Effect of Film Thickness on Low-Energy Electron Transmission in Thin CVD Diamond Films

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Diamond is a promising cold electron emitter material because of specific negative-electron-affinity (NEA) surfaces and good electron transport properties. While much effort has been directed towards characterizing the surface properties of NEA diamond, the cold emission process in diamond has not been well characterized. In this study, we inject electrons into thin CVD diamond films using a 0-20 keV electron gun, and we then detect low-energy secondary electrons that are transmitted through the films. In particular, we measure the intensity and energy distribution of the transmitted electrons as a function of the incident beam parameters (energy, current) and material properties (film thickness, doping concentration) to gain insight into the transport process and the mechanisms that influence the electron transmission characteristics. Secondary electron emission spectroscopy (SEES) and other analytical techniques are also used to evaluate the surface properties of the film.

Our initial study examines electron transmission through thin B-doped CVD diamond films of thickness 150 nm, 1.5 microns, 2.5 microns, and 4.2 microns; other film thicknesses are currently being studied. The B concentration is similar (~ 10^{17} cm^{-3}) in all but the thickest film. Therefore this first study focuses on the effect of film thickness on the transmission properties. In secondary electron yield measurements taken from the front (emitting) surface of the films, maximum yields of ~ 20 are obtained at beam energies of 1 - 2 keV, indicating that a low or negative electron affinity exists at the surface. The secondary electrons emitted from the front surface have a narrow energy distribution (FWHM ~ 0.5 eV) that is sharply peaked near the bottom of the conduction band. These emission characteristics are very similar to those observed in previous SEES measurements from single-crystal and thick CVD diamond samples, although higher yields were obtained from the more bulk-like films.

In electron transmission measurements taken from the thin films (with the beam incident on the *back* surface), a low-energy peak appears in the measured energy distribution curves (EDCs) but the emission peak is not identical in all of the measurements. Rather, the shape and energy spread of the emission peak measured from the different films can be described by one of two distributions: a sharp emission peak with FWHM ~ 0.5 - 0.7 eV or a broad distribution with FWHM ~ 2 - 3 eV. The narrow transmission peak is identical to that obtained in (reflection) EDC measurements from the front NEA surface. Further, the measured transmission yield (i.e. ratio of transmitted current to incident current) is found to be greater than or near 1 when the narrow emission peak is observed whereas transmission yields much less than 1 are measured for the broad energy distribution.

To analyze these measurements, we estimated the secondary electron transport distance for each transmission measurement by calculating the electron generation depth (and subsequent escape distance) as a function of beam energy using an electron penetration model for diamond. The trends that emerged from an analysis of the transmission data and penetration depth calculations were consistent with a low-energy secondary-electron escape depth of ~ 1 micron in the diamond films studied thus far. Specifically, the intense, narrow peak in the EDCs corresponds to the emission of low-energy secondary electrons generated within ~ 1 micron from the emitting surface, regardless of film thickness. When the secondary electrons are generated greater than ~ 1 micron from the surface, a significantly broadened distribution emerges in the EDCs. This suggests that electron interactions within the film substantially modify the electron energy distribution over these longer transport distances. The nature of these interactions needs to be better understood and is under investigation.

While a simple model can account for most of the transmitted energy distribution measurements, we have not yet identified the mechanisms responsible for the relatively low transmission yields (i.e. gain). As such, efforts are underway to correlate the transmission properties with the micro- and nano-structure of the films (using electron microscopy), and to determine whether the surface emission probability can be increased. Furthermore, our studies will examine the role of B doping on scattering and intensity loss during the transport process.