illumination. It is studied widely in different classes of inorganic materials [1, 2]. SE is the process of interrupting the recording of HG with two beams and further exposing it to one of the recording beams without changing direction (coherent SE) or using additional illumination that does not coincide with the direction of recording beam (incoherent self enhancement). Advantage of such approach is possibility to decrease recording time and light intensity during two beam recording. That offers the opportunity to increase recording area if necessary and ease requirements for recording stability. Recently the presence of SE for the surface relief gratings (SRG) induced by the light electric field modulation was shown [3].

The properties of SRG are widely studied in different disordered materials. Characteristic for SRG formation process is in a strong dependence on recording beam polarization state which determines the resulting electric field distribution in the interference pattern. Under certain circumstances the surface relief grating formation efficiency can be essentially enhanced by additional illumination [4, 5]. As motivation to examine impact of assisting light on SE for surface relief gratings serves mentioned before influence of additional illumination on SE for volume HG (incoherent SE) and for surface relief HG.

In this work azo-epoxy AAB: BADGE films were used [6] as base material. The main advantages of azo-epoxy polymers are simple and cheap synthesis, low polymerization degree. Due to their low cost AAB: BADGE films are promising material for micro and nano patterning. In ABB: BADGE films it is possible to record

good quality surface relief grating. It is also possible this process to be repeated after the grating is erased by s-polarized recording beam.

2. Experimental

The film thickness studied in this work was $\approx 3 \mu\text{m}$. The experimental setup is shown in Fig.1. The first step of the experiment was recording and testing the behavior of the initial grating recorded with two beams. Next one was process of SE when one of the recording beams is closed. The kinetics of diffracted light was fixed – reflected for recording wave length and transmitted for probing beam with small absorption. The influence of assisting light during recording and SE was examined. The adequate polarization for the light beams involved in the process was chosen.

The laser with wavelengths of $\lambda_1=532 \text{ nm}$ was used for holographic recording of initial grating and SE. Initial grating with period $\Lambda=1 \mu\text{m}$ was recorded with two beams of equal intensity. SE was carried out with one of the recording beams and for fastening the process intensity of that beam I_{SE} was increased. For assisting light laser with $\lambda_2=491 \text{ nm}$ was used.

The kinetics of diffraction efficiencies (DE) was measured continuously. Recording light diffraction from film surface in reflection mode $DE_{ref}(532)$ was measured as side order diffraction because the first order diffracted beam in reflection mode coincides with one of the recording beams. Grating formation process was controlled by $\lambda_3=645 \text{ nm}$ probing laser light in transmission mode $DE_{tr}(645)$ as well. The probing laser light intensity was chosen so low that it would have practically no effect on the process.

Surface relief depth was fixed for initial gratings recorded without and with assisting light when energy dose received $E \approx 16 \text{ J/cm}^2$ which we assumed as the basic HG, and after SE.

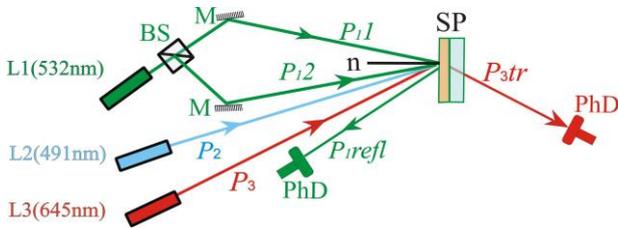


Fig. 1. Experimental setup: P_{11} , P_{12} , P_{1refl} – recording and diffracted in reflection mode light beams at $\lambda_1=532 \text{ nm}$, P_2 – assisting light beam with wavelength $\lambda_2=491 \text{ nm}$, P_3 and P_{3tr} – scanning and diffracted in transmission mode probing light beams at $\lambda_3=645 \text{ nm}$ (color online)

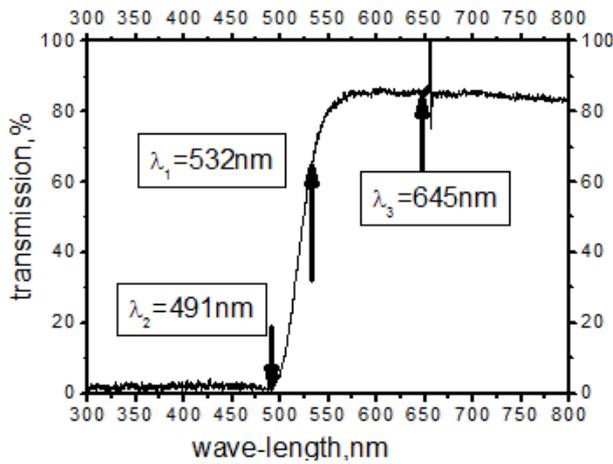


Fig. 2. Transmission spectra of $\approx 3 \mu\text{m}$ thick azo-epoxy AAB: BADGE films; corresponding transmission for lasers used in presented studies are noted with arrows

3. Results and discussion

Fig. 3 shows the kinetics of basic HG grating recording at $\lambda_1=532 \text{ nm}$ light about 4 minutes, light intensities $I_{11}=I_{12}=0.035 \text{ W/cm}^2$, so achieved energy dose $E \approx 16 \text{ J/cm}^2$. Such grating recorded without and with assisting light, we elected as base to examine the impact of different factors on the progress during self-enhancement process. Assisting light as supplemental illumination we used for softening of material to accelerate the surface grating formation process. In presented work the assisting light with constant intensity $I_2 = 0.035 \text{ W/cm}^2$ was used. Such chose is made because we found experimentally that increase of assisting light intensity worsen the process of surface relief formation process. As could be expect, assisting light stimulated the recording of initial grating both for $\pm 45^\circ$ and p-p polarization configuration.

The kinetics of the SE process of gratings is shown in fig. 4; the intensity of the beam $I_{SE} \approx 1.13 \text{ W/cm}^2$. The HG recording is shown up to an energy dose of $E_{SE} \approx 1.3$

kJ/cm^2 , at which we traditionally obtained a well-defined surface relief depth. That takes ~ 20 minutes. At lower intensities I_{SE} , recording time increases, but at intensities that are higher than 1.5 W/cm^2 , the formed SR is damaged. We should emphasize that it is essential to choose p-polarisation for SE beam. As we ascertained experimentally- at s-polarisation the initial grating can be completely erased.

Estimating the kinetics of diffraction efficiencies and surface relief depth for equal illumination doses, higher values are obtained for gratings recorded with $\pm 45^\circ$ polarized light beams. In contrast, the higher values of diffraction efficiencies and surface relief depth were achieved without assisting light illumination.

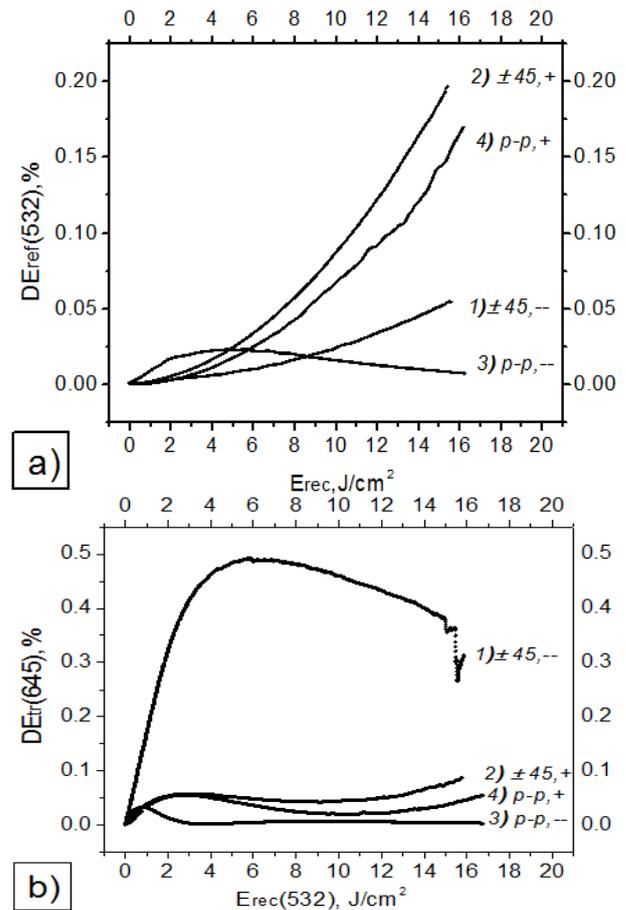


Fig. 3. Kinetics of initial grating recording at orthogonal $\pm 45^\circ$ (curves 1, 2) and p-p (curves 3, 4) polarization configuration. Recording wavelength $\lambda_1=532 \text{ nm}$, intensities $I_{11}=I_{12} = 0.035 \text{ W/cm}^2$. Curves 1 and 3 – recording without, - 2 and 4 with assisting light. Assisting light wave length $\lambda_2=491 \text{ nm}$, intensity $I_2 = 0,035 \text{ W/cm}^2$, s-polarisation; a) reading with recording $\lambda_1=532 \text{ nm}$ light in reflection mode, b) reading with probing beam wave length $\lambda_3=645 \text{ nm}$, $I_{\lambda_3} < 5 \text{ mW/cm}^2$. Sample thickness $d \approx 3 \mu\text{m}$, grating period $\Lambda=1 \mu\text{m}$. Surface relief height after illumination dose $E \approx 16 \text{ J/cm}^2$ is shown in the table below

Table 1. Dependence of surface relief depth Δh on initial HG grating recorded with or without assisting light

recording beam polarisation	Δh without assisting light (-)	Δh with assisting light (+)
$\pm 45^\circ$	12nm	60nm
p-p	3nm	7nm

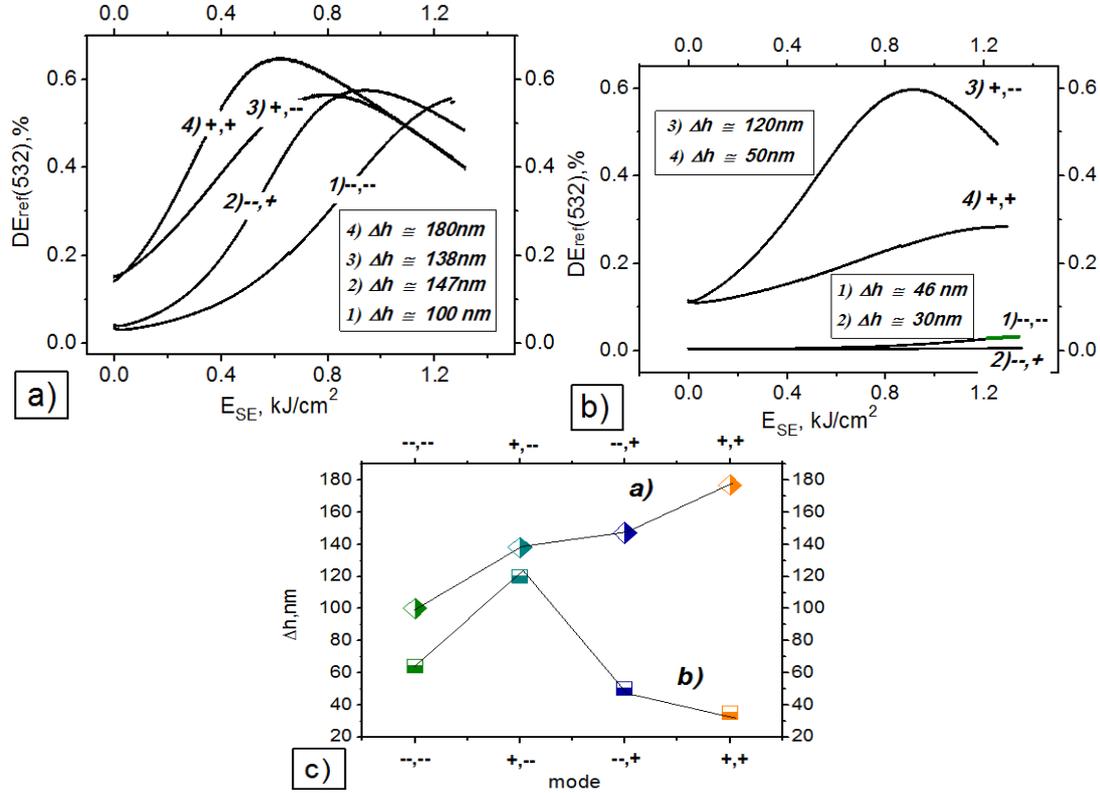


Fig. 4. Kinetics and profile of SE for base HG recorded with a) $\pm 45^\circ$ and b) p-p polarized light beams: curves 1, 3 – SE without and – 2, 4 with assisting light for previously recorded grating without (curves 1, 2) and with (curves 3, 4) assisting light. Intensity of enhancing light beam $I_{SE}=1.13 \text{ W/cm}^2$, $\lambda_1=532 \text{ nm}$, p-polarisation; assisting light intensity 0.035 W/cm^2 , wave length $\lambda_2=491 \text{ nm}$, s-polarisation; c) - the corresponding relief profile height Δh after SE at $E=1.3 \text{ kJ/cm}^2$ (presented also in insets on a and b). For reasons of transparency we used marks to note the lack (--) or presence (+) of extra light illumination - so, in the case of two marks, the first one is related to the recording conditions of base HG and second one – to the enhancing process.

We also observed that the lowest starting values of initial HGs are essential in order to enhance the appropriate surface relief. It distinguishes the SE of surface relief HG from that process on the volume holograms where the intensity modulation takes place. Let us remind that for such type of holograms we did not find the lowest values of diffraction efficiencies where HG SE would not be observed [1, 2]. In the case of SRG the surface formation process is determined by the resulting electric field vector pattern. [4]. Intensity modulation for orthogonally $\pm 45^\circ$ polarisation is absent or nearly absent. In the case of p-p polarisation small intensity modulation takes place and weak volume scalar HG recording is present as well. As we can estimate from Table 1 and figure 3a), the surface formation process for p-p polarised beam recording is in the initial stage and therefore illumination with a stronger assisting light beam can demolish that process. We tested the situation when the recording process is reduced further up to an energy dose

of $E \approx 10 \text{ J/cm}^2$ and noted that even for recording with $\pm 45^\circ$ polarized light beams the SE is insignificant or even absent. At the same time, we observed a strong enough anisotropic scattering around the light beams transmitted by the sample as well in the direction coinciding with location of diffraction both for refracted ($\lambda=532 \text{ nm}$) and transmitted probing beam ($\lambda=645 \text{ nm}$). Apparently, it is caused by surface patterning under single beam irradiation, and, as supposed, is initiated by the interference of an incident light and light scattered by surface defects [7]. (A more comprehensive review of this phenomenon going in “soft” materials is given in [8]). In some way the form of scattered light we observed, reminds the one we observed before in LiNbO₃ crystals [9] and it was proposed that holographic volume gratings are created by the interference of an incident light and light scattered by inhomogeneities in the volume of the crystal

So, we can deduce that the scattering observed in our study belongs to the holographic scattering and it appears

not just because of the surface but also the volume structural inhomogeneities.

This means that single beam holographic scattering must be taken into account when selecting the starting conditions for SE.

4. Summary

In general, the recording and SE processes of surface relief holograms depend on light polarization during recording and starting relief depth as well. For the surface relief formation process, more effective is recording and SE if holograms are recorded with orthogonally $\pm 45^\circ$ polarized light neither that is in the case of p-p polarization.

The results obtained show the possibility to enhance the efficiency of holograms recorded with relatively small light intensities and recording time via SE and/or assisting light illumination.

The assisting light illumination makes the recording of base HG more effective both for orthogonally 45° and p-p polarized light.

During the process of SE for HG recorded with $\pm 45^\circ$ light beams the assisting light illumination has a visible influence: fastening of the process, comparatively higher DE and Δh values than that is in the case without assisting light illumination. On the contrary, if the recording is created by p-p polarized light beams, the assisting light illumination has a negative effect on SE process.

Thus, it is possible to enhance surface elevation with a single beam illumination, provided the initial relief depth is sufficient and amplification conditions selected appropriately.

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*Corresponding author: marar@cfi.lu.lv