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Surface Modification of Polycrystalline Diamond Compacts by Carbon Ion Irradiation

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Abstract

Selective modification (e.g. defect creation and amorphization) of diamond surfaces is of interests for functional diamond-based semiconductors and devices. Bombarding the diamond surface with high energy radiation sources such as electron, proton, and neutrons, however, often result in detrimental defects in deep bulk regions under the diamond surface. In this study, we utilized high energy carbon ions of 3 MeV to bombard the polycrystalline diamond compact (PDC) specimen. The resultant microstructure of PDCs was investigated using micro Raman spectroscopy. The results show that the carbon bombardment successfully created point defects and amorphization in a shallow region of ~500 nm deep on the diamond surface. The new method has great potential to allow diamond-based semiconductor devices to be used in numerous applications.

Keywords: Selective modification, diamond-based semiconductors, polycrystalline diamond compact, Ion Irradiation

1 Introduction

Diamond is the hardest known material with a high atomic density and strong inter atomic bonds (covalent bond) between carbon atoms. It has excellent mechanical, optical and thermal properties for applications in machining tools, plastic processing tools, and anti-abrasion element etc. (Tanabe, 2007). Small concentration of point defects can drastically modify the properties of diamond such as optical and electrical for various applications (Field 1992, Crawford 1975, Gupta 2010, Campbell 2000).

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Residual defects in diamonds cause charge carrier trapping and compensation which degrades the electrical properties of diamond based electronic devices such as radiation detectors (Prawer 2004). The creation of photoluminescence centers such as the vacancy sites in diamond has promising applications in the development of optical solid state quantum devices (Ager 1994, Collins 1982, Martin 1999, Martin 1999, Sonnefraud 2008, Waldermann 2007, Wang 2005).

Irradiation of a substance by energetic particles can create lattice defects, such as interstitial and vacancy defects. Vacancies may also aggregate leading to larger dislocations (Field 1992, Seo, 2011). High energy particles such as electrons, neutrons, and protons are often used for irradiation treatment of materials (Campbell 2000, Newton 2002, Campbell 2002, Grilj 2013, Lohstroh 2008, Lohstroh 2010). However, these high energy radiations often result in defects in the deep bulk region as the projection range of these particles is quite high (Campbell 2000, Grilj 2013, Lohstroh 2008, Lohstroh 2010). The deep defects can be detrimental to the functioning of semiconductor based electronic devices (Campbell 2000, Ager 1994, Campbell 2002, Jamieson 1993, Prawer 1995).

In this paper we report a new method to create point defects in polycrystalline diamond compact (PDCs) using carbon ion bombardment. The host carbon atom at the lattice site is displaced when it attains an energy known as displacement energy E_d upon collision with carbon ion or by other carbon atoms. Sufficient energy has to be transferred to the carbon atom so that it does not recombine immediately, i.e. enough energy for it to move away from its original lattice site. E_d has been shown to be in a wide range from 25 – 80 eV (Campbell 2002), which corresponds to a striking particle energy, in the range 165 - 197 KeV (Campbell 2002). Most of the lattice damage is created not by the bombarded particles but by the impact of primary knock out atoms (Campbell 2000, Campbell 2002, Prawer 1995). The large carbon ions allow a low projected range so that defects are only created in and near a shallow surface region on diamond. Surface amorphization modifies the surface electrical properties of the diamond to be utilized as electrical interconnects. The vacancy and interstitial atoms on diamond surfaces stays immobile (Campbell 2002, Grilj 2013) until subjected to a temperature greater than 550 ºC. A selective irradiation of surfaces can lead to significant applications of diamond semiconductors for temperature below 550 ºC.

2 Experimental

2.1 Irradiation of PDC specimens

Polycrystalline diamond compact (PDC) samples (~8 mm in diameter and 5 mm in thickness) were irradiated at the Characterization Lab for Irradiated Materials (CLIM) using a National Electrostatics Corporation (NEC) 1.7 MV Pelletron accelerator at University of Wisconsin-Madison. The schematic of the equipment is shown in Figure 1 (Field 2013). The PDC sample pairs, as shown in Figure 2, were cemented onto stainless steel sample holders using a water-soluble silver paste from Ted Pella. The irradiation chamber was vacuumed to a pressure of $\sim 1 \times 10^{-6}$ Torr before and during the irradiation, with samples exchanged between each irradiation cycle. Negative carbon ions were produced via Cesium sputtering (SNICS) of graphite target and converted to positive ions using a nitrogen stripping gas. These C^{2+} ions were accelerated to a total energy of 3.0 MeV, and steered onto the samples. The incident ion beam, normal to the sample face, was rastered across a well-defined aperture with area of 1.874 cm^2 exposing the samples uniformly to the C^{2+} ions. The beam current ranged from 2 - 4 µA for an ion flux of 6.7×10^{12} to 1.4×10^{13} ion/cm^2s, based on the aperture size. The sample temperature was recorded on the right and left sides of the sample holder using two type-K thermocouples. Cool air spray was used to maintain the sample temperature during the irradiation process.

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