CURRENT DENSITY EVALUATION AT THE BARRIER MAXIMUM

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ABSTRACT

Currently the photoinjector is the design of choice for new FELs where high brightness and high current are required [1]. The performance of photocathodes depends on the bulk and surface properties of complex semiconductor materials. A low work function dispenser type photocathode that is self-annealed or repaired would have a substantial impact. A dispenser cathode is one in which the emitting surface is constantly renewed by replenishment of low-work-function material from a subsurface plenum. The emitting material is absorbed into the tungsten matrix and the electron-emitting surface is continually renewed by the diffusion of new material to the surface. This would allow the dispenser cathode to operate at a relatively low temperature compared to a metal cathode, and to be very robust and long-lived. Only recently, however, has the possibility that the dispenser cathode can be used as a photocathode source generated interest. It has been shown that this cathode has quantum efficiencies at least a factor of two better than the best metal cathode [2]. The possibility of a low temperature, low work function dispenser photocathode entails, however, theoretical problems.

Electron emission from materials can be induced by subjecting an emitter material to high temperatures T (thermal emission), applied fields F (field emission), or by providing energy sufficient to overcome the work function surface barrier using light (photoemission). Estimates of current density are generally evaluated under the assumption that the electron distribution function may be obtained from a thermalized Fermi Dirac distribution, that the transmission coefficient $T(E)$ may be evaluated using a WKB formalism, and that these approximations may be used in the equation for current density $J(F,T)$ given by

$$J(F,T) = \frac{qm}{2\pi^2\hbar^3\beta^2}\int_0^\infty e^{-2\theta(E)} \ln\left[1+e^{\beta(\mu-E)}\right]dE$$

where E is energy, $\beta = 1/k_BT$ is the temperature factor, q and m are the electron charge and mass, $\theta(E)$ is usually approximated by WKB. In the field emission realm, the Fowler Nordheim equation (FNE) and Richardson-Laue-Dushman (RLD) equations are accurate to within 10% as long as $\beta F \geq 6(2m\Phi/\hbar^2)^{1/2}$ where Φ is the work function, or $\beta F^{3/4} \leq (2m)^{1/2}(\pi Q^{1/4}/10\hbar)$, where $Q \approx 3.6$ eV-Å, respectively However, for combinations of work function, field, and temperature parameters, next generation photocathodes, designed to operate near 800 ˚C and 100 V/μm (such as in radio-frequency guns), may lie within the regions where neither equation is adequate.

In this work, we extend the *Airy Function Approach* to the evaluation of the transmission coefficient $T(E)$ to show how it may be obtained continuously from well below the barrier maximum to above it using an analytic formulation. The analytical form shall be compared to exact solutions based on numerical evaluations of the image-charge modified Schottky barrier. Below, we shall briefly describe the procedure to obtain $T(E)$.

In terms of $v = 2m[\mu+\Phi-\sqrt{(4QF)}]/\hbar^2$, $k^2 = 2mE/\hbar^2$, $f = 2mF/\hbar^2$, and $\kappa^2 = |v - k^2|$, $\theta(k)$ is then given by $\theta(k) = 2(fL^3)^{1/2} R(x_0/L)$, where x_0 and L represent the smallest zero and the distance between the zeros of $V(x) - E(k)$, respectively, where $V(x)$ is the image charge potential $V(x) = \mu + \Phi - Fx - Q/x$, and $R(s)$ is defined by

$$R(s) = \int_0^{\pi/2}(\cos x \sin x)^2\left[s+\sin^2 x\right]^{-1/2}dx$$

Then, the Airy Function approximation to the image charge $T(k)$ is then given by

$$T(k) = \frac{2\eta k B(k)}{2\eta k + A(k)\left(\eta^2+k^2\right)}$$

$$A(k) = \begin{cases} \exp\left(2\theta(k)\right) + \frac{1}{4}\left(\exp\left(-2\theta(k)\right)-1\right) & k^2 \leq v \\ \exp\left(-2\theta'_o\right) & k^2 > v \end{cases}$$

where $B(k) = 2$ if $k^2 \leq$ v and $1 + A(k)$ otherwise, $\eta = [|k^2-v|^2 + f^{4/3}p^2]^{1/4}$ and $p = (3/4\pi)^2\, 3^{2/3}\,\Gamma(2/3)^4 \approx 0.398593$. θ'_o is the gradient of $\theta(k)$ evaluated at $k^2 = v$. The derivation of Eq. $T(k)$ is based on a $Q > 0$ extension of a triangular barrier model coupled with an asymptotic representation of Airy functions modified to present needs. As such, the approximation above becomes better for smaller contributions of the image charge, such as when dielectric materials or interfaces between semiconductors are involved. Nevertheless, even for full image charge contributions, the approximation is reasonable for parameters characteristic of photoemission. In the presentation, we shall discuss the extension of $T(k)$ to derive modified field and thermionic emission current density estimates, and discuss the implications for photocathodes under development.

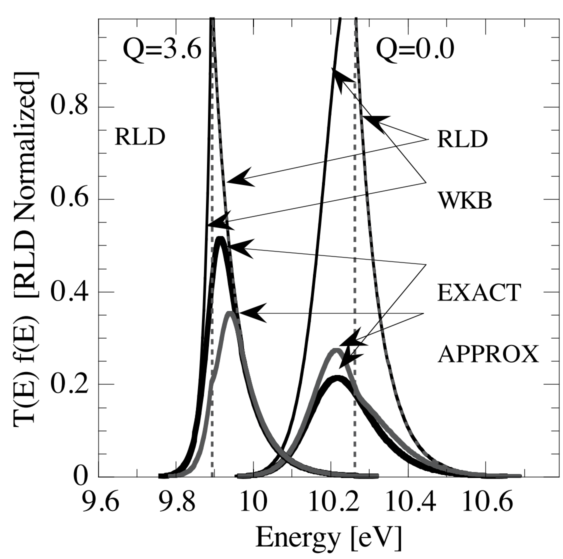

Figure 1: A comparison of the current density integrand for the RLD & WKB approximations with the exact evaluation and the approximation to $T(k)$ ("approx") discussed herein.

REFERENCES:

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