

Recording of surface-relief gratings on amorphous As-S-Se films

A.GERBREDERS^{a,b*}, J.TETERIS^a

^aInstitute of Solid State Physics, University of Latvia

^bDaugavpils University, Department of Physics, Latvia,

Holographic recording and surface-relief grating formation process on amorphous As-S-Se thin films was studied depending on recording light wavelength and light beam polarization. The gratings with the period of 0,84 μm were recorded by lasers with wavelength of 325 nm, 442 nm, 488 nm, 514 nm, 532 nm and 633 nm. The dependence of the surface-relief grating formation efficiency on the exposure dose was studied. The vertically (s), horizontally (p), circularly (L and R) polarized light beams and their combinations were used in holographic recording process. The transmission diffraction efficiency during the holographic recording process was measured by the laser light with wavelength of 670 nm. The wet etching of the samples was performed in standard organic alkaline developer produced by Hologramma Ltd and etching process was monitored by measuring the reflection diffraction efficiency at 441.6 nm. The decrease of transmission diffraction efficiency measured at 670 nm was observed by reducing the recording light wavelength. It can be explained by the decrease of recording light penetration depth in the film. The value of reflection diffraction efficiency after dissolving essentially does not depend on wavelength of recording light and reaches 11-14 %. Nevertheless, the value of maximum diffraction efficiency for every recording wavelength corresponds to various exposure doses. The spectral sensitivity and an influence of recording beam polarization position on efficiency of surface-relief formation have been discussed.

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1. Introduction

Formation of surface relief in process of selective dissolution of amorphous chalcogenide films is well-known. This process can be used in photolithography, for manufacturing of micro-optics elements, in microelectronic area and for duplicating of holographic images [1-7] and in e-beam lithography [8].

The phenomenon is based on difference in the dissolution rate of the exposed and unexposed areas of chalcogenide film surface in alkali developers.

There is interest of study of spectral sensitivity of chalcogenide photoresists in UV region because wide assortment of UV lasers recently has been manufacturing and there is a tendency to use shorter light wavelength for information recording.

In this connection, we tried to investigate diffraction gratings, recording on As-S-Se thin films with different light wavelength and different beams polarization in vision and UV spectrum area. After wet etching in alkali developers, we compared diffraction efficiency of the surface-relief gratings dependence on recording light wavelength. On experiment results we made conclusion about spectral sensitivity of As-S-Se photoresist.

2. Experimental

Amorphous As-S-Se films were obtained by thermal evaporation in vacuum of $\sim 5 \times 10^{-6}$ Torr onto glass substrates. The film thickness was in the range 1–12 μm . The samples were irradiated by different lasers with

wavelengths 325 nm, 441,6 nm, 488 nm, 514,5 nm, 532 nm and 632,8 nm with exposure from 0 to 60 J/cm^2 .

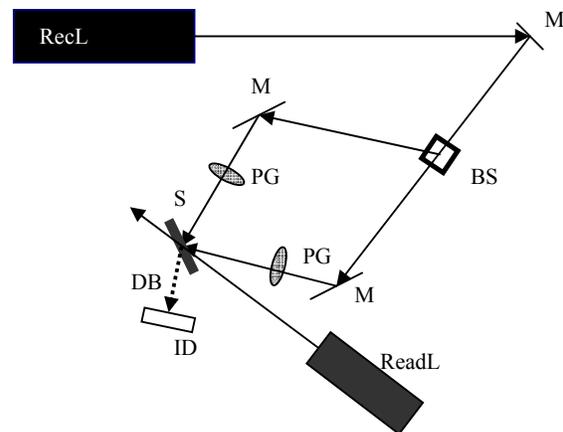


Fig. 1. Gratings recording scheme. RecL – recording laser, ReadL – reading laser 670 nm, M – mirrors, BS – beam splitter, PG – $\lambda/2$ or $\lambda/4$ wave plates, S – sample, DB – diffraction beam, ID – detector of beam intensity.

The holographic gratings with a period $A = 0.84 \mu\text{m}$ were recorded by two symmetrically laser beams of equal intensity with linear horizontal polarization (p-p). The readout of transmission diffraction efficiency was made at the Bragg angle using a semiconductor laser beam 670 nm. After recording, samples were immersed in ditch with etchant, which was based on alkaline organic solutions produced by Hologramma Ltd. In etching time readout of reflection diffraction efficiency was made at the angle 0-10 degrees using He-Cd laser beam 441,6 nm.

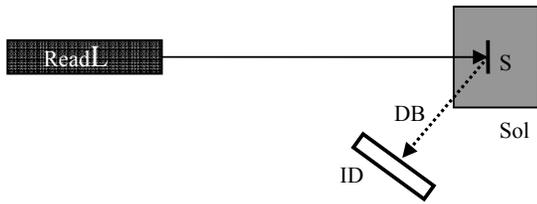


Fig. 2. Sample dissolving scheme. ReadL – reading laser 441,6 nm, Sol – ditch with developer, S – sample, DB – diffraction beam, ID – detector of beam intensity.

Fig. 3 shows the dependence of reflection diffraction beam intensity on time dissolution. The etching process was realized up reaching the maximum of diffraction intensity. After that samples were washed with distilled water, dried up, and reflection diffraction efficiency were measured.

The diffraction efficiency η is defined as $\eta = I_d/I_0$, where I_d is the intensity of the first order diffracted beam; I_0 is the intensity of the readout beam.

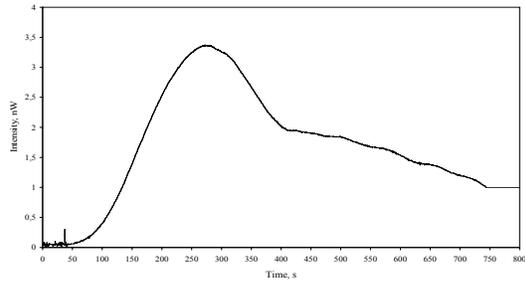


Fig. 3. Intensity of diffraction beam dependence on time of dissolution.

We also recorded gratings with s-s, s-p, R-R (L-L), L-R and s-R (or s-L) beams polarization at exposure corresponding maximum of reflection diffraction efficiency at p-p beams polarization. After that, the samples were etching the same method.

The surface relief of the samples was analyzed by Atomic Force Microscope (AFM).

3. Results and discussion

Fig. 4 shows the dependence of reflection diffraction efficiency of surface-relief gratings (after etching) on the exposure dose of laser irradiation at different wavelengths.

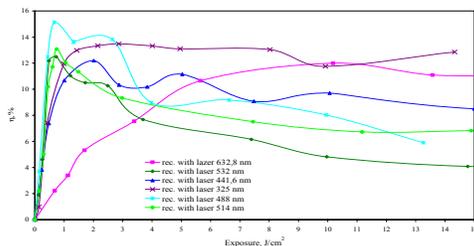


Fig. 4. Reflection diffraction efficiency dependence on recording light wavelength after dissolution. Reading laser 441,6 nm.

We can see that maximum values of diffraction efficiency are approximately equal for all wavelengths and reach 12-15 %. Probably it can mean that depth of relief is approximately equal for all samples at diffraction efficiency maximum. However, recording exposure dose for maximum reaching are different and characterize sensitivity of the photoresist.

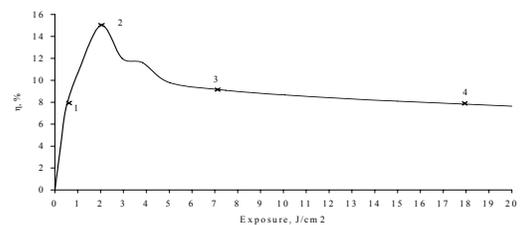
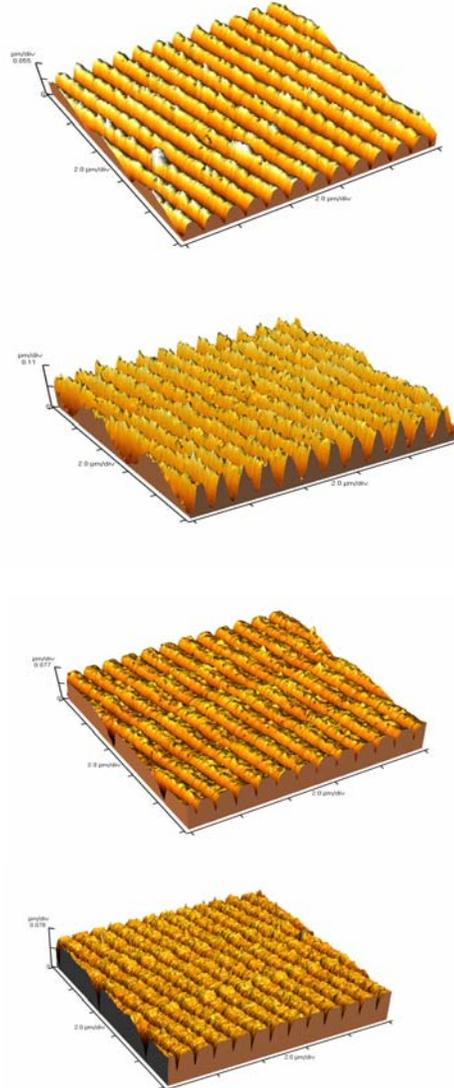


Fig. 5. AFM images of gratings after dissolving for different values of recording exposures.

Fig. 5 shows AFM pictures of gratings relief, corresponding different recording exposure dose for wavelength 488 nm. At low recording exposure value (pic. 1), we can reach depth of relief is 60-70 nm at etching time to maximum of diffraction efficiency. In the segment of maximum of diffraction efficiency, depth of relief is 170-180 nm (pic. 2). At more high values of exposure, we have a relief depth of 70-80 nm (pic. 3, 4).

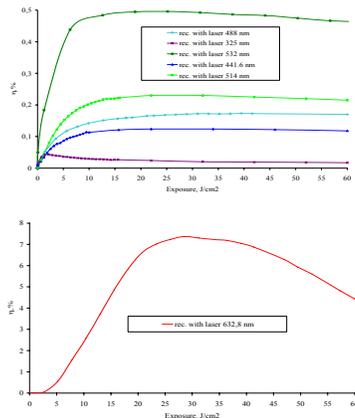


Fig. 6. Transmission diffraction efficiency dependence on recording light wavelength before dissolution. Reading laser 670 nm.

Interesting, that maximum of transmission diffraction efficiency, reading with wavelength 670 nm before etching, we can be reached at more high recording exposure dose (fig. 6). Thus the transmission diffraction efficiency is lower 0.5 % if recording light wavelength is situated behind edge of absorption. Probably, those results mean difference in depth of gratings record.

For all curves of Fig. 4 there are linear segments from zero to maximum. We can use cotangent of angle α between exposure axis and the segments as characteristic of spectral sensitivity of photoresist: $S = \cotg \alpha$. The dependence of spectral sensitivity of photoresist on recording light wavelength (λ) you can see in Fig. 7. The spectral efficiency of holographic recording, is characterized both by energetic exposure (S , J/cm^2 %, curve 1) and amount of light quanta (S_q , quantum/ cm^2 %, curve 2). It is seen from curve 2 that quantum yield for holographic recording by a light with wavelength $\lambda < 550$ nm is constant.

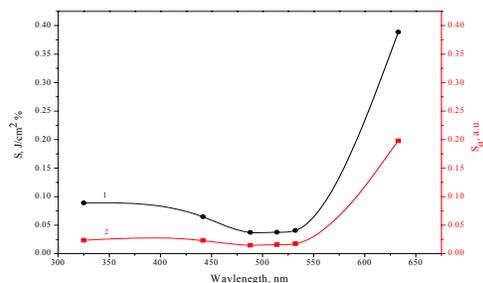


Fig. 7. Spectral sensitivity of photoresist As-S-Se.

Polarization of recording beams influence to reflection diffraction efficiency after etching approximately equal for all recording light wavelength (Fig. 8). Those results is well comport with reference

[9,10]. We can see that maximum of reflection diffraction efficiency at this period of gratings can to reach with s-s, p-p or circular polarization of recording beam. In case s-L (s-R) or p-L (p-R) polarization diffraction efficiency is a little lower.

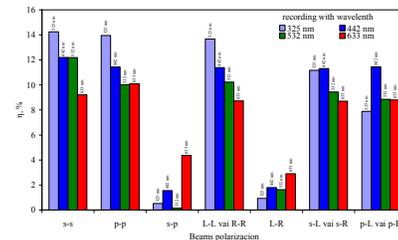


Fig. 8. Recording beams polarization influence on diffraction efficiency after etching.

4. Conclusion

On the basis of experimental results we can assert, there is possibility to record diffraction gratings on photoresist As-S-Se using lasers with wavelengths as UV area, as near the absorption edge. Obviously, the depth of gratings increase with recording light wavelength increasing and in case UV light grating appears on the surface of film. However a depth of record doesn't influence substantially on possibility of selective etching of photoresist and reflection diffraction efficiency almost doesn't depend on recording light wavelength. Photoresist As-S-Se is more sensitive for light with wavelength less 550 nm.

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*Corresponding author: agerb@mail.ru