Influence of Corona Discharge on the Formation of Submicron Periodic Holographic Structures in System Metal - Chalcogenide Glass Semiconductor

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***Abstract* — The optical registration of holographic gratings based on photostructural transformations in the structure of thin-film Ni-As2S3 and based on photoinduced interaction in the structure of Cu-As2Se3, both in the field and without of corona discharge have been studied. It is shown that the use of corona discharge during holographic recording in the structure of Ni-As2S3, and in the structure of Cu-As2Se3 leads to the increasing of holographic sensitivity of these structures and the diffraction efficiency of the recorded holographic diffraction gratings. The chemical etching of holographic diffraction gratings formed in these thin-film structures in the presence of corona discharge result in increasing in the depth and order the relief etched relief-phase diffraction gratings, as well as in increasing of their diffraction efficiency compared with samples obtained without the corona discharge.**

***Index Terms* — chalcogenide glass semiconductor, holographic gratings, corona discharge, photoinduced transformations.**

I. INTRODUCTION

In chalcogenide glass semiconductors (ChGS) various type of nanostructures can be created by optical and electron beam lithography [1]. In optical lithography, namely in deep ultraviolet, the most promising application is ChGS films [2]. The processes of optical information registration in thin film structures based on ChGS were quite intensively studied, for example, in [3-7]. In [8-10] is shown the use of corona discharge can increase the sensitivity of Ni-As_2S_3 thin film structure and diffraction efficiency of holographic gratings formed as a direct result of photostructural transformations in the ChGS film and relief phase gratings obtained after chemical etching. However, the effect of corona discharge with repeated exposure by different interference patterns (it is one of the methods for the obtaining of periodic surface relief diffractive optical elements [11]) on the relief obtaining in the Ni-As_2S_3 structure wasn't investigated.

To the best of our knowledge there is no article devoted to the influence of corona discharge to formation of holographic diffraction gratings based on photoinduced interaction in a metal-ChGS structures.

The aim of this study was to investigate the influence of the corona discharge field on the formation of holographic diffraction gratings during recording in Ni-As_2S_3 and Cu-As_2Se_3 thin-film structures and after selective etching.

II. EXPERIMENTAL

Structure for the registration of holographic diffraction gratings (HDGs) were prepared by sequential thermal evaporation in a vacuum of Ni and As_2S_3, as well as Cu and As_2Se_3 on a glass substrate. The thickness of the metal layer was about 40-50 nm, and the thickness of the semiconductor layers is equal to 1 μm for As_2S_3 and 0.27 μm for As_2Se_3. The process of holographic recording in thin metal-semiconductor structures was carried out with simultaneous charging in the corona discharge. HDGs recording were performed by the standard procedure on the holographic table. In case of Ni-As_2S_3 structure the coherent source as Ar^+ ion laser with a wavelength of λ = 488 nm and the light intensity at the structure surface E = 8 mW/cm^2. In case of Cu-As_2Se_3 structure the He-Ne laser was applied with a wavelength of λ = 632.8 mm and light intensity E = 2 mW/cm^2. HDGs etching were performed in an aqueous solution of inorganic alkali KOH (5%) for Ni-As_2S_3 and NaOH (1%) for Cu-As_2Se_3. The procedure of diffraction efficiency measurement is given in [9]. Study of the surface of the formed relief-phase diffraction gratings was carried out by atomic force microscope Nano-Station II.

III. RESULTS AND DISCUSSION

Figure 1 shows the topography of the etched surface of the crossed diffraction gratings and shape of the profile of the grating, which were recorded by two-times exposure (H= 2 J/cm^2) on the Ni-As_2S_3 structure without (a) and using the corona discharge (b). HDGs period was 0.5 μm. From the figures it is clear that the use of corona discharge leads to an increasing of order and relief depth by 30-40%. These results can be explained similarly just as was done in [9], where one HDG was recorded in the Ni-As_2S_3 structure by photoinduced transformation in ChGS.

Figure 2 shows the diffraction efficiency (η) dependence on the recording time of three HDGs (spatial frequency 500 1ines/mm) recorded in the $Cu\text{-}As_2Se_3$ structure by laser radiation (He-Ne laser, $\lambda = 632.8$ nm) in normal conditions (curve 1) and in the electric field of corona discharge of different polarity (lines 2 and 3). Using positive corona discharge (the discharge electrode is positive) results in a decreasing of the holographic sensitivity S and diffraction efficiency η (curve 2).
And on the contrary using negative potential at the discharge electrode results in the increasing of S and η (curve 3).

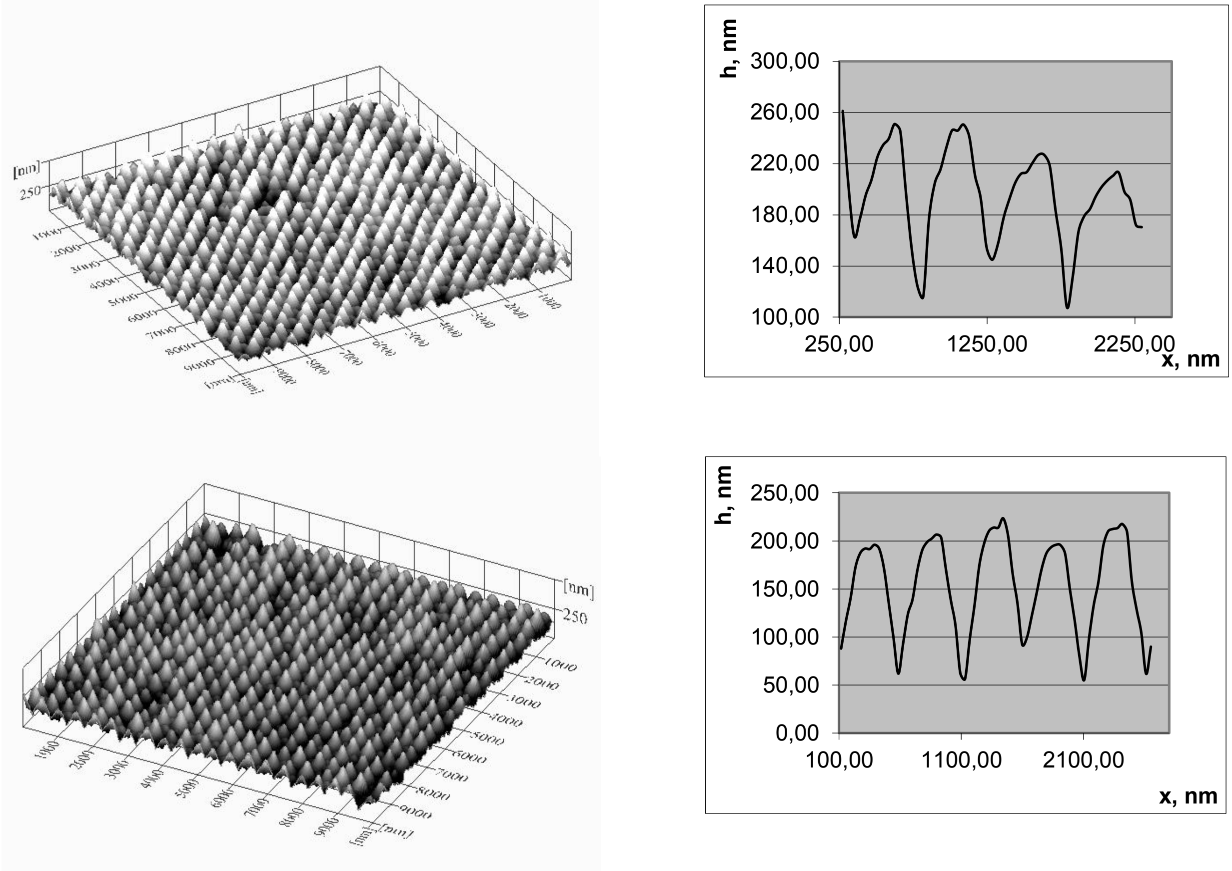

Fig. 1. Topography and profile of etched surface of crossed holographic gratings formed in $Ni\text{-}As_2S_3$ structure by holographic recording: a) - without a corona discharge; b) – using of corona discharge (U = 7.5 kV).

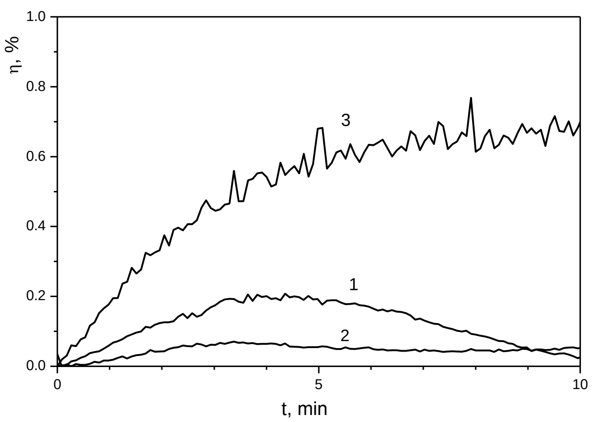

Fig. 2. The HDGs diffraction efficiency dependence on the recording time of the $Cu\text{-}As_2Se_3$ structure. Curves 1, 2, 3 with the application of the corona discharge at U = 0, 7 and -7 kV, respectively.

Maximum diffraction efficiency η of HDG during the exposure process reaches up to 0.8% in the negative corona discharge (curve 3), up to 0.2% without the application of the corona discharge (curve 1) and 0.07% with a positive corona discharge (curve 2). So values of η are caused by a relatively thin layer of ChGS (0.27 μm) and may not be optimal thickness ratio of ChGS and metal.

It should be noted that the test etching (without the optimization of the etchant and the pH of solution) of HDG formed in $Cu\text{-}As_2Se_3$ (record time is 4 minutes) in 1% aqueous solution of inorganic alkali NaOH leads to the next diffraction efficiency values: 4% for the grating recorded without corona electric field, 10% for the grating recorded in the negative corona discharge, and 2.5% for the grating recorded in the positive corona discharge. Thus the optical recording process of HDGs on the structure of $Cu\text{-}As_2Se_3$ ensures obtaining of relief-phase grating in the negative corona discharge with a diffraction efficiency of more than 2 times higher than that of normal recording (without corona discharge).

The effect of laser exposure on Cu-As_2Se_3 structure with thickness of 1 μm on its solubility in 1% aqueous solution of NaOH is shown in Fig. 3. The control of the etching process was carried out by an optical method [11] at a wavelength of λ = 0.94 μm in the transmission mode during the etching process.

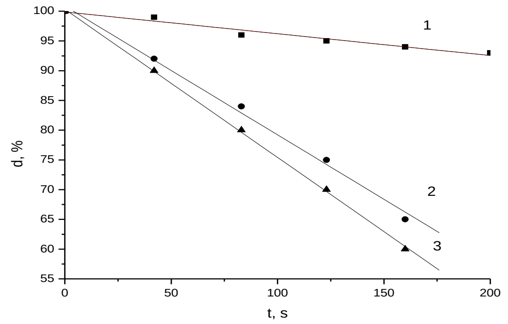

Fig. 3. The thickness change dependence on etching time in Cu-As_2Se_3 structure. Curve 1 – using exposure in the negative corona discharge, 2 – without exposure and corona discharge, 3 – using exposure without the corona discharge.

The etching process was studied at 3 samples: 1 - irradiated by uniform laser illumination (λ = 0.63 μm, E = 4 mW/cm^2 during 10 minutes) in the negative corona discharge U = 7 kV; 2 - non-irradiated, 3 - irradiated by laser (λ = 0.63 μm, E = 4 mW/cm^2 during 10 minutes) without any corona discharge field.

It is seen that the laser irradiation of Cu-As_2Se_3 structure leads to increasing of the etching rate of about 20% compared to non-irradiated structure (curve 3 and 2), and a similar exposure in the negative corona discharge reduces the etching rate of more than by 5 times (curve 1 and 2). From these results it is clear that exposure using corona discharge field leads to a much greater etching selectivity in alkaline solution than without application of corona field and to the change of the type of solubility.

The dominant mechanism of the HDG formation, in this case, is photoinduced interaction in the Cu-As_2Se_3 structure. The influence of photostructural transformations in HDG formation can be neglected, since:

1. the refractive index change of As_2Se_3 under photostructural transformations is about 0.13 [12], but the refractive index change of the Cu-As_2Se_3 is about 0.3 under photoinduced interaction [11];
2. the intensity of photostructural transformations is strongly dependent on the thickness of ChGS film (in our experiment the thickness is 0.27 μm) [13];
3. the photoinduced interaction in metal-ChGS structure weakens the photostructural transformation [14].

Apparently, for the qualitative explanation of the observed phenomena in the Cu-As_2Se_3 structure the following facts should be considered:

1. The rate of photodiffusion process is limited by the rate of metal penetration from doped region of ChGS to undoped [14].
2. The doped-undoped interface of ChGS is considered as heterojunction [14], which is formed during photodoping and moves during the exposure of metal-semiconductor [15].
3. The light exposure on this heterojunction leads to separation of electrons and holes in such a way that they create a pulling electric field to the metal ions [15].
4. It is obviously that during the application of corona discharge field to this heterostructure, the created pulling electric field, which causes positive ions moving from photodoped layer to undoped layer [15], will either increase or decrease depending on the polarity of the discharge electrode.

IV. CONCLUSION

1. It was shown that selective etching of two crossed HDGs recorded by photostructural transformations in corona discharge field in Ni-As_2S_3 structure led to an increasing of order and relief depth by 30-40%, compared with HDGs recorded without corona discharge field.
2. Using the negative corona discharge during holographic recording of HDGs based on photoinduced interaction in Cu-As_2Se_3 structure resulted in a increasing of the holographic sensitivity S and diffraction efficiency η by more than 2 times.
3. It was shown that uniform laser exposure of Cu-As_2Se_3 structure in negative corona discharge led to much greater etching selectivity in alkaline solution and to the change of the solubility type compared to exposure without application of corona discharge. This make it possible to obtain of relief-phase HDGs with diffraction efficiency of more than 2 times higher and to carry out the optical lithography process of high quality.
4. The carried out experiments and obtained results on application of corona discharge field during holographic recording in metal-ChGS structures [16,17] make it possible to considerable improvement the parameters of recorded and etched relief images. It will ensure obtaining of more qualitative diffractive optical elements and nanostructures based on ChGS, as well as the whole process of optical lithography.

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