Nitrogen-Doped Nanocrystalline Diamond Films: Thermal, Optical and Electronic Properties

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Nanocrystalline diamond (NCD) films [1,2] attract a growing interest as the material for applications in micromechanics, tribology, electronics, medicine, due to possibility to form ultrathin, hermetic, superhard, low friction, low-field electron emission, biocompatible, chemically resistant coatings. Moreover, the NCD doping with nitrogen produces the films with high conductivity of n-type [3] interesting for electrochemistry and high temperature electronics. We will summarize the data on microstructure, impurities, optical absorption, thermal conductivity and electronic properties of NCD films to show how they depend on the nitrogen doping.

The NCD films were grown on Si and transparent polished polycrystalline CVD diamond (PCD) substrates in DC plasma and microwave plasma CVD systems using $CH_4/H_2/Ar$ mixtures at low (zero to few percents) hydrogen contents, N_2 being added to the source gas in amounts up to 25%. The films examined with SEM, AFM and XRD are quite smooth, with surface roughness $R_a < 40$ nm ($R_a = 5$ nm for the NCD deposited epitaxially on PCD). With N_2 addition their resistivity monotonically decreases by 12 orders of magnitude, from10^{10} to 10^{-2} Ohm·cm. The Hall effect measurements show n-type conductivity for heavily doped NCD samples, with mobility of 1.2 $cm^2V^{-1}s^{-1}$ and carrier concentration of 3×10^{20} cm^{-3}. The thermal conductivity measured for 10-μm-thick NCD membranes by a laser flash technique is low, $k = 0.06\text{-}0.1$ W/cm·K at T=300 K, decreasing with nitrogen doping level. These k values are an order of magnitude lower than those expected for the phonon free pass length equal to the grain size.

The optical absorption of the NCD is pretty high, spanning from $4{\cdot}10^3$ cm^{-1} (0%N_2) to $4{\cdot}10^4$ cm^{-1} (25% N_2) at 500 nm wavelength, while the optical band gap E_{opt} shrinks from 0.46 äî 0.15 eV with the doping. The NCD films contain extremely high concentration of bonded (C-H) hydrogen, up to 6 at.%, as seen from IR absorption spectra. The hydrogen is known to decorate grain boundaries and defects in diamond, and its de-bonding at elevated temperatures triggers the internal graphitization in PCD [4]. Preliminary results on thermal stability of NCD will be reported and compared with that for PCD films.

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