Cold Field, Thermal-Field, and Schottky Emission from HfC(310) Sources

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Thermionic emission and cold field emission are ends in a continuum of electron emission processes; between lays Schottky emission (SE) and thermal-field emission (TFE). We work with transition metal carbide emitters which have 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 very low surface mobility. A typical clean CFE pattern is shown in Figure 1. Emission noise and fluctuations arise from thermodynamic instabilities with surface atoms moving due to field and chemical potential gradients. It is known that surface tension and field forces contribute to blunting or build-up on W field emitters. However, HfC emitters 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.

Experimental performance and modeling are reported for HfC(310) cathodes where emission is studied over a range of temperatures from 300 K or CFE mode to ~2000 K which covers TFE and SE modes. Typical ZrO/W SE sources are processed to facet the (100) plane at the apex[2]. However, the physical properties of HfC require us to artificially facet or truncate etched CFE emitters, shown in Figure 2, and operate in SE mode using standard electron optical configurations. Reduced brightness, energy spread, and moderate 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. Stable high current operation was also obtained through operation in TFE of an un-truncated HfC(310) emitters.

Operation at elevated temperatures (~1500 K) can lead to changes in surface chemistry too. Past research[3] is re-investigated to understand and possibly control these changes. Figure 3 shows such a change where emission current can increases by 1000x; due to work function reduction[4]. These and other results show the unique and robust nature of the HfC emitter which can lend to improvements for several applications.

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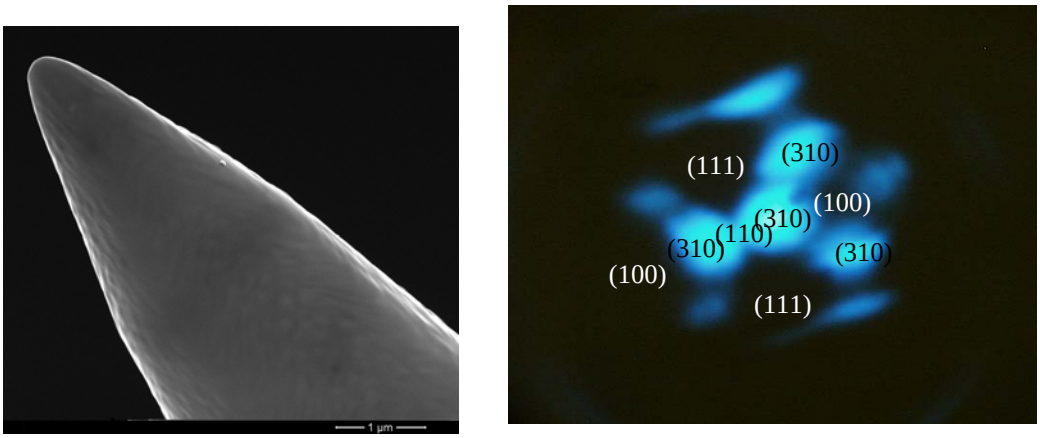
[1] W.A. Mackie and P.R. Davis, *IEEE Trans. Electron Devices*, **36,** 220 (1989).

[2] 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.

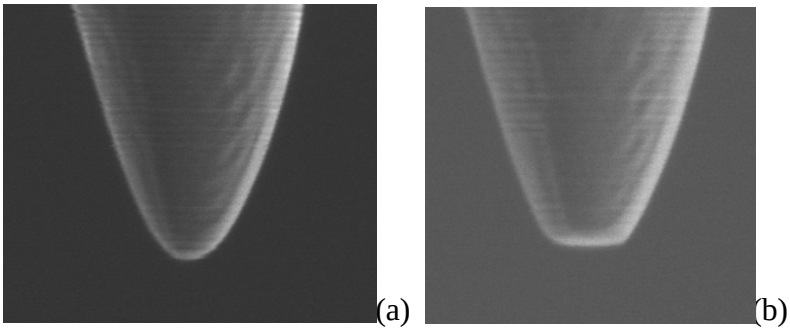
[3] W.A. Mackie, R.L. Hartman, and P.R. Davis, *Appl. Surf. Sci.*, **67,** 29-35 (1993).

[4] W.A. Mackie, R.L. Hartman, M.A. Anderson, and P.R. Davis, *JVST B* **12** (2), Mar/Apr (1994).



(a) (b)

Figure 1: (a) End form of an electrochemically etched HfC(310) CFE, tip radius is ~160 nm. (b) Field emission microscope emission image of a HfC(310) oriented emitter with major crystallographic planes delineated.



(a) (b)

Figure 2: (a) Etched HfC(310) tip with ~100 nm tip radius. (b) Micrograph of same tip after FIB removal of apex creating an ~220 nm flat.

(a) (b)

Figure 3: (a) A typical field emission pattern from HfC where the (310) planes are bright; emission level is ~10 μA. (b) The emission pattern after running for ~300 hours at 1500 K. Here the emission has increased to ~1 mA