Elastic properties of undoped and P-doped thin diamond films grown by linear antenna chemical vapour deposition

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Nanocrystalline diamond (NCD) films, doped and undoped, find potential applications in a wide variety of fields, including but not limited to electrochemistry, nano/microelectromechanical systems (N/MEMS), thermionic emission, and as protective coatings. Commercial usage does not only call for large deposition areas, in many cases, deposition at low temperature is a necessity to avoid substrate damage and film adhesion issues. The linear antenna microwave plasma-enhanced chemical vapour deposition (LA MW PE CVD) system, based on the surface wave plasma technique, is a promising candidate that fulfils both of these requirements.

NCD films of 250 nm thickness were grown on silicon substrates using a LA MW CVD system[1]. They were grown with varying phosphine (PH_3) concentration and substrate temperature (T) in a $H_2/CH_4/CO_2$ reactant gas mixture. [P]/[C] ratios from 0 ppm up to 8090 ppm at 400°C (PH_3-series), and T ranging between 400°C to 900°C for the 0 ppm (undoped T-series) and the highest [P]/[C] ratio (PH_3-T-series) were investigated. For all depositions the MW power, working pressure, and substrate-to-antenna distance were maintained at 2800 W, 0.22 mbar, and 5 cm, respectively. Film morphology and grain size were characterized by scanning electron microscopy, and the roughness was analysed with atomic force microscopy. A transition from NCD to dendrite-like ultra-NCD (UNCD) occurs for all depositions with a [P]/[C] ratio of 8090 ppm, and undoped films deposited at 900°C. Laser acoustic tests and X-ray reflectometry measurements reveal Young's modulus (E) values between (450 ± 50) GPa and (1128 ± 50) GPa and film densities between (2.9 ± 0.05) g/cm^3 and (3.46 ± 0.05) g/cm^3, respectively. E and film density varied with grain size, with the highest values for the undoped NCD film deposited at 800°C.

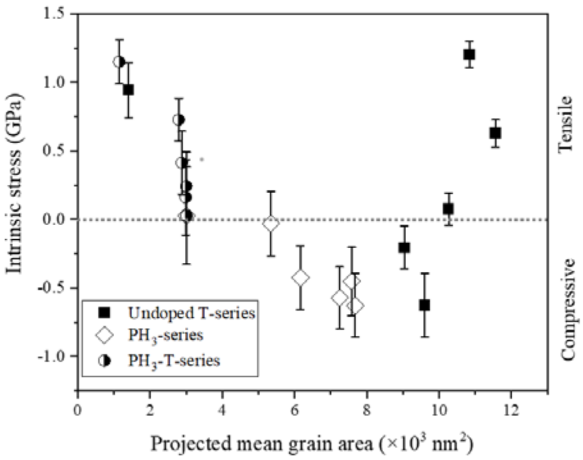

Figure 1 – Intrinsic stress as a function of the estimated grain area for the (U)NCD films.

Substrate curvature measurements show compressive residual stress in all the layers with the lowest residual stress of –0.25 GPa at the maximum [P]/[C] ratio of 8090 ppm and T of 900°C. Thermal stress, calculated from estimated E and Poisson's ratio, was subtracted from the residual stress resulting in either compressive or tensile intrinsic stress. The undoped NCD with larger grains exhibit tensile intrinsic stress while a transition from compressive to tensile intrinsic stress with decreasing grain size is observed for UNCD films (Fig 1). The origins of tensile stress are attributed to the coalescence of grain boundaries and/or changes in the surrounding carbon matrix, such as voids or hydrogen content of the films[2,3]. In addition, the secondary ion mass spectroscopy results confirm the presence of phosphorus, and other impurities such as silicon, for the layers deposited at 900°C and a [P]/[C] ratio of 8090 ppm.

References

1. Zalieckas, J. *et al., Diam. Relat. Mater.* **116**, (2021) 108394.
2. Shang, N. *et al., Diam. Relat. Mater.* **9**, (2000) 1388–1392.
3. Buck, V. *et al., Jpn. J. Appl. Phys.* **47**, (2008) 8208–8213.