Computer- assisted electron beam recording of patterns in As_2S_3 films

Vladimir ABASHKIN, Elena ACHIMOVA, Sergei SERGHEEV, Alecsandr PRISACAR
Institute of Applied Physics, Academy of Sciences of Moldova
achimova@phys.asm.md

***Abstract* — In this paper, we present the PC-assisted e-beam recording of some diffraction structures in As_2S_3 thin films with thickness about 1 µm. The square surfaces occupied by holograms on the film were from 400 x 400 µm^2 up to 1600 x 1600 µm^2. The diffraction gratings mosaic of different configurations were recorded in the vector mode. The raster mode of recording have been used for microimages and digital holograms presented in .bmp format. Digital hologram of cube image was reconstructed by He-Ne laser beam (wavelength 0.633 µm) in transmission mode and investigated. The diffractive characteristics of the designed diffraction structures and images were studied. Some multibeams diffraction and their optical properties are experimentally studied.**

Index Terms — **As_2S_3 thin films, computer-aided recording, diffraction elements, e-beam recording**

I. INTRODUCTION

Many and diverse photonic applications are based on photosensitive or electron-beam sensitive materials. Among the nonorganic recording media, the thin films from chalcogenide glass As_2S_3 are promising material for elements recording with resolution up to 10000 lp/mm [1]. So nanostructures can be formed based on structural changes using such films [2-4] as by light as by e-beam. Diffractive optical elements (DOE) can be fabricated by induced alternation of the index of refraction of thin films of As_2S_3. Induced index of refraction changes can reach up to 0,1 [2] and its wide dynamical interval give possibility e-beam forming diffraction superimposed gratings and compound images. Phase changes are more preferable for DOE formation in comparison with amplitude ones as no absorption occurs inside optical element.

DOEs manufactured by a holographic or an e-beam recording methods have recently found wide application in various optical and optoelectronic elements and devices [5]. It is well known that the fabrication of the DOEs with a non-sinusoidal profile significantly improves the performance efficiency and enables the control of the diffraction angles for maximum efficiency. Resists with low proximity effect, high sensitivity and linear dependence between the exposed dose and the profile depth are required for the fabrication of the blazed DOEs.

DOEs have many attractive features such as the constructing optical systems compactly and new functionality compared with conventional bulk optics, and industrial application of diffractive optics has increased in many fields. Owing to the improvement of reconfigurable computer platform to solve any demanding control and monitoring task and the advancement of micro/nano-fabrication techniques in recent years, diffractive optical elements such as binary optics and computer generated diffractive structures have been actively researched [4].

DOEs recorded by laser holographic technique have limit in design of optical image. On the contrary a variety of DOEs such as Fresnel lenses, gratings with linear and curves lines, variable pitch and special line profile gratings can be sophisticated recorded by e-beam. Of coarse PC program for DOE design and PC-assisted scanning electron microscope for e-beam control must be elaborated [6].

In this paper, we present the e-beam recording of some diffraction structures in As_2S_3 thin films designed by PC-assisted raster electron microscope to demonstrate software and hardware capabilities. The diffractive characteristics of the designed diffraction structures and images were studied. Some diffraction optical patterns, fine structures and reconstructed image by He-Ne laser beam (wavelength 0.633 µm) are shown in transmission mode and investigated. Their optical properties are experimentally evaluated and the design capability of the modified raster electron microscope is verified. Computer DOE design and external controls of the e- beam by PC significantly enhance the possibilities of e-beam recording. All lines of gratings and images in this report consist of a number of pixels.

II. EXPERIMENTAL

Thin films of As_2S_3 (about 1 µm) were prepared by thermally evaporation in vacuum (10^{-5} mm Hg) on glass substrate covered by semitransparent metal layer. Based on the scanning electron microscope (SEM) BS 300 (Tesla) and 16 bit control adapter NI USB-6216 the system SEM-PC has been developed. In order to design the DOE with numerical methods we have used a specialized software LabWindows/CVI-8.5 compiled in virtual instruments environment. Developed software gives possibility of e-beam positioning both in raster and vector mode of recording of diffraction structures. Square region of recording was determined by SEM magnification and was about 1600×1600 µm^2. The diffraction gratings of different configurations were recorded in the vector mode. In this case the minimum distance between pixels was about 0.05 µm. The raster mode of recording has been used for recording of the microimages presented in .bmp format. The 8-bit grayscale graphical files have been used for recording of the microimages with the dimensions 256×256 pixels and 512×512 pixels. The black/white levels were obtained by discrete varying the time exposure of e-beam at one pixel point during the recording process. The minimum exposure time/pixel was 0.1 ms.

MakeHolo software developed in our laboratory was applied for synthesis of hologram from an image. These holograms were used for subsequent recording by e-beam on the thin films of As_2S_3. In black regions of microimage the e-beam moves significantly quickly than in white ones so no evident influences of electron irradiation on recording media (thin film of As_2S_3) index of refraction occurred.

Electron beam current determining dose of electron irradiation was ranged from 1 to 2 nA. The e-beam penetrates all the depth of the thin film of As_2S_3 at accelerating voltage 25 kV.

The diffraction gratings after recording were developed at room temperature in water solution of KOH to reveal surface relief. Micro-images were recording by e-beam directly and no any addition development was applied.

III. RESULTS

Important type of DOE is a mosaic of diffraction gratings. It can be consisting of diffraction gratings with direction of mutual orientation, grating period, including variable period and so on. Diffraction patterns obtained after laser beam illumination in transmission mode depend on how many elements of mosaic are illuminated simultaneously. Multibeam diffraction of light can be obtained if laser beam spot overlaps some diffraction gratings.

The sketch of chess-board structure (Fig.1) composed from two orthogonally oriented diffraction gratings with periods 2,0 and 2,2 μm is presented. Mosaic and diffraction grating have dimensions 800×800 μm^2 and 200×200 μm^2, consequently.

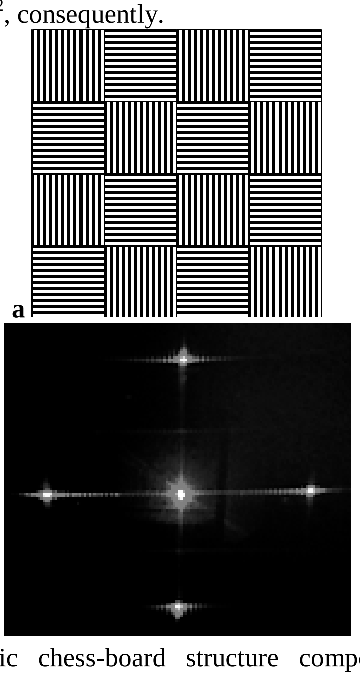


Fig.1. Mosaic chess-board structure composed from diffraction gratings (a) and it diffraction pattern (b).

Laser spot of 400 μm diameter illuminates at list two gratings so it can be seen complex diffraction pattern in transmission mode (Fig.1,b). Equal intensity diffraction spots can be clear seen from both orthogonal oriented gratings.

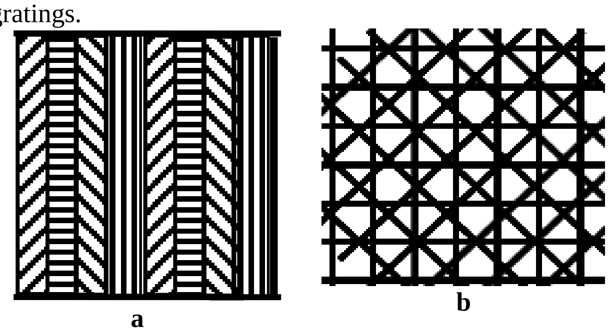


Fig.2. Part of mosaic structure with set of diffraction gratings (a) and the structure of N=4 superimposed diffraction gratings (b).

On Fig.2 (a) the sketch of fragment of mosaic composed from gratings in form of strips is presented. Four mutual orientations of gratings lines with 45^0 steps rotation were chosen to obtain diffraction pattern with circle symmetry. . Period of each grating in form of the strip and size of mosaic are 2 μm and 800×800 μm^2, consequently. Width of each strip is equal to 50 μm. Four gratings-strips with together dimension of 200 μm form the mosaic period. Diffraction pattern is presented for case when laser spot diameter is equal to 400 μm (Fig.2 (a)).

Diffraction patterns from mosaic of gratings Fig.2 (a and b) are shown on (Fig.3 (a and b)) consequently. The most brightness spots on diffraction patterns are formed by the first order of diffraction beams for both diffraction structures. Addition spots on diffraction pattern are formed when laser spot illuminates nodes of tangency of diffraction gratings lines (Fig.3 (b)).

In practical application of optical code additional diffraction spots appearance diffraction pattern are undesirable. So preferable diffraction pattern which contains only first order diffraction beams (Fig. 3a).

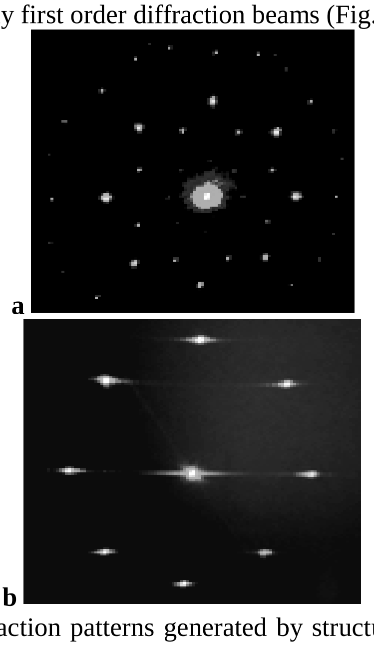


Fig.3. Diffraction patterns generated by structures shown on Fig.2 (a) and (b), consequently.

As to etching development of recorded gratings the quality of single diffraction grating is higher in comparison with the quality of superimposed ones after etching. Drawback of mosaic is horizontal stretching of diffraction spots (Fig. 3a). We consider this undesirable stretching is defined by small dimensions of strips. Optimization of dimensions of laser spot diameter and strip width can rise the quality of diffraction pattern.

Recording of diffraction gratings with variable pitch is a advantage of PC-assisted raster electron microscope in comparison holographic method of recording. Orthogonally directed diffraction gratings with linearly variable pitch from 2 μm to 1 μm were recorded in superimposed mode. This structure covers surface 400×400 μm^2. Diffraction pattern of this diffraction structure is shown on Fig.4.

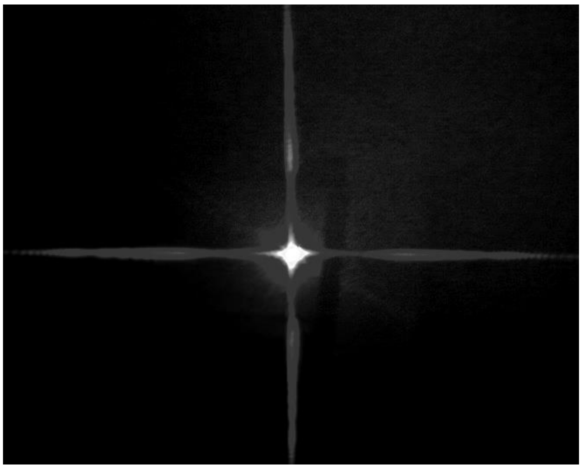


Fig.4. Diffraction pattern formed by crossed superimposed gratings with variable pitch.

Diffraction gratings with linearly variable pitch gives diffraction pattern in form of continuous line compose from ± first order spots. Obviously orthogonally superimposed diffraction gratings will produce cross of such lines (Fig.4).

Set of one hundred of concentric circles with gradation of radii in 2 μm was recorded by PC-assisted scanning electron microscope. Ring diffraction pattern generated by this set is presented on Fig. 5.

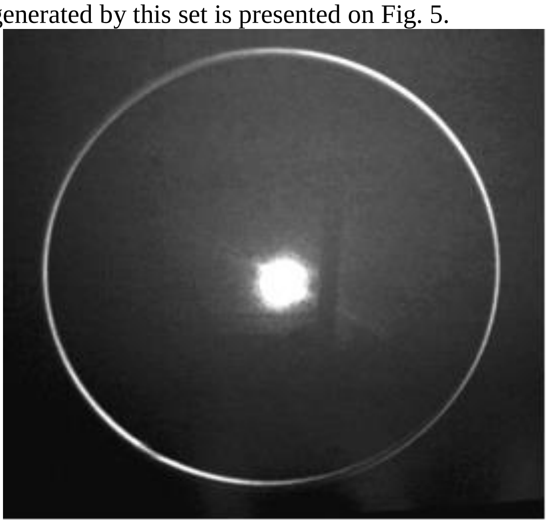
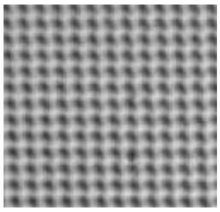


Fig. 5. Ring diffraction pattern generated by set of concentric circles

Microimages were direct recorded by e-beam into squire surface of thin film of As_2S_3 with 1.6 x 1.6 mm^2 dimension. No etching development was applied for microimages. Below are presented microphotography under compound microscope (Fig.6(a)) where can be clear seen logo of Institute of Applied Physics in abbreviation on Romanian language.



b

a

Fig.6. Institute of Applied Physics logo formed by pixels (a) and part of pixels matrix of every line on the logo (b).

The logo was composed from wide lines in turn composed a matrix of pixels. Pixel distance is equal to 3 μm. E-beam induced changes of index of refraction and darkening give possibility visualization of logo. Pointed above a matrix of pixels can be clear seen on Fig.6b. A matrix of equal distances pixels works as diffraction grating too with own diffraction pattern.

By using MakeHolo software for the synthesis of digital hologram from an image of cube with transparent sides was done. Digital hologram in the form of 8-bit grayscale graphical file is shown on Fig. 7.

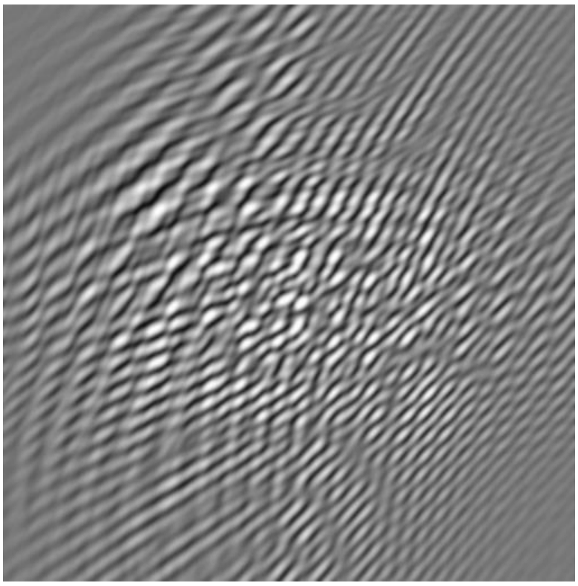


Fig. 7. Synthesized digital hologram of cube image, which image has been then recorded on As_2S_3 thin film.

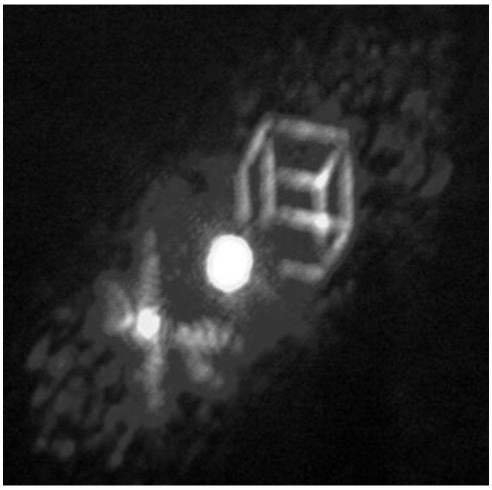


Fig. 8. Cube image in the first order reconstructed by red laser beam.

This hologram was recorded by e-beam into thin film of As_2S_3 with thickness 1μm. The surface occupied by hologram on the film was estimated as 600 x 600 μm^2. Diffraction pattern in the first order of diffraction of cube image has been reconstructed by illumination of red He-Ne laser beam (wavelength is 0,633μm, Fig.8). This pattern is presented as black/white photography. It is clear seen only one image of cube from the first order diffraction and zero order of diffraction pattern.

IV. CONCLUSION

The e-beam recording of some diffraction structures and microimages in As_2S_3 thin films designed by PC-assisted raster electron microscope was demonstrated. Developed programming HoloMake software for digital holograms calculations was elaborated. The hardware have capabilities to write as diffraction gratings as microimages too. Digital holograms were fabricated in a direct, one-step process of recording by e- beam with no etching. Diffraction patterns generated by all structures were obtained. Relief diffraction structures were formed after recording by the development in water solution of KOH. Micro-images were recording by e-beam directly and no any addition development was applied. recording by Mosaic diffraction structures generate multibeam laser light diffraction.

ACKNOWLEDGMENTS

The research described in this publication was financially supported by the next projects:

1. No. 11.836.05.04A „Straturi subţiri şi fibre optice pe baza materialelor nanocompozite organice-anorganice pentru noi dispozitive optoelectronice” in the framework of the National Programme “Nanotehnologies and nanomaterials” initiated and conducted by academician Andrei Andriesh.

2. No. 11.817.05.03A “Materiale semiconductoare halcogenice, compuşi metaloorganici şi magneţi moleculari pentru medii de înregistrare, senzori, aplicaţii optoelectronice şi fotovoltaice.”

REFERENCES

[1] J.Teteris, and M. Reinfelde. Application of amorphous chalcogenide semiconductor thin films in optical recording technologies. Journal of Optoelectronics and Advanced Materials, 1. J.Teteris, and M. Reinfelde. Application of amorphous chalcogenide semiconductor thin films in optical recording technologies. Journal of Optoelectronics and Advanced Materials, Vol. 5, 1355 (2003).

[2] J.R. Neilson, A. Kovalskiy, M. Vlček, H. Jain, and F. Miller. Fabrication of Nano-Gratings in Arsenic Sulphide Flms. Journal of Non-Crystalline Solids, Vol. 353, 1427 (2007)

[3] M. Vlcek and, H. Jain Nanostructuring of chalcogenide glasses using electron beam lithography. Journal Of Optoelectronics And Advanced Materials, Vol. 8, 2108 (2006).

[4] S. Noach, M. Manevich, N. P. Eisenberg , D. Davidov, M. Klebanov, and V. Lyubin. Optical Near-Feld Lithography in Chalcogenide Flms. Optical Materials, Vol. 28, 1054 (2006).

[5] S A Sergeev, A A Simashkevich, S D Shutov Slanted superimposed diffraction gratings formed by an electron beam in amorphous arsenic sulfide films. Quantum Electronics (October 1994), 24 (10), p. 924-926

[6] Brevet Moldova “HoloMake software for digital holograms calculation ” 2010