Characterisation of Graphitic Layers in FIB Implanted Diamond Fabricated Using Vacuum and High Presure Annealing

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Ion implantation is an engineering tool which is commonly used for doping semiconductor devices. Recently ion implantation has been successfully employed for fabrication of ultra-thin diamond films and in combination with Ga focused ion beam (FIB) milling for fabrication of device structures in diamond at submicron level [1-2]. In addition, FIB technique could be also used as ion implantation tool in diamond for fabrication of buried amorphous layers and cap diamond layers with thickness of few nanometers [3]. The graphitisation of amorphous layers in diamond is attracting significant interest due to ability to fabricate device structures containing two structural forms of carbon: diamond and graphite. Vacuum pressure high temperature (VPHP) annealing of implanted layers in (001) diamond results in formation of nanocrystalline graphitic phase with predominant orientation of c-planes normal to the diamond surface [4]. Also, it has been shown recently that annealing of implanted (111) diamond at high pressure high temperature (HPHT) results in formation of highly ordered graphite [5].

We have performed 30 keV Ga^+ FIB implantation with fluence of 4×10^{15} ions/cm^2 into both (001) and (111) oriented synthetic diamond samples and have examined the structure of the implanted regions following the implantation and VPHT and HPHT (4 GPa, 1200 ^{o}C) annealing using TEM. The cross-sectional TEM image of as-implanted sample (Fig. 1) shows that the implanted region is amorphous due to large defect density exceeding the amorphisation threshold. The swelling of the amorphous damage layer is evident (Fig 1a). EELS study has showed the presence of both sp^2 and sp^3 bonding in the implanted region. The swelling has been attributed to diamond's sp^3 bonds conversion to sp^2 bonds with significant decrease in density. The positive step height between unimplanted and implanted regions could be a result of Poisson ratio effect which arises from the biaxial compressive stress in the plane of the implanted layer [6].

Cross-sectional images of implanted regions in (001) and (111) diamond samples after VPHT annealing are shown in Fig. 2. Graphite particles are visible in implanted layers with c-planes predominantly oriented perpendicular to the surface. This correlates with thermodynamic calculations which predict that a biaxial compressive stress will orient the graphitic particles with their c axis perpendicular to the stress field [6]. In contrast to VPHT treatment, implanted layers in diamond after HPHT annealing became graphitic with high degree of crystallinity, which is visible in Fig. 3. High pressure during HPHT results in change of stress field in implanted region and introduction of third compressive stress component normal to the diamond surface. Apparently the stress tensor in implanted regions should be the same for both orientations of the diamond samples. The graphite c-planes in these samples have different orientation against stress field. However, for both sample orientations c-planes are predominantly