DAUGAVPILS UNIVERSITY
THE FACULTY OF NATURAL SCIENCES AND MATHEMATICS

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AMORPHOUS CHALCOGENIDE PHOTORESISTS RESEARCH AND DEVELOPMENT

Summary of Promotion Thesis

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Contents

The paper has been written in Latvian University Institute of Solid State Physics and G.Liberts Innovative Microscopy center of Daugavpils University during the period of 2007 till 2010.

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The Outline of the Paper

The promotion thesis consists of an introduction, its aims and objectives, the method description of experimental equipment and the research subjects, the results of the research, the theses and references, as well as the list of the author's published works. The appendix of the thesis contains – the copies of published articles issued in international publications on promotion theme.

The paper contains 47 pages, 35 pictures. The list of references contains 62 titles.

Abbreviation

UV – ultraviolet
IR – infrared
DR-1 – Disperse Red 1
PMMA - polymethylmetacrylate
PVAc – polyvinylacetate
PVB/PVA/PVAc – poly(vinyl butyral-co-vinyl alcohol-co-vinyl acetate)
AFM – atomic force microscope
DE – difraction efficiency

The Topicality of the Research

During the last forty years amorphous chalcogenide compounds have been drawing a greater scientist's attention [1, 2]. Research of such phenomenon as reversible phase change, selective etching and transmission in IR spectra area leaded to producing widely applicable products (CD and DVD discs, holograms, difraction elements, IR waveguide and etc.).

Modern technologies allow research and development of materials at atomic and molecular level (AFM, microanalysis). Resolving ability of chalcogenide photoresists by using UV illumination, electronic beams and AFM-lithography is about 30 nm [3, 4]. So As-

S-Se and As_2S_3 and other chalcogenides can be used as photoresists for nanostructuring surface. For this goal it need develop the photoresist' apply technology, optical or electron beams recording technology, etching process. Therefore, very actual is the method of immersion recording of gratings with period about 150 nm.

Laser radiation (which has high value of electric field intensity) at influence to photoresist can perform the mass transport with surface relief formation. At least there are necessary two requirements for it: a) the matrix of matter must be enough flexible; b) the matter must be photosensitive, i.e. under illumination must take place structural change (bond breaking, coagulation and etc.). This matter, in our view, can be created, i.e. it can be produced the composite on the base of known photosensitive components (for example As_2S_3, spiropyran and etc.) and organic polymeric matrix.

Clearly, in case if the composites with changeable optical parameters and direct changing surface relief under the action of laser radiation will be produced, it will open new wide possibilities for the composites using in the area of optoelectronic and optical recording.

Aims and Objectives of the Promotion Thesis

The aims:

The aims of the work are a composite photoresists obtaining on base of inorganic chalcogenide and organic compounds; research of their optical and surface properties at influence of visible and UV radiation.

Objectives:

1. Recording and etching of relief diffraction gratings on amorphous $As_{40}S_{15}Se_{45}$ thin film by lasers with different wavelength. The investigation of diffraction efficiency, spectral sensitivity and other parameters of gratings.
2. Obtain composite films on base As_2S_3 and organic polymer Disperbyk 161.
3. Research optical and surface properties of composite films on base As_2S_3 and organic polymer Disperbyk 161.
4. Obtain composite films on base As_2S_3 and organic photosensitive compounds (DR-1, spiropyran) in organic polymers (Disperbyk 161, pVAc, pVB/VA/VAc), pMMA).

5. Research optical and surface properties of composite films on base As_2S_3 and organic photosensitive compounds (DR-1, spiropyran) in organic polymers (Disperbyk 161, pVAc, pVB/VA/VAc, pMMA).

Experimental

Amorphous As–S–Se films were obtained by thermal evaporation in vacuum of ~5x10^{-6} Torr onto glass substrates. The film thickness was in the range of 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.

The holographic gratings with a period Λ = 0.84 μm 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.

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 was measured.

The diffraction efficiency η is defined as

$$\eta = I_d/I_0, \qquad (1)$$

where I_d is the intensity of the first order diffracted beam; I_0 is the intensity of the readout beam.

The dependence of diffraction efficiency on grating period studied in the interval of period from 0.13 to 1.33 μm. He-Cd laser with wavelength 325 nm was used for recording of gratings at exposure 3 J/cm^2. The grating period was changed by the variation of angle between recording beams. The grating with period of 130 nm was recorded by immersion method. The quartz prism with refractive index n=1.8 was used. The optical contact between sample and prism was realized by monoethylenglycol.

The etching process was realized up to reaching the maximum of diffraction intensity. After that the samples were washed with distilled water, dried up, and reflection diffraction efficiency was measured by laser 325 nm at the angle near to Bragg's angle. The intensity of all diffraction maximums was measured.

The reading of 130 nm grating was realized through the same prism. The diffraction efficiency of the grating calculated by the following formula:

$$\eta=I_{dif}/I_o(1-R)^2, \qquad (2)$$

where I_{dif} is intensity of diffraction beam, I_o is intensity of falling beam, R – reflection index of surface of prism.

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

There are some problems for preparation of optical homogeneous composites chalcogenide-polymer. Low solubility of chalcogenide in organic solvents and poor compatibility with majority polymers limits possibility of production of wide band of composites. Very often the coagulation of chalcogenide particles takes place at composite film drying and it lead to preparation of composite film with high coefficient of optical scattering. To improve an optical transparency of the films the polar copolymer Disperbyk-161 (produced by BYK-Chemie GmbH) with free amine groups (which producing as additive for prevention of pigments coagulation) was used. Using this polymer the transparent films of composite with the concentration of As_2S_3 up to 60 % (wt) in relation to a polymer were obtained. Originally Disperbyk 161 was planed to use as uniform polymer for all composites, but the dry film spiropyran – Disperbyk 161 didn't manage to make optical homogeneously.

The crushed arsenic sulphide was dissolved in mixture of organic solvents (N,N-dimetylformamide and diethylamine 9÷1 (wt) accordingly). Dissolution took place in a conical retort at interfusion magnetic mixer at room temperature during a few days. 10 % (wt) solution of arsenic sulphide was mixed with 30% (wt) solution of polymer Disperbyk-161 (a solvent is mixture of methoxypropylacetate and butylacetate 6÷1 (wt) accordingly) in such correlations, that after films drying on substrate a mass part of arsenic sulphide was 28, 40, 50 and 60 % (wt).

Disperse Red 1 delivered by Aldrich, CAS 2872-52-8 was chosen. The powder of DR-1 was dissolved in N,N-dimetylformamide at room temperature. 10 % (wt) solution of DR-1 was mixed with 30% (wt) solution of polymer Disperbyk-161 and with solution Disperbyk-161+As_2S_3 in such correlations, that after films drying on substrate a mass part components was: 5%(wt) DR-1 + 60%(wt) Disperbyk-161 and 5%(wt) DR-1+35%(wt) As_2S_3+60%(wt) Disperbyk-161 accordingly.

The spiropyran (by Aldrich, CAS 1498-88-0) was dissolved in chloroform at room temperature. A 5 wt % solution of spiropyran was mixed with poly(vinyl butyral-co-vinyl alcohol-co-vinyl acetate) M_w= 50 000 ÷ 80 000 (GPC) (CAS 27360-07-2), poly(vinyl acetate) M_w= 500 000 (CAS 9003-20-7) and poly(methyl methacrylate) M_w=350 000 (CAS 9011-14-7) dissolved in chloroform. The solutions were mixed in such proportion that after drying the mixtures on a substrate the concentration of spiropyran in the polymer would make 5 % wt. Also, to the solution with spiropyran and poly(vinyl acetate) there was added 10% As_2S_3 solution in organic solvents (as described above), in such a proportion that after drying the mixtures on a substrate the concentration of arsenic sulphide in the composite would be 1% wt. For studying the transmission spectra of composite in the UV region in more detail, a composition with a 1% wt. spiropyran concentration in poly(vinyl butyral-co-vinyl alcohol-co-vinyl acetate) was prepared.

Fabrication of films from composites solutions were performed by company BYK Gardner GmbH applicator, the thickness of liquid layer was 30, 60, 90 and 120 μm. A glass and quartz plates were used as substrate. For the improvement of moistening the surfactant was added in solution of As_2S_3 and Disperbyk 161 (less than 0,01 % (wt)) before application. The As_2S_3 films were dried in oven at the temperature of 303 K during 30-40 min. The films which contain DR-1 were dried in oven at temperature 423 K during 3 h. The films which contain spiropyran were dried in oven at the temperature 423 K for 30 min.

The thickness of dry films was 1.5-9 μm, determined by the Veeco Dektak 150 surface profiler.

For all films, including film of pure polymer and pure arsenic sulphide, the spectra of transmission were measured by the Ocean Optic HR4000CG spectrometer. Measuring of pure organic polymer and spiropyran containing films transmission spectrum was performed with the films on quartz substrate.

The holographic gratings with a period of Λ = 1 μm were recorded by two symmetrically laser beams of equal intensity with linear horizontal polarization (p-p). For As_2S_3 and DR1 containing films lasers with wavelength 442 and 532 nm and beams intensity 0.79 – 0.86 W/cm^2 were used. The readout of transmission diffraction efficiency was made at the Bragg angle using a semiconductor laser beam 640 nm (for recording laser with wavelength 442 nm) and 673 nm (for recording laser with wavelength 532 nm). The second order maximum of recording beam was used for reflection diffraction efficiency measuring.

For spiropyran containing films the holographic gratings with a period of Λ = 1 μm were recorded by two symmetrically laser beams of equal intensity with linear horizontal polarization (p-p), using 325 nm (beam intensity 2 x $1.8\cdot10^{-4}$ W/cm^2) and 532 nm (beam intensity 2 x $1.4\cdot10^{-3}$ – 2 x $4.2\cdot10^{-2}$ W/cm^2) lasers. The readout of transmission diffraction efficiency was made at Bragg's angle using a 640 nm semiconductor laser beam (for the 325 nm recording laser) at the 2nd order maximum of recording beam (for the 532 nm recording laser). Immediately before recording by the 532 nm laser, the samples were illuminated by a 375 nm laser beam (intensity 0.01 W/cm^2) for 5 min.

After recording, the surface relief of the samples was analyzed by Atomic Force Microscope (AFM).

For relief formation studying, the films of compositions 5%(wt) DR-1 + 60%(wt) Disperbyk-161 and 5%(wt) DR-1+35%(wt) As_2S_3+60%(wt) Disperbyk-161 were irradiated by cylindrical lens focused laser beam with wavelength 532 nm and intensity 11 W/cm^2. The focussed light spot linear sizes were 3454x25 µm. The profile of irradiated area was studied by profiler Veeco Dektak 150.

Results

In the first block of the experiment the spectral sensitivity of photoresist $As_{40}S_{15}Se_{45}$ was studied. The diffraction gratings with period 0.84 µm by laser with wavelength 325 – 633 nm were recorded. After record the etching of gratings and the measuring of their DE was performed. On this measuring base, the curves of transmission and reflection DE dependents on exposure were drawn. The spectral sensitivity was defined as tangent of inclination angle of reflection DE curve to abscise axis.

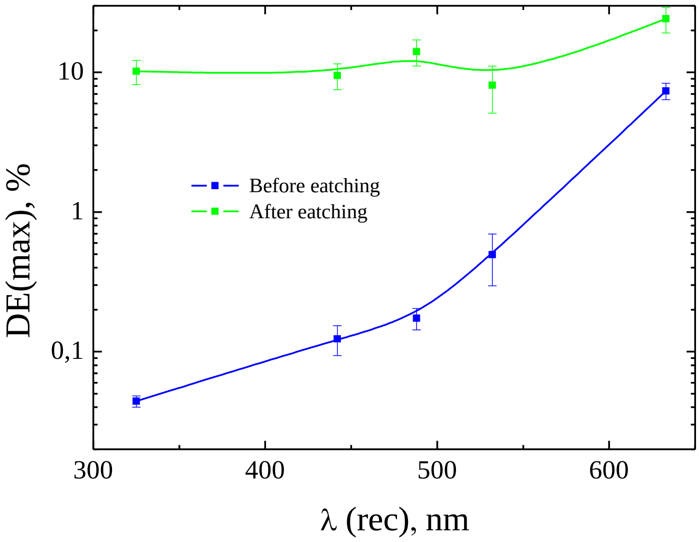

Figure 1. Dependence of maximums of transmission DE of gratings in photoresist $As_{40}S_{15}Se_{45}$ on recording light wavelength before and after etching. Reading laser 670 nm at Bregg angle.

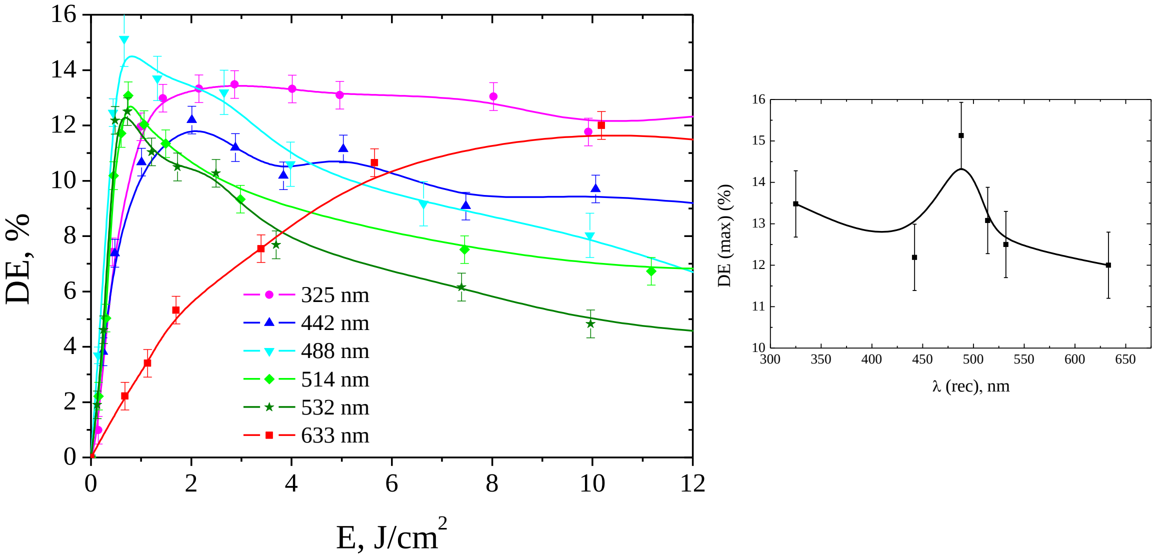

Figure 2. Dependence of reflection DE of grating in photoresist $As_{40}S_{15}Se_{45}$ on recording exposure after dissolution for different recording wavelength. Reading laser 441,6 nm. Additional graph shows the dependence of maximum reflection DE on recording light wavelength.

Reflection DE dependence on depth and character of relief of holograms was studied by AFM.

The record of holograms was performed by different polarization of recording beams.

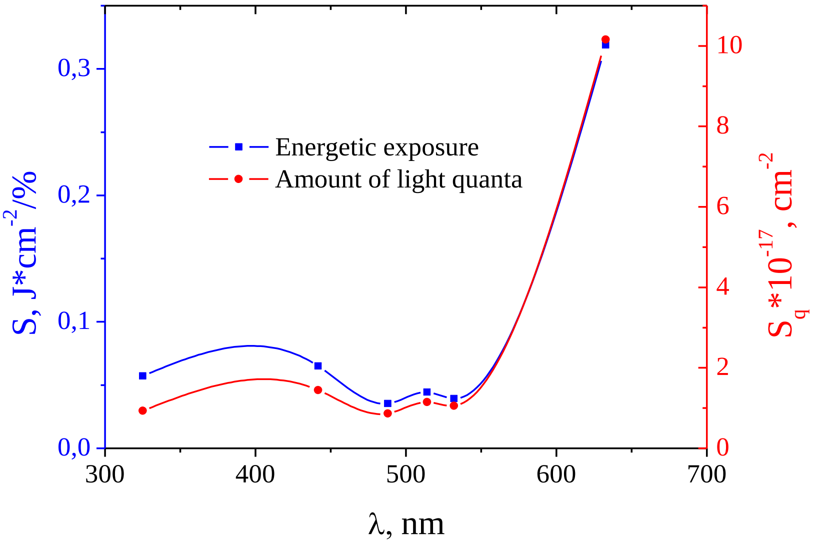

Figure 3. Spectral sensitivity of photoresist $As_{40}S_{15}Se_{45}$.

The main results of experiments are:

- Transmission DE of holograms in films $As_{40}S_{15}Se_{45}$ in the range of recording radiation 325 – 633 nm increases in 200 times at increasing of recording wavelength (0.04% at 325 nm and 7.36 % at 633 nm).
- Transmission DE after etching in the studying range of recording irradiation increases from 230 times at record by laser 325 nm to 3 times at record by laser 633 nm. For

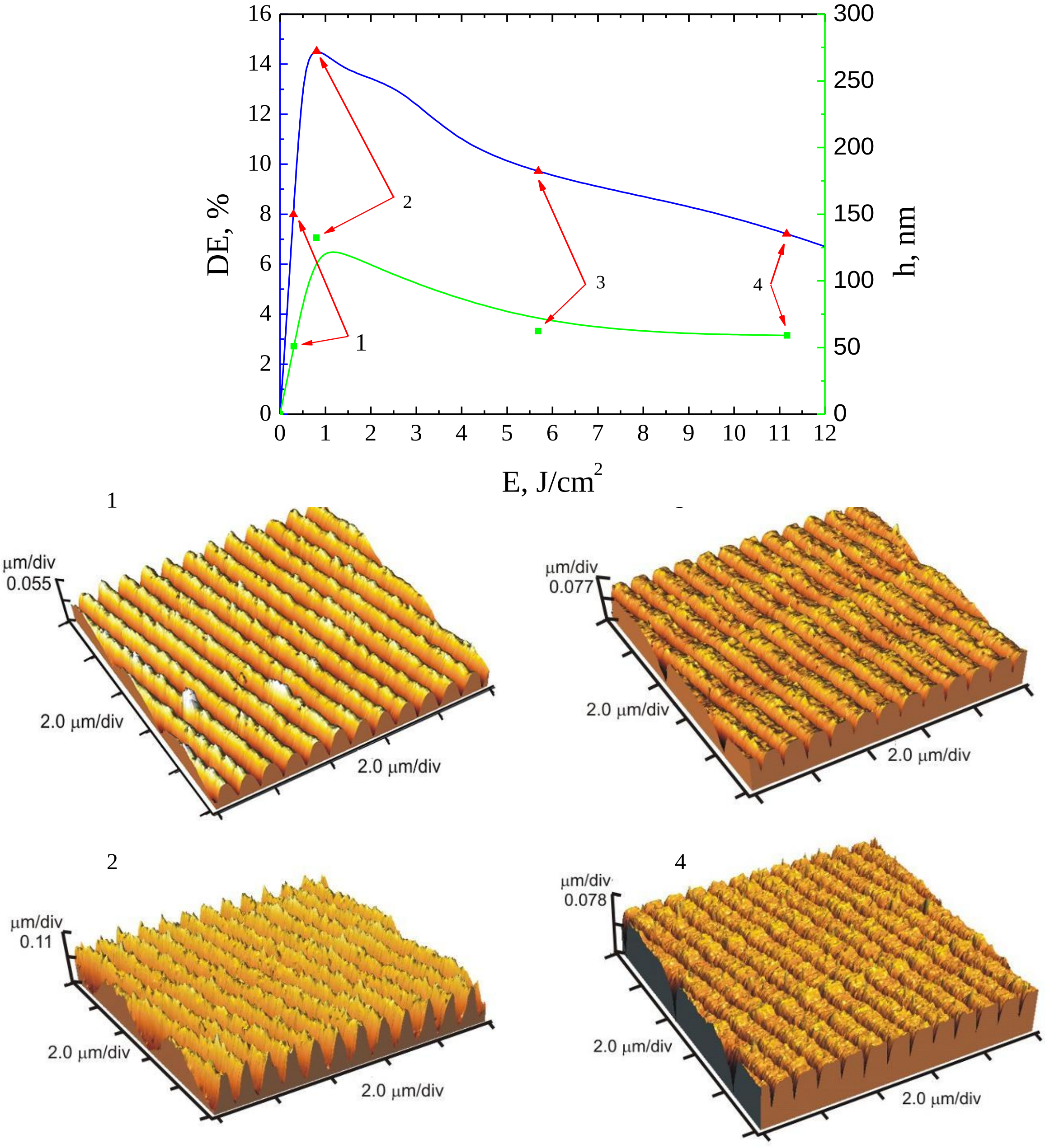

Figure 4. The dependence of DE of gratings in photoresist $As_{40}S_{15}Se_{45}$ after etching, recorded by laser 488 nm (blue) and the dependence of relief height of gratings (green) on recording exposure and AFM images of gratings.

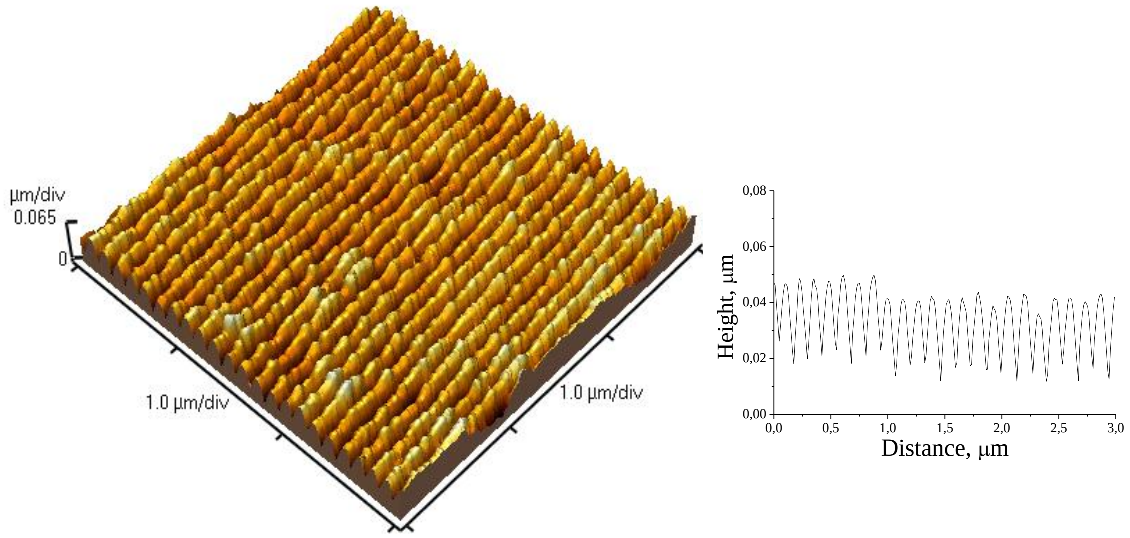

Figure 5. AFM image and profile of grating with period 130 nm, recording by immersion method.

reflection holograms the maximum value of DE was got by laser 488 nm and was 15 %.

- The maximum value of reflection DE corresponds to maximum depth of relief 132 nm.
- The maximum value of reflection DE was obtained by s-s, p-p and circular (one-way) polarization of recording beam.

In the second block of experiments DE dependence on period of etching gratings was studied, and the hologram with period 130 nm was recorded by immersion method. In result of experiments was shown, that:

- The immersion method of record by laser with wavelength 325 nm allow to get surface nanostructure in $As_{40}S_{15}Se_{45}$ films with period 130 nm and depth of relief 30 – 70 nm.
- The maximum values of reflection DE for gratings 130 and 226 nm were 5 and 13 % accordingly.

In the third block of experiments the composite photoresists on arsenic sulphide and organic polymers base were obtained. Also the photochrome - As_2S_3 – polymers composites had been made.

The composite films As_2S_3-Disperbyk 161 were obtained on glass substrates by applying of mixed arsenic sulphide and Disperbyk 161 solution. Arsenic sulphide and polymers composites are the solid solution of chains fragments =As-S- in polymeric matrix.

The transmission spectra of films with different thickness and different As_2S_3 concentration were studied. Also the transmission spectra changes were observed.

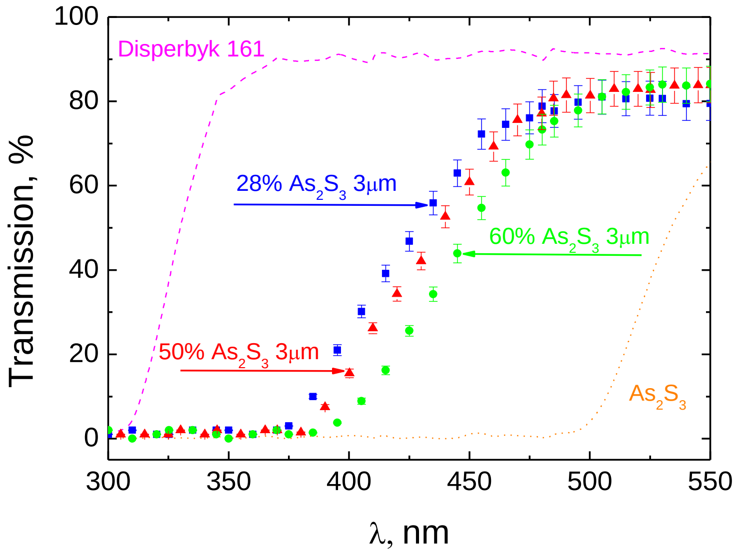

Figure 6. Transmission spectra of As_2S_3/Disperbyk 161 composite films dependence on As_2S_3 concentration.

It is known [23, 34, 35] that the influence of light on composite films DR-1-pMMA leads to surface relief formation. It is assumed that the mechanism of such phenomenon is based on influence of electric field of the polarized light to dipole molecules of photochroms. In result the molecules of polymer migrate from the lighted areas in unlit.

We supposed that the surface relief can be obtained also on composite films containing arsenic sulphide and DR-1 both. The spectral sensitivity of such composites can be laid from UV to IR area.

The composite film (Disperse Red 1)$_5$(As_2S_3)$_{35}$(Disperbyk 161)$_{60}$ was obtained; the spectra and spectra changes under light influence were studied.

The spiropyran was tested as photochrome in composites. For this composition pVA, pMMA and pVB/VA/VAc were used as polymer matrix.

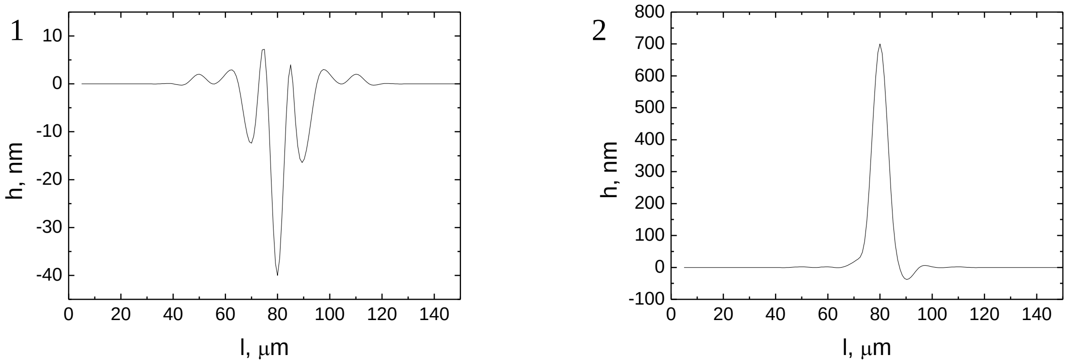

Figure 7. Character of relief of composition 40% As_2S_3 + 60% Disperbyk 161 (1) and composition 5% DR1+ 35% As_2S_3 + 60% Disperbyk 161 (2) after laser irradiation of composites through cylindric lens by laser beam 532 nm.

The experiments results are:

- Influence of light to As_2S_3 - Disperbyk 161 films leads to decline of optical transmission (to 70 %) and a shift of transmission edge to shorter wavelength area in spectral range 300-400 nm.
- The volume formations (diameter to 15 μm) appear in illumination area in the films As_2S_3 - Disperbyk 161.
- Influence of light to DR-1 - As_2S_3 - Disperbyk 161 films lead to shift of transmission curve to shorter wavelenght area.
- The peak of absorbtion (the maximum is in area 550-600 nm) in optical spectra of the spiropyran containing composites appear under UV light influence without dependence of arsenic sulphide presents.

The changes of composite surface relief under illumination of light, in particular, at holographic record were studied. Also, the composite films had been illuminated through cylindric lens by laser with wavelength 532 nm. After that the films was studied by profilometer. It was note, that:

- The influence of focusing light to 40 % As_2S_3 - Disperbyk 161 films lead to surface relief “hole”formation. The depth of “hole” is 30-50 nm at exposure about 20 – 30 kJ/cm^2.
- The influence of focusing light to 5 % DR1 - 35 % As_2S_3 - Disperbyk 161 films lead to surface relief “peak”formation. The hight of “peak” is up to 800 nm at exposure up to

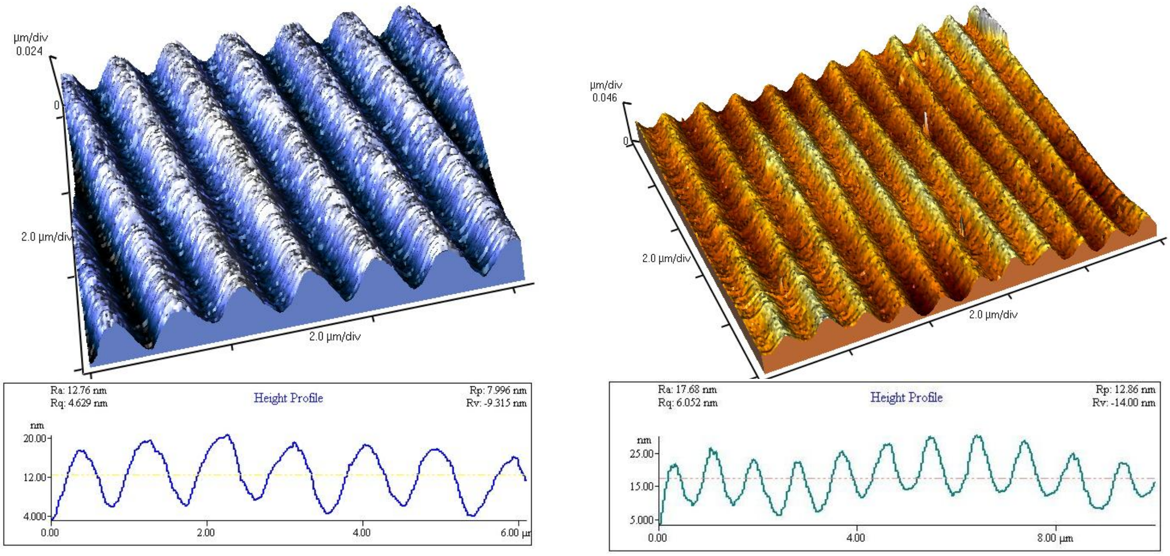

Figure 8. AFM images of surface relief and profiles of holographic gratings recorded by laser 532 nm in composites 40% As_2S_3 - 60% Disperbyk161 (blue) and 5% DR-1 - 35% As_2S_3 - 60% Disperbyk161 (yellow), film with thickness ~5 μm.

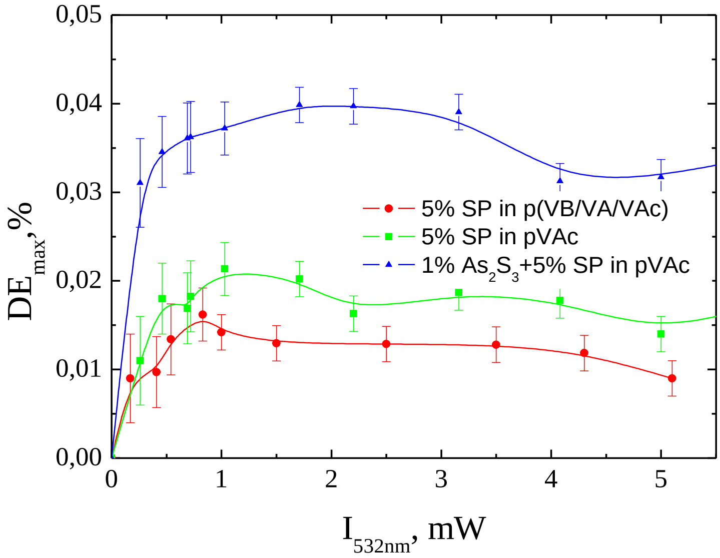

Figure 8. Dependence of transmission DE maximums on the recording beam intensity (recording and reading lasers 532 nm).

40 kJ/cm^2.

- The maximum of DE of gratings with period 1 μm in composite films $(As_2S_3)_x$(Disperbyk 161)$_{100-x}$ at $15 \leq x \leq 60$ had been obtained at the rate to 7 %.
- The depth of gratings relief in composite films $(As_2S_3)_x$(Disperbyk 161)$_{100-x}$ at $15 \leq x \leq 60$ had been reached at the rate of 15 – 20 nm.

The spiropyran was used in the work because it has a great difference in dipole moments of close (unilluminated) and open (illuminated) form of isomers [21]. We assumed that it could lead to surface relief formation in spiropyran containing composites at UV light illumination. However the isomerization transfer happened at low values of exposure (up to 0.36 J/cm^2) and polymeric matrix modification didn’t take place.

We tried to record the gratings in spiropyran-containing composites by two methods:

- Direct holographic record by laser 325 nm. The DE dependence on exposure of spiropyran containing composites in different polymeric matrix had been showed. The value of DE at the rate of 8 % had been reached at low (up to 2 mJ/cm^2) value of exposure in the film 5 % spiropyran - pVB/VA/VAc.
- Holographic record in photomerocianine form (opened modification of spiropyran).

The Theses of the Promotion Work

1. The maximum value of DE of holograms in the films $As_{40}S_{15}Se_{45}$ is defined by wavelength and exposure of recording radiation, by depth of relief.
2. Nanostructured surfaces (130 nm) can be obtained by immersion method of holographic record.
3. Two-component and three-component optical homogeneous photosensitive films can be obtained on base of chalcogenide, organic polymers and organic dyes.

Conclusions

1. The transmission DE of holograms in $As_{40}S_{15}Se_{45}$ films increased approximately in 200 times at increasing of record wavelength in 325 – 633 nm range. The reflection DE of holograms in the same films after selective etching can be reached at the rate of 15 % at record by laser 488 nm. The depth of surface relief in this case is 132 nm.
2. The surface relief with period 130 nm and depth 23 nm can be obtained in the film $As_{40}S_{15}Se_{45}$ by immersion method of holographic record by laser wavelength 325 nm.
3. The composite films $(As_2S_3)_x$(Disperbyk $161)_{100-x}$ $15 \leq x \leq 60$ with edge of transmission in the 370-500 nm range and the composite films $(DR\text{-}1)_5(As_2S_3)_{35}$(Disperbyk $161)_{60}$ with edge of transmission in the 350-650 nm range had been obtained. Influence of light to $(As_2S_3)_x$(Disperbyk $161)_{100-x}$ $15 \leq x \leq 60$ and $(DR\text{-}1)_5(As_2S_3)_{35}$(Disperbyk $161)_{60}$ films lead to shift of transmission curve to short wave area.
4. The peak of absorbtion (the maximum is in area 550-600 nm) in optical spectra of the spiropyran containing composites in polymers pVAc, pMMA and pVB/VA/VAc appear under UV light influence without dependence of arsenic sulphide presents (up to 1%).
5. The influence of focusing light to 40 % As_2S_3 - Disperbyk 161 films lead to surface relief “hole”formation. The depth of “hole” is 30-50 nm at exposure about 20 – 30 kJ/cm^2. The influence of focusing light to 5 % DR-1 - 35 % As_2S_3 - Disperbyk 161 films lead to surface relief “peak”formation. The hight of “peak” is up to 800 nm at exposure up to 40 kJ/cm^2. The reducing of As and S atoms concentration and increasing of oxygen atoms in composite $(As_2S_3)_{40}$(Disperbyk $161)_{60}$ are observed after illumination.
6. The maximum of DE of gratings with period 1 μm in composite films $(As_2S_3)_x$(Disperbyk $161)_{100-x}$ at $15 \leq x \leq 60$ had been obtained at the rate to 7 %. The depth of gratings relief in composite films $(As_2S_3)_x$(Disperbyk $161)_{100-x}$ at $15 \leq x \leq 60$ had been reached at the rate of 15 – 20 nm.

7. The direct holographic record in spiropyran containing composites was performed; the value of DE at the rate of 8 % had been reached at low (up to 2 mJ/cm^2) value of exposure. Also the reversible holographic record in photomerocianine form was performed.

The List of Publication

Publications

To perform these tasks, experiments have been conducted, which results are reflected in the publications included into the promotion work:

1. A. Gerbreders, J. Teteris. Recording of surface-relief gratings on amorphous As-S-Se films. J. Optoelectron. Adv. Mater. 2007, Vol 9, Part 10, p. 3164-3166
2. A. Gerbreders, J. Teteris. Some features of the formation of relief gratings on amorphous As–S–Se films. Latvian Journal of Physics and Technical Sciences**,** 2007, Nr 6, p. 29-36.
3. A. Gerbreders, J. Teteris. Holographic recording in polymer composites of organic photochromes and chalcogenides. Proc. SPIE, 2008, 7142, 714212.
4. A. Gerbreders, J. Teteris, E. Aleksejeva, A. Danilovs. Holographic recording in spiropyran-polymer and spiropyran-chalcogenide-polymer composite films. Latvian Journal of Physics and Technical Sciences**,** Nr 3-2009. pp. 23-29.
5. A. Gerbreders, J. Teteris, E. Aleksejeva, A. Danilovs. Optical recording in spiropyran and polymer composite films. J. Optoelectron. Adv. Mater., 2009, Vol . 11, pp. 2145-2148.
6. A. Gerbreders, J. Teteris, E. Alekseeva, A. Danilovs. Holographic recording in photochrome-chalcogenide composites. Lithuanian Journal of Physics, 2010, Vol. 50, No. 1, pp. 47-53.

Conferences:

The results have been presented in several conferences which are reflected in the following conference theses:

1. A. Gerbreders, J. Teteris. Kodināšanas procesa pētījumi As-S-Se fotorezistos. Referātu tēzes. 23. zinātniskās konferences, LU Cietvielu fizikas institūts, Rīga, 2007.
2. A. Gerbreders, J. Teteris. Recording of surface-relief gratings on amorphous As-S-Se films. Abstract Book Third international Conference on Amorphous and Nanostructured Chalcogenides (ANC-3), Brasov, Romania, 2007.

3. A. Gerbreders, J. Teteris. Some features of formation of surface-relief diffraction gratings on amorphous As-S-Se films. Book of Abstracts of the 9-th International Summer School-Conference Advanced Materials and Technologies, Palanga, Lithuania, 2007.

4. A. Gerbreders, J. Teteris. Optiskais ieraksts halkogenīdu un organisko polimēru kompozītos. Referātu tēzes. 24. zinātniskās konferences, LU Cietvielu fizikas institūts, Rīga, 2008.

5. A. Gerbreders, J. Teteris, I. Mihailova. Optical recording in organic polymer-chalcogenide composite thin films. Book of abstracts of ISNOG 2008, Montpellier, France, 2008.

6. I. Mihailova, A. Gerbreders, V. Akmene "Organisko polimēru-halkogenīdu plāno kārtiņu optiskās īpašības", Daugavpils universitātes 50.starptautiskā zinātniskā konference, 2008. gada 15-17. maijs

7. A. Gerbreders, J. Teteris. Holographic recording in polymer composites of organic photochromes and chalcogenides. Book of abstracts of the 6th international conference AOMD 2008, Riga, Latvia, 2008.

8. A. Gerbreders, J. Teteris. Optiskais ieraksts spiropirāna un organisko polimēru kompozītu kārtiņās. Referātu tēzes. 25. zinātniskās konferences, LU Cietvielu fizikas institūts, Rīga, 2009, 11. – 13. februāris.

9. A. Gerbreders, J. Teteris, J. Aleksejeva, A. Danilovs. Difrakcijas režģu ieraksts spiropirāna un organisko polimēru kompozītu kārtiņās. Referātu tēzes. 51. starptautiskās zinātniskās konferences, Daugavpils Universitāte, Daugavpils, 15.04.-18.04.2009.

10. A. Gerbreders, J. Aleksejeva, A. Danilovs, J. Teteris. Holographic recording in polymer, chalcogenide and photochrome composites. Book of Abstracts of the International Baltic Sea Region conference “Functional materials and nanotechnologies”, Riga, 2009.

11. A. Gerbreders, J. Aleksejeva, A. Danilovs, J. Teteris. Feature of holographic recording in photochrome-chalcogenide composites. Book of Abstracts of the International conference “Developments in Optics and Communications 2009”, Riga, April 24 - 26, 2009.

12. A. Gerbreders, J. Teteris, J. Aleksejeva, A. Danilovs. Optical recording in spiropyran and composite films. Abstract Book Fourth International Conference on Amorphous and Nanostructured Chalcogenides (ANC-4), Constantsa, Romania, 2009.

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