Interference lithography for 3D photonic band gap crystal layer by layer fabrication.

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ABSTRACT

We present fabrication of 3D photonic band gap woodpile crystals from photosensitive chalcogenide glass with the help of interference lithography and layer by layer construction. The alignment method is described, which is scalable to extremely small feature sizes required for photonic crystals in the visible region.

INTRODUCTION

Optical spectrum photonic band gap crystals require high refraction index materials and technology for 3D sub-micron structure fabrication. The most flexible approaches are based on semiconductor lithography processes[1,2]. Most of them require sophisticated equipment and are confined by the current state of the art feature size limit. Thus there is demand for scalable lithography technologies and new types of materials, offering easy treatment and high refractive index.

Chalcogenide glasses are highly promising materials for photonic crystals[3]. Their refractive index varies from 2.5 to 3, together with transparency from 800nm to 12 micron. They are photosensitive, and can be used as positive or negative photoresists. In addition they are amorphous materials that can be deposited on almost any other material by vacuum vapor deposition at low temperature.

EXPERIMENTAL DETAILS

Maskless interference lithography can replace classical mask lithography in the case of photonic crystals due to their periodical structure. The required periodic pattern of illuminated and dark regions can be produced by interference of two or more coherent laser beams. The advantages of interference over mask lithography are higher resolution and deep focus. The latter allows the usage of interference lithography on curved surfaces.

The woodpile photonic band gap crystal can be considered as a multi layer construction, where each different layer is a diffraction grating (see Figure 1). Hence each layer can be produced by the interference pattern of only two beams. For formation of each layer, the first
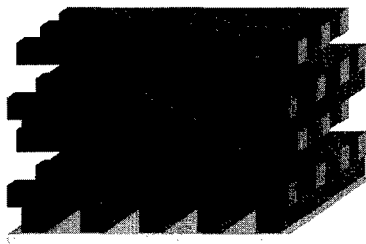

Figure 1: Woodpile Photonic Crystal

step is vacuum vapor deposition of thin chalcogenide film. The grating is obtained by using layer as a negative photoresist, after illumination and selective etching. The next step is the planarization of this grating by spin coating of Shipley photoresist, with subsequent thinning to the width of the grating. Afterwards the subsequent layers are formed in the same way. The final step is washing out of photoresist using a stripper.

All layers must be accurately aligned with each other, meaning their periods, directions and relative positions should be precisely fitted. Otherwise the desired optical properties will suffer. A technique for alignment between the two-beam interference pattern and the existing grating was developed[4]. During interference lithography the already produced layers of woodpile crystal act for incident light like an ordinary diffraction gratings, leading to several diffraction orders from each beam. The alignment can be completed in two steps, by observation of only two specific diffraction orders corresponding to different incident beams.

During the first step the period and direction of fringes are defined. When the period and direction of fringes correspond to those of the grating, some diffraction orders of different incident beams coincide. The coincidence of two beams can be verified by observation of their far field interference pattern.

The second step is fitting of the relative shift. It can be done by measurement of the total intensity of the two diffraction orders, chosen for step one. The intensity varies periodically with shift[5].

RESULTS

Multi layer photonic crystals were constructed from AsSe (see Figure 2) and AsSeTe (see Figure 3) glasses. The third and the fourth layers of the 4-layer AsSeTe sample were successfully aligned. Shipley photoresist (planarization step) was washed out leaving dielectric/air crystals.
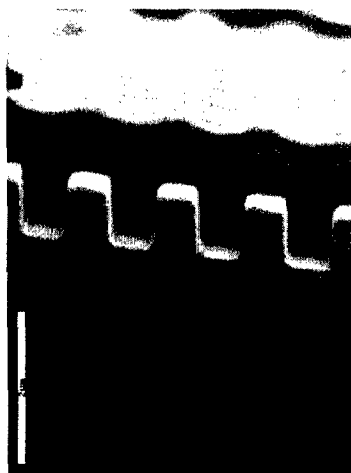

Figure 2: Two layers of woodpile photonic crystal made from AsSe chalcogenide glass and air. The period of the gratings is 1 μm.
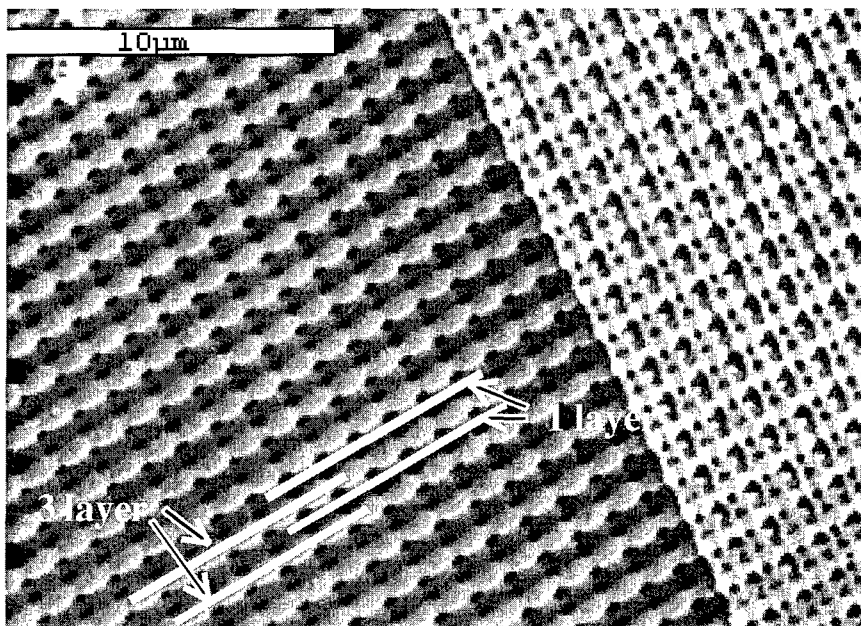
Figure 3: The 4 layer woodpile structure made from AsSeTe chalcogenide glass. The different layers are aligned with half period shift between the 1st and the 3rd layers.

DISCUSSION

The binary gratings can be obtained by interference lithography from chalcogenide glasses. There is threshold doze of illumination that converts chalcogenide glass to the insoluble state. This high sensitivity also leads to some structure fluctuations of the third and the fourth layers. The minute structure of the fourth layer can be clearly observed in Figure 3. These fluctuations are periodic due to the scattering of the incident laser beams on the previous layers. Therefore they do not contribute to the scattering losses, but definitely can change the optical properties of the crystal.

It is difficult to obtain gratings with feature size much less than half of a period. The sinusoidal laser illumination leads to more or less symmetrical patterns. However the numerical analysis of woodpile structure shows that even for 50% of the period feature size the full 3D gap can still be obtained (see Figure 4).
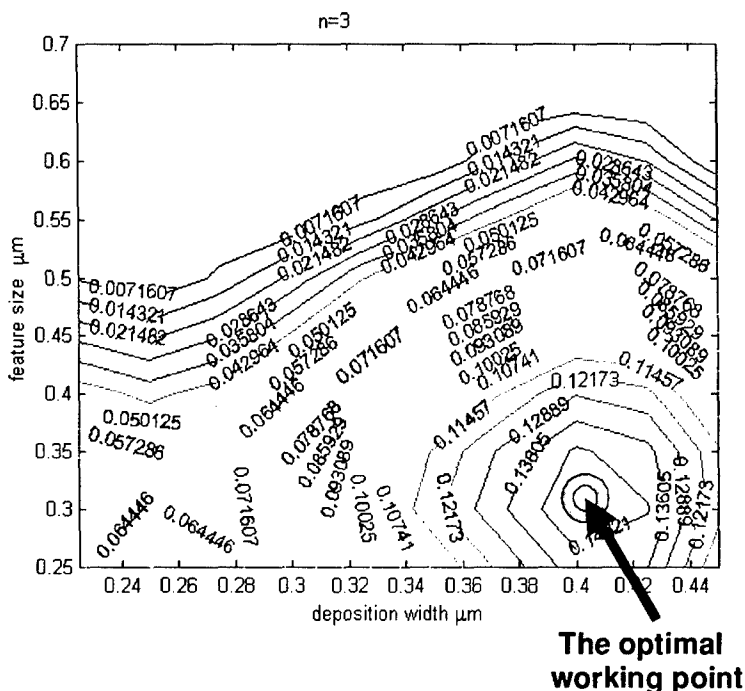
n=3

The optimal working point

Figure 4: The gap to mid gap frequency ratio map vs. deposition width of single layer and feature size of the grating.

CONCLUSION

3D woodpile photonic crystals with 1 μm period were constructed from AsSe and AsSeTe chalcogenide glasses. The use of the interference lithography significantly simplifies the process of the fabrication. The required method of fringes alignment to some reference grating was developed.

1.   S.Y. Lin, J.G. Fleming, D.L. Hetherington, B.K. Smith, R. Biswas, K.M. Ho, M.M. Sigalas, W. Zubrzycki, S.R. Kurtz and J. Blur, Nature, 394, 251, 1998
2.   S. Noda, K. Tomoda, N. Yamamoto and A. Chutinan, Science, 289, 604, 2000
3.   A. Feigel, Z. Kotler, B. Sfez, A. Arsh, M. Klebanov and V. Lyubin, Appl. Phys. Lett., 77, 3221, 2000
4.   A. Feigel, Z. Kotler and B. Sfez, submitted for publication
5.   N. Yamamoto and S. Noda, Jpn. J. Appl. Phys, 37, 3334, 1998