Holographic Recording of Surface Relief Gratings on $As_{40}S_{60-x}Se_x$ Thin Films

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Abstract: The studies of direct holographic recording of the surface relief gratings on amorphous $As_{40}S_{60-x}Se_x$ thin films are presented. These gratings were created upon exposure to polarized laser beams of various wavelengths (λ = 473 - 650 nm). The orthogonally ±45° linearly polarized light beams were used for recording. The surface structure of the relief gratings was investigated by atomic force microscopy. The influence of laser beam wavelength and spatial frequency of the gratings recorded (grating period Λ) on the surface relief gratings formation for every composition was examined.

1 INTRODUCTION

Chalcogenide glasses are widely used as materials for fabrication of optics and optoelectronics elements i.e. grids, waveguides, microlenses, photonics crystals etc. (Wang, 2013). During the past 20 years, research in the field of optical materials based on amorphous chalcogenides (ACh) has made significant advances (Kovalskyi, 2006).

The photoinduced fabrication of surface relief gratings (SRGs) on As_2S_3 films has been reported for the first time (Galstyan, 1997). This phenomenon has attracted much attention due to the possibility of direct formation of SRGs (Vlcek, 2009; Gertners, 2010). The photoinduced softening of the matrix, formation of defects with enhanced polarizability, and their lateral drift under the optical field gradient force is believed to be the origin of the mass transport (Saliminia, 2000). The photoinduced formation of SRGs in ACh mainly has been studied in As_2S_3 films by green light (Teteris, 2013). SRG recording in As-Se system by 650 nm laser was studied by *Trunov et al* (Trunov, 2010). The composition $As_{40}S_{15}Se_{45}$ was optimized for recording with 632,8 nm laser light (Reinfelde, 2011).

In this work we present the studies of SRG formation efficiency dependence in amorphous three-component $As_{40}S_{60-x}Se_x$ films on concentration relationship of S and Se by recording with orthogonally ±45° linearly polarized light beams in spectral range of various wavelengths (λ = 473 - 650 nm).

2 EXPERIMENTAL

The bulk samples of different compositions in systems $As_{40}S_{60-x}Se_x$ (x = 0, 10, 20, 30, 40, 50, 60 at.%) were prepared by direct thermal synthesis from high purity elements (99.999%) in evacuated quartz ampoules. Thin films of glassy alloy were prepared using thermal evaporation technique upon cleaned glass substrates at room temperature (Tesla Corporation, model UP-858) at a pressure of $\sim 2\times10^{-4}$ Pa, and with evaporation rate 1 - 2 nm.s^{-1}. The thickness of thin films was measured directly during their deposition by dynamic weighing method and was about 1000 nm.

The surface relief formation experiments were performed using a holographic recording system (Reinfelde, 2011). All experiments were realized at room temperatures. Recording of SRGs was performed with different lasers λ = 473 – 650 nm. The orthogonally ±45° linearly polarized light beams with equal intensities ($I_1 = I_2 \sim 0{,}6$ W/cm^2) were used for recording, thus providing the optimal conditions for surface relief grating formation. The grating period Λ was changed by varying the angle between the recording beams. The readout of the

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diffraction efficiency *η*) was performed by *p*-polarized light at the Bragg angle using diode lasers (653 nm or 672 nm). The intensity of the first - order diffracted, I_d, and transmitted I_t, beams were measured using two photodiodes. The kinetics of the recording process was monitored by the time behavior of the gratings diffraction efficiency, determined as $\eta(t) = I_d/(I_t+I_d)$. Such determination of diffraction efficiency characterizes the holographic properties of material taking into consideration the losses associated with absorption, Fresnel reflection and a light-scattering. In all experiments time of the holographic exposure was 9000 sec. The SRG profile height Δh was examined by atomic force microscopy (AFM).

3 RESULTS AND DISCUSSION

This part of the work is devoted to the study of the dependence of the first – order diffraction efficiency for each of the compositions in the surface relief formation on the wavelength of the recording laser beams.

Figure 1 shows the dependence of diffraction efficiency of surface relief gratings on the Se-content (x, at.%) in amorphous $As_{40}S_{60-x}Se_x$ thin films at holographic recording with different wavelength lasers.

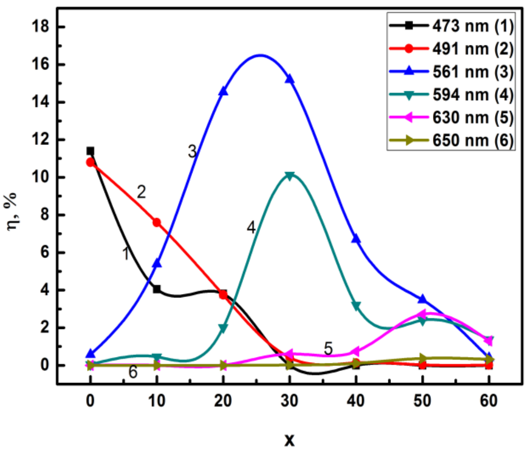

Figure 1: The first - order diffraction efficiency (η, %) dependence on selenium content (x) for $As_{40}S_{60-x}Se_x$ thin films for different recording laser wavelengths: film thickness d ≈ 1,0 µm, exposure dose E ≈ 13,4 kJ/cm^2, period of gratings Λ ≈ 1 µm.

Figure 2 illustrates the spectral dependence of diffractive efficiency η, % on wavelength of recording laser beams for studied $As_{40}S_{60-x}Se_x$ thin films.

First of all, from Figures 1 - 2 we can see that the surface relief formation efficiency changes a lot by changing the wavelength of recording laser beam. All these curves somewhere reaches theirs maximum, i.e. for every wavelength light what is used for the holographic recording exists optimal values of recording conditions for the best performance. This can be explained by the fact that for every composition is optimal wavelength closer to absorption edge of the sample (Sangera, 1996).

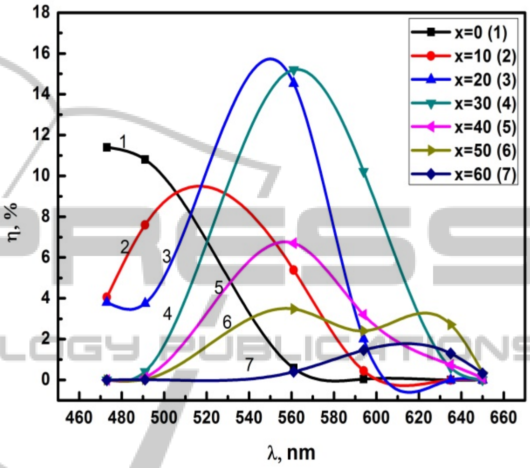

Figure 2: Spectral dependence of the first - order diffractive efficiency η, % for $As_{40}S_{60-x}Se_x$ thin films on wavelength of recording laser beams: film thickness d ≈ 1,0 µm, exposure dose E ≈ 13,4 kJ/cm^2, x – selenium content, at%.

As we can see from Figure 2, by changing wavelength laser beam from 473 nm to 561 nm for $As_{40}S_{60}$ (x = 0) the best diffractive efficiency is 11,4% at 473 nm, which is different from 561 nm case (η = 0,58%).

The maximum value of the diffraction efficiency of 15,2% is achieved by irradiation of the sample $As_{40}S_{30}Se_{30}$ by wavelength laser beam 561 nm under identical conditions (film thickness d ≈ 1µm, period of gratings Λ ≈ 1 µm). AFM scan of this sample is presented in Figure 3.

The results of detailed studies for grating period influence on diffractive efficiency and SRG formation by 594 nm laser recording are shown in Figures 4 and 5, respectively. The relief depth up to 467 nm was obtained for a period of Λ=3,59 µm (see AFM scan in Figure 6). The curves of dependencies show the existence of an optimal grating period Λ_{opt} ~ 4 µm, where, at a stated illumination dose E, the profile height Δh and diffraction efficiency have a maximum values while falling down versus smaller and greater periods for the same value of E. For

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$As_{40}S_{60}$ (x = 0) as well $As_{40}S_{50}Se_{10}$ (x = 10) changes of diffractive efficiency and height profile are not very significant.

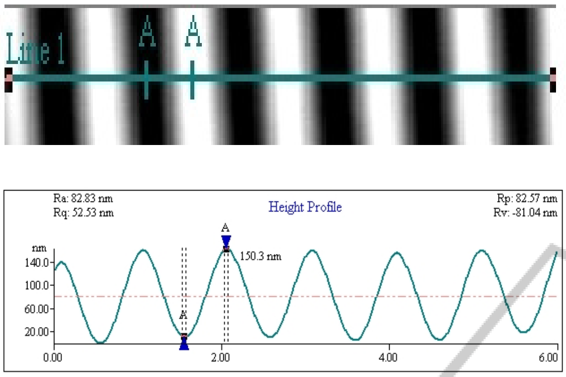

Figure 3: AFM scan of the $As_{40}S_{30}Se_{30}$ SRG formed by the exposure of a 561 nm wavelength laser beam.

At the same time maximum values of the diffraction efficiency – 63% and 66% are achieved for $As_{40}S_{30}Se_{30}$ and $As_{40}S_{20}Se_{40}$ thin films, respectively.

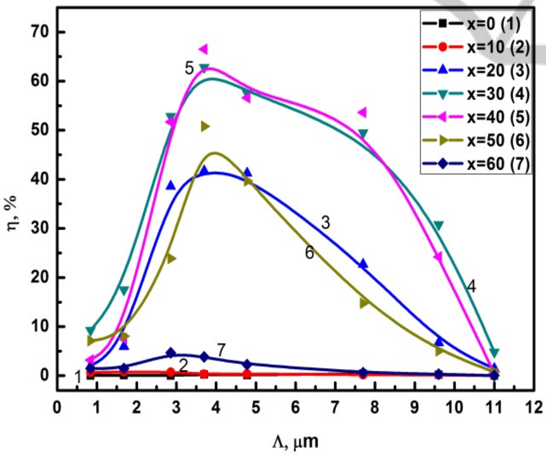

Figure 4: The first - order diffraction efficiency (η, %) on grating period (Λ, μm) for $As_{40}S_{60-x}Se_x$ thin films: films thickness d ≈ 1,0 μm, exposure dose E ≈ 13,5 kJ/cm^2, x – selenium content (at.%), recording laser wavelength λ = 594 nm.

According to (Reinfelde, 2014) the grating period affects the SR formation efficiency. The value of Λ_{opt} for holographic recording of SRGs with orthogonally ±45° linearly polarized light beams depends on the film thickness and exposure dose. The reason for the existence of Λ_{opt} could be related to some equilibrium state between the surface tension and SR grating formation forces created by the light intensity gradient perpendicular to the film plane.

It is known that the first - order diffraction efficiency for sinusoidal surface relief transmission gratings depends on a relief height is given by $\eta \sim \Delta h/\Lambda$ (Yokomori, 1984). Therefore some similarity in the curves of diffraction efficiency in Figure 4 and curves of relief height in Figure 5 can be observed.

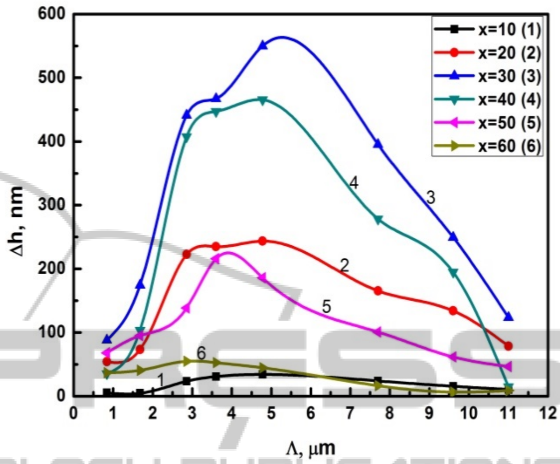

Figure 5: Relief profile height Δh, with grating period Λ, μm for $As_{40}S_{60-x}Se_x$ thin films: film thickness d ≈ 1,0 μm, exposure dose E ≈ 13,5 kJ/cm^2, x – selenium content, at%, recording laser wavelength λ = 594 nm.

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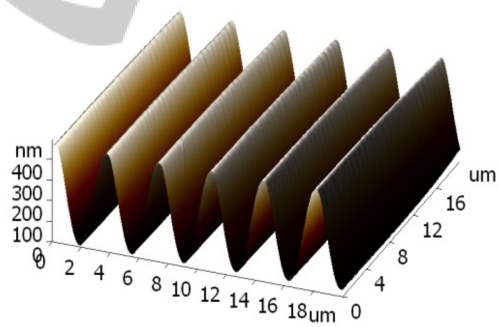

Figure 6: AFM scan of the $As_{40}S_{30}Se_{30}$ SRG formed by the exposure of a 594 nm wavelength laser beam: film thickness d ≈ 1,0 μm, exposure dose E = 13,5 kJ/cm^2.

Figure 7 illustrates the compositional dependence of the optical bandgap E_g of $As_{40}S_{60-x}Se_x$ thin films and light quantum energy E_{opt} for optimal holographic recording. It is seen that the values of E_{opt} can be expressed as $E_g+(0.1\text{-}0.2)eV$. According to (Tanaka, 2011) the optical absorption coefficient at such light quantum energy for chalcogenide materials is about $\alpha = 10^4$ cm^{-1}. The light penetration depth in the film at such optical absorption coefficient is $d_p = 1/\alpha = 1\ \mu m$. This value coincides to the thickness of studied films. It is known that the whole illuminated depth of the film, where the laser light intensity is sufficiently strong, takes part in the formation process of photoinduced SRGs (Reinfelde, 2013).

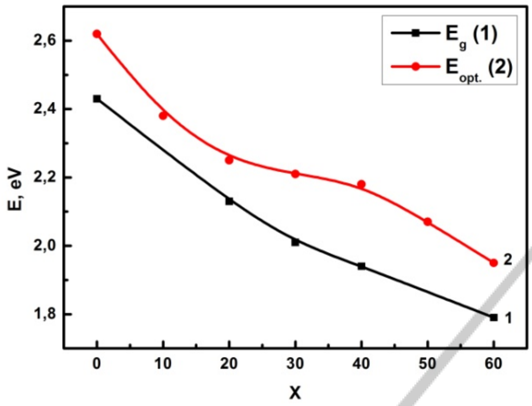

Figure 7: Compositional dependence of the optical bandgap E_g [data from (Gonzalez-Leal, 2003)] and optimal quantum energy E_{opt} of light for recording in 1 µm $As_{40}S_{60-x}Se_x$ thin films with a grating period Λ = 1 µm.

Consequently, the optical properties of recording material and thickness of the films must be considered for optimization of SRG recording.

4 CONCLUSIONS

The optimal wavelengths for holographic recording of surface relief gratings with orthogonally ±45° linearly polarized light beams in As40S60-xSex (x = 0, 10, 20 … 60 at.%) thin films have been established. An influence of grating period on surface relief formation efficiency is shown.

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REFERENCES

Wang R., 2013. *Amorphous Chalcogenides. Advances and Applications,* CRC Press Taylor & Francis Group, p.318.
Kovalskyi A., Vlcek M., Jain H., Fiserova A., Dubey C.M., 2006. Journal of Non-Crystalline Solids, 352, 589-594.
Galstyan T. V., Viens J.F., Villeneuve A., Richardson K., Duguay M. A., 1997. Journal of Lightwave Technology, 15, 1343.
Vlcek M., Schroeter S., Brueckner S., Fehling S., Fiserova A., 2009. Journal of Materials Science: Materials in Electronics, 20, 290-293.
Gertners U., Teteris J., 2010. Journal of Optical Materials, 32, 807-810.
Saliminia A., Galstyan T.V., Villeneuve A., 2000. Physical Review Letters, 85, 4112-4115.
Teteris J., Reinfelde M., Aleksejeva J., Gertners U., 2013. Physics Procedia, 44, 151-158.
Trunov M.L., Lytvyn P.M., Nagy P.M., Dyachynska O.M., 2010. Applied Physics Letters, 96, 111908.
Reinfelde M., Teteris J., 2011. Journal of Optoelectronics and Advanced Materials, 13/11-12, 1531-1533.
Sangera Jas S., Nguen Vinh Q., Aggarwal Ishwar D., 1996. Journal of American Ceramic Society, 79(5), 1324-1328.
Reinfelde M., Teteris J., Potanina E., 2014. Canadian Journal of Physics, 92, 1-4.
Yokomori K., 1984. Journal of Applied Optics, 23, 2303-2310.
Tanaka K., Shimakawa K., 2011. *Amorphous Chalcogenide Semiconductors and Related Materials*, Springer.
Gonzalez-Leal J.M., Vlček M., Prieto-Alcon R., Stronski A., Wagner T., Marquez E., 2003, Journal of Non-Crystalline Solids, 326&327, 146-153.
Reinfelde M., Teteris J., 2013. Journal of Non-Crystalline Solids, 377, 162-164.

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