Fabrication of Pure Amorphous Diamond by Ion Implantation and Thermal Annealing

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Carbon allotropes have diverse properties depending on internal structure and bonding. Graphite and diamond are two main carbon allotropes with sp^2 and sp^3 hybridized bonds, respectively. The amorphous carbon has both sp^2 and sp^3 bonds and its properties are determined by sp^2/sp^3 ratio. The amorphous carbon with high sp^3 fraction (up to 88%) is known as diamond-like carbon and has outstanding mechanical properties. However, until recently [1] the observation of purely sp^3 tetrahedral amorphous carbon has not to be reported. Commonly used ion beam induced amorphisation in diamond results in formation of disordered carbon regions with variable sp^2/sp^3 ratios through transition of some broken sp^3 bonds into more stable sp^2 bonds with corresponding density reduction [2-5]. Depending on the annealing conditions the disordered carbon can be converted into polycrystalline (vacuum pressure annealing) [4, 6-7] or highly oriented graphite (high pressure annealing) [8]. In this study a new method of fabrication of pure amorphous diamond (100% of sp^3 bonds) through ion implantation and thermal annealing has been demonstrated.

The channels of disordered carbons were fabricated into single crystal diamond at depth around 1.8 m by 1 MeV He^+ ion implantation through thick metal mask with apertures. The width of apertures was in range 25 - 200 nm. The implantation fluence was 2×10^{17} ions/cm^2. Samples were annealed in vacuum at 950 ^oC for 2 hours. Small implantation volume and rigid properties of diamond lattice allows to supress swelling effect in disordered carbon channels. The implanted regions were studied after ion implantation and after thermal annealing using conventional and analytical electron microscopy.

The absence of diffraction contrast in TEM images of implanted channel as well as diffraction pattern (Fig. 1) confirms its amorphous structure. The carbon K-edge EELS spectra (Fig. 2a) show the prominent peak at 285 eV (π^* peak) indicating the presence of sp^2 bonded carbon in implanted channel after ion implantation. Thus, despite the suppression of swelling in disordered channels and large internal strain there is transition of some sp^3 to sp^2 bonds during amorphisation of diamond. TEM study of implanted diamond after thermal annealing showed no change in structure of channels - they remained amorphous in structure without any traces of graphitisation. However, EELS study of carbon K-edge revealed the absence of peak at 285 eV (Fig. 2b). The disappearance of π^* peak indicates the complete conversion to σ bonds and the formation of amorphous 100 % sp^3 bonded carbon or pure amorphous diamond.

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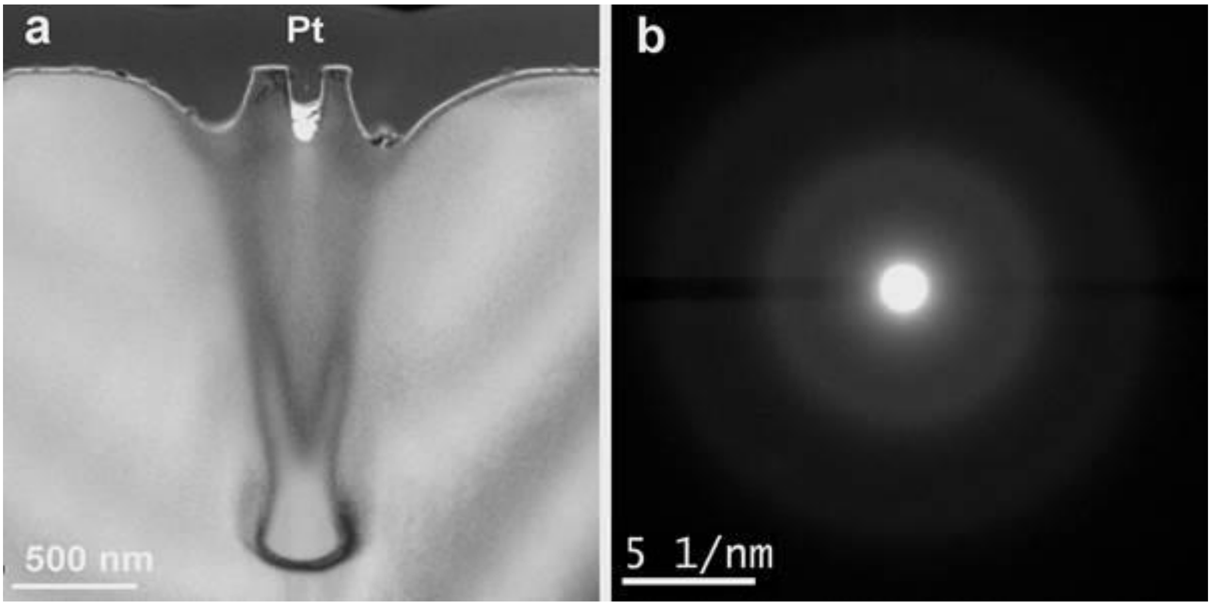

Fig.1. a) Bright field cross-sectional TEM image and b) corresponding diffraction pattern of disordered carbon channel in diamond after 1 MeV He^+ implantation.

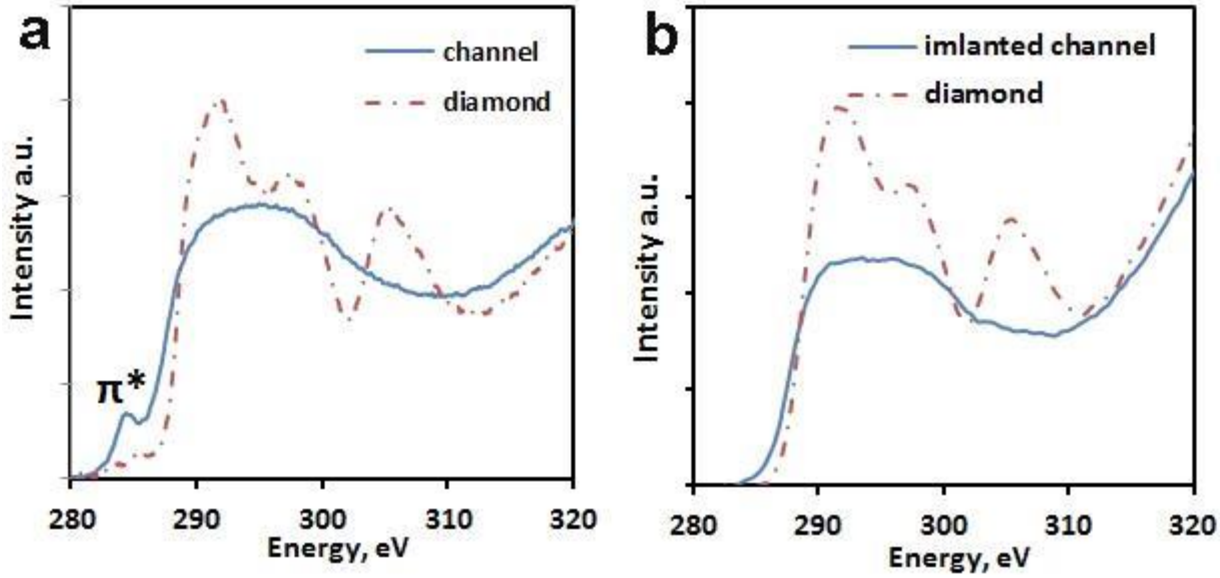

Fig.2. EELS spectrum of carbon K-edge in implanted channels and bulk diamond after a) ion implantation and b) thermal annealing.