349d Growth, Grain Boundary Nanostructure, and Transport Properties of Doped Ultrananocrystalline Diamond Thin Films

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The structure-properties of nanocrystalline diamond films grown using hydrogen-poor plasma chemistries are unique. In particular, the grain boundary (GB) structure and volume fraction of GBs in these materials gives rise to many unique materials properties not found in either amorphous or microcrystalline carbon films with high sp3 content. In this presentation we will summarize our recent work to further understand the GBs in ultrananocrystalline diamond (UNCD) thin films made using microwave plasma chemical vapor deposition and argon-rich plasma chemistries, in which small additions of N2 or H2 gas have a dramatic affect on the nanostructure and transport properties. For instance, a combination of high room-temperature electrical conductivity, carrier concentration and mobility is difficult to achieve in either crystalline or amorphous diamond films. However, for ultrananocrystalline diamond thin films grown using argon-rich Ar/CH4/N2 gas mixtures, nitrogen is incorporated within the GBs preferentially, is predominantly R-bonded, and gives rise to RT -1•cm-1, with carrier concentrations andΩconductivities as high as 250 mobilites of ~1021 /cm3 and ~2 m2•V-1•s-1, respectively. The addition of small amounts of H2 to the plasma dramatically reduces the RT conductivity by about 8 orders of magnitude. The frequency-dependent dielectric properties of “H-doped” UNCD films exhibit capacitances ranging from ~200-10 uF for f=102-106 Hz, and can be tuned via the application of small DC offset voltages, raising the potential for this material as a low-trap tunable dielectric for RF-MEMS applications. In contrast, the thermal conductivities of amorphous carbon films (as low as 0.01 W/mK) are much lower than those of single crystal and microcrystalline diamond (as high as 2200 W/mK, the highest of any known material). Nanocrystalline diamond films are expected to exhibit poor thermal conductivities due to the high density of interfaces. The interfacial thermal conductance (Kapitza conductance) of most materials falls in the range of 50-200 MW/m2•K. If UNCD were to exhibit the same kapitza conductance, then, assuming the grains have the same thermal conductivity of natural diamond, one would expect a RT thermal conductivity even lower than that of amorphous carbons. However, we measurements on both undopedωhave performed an extensive series of 3 and hydrogen-doped UNCD thin films, and have measured thermal conductivities from 12-25 W/m•K. Since the average grain size of UNCD is well characterized as between 2-5 nm, it can be straightforwardly calculated that the kapitza conductance of UNCD is about 9000 MW/m2•K, much higher than any other known material. Our ongoing work to examine thermal transport in nitrogen-doped UNCD and hybrid nanocarbons will also be discussed. *This work was supported in part by the US Department of Energy, BES-Materials Sciences, under Contract W-13-109-ENG-38

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