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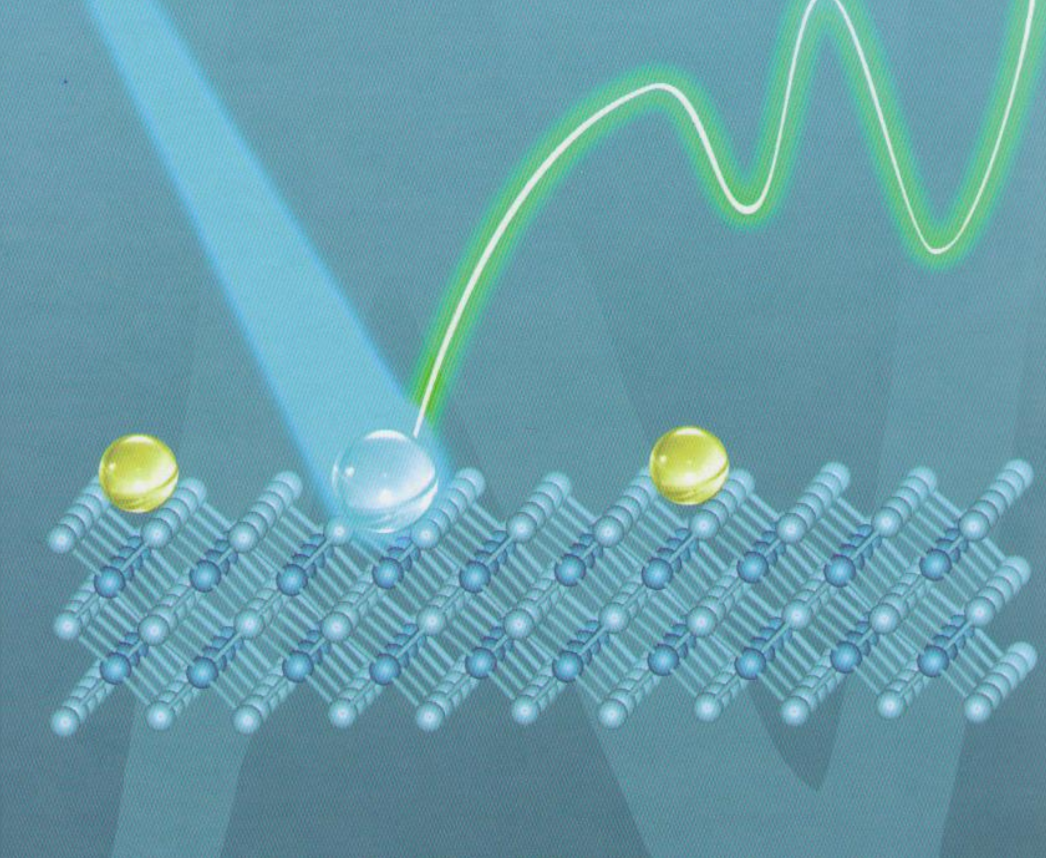

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NANOSTRUCTURING OF DIAMOND AND OPTICAL DIFFRACTION GRID FORMATION BY BORON ION IMPLANTATION

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The present study relates to a new fabrication method of diffractive optical elements with diamond nanostructuring. The diffraction grating was obtained on diamond by implantation of boron ions through a mask. Formation of periodic diffraction microstructures on the diamond surface was monitored by optical, electron and atomic force microscopy techniques.

1. Introduction

Modern tasks of integrated optics require the use of special new materials and the development of novel technologies for production of components and devices based on them. One of the specific areas is diamond optics. The interest to diamond is explained by its radiation resistance and high thermal conductivity. Diamond optical elements possess a wide transparency window from 0.2 to 5 μm. Diamond is stable up to very high temperature and in aggressive environments. In practice, diamond is used for production of various diffractive optical elements (DOE) as gratings, focusers, equalizers, *etc.* Diamond DOE can be applied for the high-power beam of a CO_2-laser up to 20 kW/cm^2 power density [1,2] to create photonic crystal resonators, quantum information storage devices [1] and to control the radiation fluxes in X-ray optics, for example, using a diamond Bragg mirror with a reflectivity of 100 % [3]. For fabrication of periodic DOE on the diamond surface various technological methods were used, such as manufacturing with powerful pulses of excimer laser, etching in a gas stream of transport gas.

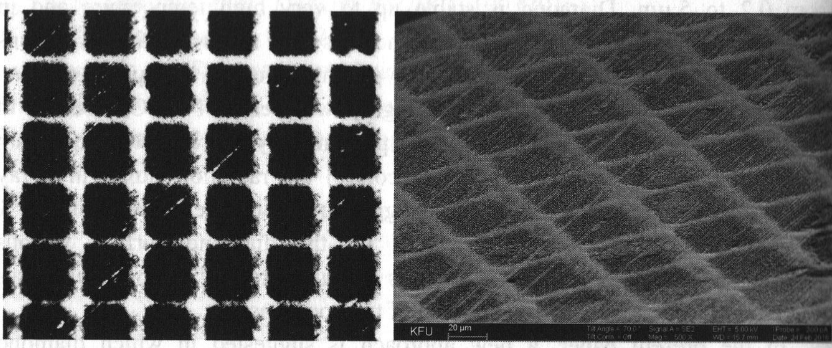
In the present paper, a new approach is suggested in which diamond periodic diffractive structures are formed by ion implantation through the mask surface. Previously, this technology was successfully tested for the DOE production on silica glass by implantation of noble metals [5]. The objective of this study is to analyze a possibility to fabricate DOE on diamond surface by boron ions implantation.

2. Experimental

Formation of a DOE on the diamond polished surface was done by B^+-ion implantation with energy of 40 keV, dose of 1.3×10^{18} ion/cm^2 and current density of 15 μA/cm^2 using an ion accelerator ILU-3 through the metal mask with the grid square cells of 40 μm. Local morphology and surface structure of the implanted diamond was analyzed by scanning electron microscopy (SEM, Merlin, Carl Zeiss), equipped with a detector of electron backscatter diffraction HKL NordLys (Oxford Instruments), and atomic force microscopy (AFM, FastScan, Brucker). Optical characterization of the fabricated DOE was performed by an optical microscope Polar-1 (Micromed) and Raman spectroscopy. Analysis of optical diffraction patterns from the DOE was carried out with a He-Ne laser at the wavelength of 632.8 nm. Modelling of concentration profiles of implanted boron in diamond by the SRIM-2013 algorithm showed that boron atoms were accumulated in the 100 nm thick surface layer of diamond.

3. Results and discussion

Fig. 1 shows the grid image formed on the diamond surface by B^+ implantation through the mask observed in optical microscope (Fig. 1a) and SEM (Fig. 1b). The periodic microstructure is composed of alternating dark square cells belonging to the implanted areas of the sample surface separated by walls (open area) of unimplanted diamond.



a b

Figure 1. Images of the diamond surface implanted with boron ions through the mask observed by optical microscopy (a) and SEM (b).

Structural characterization of the implanted area of diamond was carried out by electron backscatter diffraction probing the near-surface region of the sample. Unlike the Kikuchi diffraction in the form of strips parallel to the planes of the diamond crystal lattice for implanted areas, in our diffraction pattern only broad diffuse rings were observed. This is indicating on some destruction of the crystal lattice in the implanted diamond surface and formation of amorphous carbon nanostructures.

The AFM image of the diamond fragment DOE near the wall (dark area in Fig. 1a) between the implanted cells (light rough area in Fig. 1a) evidences that the implanted diamond surface (cells) are raised above the original surface by ~100 nm. This effect is attributed to swelling of irradiated regions (grids) of the sample characterized by the lower density (graphite = 2.09–2.23 g/cm^3) as compared with the density of diamond, 3.47–3.55 g/cm^3.

Raman spectra of the implanted samples under excitation with an argon laser at 522 nm confirms the destruction of diamond. Together with a well-known diamond intense line at 1336 cm^{-1} after the ion implantation weaker lines in the region near 1560 cm^{-1} appeared indicating the graphitization process. As a result of B^+-ion implantation of diamond a formation of boron carbide could be expected. However, boron carbide lines in the Raman spectrum in the range of 200–1200 cm^{-1} [5] were not detected. Meanwhile, some chemical bonds or small fragments consisting of boron and carbon atoms not recognized by Raman spectroscopy, may be present in the graphitized diamond implanted with boron ions [6].

It should be noticed, that diamond implanted with boron ions leads to both changes in chemical composition (accumulation of boron) and to modification of carbon substrate nanostructure, *i.e.* the formation of periodic domain with graphitic matter. The implantation through a mask has resulted in specific periodic microstructures with periodically variable distribution of optical properties in the surface layer, *i.e.*, between the walls of the diamond lattice with the refractive index $n = 2.42$ and graphitized cells, $n_{grafit} = 2.1–2.23$. Therefore, the periodic microstructure formed with the graphitized areas on diamond can be used as a two-dimensional photonic crystal, or DOE. As an illustration, Fig. 2 shows the diffraction image that was initiated by optical reflection from the diamond grid using a He-Ne laser at 632.8 nm. Manipulating with the ion implantation regimes, thereby changing the effective refractive index of individual areas in the DOE, one can control its optical and diffractive characteristics.

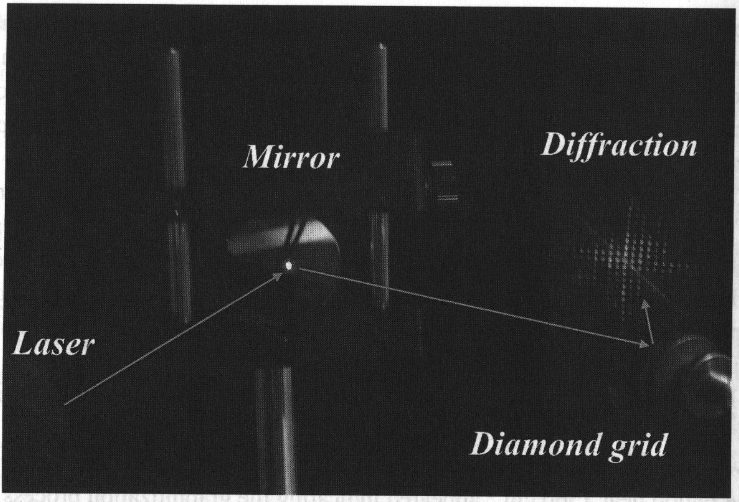


Figure 2. Image of reflected diffraction pattern on the screen from the diamond grid by probing with a He-Ne laser. A diamond sample is fixed to the metal holder.

4. Conclusion

We consider the process of low-energy high-dose implantation of diamond with boron ions through the surface mask and demonstrated successive realization of the new approach for creation of DOE. On the diamond surface periodic microstructures were fabricated and the phase contrast was provided by the graphitized diamond areas.

Acknowledgments

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