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IT-13-P-2936 Characterisation of the FIB Induced Damage in Diamond

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Despite diamond's extreme properties a TEM sample from diamond can be relatively easy prepared using FIB milling [1]. However, FIB milling results in formation of amorphous damage layers [2-3]. In addition, the rearrangement of broken diamond sp^3 bonds into graphitic sp^2 bonds is possible.

To study the initial stages of the damage formation (001) diamond sample was irradiated with 30 keV Ga ions with doses ranging from 2×10^{14} to 10^{16} ions/cm^2. Continuous milling effect has been studied using rectangular trenches 4×4 μm^2 and 2 μm deep formed using 100 pA beam current. The near surface regions of the trenches contained two types of damage: the bottom-wall, where the ion beam was normal to the surface and the side-wall, where it was at low angle to the trench walls.

For the dose 2×10^{14} ions/cm^2 the point defect density was below amorphisation threshold and implanted region remains crystalline. For the dose 4×10^{14} ions/cm^2 and above most of implanted region had defect density above amorphisation threshold and became amorphous (Fig. 1). The bottom part of the implanted layer remains crystalline but distorted due to still large number of point defects (Fig. 1b). EELS examination showed the presence of both sp^2 and sp^3 bonding in the damage corresponding to two different chemical states of carbon. The swelling of the amorphous damage layer shown in Fig. 1a is related to diamond's sp^3 bonds conversion to sp2 bonds with significant decrease in density. Using a mass balance calculation the density of the amorphous layers was determined. The density decreased with ion dose increased, and reached density of graphite (2.24 g/cm^3, 80% sp^2) for highest dose. For continues milling the thicknesses of the amorphous damage layers were measured to be 16 nm for side-walls and 44 nm for the bottom-walls (Fig. 2a). Concentration of Ga atoms was found to be 20 and 32 at.% for side-wall and bottom-wall damage layers. The thickness of the initial amorphous damage layers exponentially grows with ion dose (Fig. 2b) and has a tendency to saturate at the value which was measured for continuous milling.

The FIB induced damage in diamond comprises amorphous and crystalline components and is a result of complex process of ion penetration, swelling and sputtering. Amorphisation in diamond results in transition of sp^3 bonds to sp^2 corresponding to two different chemical states of carbon with accompanying density reduction. High concentration of Ga atoms is a result of accumulation of implanted atoms in damage layers due to short penetration depth and low sputtering yield in diamond.

References

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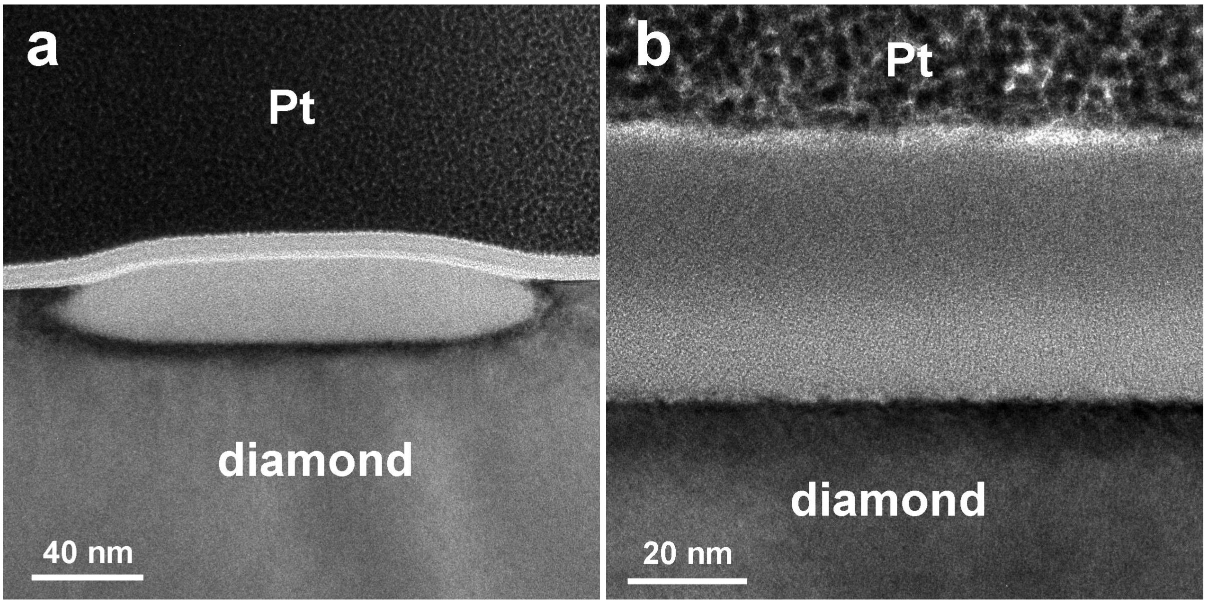

Fig. 1: TEM image showing damage in diamond after implantation of 4×10^{15} Ga/cm^2 (a) and mag-nified TEM image of amorphous-diamond interface (b).

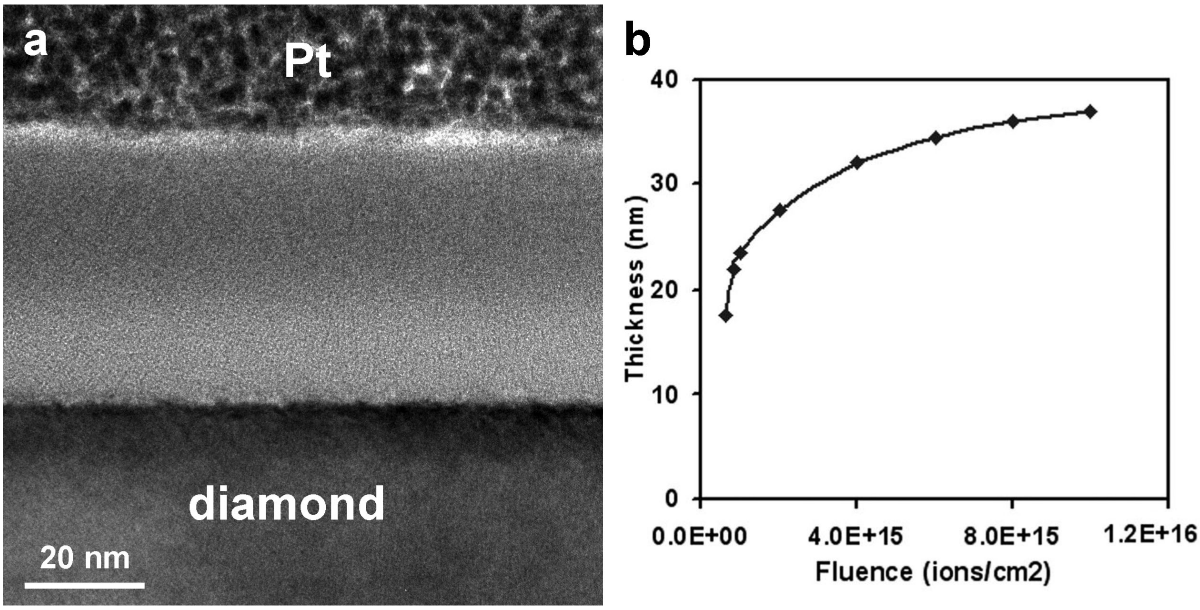

Fig. 2: (a) TEM image showing damage in diamond after continues milling; (b) the measured thick-ness of the amorphous damage layers as a function of the implantation dose.