A Brightness Comparison Of Thermionic Electron Sources In A TEM*

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A BRIGHTNESS COMPARISON OF THERMIONIC ELECTRON SOURCES IN A TEM

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In the quest for thermionic electron sources that are much brighter than the standard tungsten filament, manufacturers have given us first LaB$_6$ and then, after a space of several years, CeB$_6$ single crystals. This paper compares three different electron sources under typical operating conditions in a Philips EM420T transmission microscope.

Brightness, in units of A cm$^{-2}$ str$^{-1}$, is calculated using the following equation:

$$B = \frac{4I}{(\pi d\theta)^2}$$

where $I$ is the electron beam current at the specimen plane, $d$ is the electron beam diameter in centimeters of the focused probe at the specimen plane, and $\theta$ is the convergence angle in radians of the focused probe at the specimen plane. The brightness should be constant at any point in the optical system and independent of the strength of the C1 lens or the size of the condenser aperture.

The Philips EM420T was operated at 120 kV with three new thermionic emitters: a standard tungsten filament loop, a LaB$_6$ cathode ($<100>$ crystal orientation, 90° cone angle, 15 μm radius round tip, tungsten wire supports), and a CeB$_6$ cathode ($<100>$ crystal orientation, 60° cone angle, 5 μm diameter flat tip, compression mount). The tungsten filament was supplied by Philips, the LaB$_6$ cathode was manufactured by Denka, and the CeB$_6$ cathode was manufactured by FEI. Each of the sources was mounted identically in the Wehnelt cylinder, i.e. 0.2 mm back from the Wehnelt's outer surface. Each cathode was biased identically. The tungsten filament was saturated normally. The LaB$_6$ and CeB$_6$ cathodes were heated to the point at which the beam current and the source image no longer changed significantly. However, none of the sources was heated so much that the structure of the source image disappeared. The electron beam current was measured by focusing the beam to its smallest size in the image mode, putting the microscope into the diffraction mode, selecting a small camera length, and then shifting the diffraction spot into a Faraday cup in the viewing chamber. The Faraday cup was connected to a Keithley 602 electrometer. The FWTM (full width tenth maximum) beam diameter was measured using the same Faraday cup with the microscope in the image mode. The beam currents and diameters were measured using several condenser apertures and differing strengths of the C1 lens. The convergence angle was determined by measuring the radius of CBED (convergent beam electron diffraction) discs from a material and then dividing that radius by the calibrated camera length.

Comparisons of the brightness measurements, the largest beam diameters, and the greatest beam currents are presented in Table 1. CeB$_6$ was 4 times brighter than LaB$_6$, and LaB$_6$ was three times brighter than tungsten. The large difference in brightness between the two hexaboride cathodes probably is due to their different geometries and to their different support structures since the work function of LaB$_6$ is not substantially greater than that of CeB$_6$. Unfortunately, the typical lifetime of the CeB$_6$ cathodes used in our microscopes has been only 720 hours due to cracks that develop in the crystal volume between the compression mount structures (see Fig. 2). The cracks may form because of frequent thermal cycling: our standard operating procedure is to cool a LaB$_6$/CeB$_6$ cathode before inserting or removing samples to reduce the risk of degrading the emission properties by contamination. Therefore, it seems that for those microscopes in which the cathode must be heated
and cooled frequently, the best combination of brightness and lifetime may be found in wire-supported hexaboride crystals with a small cone angle.\textsuperscript{3}

References:

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Table 1. - Cathode brightness and related measurements at 120 kV. See text for physical description of cathodes.

<table>
<thead>
<tr>
<th>Cathode</th>
<th>Brightness (A cm(^{-2}) str(^{-1}))</th>
<th>FWTM Beam Diameter (µm)</th>
<th>Beam Current (µA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten</td>
<td>((9.1 \pm 0.8) \times 10^4)</td>
<td>1.0 ± 0.15</td>
<td>0.10 ± 0.01</td>
</tr>
<tr>
<td>LaB(_6)</td>
<td>((2.7 \pm 0.2) \times 10^5)</td>
<td>0.74 ± 0.11</td>
<td>0.15 ± 0.02</td>
</tr>
<tr>
<td>CeB(_6)</td>
<td>((1.1 \pm 0.1) \times 10^6)</td>
<td>0.41 ± 0.06</td>
<td>0.21 ± 0.02</td>
</tr>
</tbody>
</table>

Fig. 1. - CeB\(_6\) in compression mount after 660 hours of use. Arrows point to two cracks in portion of crystal between mount structures.