Diamond & Related Materials 18 (2009) 870–876

Contents lists available at ScienceDirect

Diamond & Related Materials

journal homepage: www.elsevier.com/locate/diamond

Direct fabrication of three-dimensional buried conductive channels in single crystal diamond with ion microbeam induced graphitization

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ARTICLE INFO

Available online 13 November 2008

Keywords:
Diamond crystal
Implantation
Electrical conductivity
Ohmic contacts

ABSTRACT

We report on a novel method for the fabrication of three-dimensional buried graphitic micropaths in single crystal diamond with the employment of focused MeV ions. The use of implantation masks with graded thickness at the sub-micrometer scale allows the formation of conductive channels which are embedded in the insulating matrix at controllable depths. 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.

In the present work we describe the sample masking, which includes the deposition of semi-spherical gold contacts on the sample surface, followed by MeV ion implantation. Because of the significant difference between the densities of pristine and amorphous or graphitized diamond, the formation of buried channels has a relevant mechanical effect on the diamond structure, causing localized surface swelling, which has been measured both with interferometric profilometry and atomic force microscopy. The electrical properties of the buried channels are then measured with a two point probe station: clear evidence is given that only the terminal points of the channels are electrically connected with the surface, while the rest of the channels extends below the surface. IV measurements are employed also to qualitatively investigate the electrical properties of the channels as a function of implantation fluence and annealing.

1. Introduction

The process of graphitization induced in diamond by ion implantation was first investigated by Vavilov et al. in the 70s [1]. This pioneering work triggered a series of studies on the effects of ion induced damage on the electrical transport properties of diamond. Hauser et al. demonstrated that the electrical properties of ion-implanted diamond layers were similar to those of amorphous carbon produced by sputtering graphite [2,3]. The hopping conduction in diamond implanted with carbon ions at different energies and fluences was investigated by Prins [4,5], who interpreted the onset for this process with mechanisms of vacancy–interstitial interaction, focusing on the different mobility of vacancy and interstitial defects in the crystal. In a series of Ar and C implantation experiments carried at different temperatures, Sato et al. demonstrated that target temperature during implantation has a strong influence on the ion damage processes that determine the increase in conductivity, as confirmed by Raman characterization [6,7]. The effect of C and Xe ion induced graphitization in polycrystalline samples grown by chemical vapor deposition was studied by S. Prawer et al., demonstrating that the fluence dependence of the electrical conductivity of the implanted area is similar to what measured in single crystal diamond [8]. Selective Co ion implantation on self-supporting diamond films was employed by B. Miller et al. to pattern conductive areas on which subsequent redox electron transfer and metal deposition were demonstrated [9]. S. Prawer et al. performed IV measurements *in-situ* during C and Xe implantation at different temperatures, showing complex non-monotonic dependencies of the electrical conductivity from the ion fluence. These trends confirm that the critical fluence at which a sharp decrease in conductivity (due to the formation of a continuous conducting pathway) is observed strongly depends from the implantation temperature [10,11]. B implantation studies carried by F. Fontaine et al. on polycrystalline diamond [12] confirmed the basic interpretation of the process, while introducing two different critical fluences. In their interpretation, when a "percolative threshold" fluence is reached, a continuous conductive path of sp^3-like defects is established in the implanted material and variable range

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doi:10.1016/j.diamond.2008.10.068