End-form Changes in High Brightness HfC Electron Sources

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We continue to work on a new electron source for high brightness applications. Presently, commercial high-brightness sources operate in the extended Schottky emission (ESE) or cold field emission (CFE) modes both using tungsten as the base material. It is known that surface tension and electric field forces contribute to blunting or build-up on these W-based emitters which limits I', the angular intensity. Generally the maximum value of I' for ZrO/W sources is ~1 mA/sr.[1] HfC sources can be operated at high temperatures and high fields without surface migration thereby not limiting I' to a relatively small range; HfC sources have been operated to >60 mA/sr. Reduced brightness calculations and comparisons to ZrO/W sources have been made (see Table I). These data show the higher brightness levels with HfC and are the result of the high field at the apex.

Modeling and experimental performance on test stands and in a Philips XL40 FEG SEM are reported for HfC(210) and (110) cathodes where emission is studied for temperature ranges of 1850-1950 K. The field is high on curved end-forms giving rise to the very high optical reduced brightness levels to ~8 x 10^9 $A/m^2/sr/V$.

We have investigated operation in various pressures of ambient air to ascertain HfC's utility in this regime; pressures from 4 x 10^{-10} to 8 x 10^{-8} torr. As the pressure increases we find that the total current increases over time. The probe or beam current remains stable or increases slightly as well (see Fig. 1 for typical trends). Interestingly, these increases are not permanent but can be re-set to initial levels by reducing the pressure and field for several hours.

When operating these sources at these high temperatures and slightly elevated pressures we note that preferential sublimation can occur. This enlarges the (100) and at least the (111) planes which gives a small radius protrusion on the (110) direction which persists. We have grown HfC(110) crystals and fashioned them into emitters as with the (210) sources. Operation of this orientation develops the (110) apex into a very high field region (see Fig. 1). Measurements of I'and B_r will be shown along with data from operation in the XL40 FEG SEM.

These data demonstrate the potential for the HfC(210) or HfC(110) sources. Higher angular intensities are possible as well as the potential for higher electron optical brightness which is due primarily to the ability to use the rounded emitter end-form in the Schottky-type emission regime.

[1] L.W. Swanson and G.A. Schwind, in Handbook of Charged Particle Optics, edited by J. Orloff (CRC, Boca Raton, FL, 1997), Chap. 2, pp. 77-102.

Table I: Brightness comparisons from modeling

Cathode type	Apex size (nm)	V_{ext} (V)	I'_{ave} (@ BLA) (mA/sr)	F (@ apex) (V/m)	B_r ($A/m^2/sr/V$)
ZrO/W	300 flat dia	3500	0.182	0.67×10^9	2.94×10^8
HfC	130 radius	3500	0.282	1.85×10^9	5.63×10^8
HfC	130 radius	5000	16.26	2.75×10^9	2.46×10^{10}
HfC	200 radius	3500	0.108	1.61×10^9	2.32×10^8
HfC	200 radius	5000	7.123	2.40×10^9	1.26×10^{10}
HfC	260 radius	3500	0.04	1.31×10^9	8.60×10^7
HfC	260 radius	5000	1.58	1.95×10^9	2.38×10^9

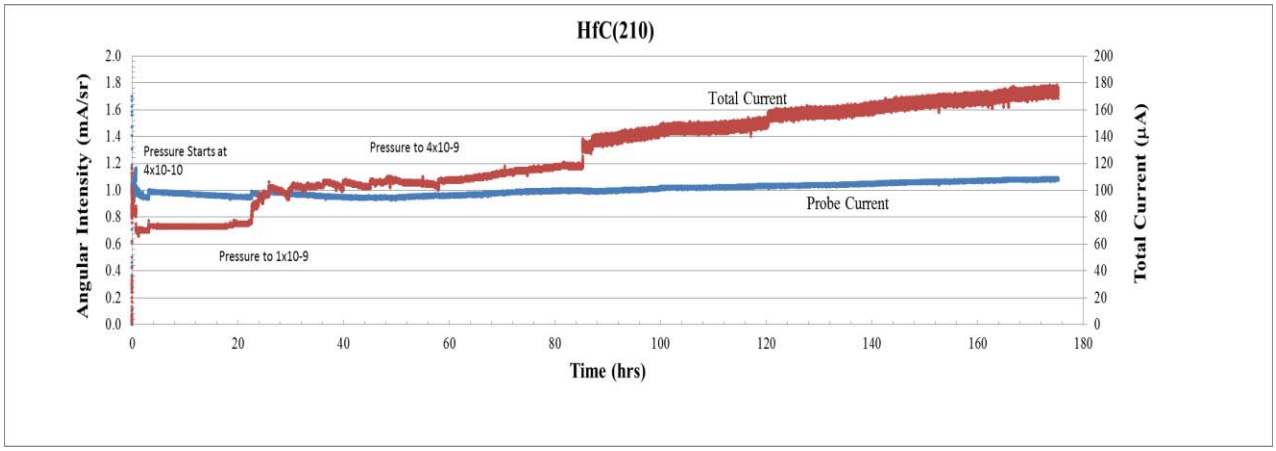
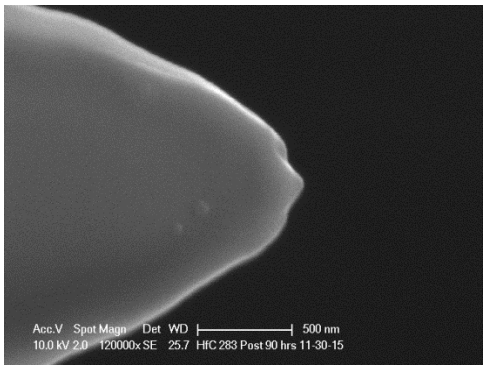


Figure 1: Typical current traces of an HfC(210) emitter operated at 1850 K. Initially operated at a base pressure of 4×10^{-10} torr, then adjusted to 1×10^{-9} torr and finally to 4×10^{-9} torr for the remainder of time. Probe current remains essentially constant but total current increased.

2a



2b

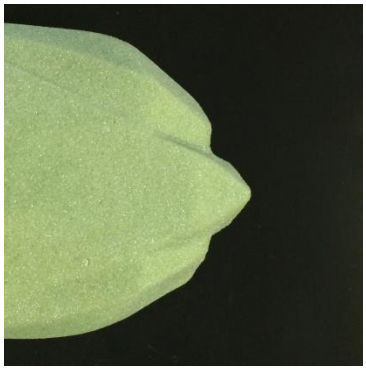


Figure 2: SEM image of the preferentially evaporated HfC(110) emitter on the left (2a). The right image (2b) shows a geometrical model of the surface used to identify crystallographic planes.