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TEM Characterisation of Nanofabrication Process in a Single Crystal Diamond

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Single crystal diamond has attracted enormous interest as a solid state platform for quantum information processing [1-4]. For example N-V centers in diamond, show remarkable quantum properties such as long coherence times and single spin readout which makes them ideally suited for use as qubits in a quantum computer architecture [1, 3]. In order to take advantage of these properties, it is highly desirable to fabricate photonic components in diamond on nano-scale level. Recently we demonstrated fabrication of three-dimensional structures in a single crystal diamond on micro scale level using lift off technique [5]. High fluence MeV ion implantation was used to create a buried damage layer and eventually a graphite-like layer upon annealing. The etchable graphitic layer can be removed to form a free standing membrane into which the desired structures can be sculpted using focused ion beam (FIB) milling.

In this work formation of ultra thin diamond films and buried damage layers was studied using cross-sectional TEM. To create ultra thin films the single crystal (100) diamond samples (produced by Sumitomo) were implanted with 1.8 and 2 MeV He^+ ions to a fluence of 3-10×10^{16} ions·cm^{-2} at room temperature. In this case two damage layers with a single-crystal diamond layer 'sandwiched' between were created. Cross sectional TEM samples were prepared using a dual beam FIB system straight after ion implantation and after thermal annealing. TEM showed two damage layers (with weak contrast on FIG. 1a) and thin (~165 nm) diamond layer in between. The depth of damage layers correlates well with that calculated using the SRIM2003 program [6]. Diffraction analysis together with high-resolution imaging confirmed that the damage layers are amorphous in structure while the layer in between is a single crystal diamond (FIG. 1b) with heavily damaged crystalline interfaces.

The samples were thermally annealed at 550^o and 1260^o C in air for 1 hour. The thickness of the damage regions remains the same which indicates the absence of solid phase recrystallisation. The annealing at 550^o C results in the formation of a new phase in the middle of the damage layers (FIG. 2a). Selected area diffraction and the HREM imaging of central region showed that the dominant phase is fine grain polycrystalline graphite. However, there are still present two thin amorphous layers between graphitic phase and crystalline diamond interfaces. That means that there is some critical defect density for graphitization at a given annealing temperature and another slightly lower critical density for amorphisation. In case of annealing at 1260^o C TEM study showed graphitization of entire amorphous damage layers (FIG. 2b). However higher temperature annealing will be required to remove residual damage in diamond layers.

To create 3-D device structures in these ultra thin diamond layers the cap diamond layers were removed using lift off method [5]. Next using FIB milling we fabricated different device structures like cantilevers, optical cavities, waveguides in thin diamond layers on nano scale level.

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