Employment of Focused MeV Ion Microbeams for the Fabrication of Buried Graphitic Channels in Diamond

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INTRODUCTION

We report about the development of a novel method for the fabrication of three-dimensional buried graphitic micropaths in single crystal diamond with the employment of focused MeV ions [1]. The use of implantation masks with graded thickness at the sub-micrometer scale allows the formation of conductive channels which are embedded at controllable depths in the insulating matrix. In particular, the modulation of the channels depth at their endpoints allows the surface contacting of the channel terminations with no need of further fabrication stages.

ION IMPLANTATION IN DIAMOND

The process of damage induced by energetic ions in matter occurs mainly at the end of ion range, where the cross section for nuclear collisions is strongly enhanced, after the ion energy is progressively reduced by electronic collisions occurring in the initial stages of the ion path [2]. In particular, the permanent conversion of ion-implanted diamond to a graphite like phase upon thermal annealing occurs when a critical damage density (usually referred as "graphitization threshold") is reached [3]. The damage density profile of 1.8 MeV He^+ ions in single crystal diamond for a typical implantation fluence of 1×10^{17} cm^{-2} is reported in figure 1.

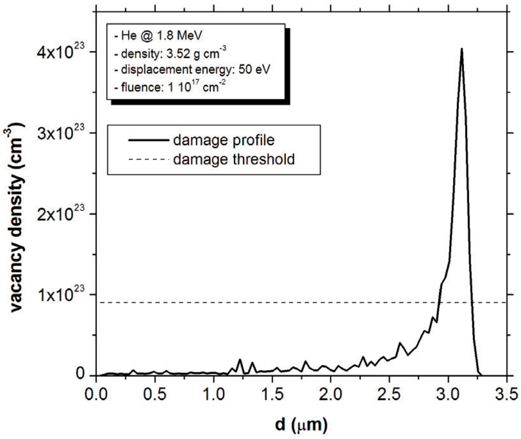

FIG. 1. *TRIM Monte Carlo simulations of the damage density profile induced in diamond by 1.8 MeV He^+ at a fluence of 1×10^{17} cm^{-2} (solid line), together with the graphitization threshold (dashed line).*

VARIABLE-THICKNESS SAMPLE MASKING

In order to connect the endpoints of the channels to the sample surface, a three dimensional masking technique was developed to modulate the penetration depth of the ions from their range in the unmasked material up to the sample surface with increasing thickness of stopping material. The basic concept is shown schematically in figure 2.

In figure 2, the sample is represented in cross section view (two schematics in the first line) and from the top view (second line). The effect of ion implantation is depicted before (left column) and after (right column) the linear scanning of an ion microbeam. The ion microbeam hitting the sample perpendicularly to the top surface is represented as the vertical line in the top-left schematic, while the variable thickness mask is represented above the sample, both in the cross-sectional and top view. After the ion implantation (right column), the formation of a damaged layer at a variable depth in the material is represented by the dark line.

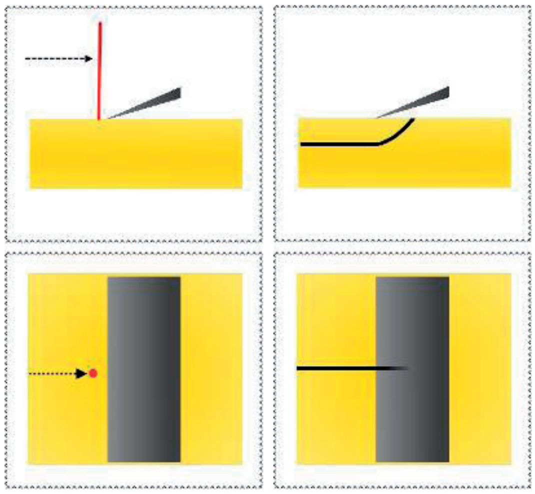

FIG. 2. *Schematics of the three-dimensional masking technique adopted to control the penetration depth of implanted ions.*

ION IMPLANTATION

After masking, the samples were implanted at the ion microbeam line of the AN2000 accelerator of the Legnaro National Laboratories with 1.8 MeV He^+ ions focused down to a micrometer-sized beamspot. The ion microbeam was raster-scanned over the area of interest, in order to achieve a uniform fluence delivery. Different test channels were implanted at fluences comprised between 2×10^{16} cm^{-2} and 6×10^{17}cm^{-2}. The ion current was of the order of 10-300 pA, ensuring implantation times of the order of 5-30 min.

ELECTRICAL CHARACTERIZATION

The electrical conduction properties of the buried channels were measured with a 4145B Semiconductor Parameter Analyzer by Hewlett Packard; two tip probes were employed in voltage source mode. As expected, only the endpoints of the channels are electrically connected with the electrodes at the sample surface, while they are buried in the insulating diamond matrix.

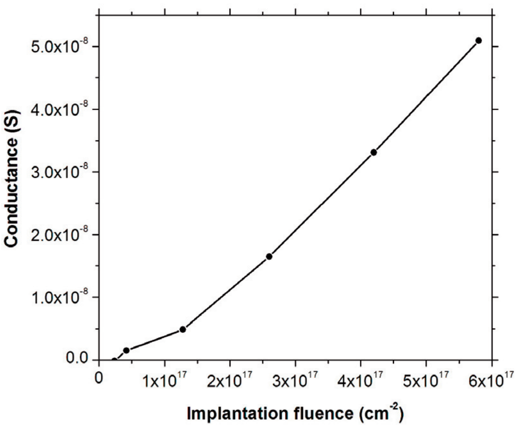

FIG. 3. *Conductance of channels implanted at increasing ion fluences.*

The conductivity of the channels areas displays a clear dependence from the implantation fluence. It was demonstrated in following works [1] that thermal annealing causes the complete graphitization of channels implanted above a critical threshold level, whose conductivity dramatically increases to values similar to that of amorphous graphite. On the other hand, thermal annealing has the effect of restoring the pristine diamond structure in channels damaged at low levels.

CONCLUSIONS

We demonstrated the monolithical fabrication and electrical characterization of buried graphitic channels in diamond with MeV ion implantation through three-dimensional masks. The electrical characterization of the channels strongly indicates that the ohmic conduction occurs in deep channels which are disconnected from the sample surface, with the exception of their endpoints, which are in electrical contact with surface metal electrodes. This innovative fabrication technique can be effectively employed for the direct fabrication of electrodes in three-dimensional diamond-based particle detectors.

ACKNOWLEDGMENTS

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