Emissive and Cooling Properties of Carbon Based Materials for Microelectronics

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Among carbon-based materials, diamond and nanotubes exhibit field emission characteristics, which can be very useful for applications. These include low extraction field, high current density and long operating time [1-3]. In general, the current voltage characteristics of the nanotubes follow a Fowler-Nordheim type tunneling law. To study field emission from both metallic and semiconducting nanotubes, Mayer et al. [4-6] have developed a scattering formalism, which goes beyond the simplified one-dimensional kinetic treatment used by Fowler and Nordheim and most subsequent analyses. By contrast, Mayer et al. [4-6] have used a transfer- matrix formalism which incorporates three dimensional aspects of the atomic structure with the field emission tunneling process. Using this formalism, they have investigated field emission and FEED from metallic (5,5) and semiconducting (10,0) capped and open single walled nanotubes (SWNT) [7-9], the effect of absorbates on field emission and FEED from SWNT [10], field emission from multi-walled nanotubes (MWNT) [11], and other properties involving radiation [12,13]. These results will be briefly reviewed in light of application as high current, low voltage electron sources.

Lerner et al. [14, 15] formulated a quantitative theory of charge injection into nitrogen-doped diamond to explain the low voltage emissive properties of thin film composite metal (semiconductor)/diamond cathode sources. The field emission process in these composite devices has been modeled as a three-step process involving electron injection, transport, and vacuum emission. Others have suggested similar qualitative models, but the work of Lerner represents a first attempt at a detailed mathematical and quantitative formulation, which is consistent with experimental results of Okano et al. [16], Xu et al. [17], and others. The charge injection process is also applicable beyond emissive devices as described in the work of Miskovsky and Cutler on microelectronic coolers [18, 19]. In these devices, the Nottingham cooling effect is used to extract heat from a “hot” source (e.g., microprocessor or sensor) whose temperature must be kept constant. The mechanism for this process uses essentially the same three-step model in a thin film metallic diamond composite. A simple quantitative theory using the kinetic formalism has been given by Miskovsky and Cutler [18,19] and is briefly reviewed.

Lastly, Chung et al. [20] have proposed using Nottingham cooling in a thermoelectric device which is in principle more efficient than conventional solid state thermoelectrics. This will briefly be discussed.

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