On the Extraction of Data from Field Emission Experiments with Nanoscale Objects

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For extraction of reliable data from field emission measurements, we performed systematic studies of exact geometry of field emitters using high-resolution transmission electron microscopy (HRTEM). Electric fields were numerically calculated based on the exact geometry of the tip. This technique was applied to composite field emitters consisting of nanoclusters of one or a few diamond nanoparticles on a sharp metal needle. For the first time, atomic resolution of the morphology of the underlying metal surface and that of a deposited diamond particle were observed in HRTEM before and after field emission experiments.

The assumptions made to simplify the interpretation of field emission data have become so much a part of the data analysis process that their applicability is usually assumed universal. This neglect can lead to substantial errors in interpretation. When solving the Fowler-Nordheim equation it is often assumed that the barrier for electrons is triangular in shape (d = phi/F), even when image-potential correction factors are included. It is well known that this is not accurate; however, it is assumed, that only minor corrections will result if the barrier is more complex. When dealing with features of emitters at sub-micron-scale such an assumption can yield acceptable results, but it can be shown that even with ideally-shaped emitters such an assumption results in large error when considering emitter features at the nanoscale [1]. It is also routine to assume the field near the emitting surface has a simple dependence on the radius of curvature at the surface, typically F 1/r. This is not necessarily true and can lead to numerous errors in interpreting data, particularly when the emitting surface is not ideally shaped.

When considering composite structures (e.g. dielectric coatings or particles on metallic emitter), it is usually assumed that the applied field either penetrates the dielectric completely and terminates at the metal surface or terminates at the dielectric surface, thus simplifying the emission barrier model to be either the metal-dielectric interface or the dielectric-vacuum interface. The complexities arising from screening effects are usually erroneously overlooked. In addition the effects of the emission process itself (i.e. high current and high field, especially when not uniform) are almost universally ignored; that is, there is an obvious absence of studies on the effects of emission on field emitting structures themselves (i.e. before-and-after studies).

In this paper we describe and apply an assumption-free procedure for analyzing field emission data. Through the use of high-resolution TEM before and after emission, the exact geometry of emitters can be determined. With this knowledge, numerical calculations can then be performed to accurately determine local fields at the emitting surface, and thus a more accurate potential barrier can be determined. The result is a more precise determination of physical parameters of interest (i.e. work function, emission area, etc.).

J. J. Saenz, Theory of Field Emission from nanowires: Determination of local work functions from Field Emission data, EuroFE 2001, Alicante, Spain, Nov. 12-16, 2001.