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Formation of buried conductive micro-channels in single crystal diamond with MeV C and He implantation

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ABSTRACT

As demonstrated in previous works, implantation with a MeV ion microbeam through masks with graded thickness allows the formation of conductive micro-channels in diamond which are embedded in the insulating matrix at controllable depths [P. Olivero et al., Diamond Relat. Mater. 18 (5–8), 870–876 (2009)]. In the present work we report about the systematic electrical characterization of such micro-channels as a function of several implantation conditions, namely: ion species and energy, implantation fluence. The current–voltage (*IV*) characteristics of the buried channels were measured at room temperature with a two point probe station. Significant parameters such as the sheet resistance and the characteristic exponent (α) of the *IV* power-law trend were expressed as a function of damage density, with satisfactory compatibility between the results obtained in different implantation conditions.

1. Introduction

Since the pioneering works by Vavilov and Hauser in the 1970s [1,2], the modification of the electrical transport properties of diamond when subjected to ion damage has been widely investigated. After the early demonstrations that the electrical properties of ion-implanted diamond layers were similar to those of amorphous carbon [3], the hopping conduction mechanisms in C-implanted samples were studied by Prins [4,5]. The influence of target temperature during Ar and C implantation was investigated by Sato et al. [6,7], while the first studies on polycrystalline samples grown by chemical vapor deposition were conducted by Prawer et al. [8]. The effect of ion fluence was systematically studied in samples implanted with C/Xe and B in a series of works by Prawer et al. [9,10] and Fontaine et al. [11], respectively. An extensive current–voltage (*IV*) characterization in temperature of Xe-implanted diamond was carried by Reznik et al. [12,13], allowing the extraction of a number of characteristic energies for hopping conduction sites [14].

A widely accepted interpretation of the modification of the electrical properties of damaged diamond is based on the existence of two damage regimes. When the damage density is below a critical threshold (often referred as "graphitization threshold" or "amorphization threshold"), the conduction mechanism can be described with the variable range hopping within a sparse network of defective sp^3 and sp^2 sites, while at higher damage densities a continuous network of sp^2-bonded defects is formed, which leads to the permanent graphitization of the structure upon thermal annealing and to the subsequent appearance of metallic conductivity.

It is worth stressing that all of the above-mentioned works were performed by damaging the samples in superficial regions with heavy ions at energies in the 10^1–10^2 keV range. Remarkably, the possibility of fabricating sub-superficial channels with damage-related conductivity induced by MeV ions has been explored in a limited number of works, both in the sub-graphitization [15] and in the graphitization [16] regimes. Recently, we demonstrated that it is possible to create buried conducting micro-channels in diamond with MeV ion implantation through variable-thickness masks, allowing the emergence of the channels at their endpoints, thus in electrical contact with the sample surface electrodes [17]. Moreover, in a recent work such structures were characterized with *IV* measurements in temperature, allowing the elucidation of variable-range-hopping conduction mechanisms in as-implanted samples [18].

In the present work, we report about the systematic *IV* characterization at room temperature of buried micro-channels as a function of several implantation conditions: ion species and energy (6 MeV C, 1.8 MeV He), and implantation fluence ($3\cdot10^{15}$–$4\cdot10^{16}$ cm^{-2} and $3\cdot10^{16}$–$6\cdot10^{17}$ cm^{-2}, respectively).

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