X-Ray Absorption Microscopy and Spectroscopy Study of Ultra-thin Nanocrystalline Diamond Films

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Introduction

The growth conformal and continuous diamond films at extremely low thickness (< 100 nm) presents a scientific and technical challenge that is crucial for a range of applications including cold cathodes, flat-panel displays, atomic force microscopy (AFM) tips, wear-resistant coatings on micro-scale machine tools, and micro- and nano-electromechanical systems (MEMS/NEMS) devices, particularly RF switches and resonators for which mechanical and tribological properties must be optimized. The key challenge is to promote growth on substrates like silicon for which diamond does not naturally nucleate. Controlling the initial nucleation density via surface pre-treatments is the key to obtaining ultra-thin, continuous diamond films on substrates. In a recent study, the nucleation density was shown to play a crucial role in improving mechanical properties as well as thermal diffusivity in ultrathin nanocrystalline diamond (NCD) films[1]. The smoothness and compositional uniformity may also increase the fracture resistance and reduce mechanical dissipation[2]. Additionally, the quality of the film-substrate interface depends on nucleation, and plays a dominant role in reducing internal friction in NCD films, suggesting that a higher quality factor (Q) can be obtained in NCD resonators where the film-substrate interface is tailored with an improved nucleation process[3].

Methods and Materials

Ultra-thin nanocrystalline diamond (NCD) films (thickness ~ 60 nm) deposited using a novel two-step seeding process have been characterized by X-ray PhotoElectron Emission Microscopy (X-PEEM) combined with X-ray absorption near edge structure (XANES), X-Ray Photoelectron Spectroscopy (XPS), and atomic force microscopy (AFM) techniques. This study reveals the crucial role that the seeding process plays in obtaining extremely high nucleation densities ($>10^{12}$ nuclei/cm^2). In addition, to understand the morphology and bonding structure of these films, the substrate at both steps of seeding, the nucleation (bottom) surface of the film, and the top-side of the same film are studied.

Results

The results show that a very thin layer of hydrogenated amorphous silicon carbide is formed on the surface of the substrate during the first step of the seeding process, and this layer helps to spread nanodiamond seed particles uniformly over the substrate during the second step. This provides an ideal nucleation surface to grow ultra-thin, phase-pure NCD as revealed by AFM images and XANES spectra obtained from the both the top and bottom surfaces.

Discussion

In conclusion, the first comprehensive study of the bonding phase and chemistry for each stage of this nucleation process and for the film-substrate interface has been achieved.

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[2] Espinosa, H. D. et al. Fracture strength of ultrananocrystalline diamond thin films-identification of Weibull parameters. *Journal of Applied Physics* 94, 6076-84 (2003).

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