Electron Emission from Hafnium Carbide

William A. Mackie and Gerald G. Magera
Applied Physics Technologies, Inc.
1600 NE Miller Street
McMinnville, Oregon, USA, 97128-8486
bmackie@a-p-tech.com

Abstract: HfC was evaluated as a cold field emission source. Single crystal HfC was produced and fabricated into cold field emitters, then angular intensity and reduced brightness were determined from experimental *I(V)* data. Energy distribution data were in agreement with a theoretical model. The reduced brightness, energy distribution, and emission stability are compared to commercially available sources which show that HfC produced a higher brightness and a lower energy spread than a W cold field source or a ZrO/W Schottky emitter. HfC maintains its emission level for one hour in moderate UHV condition; a dramatic improvement over the stability of W. This combined with a durability that allows for frequent flash cleaning without degradation of the emitter end form make HfC a highly promising source. We compared stability and noise to emission from a tungsten tip at the same angular intensity. By increasing the emitter temperature slightly, stability is improved while maintaining a low energy spread.

Keywords: carbide; field emission cathode; hafnium carbide; high brightness; electron source.

Introduction

Past research has studied single-crystal transition metal carbides operating in thermionic or field emission modes.[1] In particular, hafnium carbide cathodes have properties making them attractive candidates for stable emission sources in moderate to good vacuum applications. The use of HfC or ZrC with a (310) orientation provides a relatively low work function emitting surface (3.4 eV) that has a very low evaporation rate, is resistant to ion bombardment and sputtering[2], has a high melting point (~4200 K), and has a very low surface mobility. These field emission sources can operate at high current densities and using the mini Vogel mount can withstand many thousands of flash heating cycles. The robustness of this material has been demonstrated in field emission, photo-field, and thermionic studies.

Experimental

Single crystal HfC with a (310) orientation are electrochemically etched (radii ~200 nm) and Vogel mounted for mechanical stability and to enable flash cleaning and operation at elevated temperatures as needed. Fig. 1 shows typical clean field emission patterns from a (310) oriented carbide emitter. We have operated these

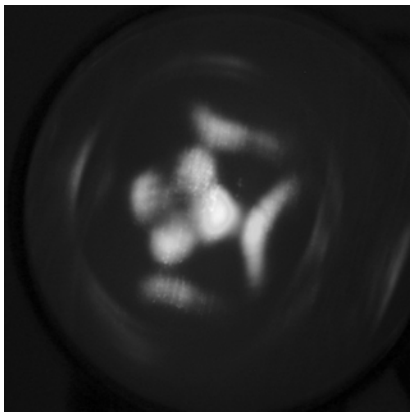

Figure 1: Field emission microscope image of a HfC emitter showing a clean pattern of a (310) oriented field emitter.

emitters at room and slightly elevated temperatures over large ranges of pressures and compiled data on emission stability. We have achieved stable, 300 K emission for hour periods between flashes in UHV. Through use of a relatively simple analog feedback circuit we have achieved even greater stability and have done so for pressures from UHV to 1 x 10^{-7} Torr. In UHV operation at 300 K these cathodes have a low energy spread making them attractive when compared to Zr/O/W Schottky sources for several applications.

Results and Discussion

In an application in which the resolution is limited by chromatic aberrations, one can improve the performance over a commonly used Schottky emitter, by using a cold field emission source (CFE) [3]. Experimental *I(V)* data were taken from which angular intensity and then reduced brightness were calculated. A software program was written to calculate from first principles the FWHM energy spread over a range of geometrical and tunneling parameters. The theoretical model and experimental results are in good agreement. These results are highlighted by the result from a 200 nm HfC(310) operating at 0.02 mA/sr which produces a FWHM energy spread of <300 meV, while producing a reduced brightness of 1 x 10^9 A/cm^2 sr V. When compared to a typical 550 nm ZrOW Schottky emitter operating at its low energy spread mode (0.3 mA/sr) this translates to a 50% (~300 meV) reduction in energy spread while also producing a reduced brightness >5x higher. These HfC results also compare favorably to a

CFE tungsten source due to the ~1.2 eV lower work function of HfC. Both the energy spread and the brightness measurements of HfC are improved over W when compared operating at an equivalent angular intensity (see Fig. 2).

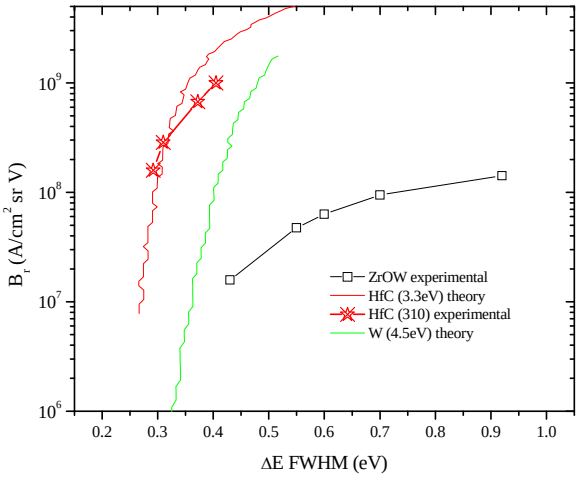

Figure 2: Reduced brightness versus energy spread.

Emission areas for beam or probe currents are quite small, usually a few nm in diameter. Beam instabilities arise from emission sites which can change due to migration of neutral contamination and larger time scale work function changes again due to contamination. By averaging currents over more emission sites it is possible to increase stability as shown in Fig. 3.

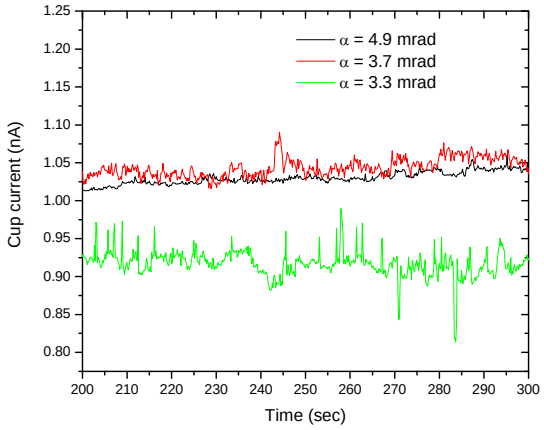

Figure 3: Probe or beam current traces over time for different emission areas.

Another factor which impacts emission stability is temperature (shown in Fig. 4). It is not feasible to control probe current directly in a SEM applications for example. However, we can implement control by utilizing the correlation between the monitor and probe currents. The monitor current comes from an azimuthally symmetric emission area surrounding the beam site. This current is captured on an aperture in the beam path.

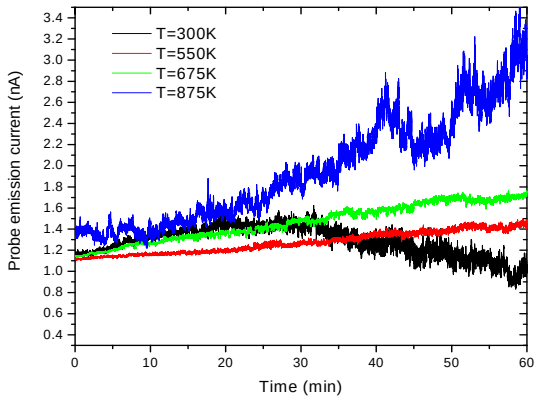

Figure 4: Probe current stability is a function of emitter temperature; higher temperatures increases noise however temperatures just above room temperature seem optimal.

Even with the relative changes in probe and monitor currents, we have demonstrated a marked correlation between the two. While probe current changes are mirrored by monitor current changes, the amplitudes do not always correspond. With the control circuit activated, emission stability and to some extent noise is controlled as seen in Fig. 5.

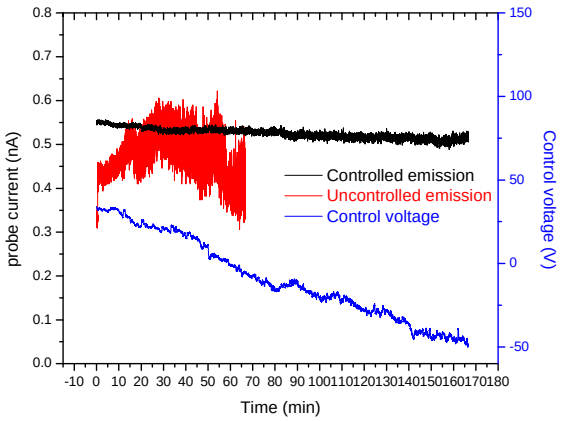

Figure 5: Probe current traces for >2 hours; without control (red trace) and with control (black trace). Shown in blue is the control voltage applied to the extractor.

References

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