# Field Penetration, Electron Supply and Effective Work Function in Semiconductor Field-Emission Cathodes

Charles E. Hunt and W. Dawson Kesling

*Department of Electrical and Computer Engineering*
*University of California*
*Davis, California 95616 USA*
*Phone: (916) 752-0583*
*FAX: (916) 752-8428*

## ABSTRACT

It is widely assumed that n-type silicon field-emission cathodes should be heavily doped to maximize the availability of electrons at the emission surface. Field emission from semiconductors, however, is different than from metals in that, among other things, the concept of an independent supply function is likely not valid. Penetration of the external field into semiconductor cathodes, which is dependent on dopant concentration, enables hot electron accumulation and impact ionization near the surface. The application of the Fowler-Nordheim model, as is useful with ideal metal cathodes, is insufficient for this more complicated condition. As donor concentration decreases in the cathode, the electron supply is increasingly drawn from the larger volume of the semiconductor away from the tunneling surface. Furthermore, the drift of electrons within the semiconductor creates a condition where the tunneling electrons at the surface need to overcome an "effective" work function, which is less than the equilibrium value. The result is a higher current density from an applied external field than would be obtained from a metal or degenerately-doped semiconductor with the same equilibrium work function. We present here modeling results which suggest that an "optimum" doping level exists somewhere between light and degenerate concentrations.

The analysis presented here builds on recent work [1], which includes much of the relevant physics, in four significant ways: we include the velocity saturation of mobile carriers, we allow for the possibility of avalanche multiplication of carriers due to impact ionization, we include a three-dimensional model for carrier flux in the bulk to approximate the practical situation of conical emitters, and we allow for different surface emission models. To simplify the analysis, we neglect temperature considerations and surface carrier conduction. The results indicate that nondegenerately-doped semiconductor field emitters should emit at lower applied voltages than comparable "metal-like" heavily-doped cathodes. This is consistent with our earlier experimental results [2], although our direct comparison with experimental cathodes from other investigators is hampered by the extreme sensitivity of field emission to tip geometry and surface conditions. Modeling results showing carrier supply and effective work function at various doping levels, for a fixed surface field, are presented.

[1] V.A. Fedirko, N. A. Duzhev and V. A. Nikolaeva, 7th IVMC, Grenoble (1994)
[2] J. T. Trujillo and C. E. Hunt, J. Vac. Sci. Technol., B11, 454 (1993)