Lifetime Performance of Nanocomposite Scandate Tungsten Cathodes

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Abstract: *Nano-composite scandate tungsten cathodes have shown superior performance to other thermionic cathodes. Lifetime emission data is an essential evaluation metric of powder quality for use in vacuum electron devices. Commercially viable large batch scale production of NST powder with lifetime data meeting industry demands will be essential to the vacuum electron device industry. Comparing commercially fabricated NST powder to laboratory NST powder is an evaluation metric for determining powder quality.*

Keywords: Cathodes, nano-composite, scandate, thermionic, high current density, long lifetime, dispenser

Introduction

Nano-composite scandate tungsten (NST) cathodes maintain low work functions like traditional oxide coated cathodes but are favored in vacuum electron devices (VEDs) due to their higher current density capabilities [1].

NST cathodes can offer 10 A/cm^2 emission density at 850°C thereby promising lifetimes on the order of 100,000 hours; they also achieve over 100 A/cm^2 emission current density at 1,150°C without sacrifice in lifetime. NST cathodes are comprised of 1-2 µm tungsten particles sintered into a 25-28% porous tungsten matrix with well distributed 30-50 nm scandia particles, the matrix is filled with a barium calcium aluminate emissive material [2].

Cathode Testing Set-up

Process Summary: A number of cathode emission test vehicles (CETVs) have been built specifically for cathode testing. This includes an UHV cube configuration seen in Fig. 1(a). The CETVs are in a closely-spaced diode (CSD) configuration. Cathodes are installed in CETVs, activated at 1150°C for 24 to 48 hours, and pulse tested.

Cathode Testing Cubes: The CETVs in an UHV CSD configuration were done with simplicity in mind. Each cube is an individual system with a copper anode and heater assembly. The anodes are 1 mm above the cathode's emitting surface. All pellets are machined to fit tightly within titanium-zirconium-molybdenum (TZM) heaters that are surrounded by molybdenum shields to prevent heat radiation under high vacuum.

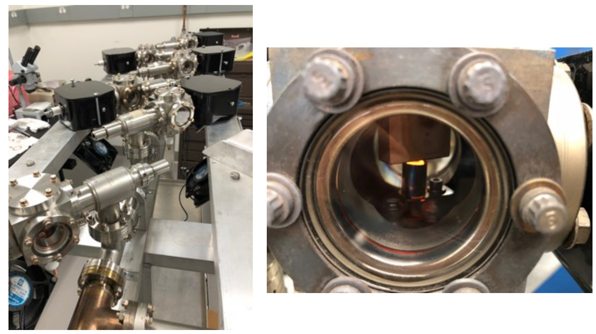

Figure 1. (a) Cathode testing UHV cube system with six cubes. (b) One cathode testing cube using an UHV CSD configuration.

The cubes are separated from each other by high temperature valves connected to a vacuum envelope that allows the entire system to be put under vacuum by a turbo molecular pump. Once the cathodes are installed, the CETVs are baked out to 200ºC for a minimum of 72 hours while vacuum levels are monitored to reach ≤ 5×10^{-7} Torr, then the individual cubes' ion pumps are turned on to achieve vacuum levels of ≤ 10^{-9} Torr. The CETVs' design allows cathodes to be installed and removed easily for quick turnover. The CETVs are designed for pulsed measurement.

The cathode temperatures are measured in degrees centigrade brightness (ºC_{br}) using a disappearing-filament optical pyrometer through a glass window looking in on the heater and cathode assembly seen in Fig. 1(b).

Cathodes are tested by a high-voltage, 2 µs duration pulse with a repetition rate of 20 Hz modulator directly connected to the cathode/heater assembly. Using an oscilloscope, the electron emission current from the cathode is measured through a current transformer [3].

Cathode Performance

To evaluate cathode performance, I-V plots at different temperatures are used to verify emission capabilities. Cathodes are tested immediately after activation and then tests are repeated on a five-week schedule to monitor performance drops. The following plots show cathode emission data immediately after activation followed by lifetime testing for data plotted at 7500 hours and 4000 hours.

The space-charge-limited (SCL) current densities were determined by Child-Langmuir (three halves power) law, from the 1.5 slope of the logarithmic current versus voltage plot. The concentration of Sc_2O_3 observed in the Sc_2O_3-added tungsten powder is 3.5% and 5%.

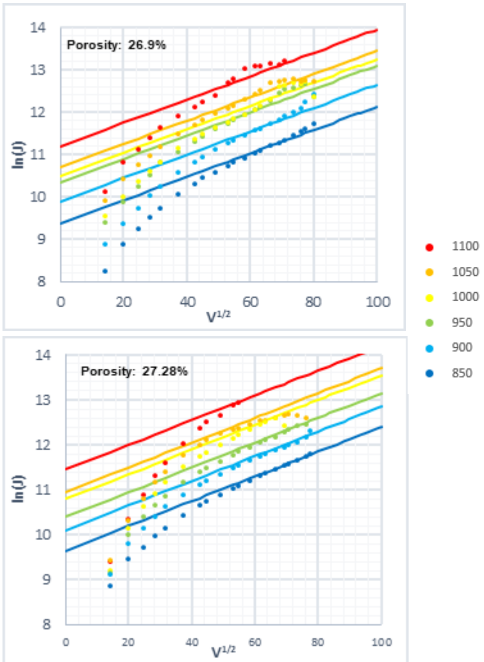

Figure 2. Initial Schottky plot for (a) 5% Sc_2O_3-W lab cathode, (b) 3.5% Sc_2O_3-W commercial cathode, (c) Zero field current density for 5% lab cathode and 3.5% commercial cathode.

J_0, A/cm²	850 °C	900 °C	950 °C	1000 °C	1050 °C	1100 °C
Lab	7.4	12.5	21.2	22.5	33.2	52.2
Commercial	6.6	10.5	14.1	20.4	35.9	42.0

Initial Emission Data: Initial Schottky data for two cathodes following activation is represented by the two plots in Fig. 2. Fig. 2(a) shows plotted data for a UC Davis lab cathode, with 5 wt% of Sc_2O_3-W concentration. The lab cathode has zero field current densities of 12.5 A/cm² at 900°C_{br} and 52.2 A/cm² at 1100°C_{br} in Fig. 2(c). The plot in Fig. 2(b) shows a cathode made from commercial NST material with 3.5 wt% of Sc_2O_3-W concentration. The commercial cathode indicates zero field current densities of 10.5 A/cm² at 900°C_{br} and 42 A/cm² at 1100°C_{br} in Fig. 2(c).

Lifetime Data Evaluation: Fig. 3(a) shows plotted data after 4000 hours for the lab cathode demonstrating SCL current densities of 6 A/cm² at 900°C_{br} and 35 A/cm² at 1100°C_{br}. At 7500 hours Fig. 3(b) has the commercial cathode demonstrating SCL current densities of 7 A/cm² at 900°C_{br} and 31 A/cm² at 1100°C_{br}.

Both cathodes presented in this paper demonstrated performance drops in their lifetime data compared to the initial emission data taken after activation. Dispenser cathodes in many vacuum electron devices can generate zero field current densities of approximately 10 A/cm² at 1150°C with lifetimes of around 1000 hours [2]. Therefore, cathodes demonstrating 31 A/cm² at 1100°C_{br} after 7500 hours and 35 A/cm² at 1100°C_{br} after 4000 hours expresses similar emission characteristics as previously reported NST cathodes.

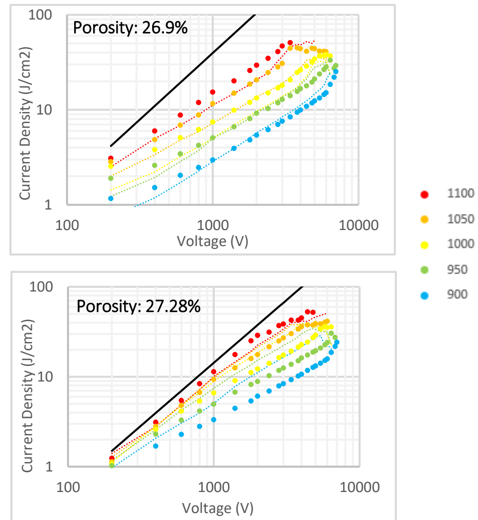

Figure 3. Lifetime emission (a) characteristics of 5% Sc_2O_3-W content lab cathode at 4000 hrs (b) characteristics of 3.5% Sc_2O_3-W content commercial cathode at 7500 hrs.

Conclusion

The commercially produced NST cathode demonstrated comparable performance to a laboratory produced NST cathode. Both cathodes performed comparably to previously reported data for NST material.

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