Hafnium Carbide Thermal Sources in O_2, CO and CO_2 Environments

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Abstract: *We have tested thermionic cathodes using (210) and (310) oriented hafnium carbide. These have been operated in UHV, and pressures of oxygen, CO_2 and CO to 5×10^{-5} Torr. Emission data show slight initial improvements due to work function lowering. Relatively stable operation at 1900 K in oxygen or CO_2 at 1×10^{-6} Torr is reported.*

Keywords: carbide; thermionic cathode; hafnium carbide; electron source.

Introduction

In general, the transition metal carbides have unique properties that can make them well suited for use as thermionic emitters in areas where conventional cathodes would quickly fail. These uses could entail operation in residual oxygen, CO, or CO_2 atmospheres. The important quantity needed to ascertain the utility of a cathode material is the thermionic work function. Much of the data earlier reported were from sintered material[1,2] or from operation in UHV[3]. Previous work by the authors has shown that HfC had a lower clean work function than that of other transition metal carbides[4] so this work emphasized use of that material.

Electron emission from metal surfaces is well understood. However, there can be several factors which give some uncertainty to the work function calculated experimentally; primarily the value of the reflection coefficient and other pre-exponential factors in Richardson's equation. For this study we assume the pre-exponential constant to have the analytically obtained value of 120 $A/cm^2/K^2$, and obtain the theoretical emitted electron current for the zero field conditions by extrapolation from a Schottky plot (see Fig. 1). In this way we arrive at values of the "effective" thermionic work function which can be a function of temperature for the material under investigation.

Experimental

Single crystal cathode material is grown in our facilities. Stoichiometry is controlled through the addition of carbon to the starting sintered stock and in controlling the zone refining process. The oriented single crystal material is reduced in size to 0.010-inches (250 μm) diameter and pressed into a cylindrical graphite holder as shown in Fig. 2(a). The holder serves to confine the emission to the oriented cathode surface and allows for ease in Vogel-mounting as shown in Fig. 2(b). The cathode is held in a suppressor with the flat emission surface flush with the aperture. An extractor and a phosphor screen finish the electron path and allow for current measurement as well as viewing any changes in emission uniformity. The system base pressure was generally <1 x 10^{-7} Torr.

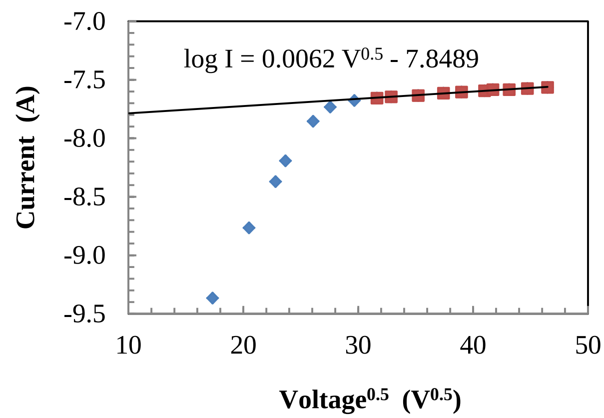
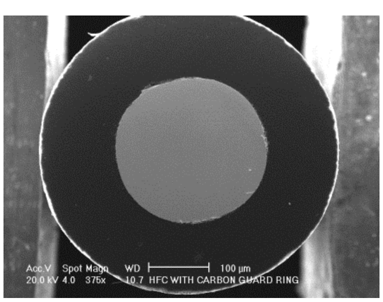
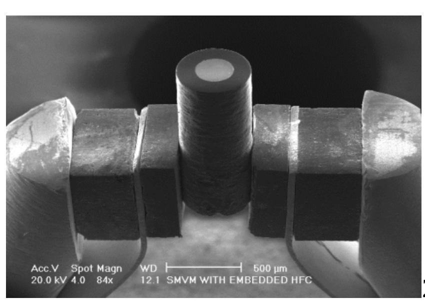


Figure 1: Typical Schottky plot; square root of the extraction voltage vs. log of the emitted current. The temperature limited values are extrapolated back to the theoretical zero field value used in evaluating the work function.



2(a)



2(b)

Figure 2: (a) Top view of 250 μm diameter HfC(310) cathode embedded in graphite. (b) Overall view of Vogel mounted cathode assembly sandwiched between pyrolytic graphite heater blocks.

Results and Discussion

We have operated these thermionic cathodes in several gases (air, O_2, CO, and CO_2) using cathode materials including HfC(210), HfC(310) and for comparative purposes Hf(poly). Pressures have generally been in the 10^{-6} to 10^{-5} Torr range but we have also investigated operation at oxygen pressures to 10 mTorr. A partial table has been assembled to list work function values obtained to date (see Table I).

We have previously seen that the work function is reduced slightly for carbide cathodes when exposed to small amounts of oxygen. The work function as a function of oxygen pressure is depicted in Fig. 3 for a HfC(310) surface. These data follow earlier observations of the decrease in the work function presumably due to an oxy-carbide formation at the surface.

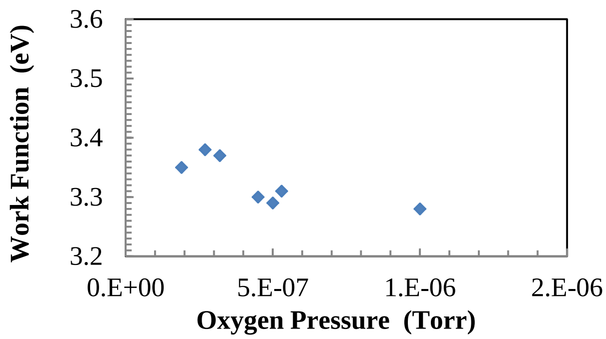


Figure 3: Effective thermionic work function measured at a constant temperature of ~1900 K vs. oxygen pressure.

Operating carbide thermionic cathodes at pressures higher than 5 x 10^{-5} Torr limits the lifetime through accelerated surface evaporation. We have noted an approximate 40x increase over the UHV measured evaporation rate when the pressure is 5 x 10^{-5} Torr at a temperature of 1950 K. When the oxygen pressure is increased further the cathode surface becomes oxidized, EDS studies show carbon removal leaving HfO. Operation in mTorr is destructive to the cathode through a growth of a thick oxide layer even though we do still obtain a reduced emission current.

Operation over time has been examined as well to see if some of the changes noted are long lived. The emission level is sustained while the material is at pressures of oxygen, CO, or CO_2 <1 x 10^{-5} Torr but recovers to the initial values when residual gas pressures are reduced with the cathode operating at ~1900 K during the process. Fig. 4 depicts operation for >500 hours of a HfC(210) cathode with no noticeable damage to the emitting surface.

We have been encouraged by these results and find that at moderate pressures certain gases do not harm the emitter but actually slightly enhance the emission. Further studies are currently underway which we will be summarizing at the conference.

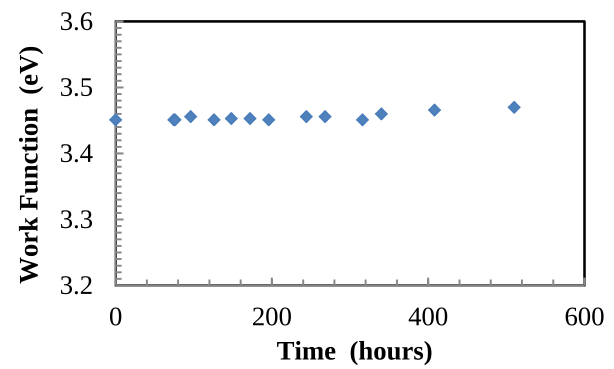


Figure 4: Emission current for a 50 μm HfC(210) emitter operating at 1900 K and an oxygen pressure of 1 x 10^{-6} Torr.

References

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Table I: Effective Work Function Data for HfC and Hf Cathodes

Material	<10^{-7} Torr (UHV)	10^{-7} Torr O_2	10^{-6} Torr O_2	10^{-6} Torr CO	10^{-7} Torr CO_2	10^{-6} Torr CO_2
HfC(210)	3.42 eV	3.36 eV	3.40 eV		3.41 eV	3.39 eV
HfC(310)	3.37 eV	3.35 eV	3.29 eV	3.36 eV		3.35 eV
Hf(poly)	3.75 eV	3.75 eV	3.64 eV			