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EXPERIMENTAL GUN BRIGHTNESS MEASUREMENTS ON A 300 kV CFEG

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Effective use of the ANL 300kV CFEG/AAEM¹ requires a knowledge of the probe current and size distribution during operation. In most cases this can be calculated once basic parameters of the system are experimentally determined. Central to this is a determination of the source brightness of the Cold Field Emission Gun (CFEG) under standard operating conditions of the instrument. For the last ten years most probe calculations of CFEG's have been done assuming a brightness parameter of $\beta \sim 1 \times 10^9 \text{ A/cm}^2/\text{sterad}$ at 100 kV, while few if any experimental values have been reported at 300 kV. Using β and the relationship that the operating probe diameter is obtained by adding in quadrature the Gaussian probe size (d_g , the CFEG source contribution), and the diameters of least confusion due to spherical aberration (d_s) and diffraction limits (d_d) one obtains the total probe size d_t as³:

$$d_t = \sqrt{d_g^2 + d_s^2 + d_d^2} : d_g = \frac{2}{\pi\alpha} \sqrt{\frac{I_p}{\beta}} : d_s = 0.5 C_s \alpha^3 : d_d = 1.22 \frac{\lambda}{\alpha} \quad (1)$$

where α is the convergence half angle, I_p the probe current, C_s the spherical aberration coefficient of the probe forming lens, and λ the wavelength of the electron beam. This relationship is plotted in figure 1 for various values of C_s at 300 kV and assuming that $d_g = 0$ (i.e. neglecting the source term).

In order to determine β , and thus characterize the source, we have measured the probe size, current and convergence angles on the ANL AAEM and from this calculated the effective brightness as a function of operating conditions. To measure the probe size we scan the probe across the edge of 5-30 nm $\langle 100 \rangle$ oriented MgO cubes and measure the signal rise profile to determine the Full Width Half Maximum as described by Michael.² Figure 2 shows examples of these probe profiles for various half angles at 300 kV for a probe current of 0.45 nA, obtained using a Virtual Objective Aperture (VOA) of 30 microns. Probe currents were measured using electrically isolated apertures in the probe forming system, while the convergence angles were calibrated independently using electron diffraction by measuring the diameter of Au $\langle 220 \rangle$ reflections in a $\{100\}$ zone axis orientation as a function of the condenser lens current. In figure 3 we show the experimental results of the variation in probe size with α at 300 kV. These values can be compared with figure 1, noting that the effective probe size is larger due to the fact that these measurements now include the CFEG source term d_g , which was not included in the calculations of figure 1. We see that the minimum probe diameter at $\sim 5-6 \text{ mr}$, corresponds to the expected range based upon the nominal C_s of this system of $\sim 5 \text{ mm}$. Taking this data we can now compute the apparent brightness of the system as shown in figure 4. The maximum occurs at $\sim 0.6 \times 10^9 \text{ A/cm}^2/\text{sterad}$. This value must be corrected for the contributions of d_s and d_d to d_t and from this we compute $d_g = 0.92 \text{ nm}$ and effective source brightness for the system of $\beta = 8.6 \times 10^8 \text{ A/cm}^2/\text{sterad}$ from eq.(1). A value which is within experimental errors of the commonly used parameter at 100 kV, but is less than the expected value of $\sim 4 \times 10^9 \text{ A/cm}^2/\text{sterad}$.

References:

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- 2.) C. Colliex, Ultramicroscopy 18: pg. 131, 1985
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- 5.) This work was supported by US. DoE under BES-MS W-31-109-Eng-38 at ANL.

Figure 1.) Calculated Probe Size as a function of C_s and convergence half angle for a 300 kV CFEG system. These calculations assume that $d_g = 0$ nm, while the numbers in the square boxes refer to the C_s value in mm.

Figure 2.) Experimental line profiles obtained by scanning a focused probe across $\langle 100 \rangle$ MgO cubes as a function of half-angle. Illustrating the change in resolution as a function of α .

Figure 3.) Probe size measurements vs convergence half-angle at 300 kV $I_p = 0.45$ nA

Figure 4.) Brightness measurements vs. convergence half-angle at 300 kV $I_p = 0.45$ nA