The energy spread of a LaB\textsubscript{6} cathode operated in the virtual source mode

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Abstract. The LaB\textsubscript{6} cathode has been the brightest thermionic source used in microprobe applications requiring longer lifetime [1-2]. It is x100 lower in brightness than thermal field emitters (TFE) ca Zr/W(100) [3]. There are attractive similarities between these cathodes in terms of work function and operating temperature that are worth considering. Major differences include their respective source sizes (>10µm vs 30nm) and energy spread of 1-2 eV vs 0.6-0.7eV for the LaB\textsubscript{6} and TFE, respectively [4,3].

We report here on the experimental measurement of the energy spread of a LaB\textsubscript{6} cathode operated in the virtual source mode. The cathode used has an end-form measuring 15µm. Total energy spread values obtained using a dedicated electron energy analyser shows values of 0.4eV-0.7eV, significantly lower than typical values in the thermionic mode of 1-2eV.

1. Introduction
The Lanthanum Hexaboride (LaB\textsubscript{6}) electron cathode have been recognised as the highest brightness thermionic source since its introduction in the early 1970s [4]. This cathode is preferred to the conventional tungsten heated filament due to its relatively smaller source size but much higher brightness with respect to tungsten by about x10. The latter property has improved the microscopes’ spatial resolution at lower electron beam energies. However, a fundamental impediment with all thermionic electron sources in comparison to the more recent point source cathodes lies in the configuration of the electron source (i.e. gun) part of the microscope. This, for most thermionic types, has been used with a Wehnelt electrode to aid focussing and control of the electron emission, see Figure 1. The Wehnelt electrode consists of a cylindrical cap with a small central hole where the cathode is located behind it. In operation of the source, a focussed cloud of electrons is formed in front of the Wehnelt which typically measures about 10-20µm in diameter. This first cross-over of the probe causes a broadening in the velocities of the emitted electrons, due to Coulomb interaction, that in turn causes a broadening in the final beam diameter via the chromatic aberration component of the electron beam. Values of the energy spread of the emitted electrons in such configuration of greater than 2eV can result at moderate to higher beam currents. This is a much worst value than the natural spread of thermally emitted electrons at such temperatures (estimated to be in the order of 0.4eV).
These two properties have been improved upon by using a point source such as the Zr/W(100) Schottky electron emitters (also referred to as thermal field emitters, TFE) [5](Fujita 2010). In this case, see Figure 1, the projection of the emitted electrons appears to come from a virtual source of a much smaller size than the diameter of the TFE cathode and is normally assumed to be in the range of 20-30nm. The LaB₆ and the TFE cathodes, however, share two fundamental properties that are worth exploiting in probe forming systems. These are similar work function (2.6-2.8eV) and the same operating temperature of 1800K. The work reported here is a measurement of the energy spread of a LaB₆ cathode when operated in the virtual source mode and shows that by operation in this mode one achieves an energy spread similar to that of the typical TFE cathodes.

2. Energy spread measurements

Operation of the LaB₆ cathode was performed in the virtual source mode using a YPS M20 minimodule which is comprised of an extractor and suppressor electrodes with a cathode in the virtual source configuration shown in Figure 1. The M20 was designed to fit a standard Kimball physics ES-423E LaB₆ emitter, with a 19-20µm flat and a 90 degree cone angle, see Figure 2, with a 1mm suppressor aperture that allows the LaB₆ crystal to protrude by up to 0.2mm above the suppressor electrode. The M20 module was then loaded into a single lens electrostatic mini-electron column, comprising of a grounded anode electrode and a lens electrode, for beam formation.

Figure 2 LaB₆ emitter prior to operation a) LaB₆ crystal and b) 19.6µm (100) flat.
With a 50µm aperture in the extractor electrode of the M20 a beam current of up to 1µA could be obtained from the mini-electron column. The maximum beam current is limited by the total emission current from the LaB₆ emitter, > 3mA, that could be delivered by the power supply.

The energy spread measurements were performed using a VG CLAM100 hemispherical electron energy analyser with an electrostatic lens on the entrance optics. A beam of electrons was fired at a Ag coated sample with the subsequent electron spectra collected in the CLAM100. The elastic scattered electrons could then be used to represent the electron source energy spread.

3. Results

| Filament Temperature (K) | 1600 | 1625 | 1650 | 1675 | 1700 | 1725 | 1750 | 1800 |
|--------------------------|------|------|------|------|------|------|------|------|
| ΔE FWHM Ve = 600V (eV)   | 0.41 | 0.43 | 0.44 | 0.45 | 0.47 | 0.48 | -    | -    |
| ΔE FWHM Ve = 300V (eV)   | -    | -    | 0.42 | -    | 0.45 | -    | 0.48 | 0.54 |

Table 1  Energy spread with filament temperature at Ve = 600V and Ve = 300V.

Operation of the LaB₆ emitter at a fixed extractor voltage showed an increase in the energy spread as the temperature of the emitter was increased, see Table 1. This is as expected with TE emission and TFE, but the increase in the energy spread is in the high energy tail as can be seen in Figure 3 which is in keeping with a TE emission mechanism.

From Table 1 it can be seen that the temperature dependence of the energy spread is repeated when the extraction voltage is dropped to 300V. The change in the extraction voltage in Table 1 shows a limited effect on the energy spread. Figure 4 shows the energy spread spectra as the extraction voltage is increased from 200-800V. It is important to note that the LaB₆ emitter used in this experiment is different than the one discussed above, although of the same type. The energy spread obtained shows a
FWHM value which is constant at 0.66±0.01eV over these extraction voltages and with a beam current of 250-300µA.

![Energy spread with increasing extraction voltage](image.png)

**Figure 4** Energy spread with increasing extraction voltage: *note the peaks have been offset 0.2eV from each other for ease of viewing.*

### 4. Discussion and Conclusion

From the Richardson theory of electron behaviour, a 0.04eV increase in the energy spread is predicted for a 125K increase in the temperature as opposed to the 0.07eV increase measured in Figure 3. This, however, may have been caused by a small electron interaction and is also within the experimental errors for such measurements. What is more important here is that the measured energy spread reflects the expected increase in the high energy tail of the peak due to thermionic electron emission. The results shown in Figure 4 demonstrates that there are no increase in the energy spread with increasing the electric field around the LaB$_6$ emitter. This also points to a pure thermionic electron emission mechanism.

In conclusion, the results obtained here show that operating the LaB$_6$ in the virtual source mode results in a much smaller electron energy spread than normally obtained in conventional operation of this type of electron cathode. This should aid one to obtain a superior spatial resolution at lower beam voltages. Operating the source in this mode also results in a much smaller source size thus, estimated to be at least x10 smaller than its thermionic mode, thus positively contributing to superior source electron optical characteristics.

### References

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