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Polycrystalline Diamond Films produced by Hot-Filament Chemical Vapor Deposition

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Diamond polycrystalline films have shown a unique combination of properties such as high wear resistance, high hardness, the lowest friction coefficient compared to metal and ceramic coatings, chemical inertness, excellent thermal conductivity, tunable electronic properties, and biocompatible properties. Moreover, Ultrananocrystalline diamond (UNCD) films exhibit high electrical conductivity with either nitrogen incorporated in grain boundaries or boron doping via substitution of B for C atoms in the diamond lattice [1]; such properties enable a broad range of applications directed to a new generation of mechanical, electronic, energy generation, and bio-medical devices. Hot-filament chemical vapor deposition (HFCVD) has been used to grow diamond films with various microstructures at different substrate temperatures. The systematic study of substrate-filament distance, substrate temperature, and chemical environment between substrate and filaments has been performed with in this work.

The films have been grown on silicon substrates and have been analyzed using a variety of characterization techniques nevertheless this work is focused on electron microscopy results. Surface morphology, film thickness, and nanostructure were characterized using scanning electron microscopy (SEM, ZEISS SUPRA-40) and high-resolution transmission electron microscopy (HRTEM, JEOL 2010F). Samples for HRTEM analysis were prepared using a focused ion beam (ZEISS FIB-SEM CROSSBEAM 340) process. Crystallinity and grain sizes of UNCD films were investigated via complimentary HRTEM, electron diffraction and X-ray Diffraction (XRD, Rigaku Ultima III, Cu Kα radiation). The schematic of HFCVD system (Bluewave) used in this work is shown in figure 1.

Changes on the distance between the hot filament and the surface of the substrate produced films with different structures from graphene to graphite to UNCD. The substrate holder can be moved up and down to adjust the distance between the surface of the substrate and the filaments. The filament-substrate distances used in the experiments described here were 5, 15, 20, 25, 30 and 35 mm. Table 1 shows the phases present in samples prepared at different distances. The effect of temperature was studied at 400 °C and 450 °C. The substrate was continuously rotated during film growth to provide a uniform temperature and the film was grown for 2 hours. SEM images show the morphologies of thin films grown at different filament-substrate distances and substrate temperatures, SEM also was used to measure the film thickness. The larger film thickness variations across the film surface, observed for films grown at 5 and 15 mm filament-substrate distance, are mainly driven by the number and position of the filaments at closer distances due to thermal radiation effects. The crystallinity characteristic of the diamond phase in the UNCD films, determined by electron diffraction patterns, was confirmed by XRD analysis on selected films grown at 15 mm, 20 mm, 25 mm, and 35 mm filament-substrate distance at 450 °C heater temperature. HFCVD growth of UNCD films can be perform at relatively low temperature, this is a fundamental fact for applications directed to fabrication of Thin Film Transistors (TFTs) or Schottky diodes with hydrogenated surface for electronic power devices [3].

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Filament-substrate distance (mm)	Phases observed
5	Graphite and structural disordered graphene
15	UNCD embedded in a graphite matrix structure
20	Characteristic UNCD structure
25	Characteristic UNCD structure
30	UNCD embedded in a graphite matrix structure
35	Characteristic UNCD structure

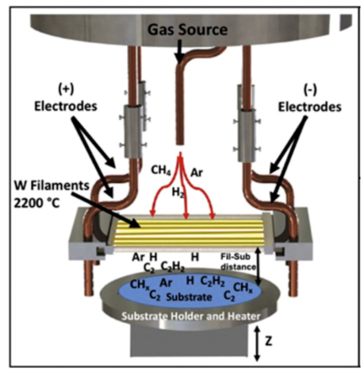

Table 1 phases observed at different distances and Figure 1. Schematic of HFCVD system (Bluewave) used in this work. Features and arrangement of 8 parallel and two angled tungsten (W) filaments held on a molybdenum (Mo) frame positioned above the substrate holder.

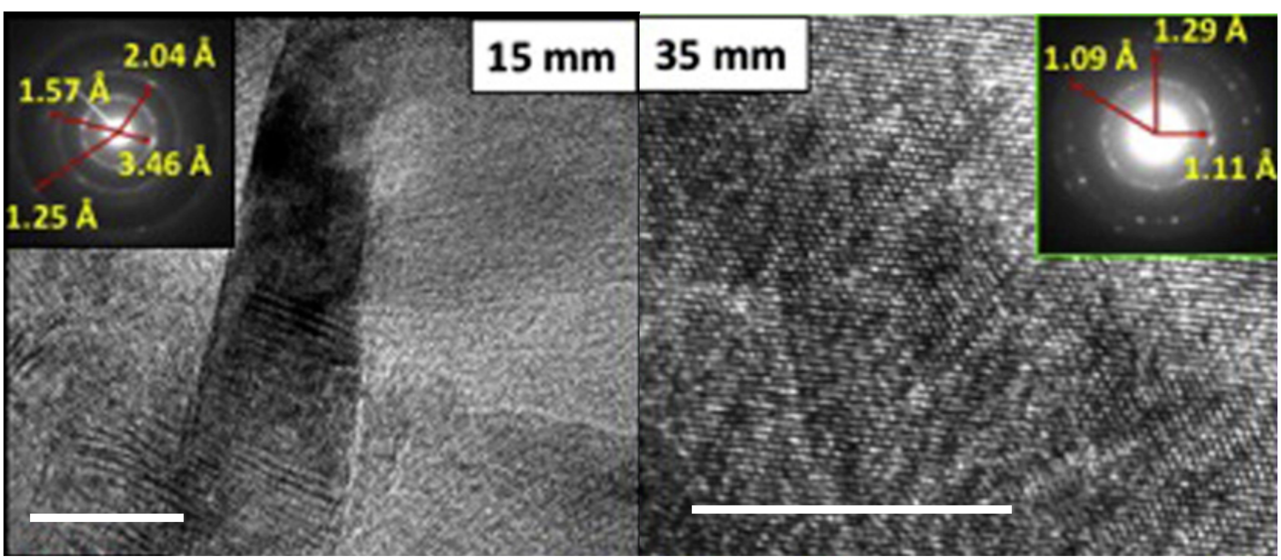

Figure 2. HRTEM images from films grown at different filament-substrate distance and 450 °C heater temperature: 15mm (large graphite-small UNCDmixture), 35 mm (UNCD films). Scale bar 10 nm.

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