Field emission enhancement by graphitic nano-scale channels through ta-C layers

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A key issue in field emission (FE) from CVD diamond and other carbon films is to understand the role that non-diamond inclusions and conduction pathways in the material have on the FE process. FE is significantly enhanced, apart from geometric enhancements due to rough surface morphologies, by the presence of non-diamond phases embedded in the diamond matrix. These phases appear in the form of grain-boundaries, graphitic inclusions, graphite nano-particles and others. It is, however, not clear in most reports, what the relative contribution of surface morphology and the presence of conductive channels to improved emission is. To investigate the possibility of FE originating from graphitic regions in a perfectly smooth material, we performed ion-irradiation to selectively transform diamond-like carbon (sp^3 bonding) into graphite like (sp^2 bonding) material. Single ion tracks were formed by implanting high-energy single ions at extremely low doses through a thin smooth amorphous tetrahedral–amorphous–carbon (ta-C) layer. The layers were thin enough for the ions to penetrate through them and stop in the substrate. N-doped conductive and un-doped ta-C films were used and the FE results were compared. Four ion-implantation schemes were used: (a) 1 GeV U ions at a low dose; (b) sub MeV Xe ions at a low dose; both were meant to form well separated single ion tracks through the material; (c) sub MeV C ions at a high dose, for complete material transformation; and (d) un-implanted sample as a control. Field emission turn-on conditions were carefully studied for these, employing a very slow voltage ramp-up, to avoid undesired vacuum electric discharges, known to result in a 'conditioning' affect on FE. Field emission seems to initiate at the lowest applied field for samples that include nano-scale graphitized channels threading all the way through the layer, as realized by single ion implantations. A 40% reduction in the field required for emission onset is found for all samples with single ion tracks compared to the un-implanted sample. However, the sample implanted for full coverage transformation shows no emission up to at least 100 V/μm. The observed improvement in FE is shown to be consistent with field enhancement calculations due to conductive pathways in the material.