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Ultra-smooth single crystal diamond surfaces resulting from implantation and lift-off processes

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A method for obtaining a smooth, single crystal diamond surface is presented, whereby a sacrificial defective layer is created by implantation of a regular (4 nm roughness) Ib diamond plate. This was then graphitized by annealing before being selectively etched. We have used O^+ at 240 keV, the main process variables being the ion fluence (ranging from 3×10^{15} to 3×10^{17} cm^{-2}) and the final etching process (wet etch, H_2 plasma, and annealing in air). The substrates were characterized by atomic force microscopy, optical profilometry and white beam X-ray topography. The influence of the various process parameters on the resulting lift-off efficiency and final surface roughness is discussed. An O^+ fluence of 2×10^{17} cm^{-2} was found to result in sub-nanometer roughness over tens of μm^2.

1 Introduction The interest in boron-doped diamond for electronic devices is increasing because of its attractive electrical properties: wide band gap, high thermal conductivity, high mobility, and high breakdown electric field. Recently, nanostructuring diamond monocrystalline plates into 2D (delta-doped layers, membranes) or 1D objects (pillars, suspended cantilevers) [1] is becoming increasingly relevant for a number of applications of this material (e.g., field effect transistors (FETs), sensors, and nanoelectromechanical systems). In particular, the δ-doped diamond structure has been considered for some time because of its possible application as an electrical switch in FETs, expected to commute high power at high frequency. A δ-doped diamond structure requires a very thin metallic boron-doped p^+ layer ($[B]_{p+} \geq 5 \times 10^{20}$ at cm^{-3}), called the "δ-layer," intercalated between two low boron-doped layers (non-intentionally doped, NiD) ($[B]_{NiD} \leq 1 \times 10^{17}$ at cm^{-3}).

In previous studies [2], it has been shown that the single crystal diamond substrates play a very important role for the quality of the epitaxial growth and that they also have a significant influence on the electrical properties of the devices which are subsequently fabricated. In the case of delta layers, the roughness requirements on the individual surfaces and interfaces translate into specifications of the starting substrates that become quite stringent at the nanometric scale. These specifications led us in this study to develop a method for smoothing the single-crystal diamond 4 nm-rough as received from the supplier surface down to the nanometric scale while maintaining a superficial structural quality compatible with defect-free epitaxial growth. In this work, we report the technique of surface smoothing using implantation and a subsequent lift-off process using either hot acid or hydrogen plasma, followed by annealing in air [3–10].

2 Single crystal diamond substrate Nowadays, many types of single crystal diamond substrates are available on the market, such as Ib or IIa high pressure and high temperature (HPHT), IIIa chemical vapor deposition (CVD), among others. For our study, we required a substrate with small misorientation, high crystalline quality (low defect density) and, in particular, the smoothest possible surface.