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TWO DIMENSIONAL PHOTONIC STRUCTURES BASED ON As-S CHALCOGENIDE GLASS

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Two-dimensional photonic structure has been imprinted on the surface of arsenic sulphide glass using the pulses of a femtosecond laser. Due to the interaction of the laser beam with the glass, the laser traces were obtained as hillocks of around 150-200 nanometer in height, or holes of depth around 100-300 nm, without the need for a later etching stage as in the usual practice. The calculation of the band structure shows a photonic band gap between 0.9 and 1.0 c/a. By varying the energy of the laser pulse we have the possibility to choose between the two possibilities to produce a photonic structure made-up of hillocks or a photonic structure consisting of holes. The value of the threshold pulse power which controls the resulting surface morphology and the obtained photonic structure has found to be around 15 mW. The surface topography of the structures obtained has been investigated by atomic force microscopy (AFM).

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1. Introduction

Photonic structures are important components of the optoelectronic circuits used in telecommunications and in non-linear optics, as lossless guiding [1], tightly bent 90^o waveguides [2], and on-chip integration, as they can combine optical waveguides, resonators, dispersive devices and modulators.

Chalcogenides are infrared glasses made from the combination of the chalcogen elements (S, Se and Te) with arsenic, phosphorus, germanium or other elements. The glasses have low softening temperatures and, therefore, can be processed easily by various thermal methods.

Recently it was shown that various 2D or 3D structures can be inscribed on the surface and bulk of an arsenic sulphide glass by the action of femtosecond laser pulses followed by etching in alkali or amine based etchants [3, 4].

In this paper it is sown that column-like photonic structures or holes structures can be inscribed directly on the surface of a bulk glass of As_2S_2, in one step, without using etching.

2. Materials and methods.

The As_2S_3 plate has been obtained from a bulk glass by grinding and fine polishing. The amorphous structure of the material was tested by X-ray diffraction. For long storage in atmosphere a very thin film of As_2O_3 (arsenolite) are formed on the surface.

The laser irradiation was made with a Synergy Pro Ti-Sapphir pulsed laser working in femtosecond regime. The laser emission band is between 750 and 850 nm and the repetition rate is tens of MHz. The minimum diameter of the laser is 1-2 μm.

A Thorlabs NanoMax300 XYZ table, controlled by computer allows for fine positioning of the laser in order to get various geometrical configurations of the irradiated zone (square lattice of points, hexagonal lattice, etc.).

As an example we have registrated on the surface a hexagonal lattice of points imprinted by laser pulses.

Atomic force microscopy measurements have been carried on the surface of the not-irradiated and irradiated surface in order to compare the configuration of the recorded points.

3. Results

The original surface of the bulk As_2S_3 sample used for laser recording was evidenced by AFM pictures. Fig. 1 shows not irradiated. No morphological details are seen on the surface.

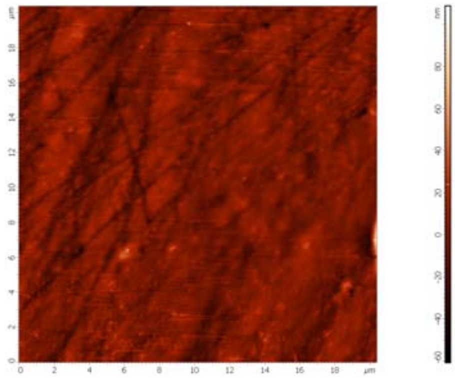


Fig. 1 Sample surface before irradiation.

After the imprint of the lattice of points by laser pulses, the irradiated positions on the surface change (Fig. 2), depending on the power of the pulse used for writing.

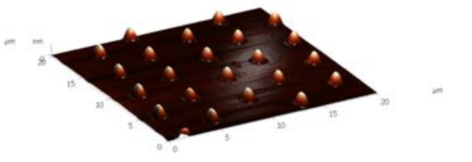
a b

Fig. 2 Surface of As_2S_3 after irradiation when a) the pulse energy is below the threshold energy b) the pulse energy is above the threshold energy

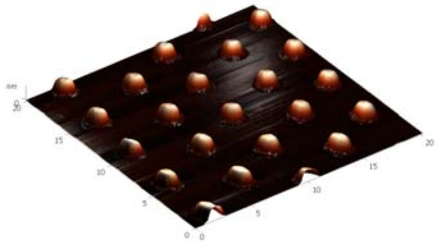
Fig. 3 shows the change of the recorded lattice when the geometry is preserved but the power of the laser pulse is changed from very low to very high one.

It is observed the transition from the column-like structure to hole-like structure when the laser pulse power overcomes the threshold energy: in the case of arsenic sulphide this threshold is situated at 15 mW.

The height of the columns is around 100-200 nm, while the depth of the holes can reach 100-300 nm.

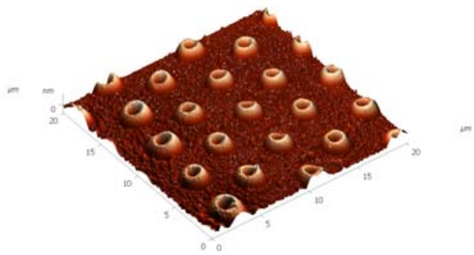


a

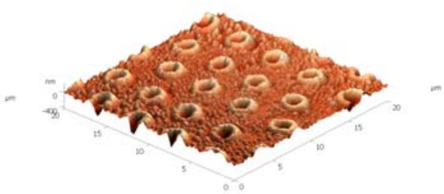


b

c



d



e

Fig. 3 Sample surface after irradiation using different pulse powers:
a) 5mW, b) 10 mW, c) 15 mW, d) 20 mW, e) 25 mW

Fig. 4 shows the band structure calculated for the lattice constant used experimentally (5 micrometers).

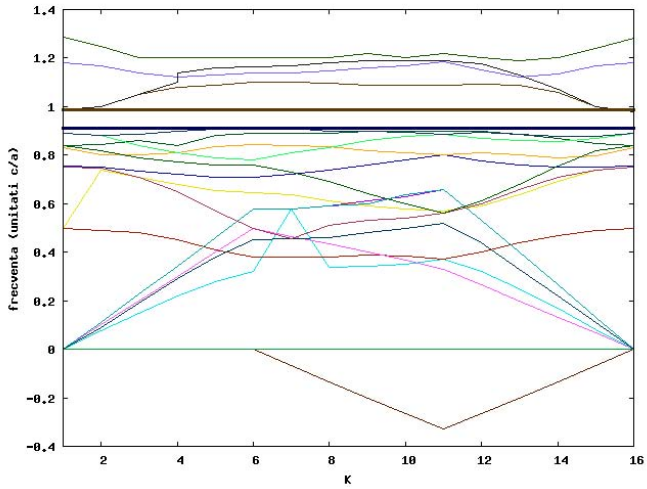


Fig. 4 Calculated band structure for ε = 7.3 and a = 5 μm

4. Discussion

In the formation of the photonic structures we have used the photo-expansion phenomenon in As_2S_3 glass. The key advantage of this procedure is, that it is a one-step optical process, which requires no later etching process to have the desired final surface morphology of photonic crystal.

Illuminating the chalcogenide glass with super-bandgap light causes both photodarkening and photo-expansion.

Photodarkening is a photo-induced red shift of the optical absorption edge, which is accompanied by an increase in the index of refraction in the transparent spectral range [5].

Photo-expansion [6] is the increase in volume of the network of a light affected chalcogenide glass. In As_2S_3 the glass network expands by around 0.5% due to this photostructural change [7]. However when the irradiated volume is constrained in an exposed matrix (like in our case) stress at the interface leads to higher volume changes. Hisakumi and Tanaka [8] reported a 2% expansion by illuminating a portion of the As_2S_3 glass sample with 632.8 nm light from a He-Ne laser.

The order of magnitude of photo-expansion corresponds well to the size of the hillocks observed on the surface of the laser irradiated area of our bulk glass As_2S_3.

5. Conclusions

We have demonstrated that two-dimensional photonic structures can be printed on the surface of bulk chalcogenide glass of composition As_2S_3. Regular columns obtained by photo-expansion of the glassy material have the height of 150-200 nanometers, while the holes formed by high energy irradiation have the depth of 100-300 nanometers.

The inscription process is achieved in one step, without etching, is simple and efficient.

Acknowledgement

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References

[1] M. Bayindir, B. Temelkuran, E. Ozbay, Phys. Rew. Lett. 84, 2140 (2000)
[2] S. Noda, K. Tomoda, N. Yamamatu, A. Chutinan, Science 289, 604 (2000)

[3] A. Popescu, S. Micloş, D. Savastru, R. Savastru, M. Ciobanu, M. Popescu, A. Lorinczi, F. Sava, A. Velea, F. Jipa, M. Zamfirescu. J. Optoelectron. Adv. Mater. 11(11), 1874 (2009)
[4] M. Popescu, F. Sava A. Lőrinczi, A. Velea, M. Vlček, H. Jain, Phil. Mag. Lett. 1-7, (2009)
[5] Y. Utsugi, Y. Nizumisha, Jap. J. Appl. Phys. 31, 3922 (1992)
[6] K. Tanaka, Rev. Solid State Sci., Vol. 4, 641 (1990)
[7] H. Hamanaka, Ke. Tanaka, A. Matsuda, I. Iizima Sol. State. Comm. 19, 499 (1976)
[8] H. Hisakumi, Ke. Tanaka, Appl. Phys. Lett. 65, 2925 (1994)