Recent Progress on Scandate Cathodes

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Abstract: *We report recent progress on scandate impregnated cathodes, including development of a miniature cathode assembly with cathode diameter 0.035 inch and dissipating less than 0.5 watt. Also, the synthesis of new impregnants which provide better barium delivery is reported on. Scandate cathodes, as a rule, are deficient in barium and must be pressed and sintered to low densities to compensate. Auger studies on operating cathodes showing scandium evolution and replenishment are presented.*

Keywords: scandate cathode; impregnated cathode, miniature cathode assembly.

Introduction

The nanoparticles of scandium oxide in scandate cathodes can easily displace half of the pore volume of the tungsten matrix. Normally, the tungsten particles are doped 2-5 weight % with scandium oxide. This has led to insufficient barium-calcium-aluminate in the matrix. Furthermore, the impregnant forms a compound with the Sc_2O_3 [1] that further reduces free barium delivered to the cathode. As a result, BCA content should be about 12% of tungsten weight instead of the normal 6%. To ameliorate this problem, scandate cathodes are generally pressed and sintered to low matrix densities – less than 60% of tungsten solid density vs. 80% on standard all-tungsten cathodes [2]. However, this leads to low matrix strength. We report on new impregnants that deliver more barium in higher density matrices. Because of their greater than 5X higher current density capability, scandate cathodes are good candidates for miniaturization. Pierce guns can be constructed with very small focused beams and modest area convergence. Thus, they offer a way forward for powerful linear beam amplifiers above 75 GHz. We have developed a miniature Pierce gun with scandate cathode only 0.035-inch diameter. *In situ* Auger studies of the evolution of surface elements provides valuable insight into emission mechanisms of scandate cathodes. Scandium atomic surface concentration of 12% is seen within 30 minutes of cathode turn-on. There has been much speculation on the nature of this layer [1][3].

Impregnant Synthesis

We have found that our scandate cathodes are often barium deficient unless sintered at low densities and doped at low Sc_2O_3 levels. Figure 1 shows a portion of the BaO-CaO-Al_2O_3 (BCA) phase diagram.

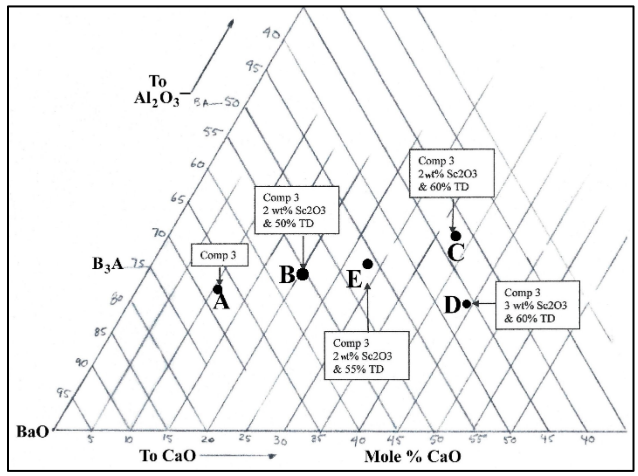

Figure 1. Phase Diagram

Point A shows an often-used BCA composition for a standard pure-tungsten cathode. Points B, C, D, and E show the impact of this BCA on various matrix porosities and Sc_2O_3 weight percentages. We assume a complete reaction of the BCA with Sc_2O_3 to form a Ba-Sc-Al oxide compound with a residue of unreacted BCA. A calculation of remaining unreacted BCA is shown at Points B, C, D, and E. Point B shows BCA content at a 2 wt. % of Sc_2O_3 and a 50% matrix density. This point has shifted notably lower to a BaO only 55 mole % vs. 67% in the nominal (Point A) case. This composition is expected to deliver less barium to the cathode surface. Point C, with a 60% matrix density, lowers available BaO even further. Point D, with an increase to 3% Sc_2O_3, lowers it further again. Points C and D lie in a compositional range that, based on experimental data, renders the cathode unreactive, i.e., unable to supply sufficient barium for operation. Point E is an intermediate case. We have developed impregnant compositions that shift the BaO mole % back toward Point A. Emission results will be presented.

Miniature Cathode Assembly

A diagram of the cathode assembly is shown in Figure 2. The cathode pellet is 0.035-inch diameter and is welded to a molybdenum heater enclosure. This heater enclosure, due to its length, allows sufficient interface area between heater and enclosure to radiatively heat the enclosure at modest heater temperatures. Thus, the heater does not need to be potted, which is impractical at such sizes. The heater is only 0.030-inch diameter, and is the coil-over-coil type. Two heat shields made of ceramic are threaded over the heater leads and prevent excessive heat loss from the back of the heater enclosure. A thin, 0.0005-wall molybdenum-rhenium primary support sleeve is welded to the step on the heater enclosure. It is, in turn, welded at its base to the strengthener bushing. That, in turn, is welded to the crimped sleeve-insulator assembly. The crimped sleeve doubles as a heat shield to capture and reflect radiation coming from the cathode and its support sleeve. The support sleeve also acts as a heat shield. It reflects heat from the heater enclosure. The net result is a cathode assembly that dissipates less than 0.5 watt.

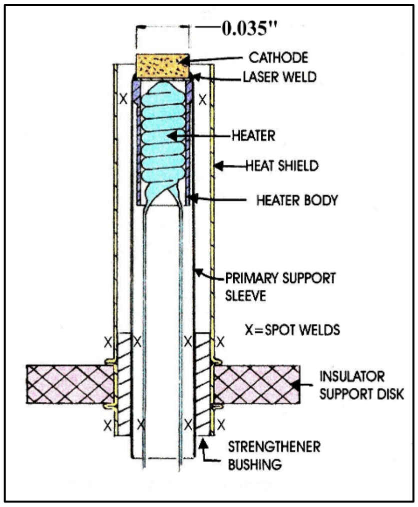

Figure 2. Miniature cathode assembly

Surface Studies on Operating Cathodes

We carried out *in situ* Auger scans on scandate cathodes during activation. Scandate cathodes are activated at 1150º C_b and can take a day to achieve full emission. Emission current is usually extracted during activation. Figure 3 shows the evolution of scandium and other species as the cathode is operated.

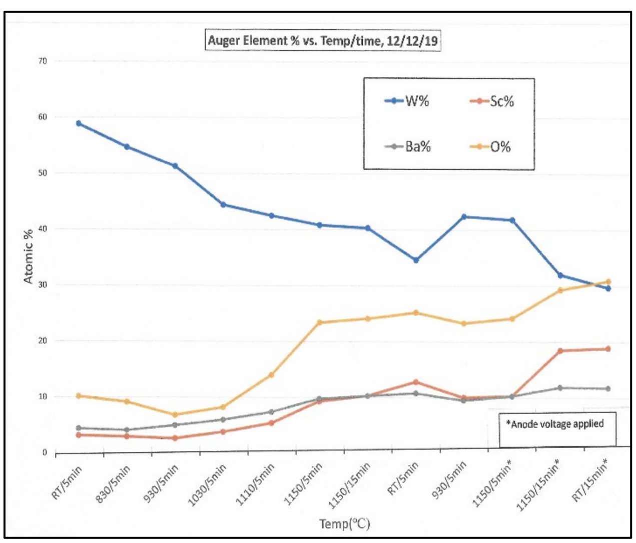

Figure 3. Auger study on activating cathode

An initial argon sputter cleaning was carried out to remove spurious carbon and residues of impregnant left on the cathode. The temperature was then ramped up and Auger scans taken at each step. Scandium, as well as barium and oxygen, is very quick to appear, as shown in the figure. Within five minutes after the cathode temperature arrives at 1150º C_b, the Sc is 9.3 At. %. 15 minutes later, it is at 10.3 – 12.8%. Then anode voltage is applied and 15 minutes later, Sc has reached 19.3%. Moreover, continued operation does not yield a lower tungsten signal (below 30.1%) nor does it yield greater than 19.1% Sc. In other words, Sc saturates around 20% At. We then argon sputtered the surface down to bare tungsten and activated again. The process repeated. Sc rose to 20% and saturated, Ba reached 12% and saturated, oxygen came up to 30.6%, all saturating within 30 minutes.

Conclusions

A scandate cathode only 0.035-inch diameter was developed. At its operating temperature, it dissipates only 0.5 watt. In a Pierce gun, it produced a minimum beam diameter of less than 0.010 inch. New impregnants were developed that allow higher matrix density and higher pellet strength with sufficient Ba delivery. Sc_2O_3 weight percentages above 3% and pellet densities above 60% are now possible. These allow adequate barium coverage of the cathode surface. *In situ* Auger studies reveal scandium atomic percentages of 20% within 30 minutes of cathode turn-on. It continues at 20% for an indefinite time after that. The W1 tungsten signal never drops below 30%. The escape depth of the W1 Auger signal is about 5Å. This argues against a thick, continuous semiconductor layer. Furthermore, after sputtering away the surface layer, the Sc appears again within 30 minutes after cathode turn-on. This is evidence of rapid scandium replenishment even at low cathode temperatures.

Acknowledgments

This work was supported by the DARPA INVEST program.

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