Surface relief grating recording with different period on chalcogenide nanomultilayers

A. Meshalkin, E. Achimova, V. Abaskin,
G. Triduh, A. Prisacar
Institute of Applied Physics
Chisinau, Moldova
alexei@asm.md

O. Paiuk, L. Revutska, A. Korchovyi, A. Stronski
V. Lashkaryov Institute of Semiconductor Physics
National Academy of Sciences of Ukraine
Kyiv, Ukraine
paiuk@ua.fm

***Abstract*— Chalcogenide glasses nanomultilayer structures based on As_2S_3-Se were used for direct surface relief grating formation by polarization holographic recording. The SRG depth in dependence of grating period was investigated. Analyses of diffraction efficiency kinetics and AFM images of recorded SRG showed that grating period increasing led to the SRG depth increasing in linear way. It is revealed that SRG recording rate is much more for gratings with greater periods, while the modulation depth remains approximately the same for all gratings and consists about 0.22.**

***Index Terms*— Amorphous chalcogenide glasses, nanomultilayer structures, surface relief grating, holographic recording.**

I. Introduction

Amorphous chalcogenide glasses (ChGs) provide wide applications in the field of photonics and optoelectronics [1,2]. Among the variety of photoinduced phenomena in ChGs the effect of direct surface relief grating (SRG) formation by lateral mass transport has attracted much attention [3-5]. The effect of light induced surface deformation in ChG is intensively studied both experimentally and theoretically, however many details of the process remain unclear. The first report of photo-induced mass transport observed in As_2S_3 revealed polarization dependence (vectorial) nature of this effect [6]. Later, vectorial SRG were formed in As-Se, As-S-Se, Ge-Se chalcogenide films and As_2S_3/Se multilayer structures. Among ChGs thin films amorphous nanomultilayer structures (NML) are attractive because of the prominent photoinduced effects [7-9].

Two distinct mechanisms of SRG recording in ChGs thin films are distinguished depending on the polarization of writing beams: small scalar SRGs induced by photoinduced volume change, and giant vectorial SRGs induced by lateral mass transport [10]. Earlier [11] we have shown, that the diffraction efficiency (DE) of light-induced SRG recorded on NML structures strongly depends on polarization states of recording beams. Enhanced DE is obtained when the recording beams have orthogonal linear ±45° or circular LCP:RCP polarizations. However, the relationship between the DE of SRG and its period wasn't studied for NML structures based on ChGs.

In this work, we present an study of the direct SRG formation with different period in As_2S_3-Se NML structure under holographic recording. We investigate how the SRG period influences the SRGs efficiency and SRG depth and demonstrate that grating period influences the SRG depth in linear way.

II. Materials And Methods

The experiments were performed on 1.7 μm thick As_2S_3-Se NML structure deposited on rotated glass substrate by thermal evaporation from two isolated boats with bulk As_2S_3 and Se glasses. A thickness of each As_2S_3 nanolayer was 9 nm and 6 nm of Se nanolayer correspondingly. More detailed description of deposition process can be found in paper [12]. The SRGs were formed using a holographic setup [11] with wave plates for obtaining the different states of polarizations. Edge of As_2S_3-Se NML absorption light of DPSS laser operating at 532 nm was used. A beam splitter was used to obtain the two interfering beams and the angle between those beams was adjusted to provide the necessary spatial modulation periods. Gratings with period from 960 to 3000 nm (960, 1170, 1410, 1920 and 3000 nm) have been recorded by adjusting the writing angle. An optical intensity of 3.2 W/cm^2 was incident on the sample surface. Quarter wave retarders were used to obtain circular polarization configuration LCP:RCP. To monitor the dynamics of the formation of SRGs we used the evolution of diffraction efficiency (DE: the ratio of intensities of the transmitted first diffracted beam to the zero one before recording). A laser diode beam at wavelength 650 nm was used for DE monitoring. The surface relief structure of the gratings on As_2S_3-Se NML structure was investigated by Nanoscope III atomic force microscope (AFM) after the holographic gratings were recorded.

III. Results And Discussion

Based on our previous studies we consider that the main process during polarization holographic recording in NML is surface relief formation. This implies that the DE value depends on the SRG height and we can investigate the SRG formation by means of the changing of DE value during holographic recording.

The exposure time was chosen as time when saturation of DE was observed for grating with period 1170 nm. Saturation of DE reaches at saturation of the SRG height growth. For grating with 1170 nm period it was 34 minutes corresponded the exposure energy about 6.5 kJ/cm^2. This exposure energy was used for all other periods of gratings. DE kinetics of SRG recording using LCP:RCP polarization states of recording beams are shown in Fig. 1.

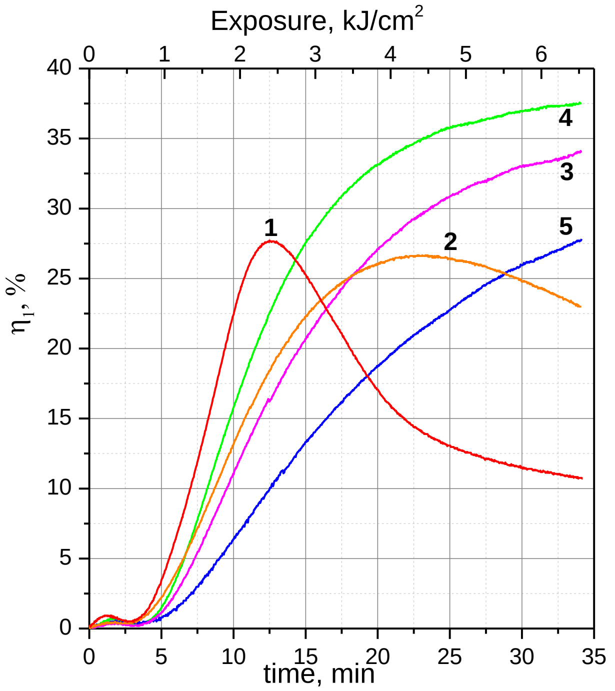

Fig. 1. The first order diffraction efficiency as a function of exposure time for gratings with period: 1 – 3000 nm; 2 – 1920 nm; 3 – 1410 nm; 4 – 1170 nm; 5 – 960 nm.

AFM investigations showed high quality of the recorded surface relief's of gratings which had profiles close to the sinusoidal ones. AFM image of recorded SRG with period 3000 nm and its surface profile are shown in Fig. 2.

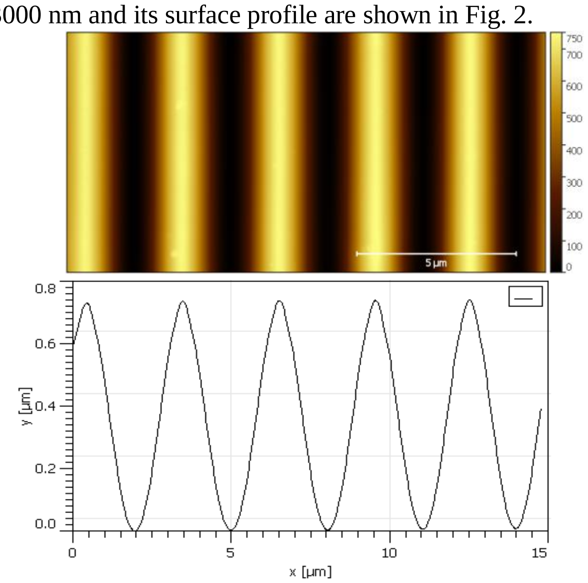

Fig. 2. AFM image of recorded SRG with period 3000 nm and its surface profile.

The SRG height was changeable and varied as a function of the SRG period. Based on the obtained AFM results, for all gratings the modulation depth μ was determined as μ=h/Λ, where h is SRG height and Λ is grating period. In assumption that SRG growth is linear in exposure time, recording rate is calculated as ratio (SRG height / recording time). The SRG height, modulation depth, recording rate and DE for different period of recorded gratings are presented in Table 1.

Table 1. SRG height, modulation depth, recording rate and DE of recorded gratings with different periods.

Λ, nm	**SRG height, nm**	**Modulation depth μ=h/Λ**	**Recording rate, nm/min**	**η, %**
3000	735	0.245	21.6	10.7
1920	450	0.234	13.2	23.0
1410	300	0.213	8.8	34.0
1170	250	0.214	7.3	37.5
960	207	0.216	6.1	27.8

As it is seen from Table 1, increasing of period leads to SRG height increasing while exposure energy was equal. It means that SRG recording rate is much more for gratings with greater periods (from 6.1 nm/min for 960 nm period to 21.6 nm/min for 3000 nm period). Meanwhile the modulation depth was approximately the same for all gratings and averaged 0.22.

Obtained by AFM SRG heights for gratings with different periods were plotted as shown in Fig. 3.

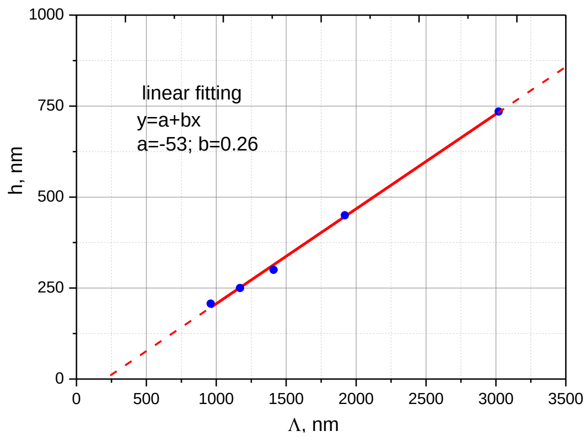

Fig. 3. The dependence of SRG height on grating period.

As it is seen form Fig. 3. the SRG height has linear dependence on grating period (in investigated period range) and could be expressed as h(Λ)=0.26Λ-0.53.

In order to calculate the SRG height from the experimental data and compare them with the theoretical prediction, we have derived the expression for the first order diffraction efficiency as a function of surface relief height.

$$\eta = J_1^2\left(\frac{\pi}{\lambda}\cdot\left(h\cdot(n-1)\right)\right)$$

, where J_1 – is Bessel function; λ –wavelength, used for DE measurement; n – refractive index of grating material; h – SRG height.

This theoretical estimation is in good agreement with the experimentally measured kinetics of DE.

IV. Conclusions

Chalcogenide nanomultilayer structures based on As_2S_3-Se were used for direct SRG formation by polarization holographic recording. The SRG depth in dependence of grating period was investigated. Analysis of diffraction efficiency kinetics and AFM height data of recorded SRGs showed that grating period increasing led to the SRG depth increasing in linear way. The SRG with the largest height, of about 735 nm, was obtained with Λ equal 3000 nm. It is revealed that SRG recording rate is much more for gratings with greater periods, while the modulation depth remains approximately the same for all gratings and consists about 0.22. The obtained results will help to understand the mechanism of the formation of SRG that is obviously not clear till now.

Acknowledgment

The research was supported by the bilateral Moldova-Ukraine project (17.80013.5007.03/Ua).

References

[1] R.Wang, Amorphous Chalcogenides: Advances and Applications. PanStanford Publishing, Singapore, 2014.

[2] A.V. Stronski, M. Vlček, "Photosensitive properties of chalcogenide vitreous semiconductors in diffractive and holographic technologies applications", J. Optoelectron. Adv. Mater. vol. 4, pp. 699–704, 2002.

[3] E. Achimova, "Direct surface relief formation in nanomultilayers based on chalcogenide glasses: A review," Surf Eng Appl Electrochem., vol. 52, pp. 456–468, 2016.

[4] M.L. Trunov, P.M. Lytvyn, S.N. Yannopoulos, I.A. Szabo, et al., "Photoinduced mass-transport based holographic recording of surface relief gratings in amorphous selenium films," Appl Phys Lett. vol. 99, p. 051906, 2011.

[5] V. Cazac, A. Meshalkin, E. Achimova, V. Abashkin, et al., "Surface relief and refractive index gratings patterned in chalcogenide glasses and studied by off-axis digital holography," Appl. Opt. vol. 57, pp. 507-513, 2018.

[6] A. Saliminia, T.V. Galstian, A. Villeneuve, "Optical field-induced mass transport in As_2S_3 chalcogenide glasses," Phys Rev Lett. vol. 85, pp. 4112–4115, 2000.

[7] A. Stronski, E. Achimova, O. Paiuk, A. Meshalkin, et al., "Optical and electron-beam recording of surface relief's using $Ge_5As_{37}S_{58}$–Se nanomultilayers as registering media," J Nano Res. vol. 39, pp. 96–104, 2016.

[8] A. Stronski, E. Achimova, O. Paiuk, A. Meshalkin, et al., "Direct magnetic relief recording using $As_{40}S_{60}$:Mn–Se nanocomposite multilayer structures," Nanoscale Res Lett. vol. 12, p. 286, 2017.

[9] S. Kokenyesi, "Amorphous chalcogenide nano-multilayers: research and development," J Optoelectron Adv Mater. vol. 8, pp. 2093–2096, 2006.

[10] M.L. Trunov, P.M. Lytvyn, P.M. Nagy, O.M. Dyachyns'ka, "Real-time atomic force microscopy imaging of photoinduced surface deformation in As_xSe_{100-x} chalcogenide films," Appl. Phys. Lett. vol. 96, p. 111908, 2010.

[11] E. Achimova, A. Stronski, V. Abashkin, A. Meshalkin, O. Paiuk, A. Prisacar, P. Oleksenko, G. Triduh, "Direct surface relief formation on As_2S_3–Se nanomultilayers in dependence on polarization states of recording beams," Opt. Mater., vol. 47, pp. 566-572, 2015.

[12] A. Stronski, E. Achimova, O. Paiuk, V. Abashkin, A. Meshalkin, A. Prisacar, G. Triduh, O. Lytvyn, "Surface relief formation in $Ge_5As_{37}S_{58}$–Se nanomultilayers", J Non Cryst Solids., vol. 409, pp. 43-48, 2015.