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Use of HfC(310) as a High Brightness Electron Sources for Advanced Imaging Applications.

J.M. Lovell[1], W.A. Mackie[1,2], T.W. Curtis[1], and G.G. Magera[1].

[1.] Applied Physics Technologies, Inc. 1600 NE Miller St., McMinnville, OR, 97128, USA.
[2.] Linfield Research Institute, 900 SE Baker St., McMinnville, OR 97128, USA.

This paper continues our work to demonstrate a new electron source for applications where high brightness is required. Thermionic emission and cold field emission are ends in a continuum of electron emission processes; between lays extended Schottky emission (ESE) and thermal-field emission (TFE). Presently, commercial electron sources operate in the extended Schottky or cold field emission (CFE) modes both using tungsten as the base material. It is known that surface tension and field forces contribute to blunting or build-up on these W based emitters. However, HfC sources have activation energy for surface migration much large than for W. This coupled with loosely bound surface contaminants mean operation at elevated temperatures can keep the surface clean but not trigger geometric changes.

Transition metal carbide emitters have very high current capability, can be tolerant of moderate vacuum, and are capable of stable operation over a large temperature range. HfC(310) provides a relatively low work function (~3.4 eV), has a low evaporation rate[1], is resistant to ion bombardment and sputtering, has a high melting point (>4000 K), and a low surface mobility.

Both modeling and experimental performance are reported for HfC(310) cathodes where emission is studied over a range of temperatures to ~2000 K which covers TFE and SE modes. Reduced brightness, energy spread, and stability values were obtained in CFE operation with energy spread (~310 meV) lower by a factor of two and reduced brightness (~3 x 10^8 A/m^2/sr/V) higher by a factor of five than a ZrO/W Schottky source. However, oper$_2$ation in extended Schottky mode resulted in electron optical reduced brightness levels to ~8 x 10^9 A/m^2/sr/V, roughly 10-100x higher than commercial Schottky sources. We use $B_r = I'/(\pi r_v^2 V_E)$ to calculate reduced brightness where I' is angular intensity, r_v is the virtual source radius obtained from modeling, and V_E is the beam voltage.

In terms of angular intensity, HfC sources are capable of higher levels than commercial ZrO/W Schottky sources due to the nature of the material. ZrO/W sources require a balance of electric field and temperature to keep the W-substrate end-form constant. This field/temperature balance is also needed in the supply of ZrO to the apex but puts limits on the angular intensity. HfC sources have no need for a material supply and because of their robustness can be operated at high temperatures and high fields thereby not limiting the angular intensity to a relatively small range. Generally the maximum value of I' for ZrO/W sources is ~1 mA/sr[2] whereas HfC sources have been operated to >60 mA/sr.

HfC(310) emitters with several end-form geometries were operated in a Philips XL40 FEG SEM and compared with ZrO/W(100) emitters operated under similar conditions. Several improvements were noted during operation due primarily to the end-form geometrical differences. For example we compared a ZrO/W emitter with a facet diameter of ~300 nm to a HfC emitter with a rounded end-form radius of ~220 nm.

We were able to obtain much higher beam currents with HfC as compared to ZrO/W sources for identical SEM operating conditions. Fig. 1 compares Faraday cup measured beam currents using the XL40's larger 1200 μm aperture. The extraction voltage range differed slightly; the ranges shown in the figure were 3.5-4.5 kV and 4.0-5.0 kV for the ZrO/W and HfC sources respectively. Note too that the column current is directly proportional to the average angular intensity of the source since the drift tube of the XL40 collects emission prior to the beam limiting aperture; here ~8 μA is roughly equal to ~0.5 mA/sr. The higher axial current delivered by the HfC source is a function of the emission distribution which peaks axially whereas the ZrO/W source has a flat distribution surrounding the axial direction. [2]

Beam current fluctuations over time were also measured in the XL40. Faraday cup measured beam currents we collected over time where we observed standard deviation values of ~0.04% and ~0.07% for ZrO/W and HfC respectively.

There are certainly several differences between ZrO/W and HfC operation. Specifically the nature of the materials necessitates different emitter crystal mount methods; spot welding vs. the Vogel mount[3]. More heater power was needed for the HfC and more heat was generated in the gun which ideally needs to be reduced. Optimization of gun geometry is presently being addressed along with operation under different SEM settings. Rounded vs. truncated emitters are also being explored further.

However, with this work we have documented the potential for the HfC(310) source operated in extended Schottky mode. Broader angular intensities are possible since these sources are not dependent upon a supply function of Zr/O and hence can operate over a larger range of temperatures, fields, and pressures. Of greater importance is the potential for higher electron optical brightness which is due primarily to the ability to use the rounded emitter end-form in the Schottky emission regime.[4]

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[4] The authors acknowledge that financial support was provided in part by Air Force Research Laboratory (AFRL). Joe Hancock is thanked for electronic and vacuum system support.

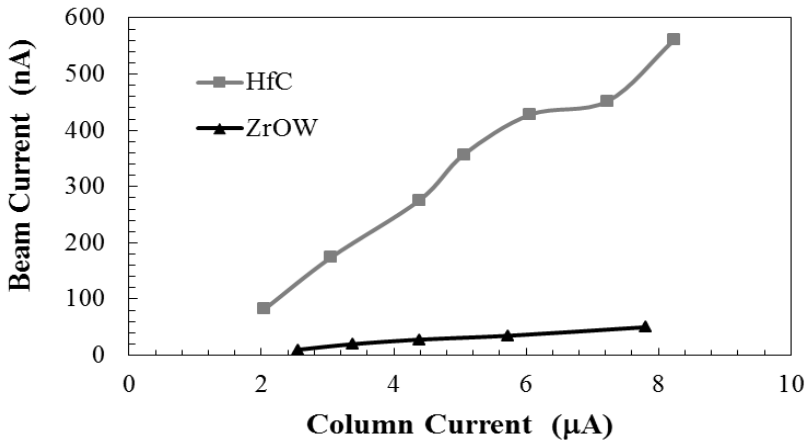

Figure 1. Measured beam currents compared using the 1200 mm aperture and identical SEM settings.

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