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Structural characterization of 8 MeV ^{11}B implanted diamond

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ABSTRACT

Boron is the most effective dopant element in diamond and the capability to introduce high densities of boron makes ion implantation a potential key technology to verify superconductivity in diamond. However, its optimization involves many experimental parameters (i.e. ion energy, fluence, current, annealing times and temperature) and the effectiveness of B implantation to induce superconductivity in diamond is still to be demonstrated. So far, a limited number of works in the range of high (i.e. > 5 MeV) B ion energies have been carried, despite the promising perspective offered by deep implantation to fabricate sub-superficial superconductive structures in diamond. To this scope, in the present work, we report on the study of the structural effects of high-energy boron ion irradiation on diamond. Monocrystalline diamond sample was irradiated with an 8 MeV ^{11}B microbeam across multiple square areas, characterized by a different combination of fluences and ion currents. After the implantation, the sample was characterized by Raman spectroscopy and Atomic Force Microscopy to assess its structural modifications and the related surface swelling. Significant variations related to the irradiation condition have been determined.

1. Introduction

Diamond doping at very high concentrations represents a challenging process, in particular because of the high diffusion, but it opens to technologically appealing applications such as the fabrication of semiconducting and superconducting devices in an extreme material operating at high temperatures. In particular, Moussa and Cohen [1] theoretically predicted that heavily boron doped diamond without electronically compensating defects (i.e. boron concentrations of 20% - 30%) should display a superconducting behavior with a critical temperature above 80 K, but up to now optimal crystal synthesis conditions were not achieved yet. Alternative strategies are under study for the incorporation of substitutional boron atoms at very high concentrations within the diamond lattice, thus overcoming the limits of chemical vapor deposition growth. MeV ion beam implantation has proven to represent a promising route, allowing the creation of semiconducting sub-superficial highly-B-doped layers [2–4]. The observation of the superconducting charge transport mechanisms in strongly-B-doped diamond via ion implantation requires specific strategies to minimize collateral structural damage effects which are critically detrimental. These collateral effects occur in correspondence of the depth at which the ions are implanted at the highest concentration, i.e. the end-of-range damage peak. In the specific case of B doping in diamond, these collateral defects dramatically affect the electrical conduction properties of the material, thus limiting the predicted increase of the superconducting transition temperature, since vacancies or interstitial boron atoms act as compensating defects [4,5].

Moreover, the progressive defect accumulation in diamond promotes a phase transition of the damaged area to graphite after high temperature annealing when a critical vacancy density (usually referred as graphitization threshold, generally ranging within 2– 6 × 10^{22} vacancies cm^{-3} [6–9]) is reached. On the other hand, regions implanted below this critical value restore to a large extent the pristine diamond structure since a large fraction of the Frenkel pair defects recombine upon thermal treatment [10]. In this context, if suitably assessed, MeV ion irradiation would offer appealing perspectives with respect to the more readily available and widely employed ion irradiation processing carried in the keV energy range [2,11,12]. Firstly, the possibility of creating deep sub-superficial structures offered by the use of high-energy ions would allow a higher degree of integration in the engineering of embedded superconductive structures in a 3D geometry, with potential impact in specific applications such as for example the design of SQUID (superconducting quantum interference devices) devices integrated with MEMS (microelectromechanical systems) structures [13].

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