Advanced Nano-Scandate Cathode

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Abstract: Scandate cathodes have the potential to replace conventional cathodes because of their improved emission characteristics. Nevertheless, it remains a challenge in this field to produce scandate cathodes with uniform surface emission in a reproducible manner. In this study, we report on scandate cathode emitters prepared from a novel nano-scandia/tungsten composite powder. Processing improvements have been developed to yield high-quality emitter surfaces. Emission testing demonstrates a greater than 200°C decrease (improvement) in knee temperature versus the standard M-type cathode. There is an on-going effort to quantify the work function of the cathode surface prior to and following activation.

Keywords: scandate cathode, tungsten, scandia nanopowder, knee temperature, work function

Introduction

Vacuum electron devices (VEDs) employ well developed thermionic cathode technology. Standard M-type cathodes, i.e. porous tungsten (W) impregnated with barium calcium aluminate and coated with platinum group metal(s), are the most commonly used emitter in commercial VEDs. However, for longer operational lifetimes or lower operational temperatures, and/or for novel applications requiring higher emission current densities, different cathode compositions have been investigated, with much of the focus on scandate cathodes.[1]

Investigations of the surfaces of scandate cathodes by electron microscopy and photoelectron spectroscopy, aided by computation, have recently been reported in the literature.[2,3] The purpose was to better understand the reason for the high emission current densities exhibited by scandate cathodes, for which there is still not a consensus agreement in the community, although there are two prevalent hypotheses. One is that scandium stabilizes a particular oxide surface structure with a low work function.[4] The other is that scandium acts as a "cleaning agent" to regulate the concentration of oxygen on the tungsten surface.[5]

Many variations of the scandate cathode have been developed, including the pressed scandate cathode, the traditional impregnated scandate cathode, the mixed matrix (MM) scandate cathode, the top-layer scandate cathode, the liquid-solid (L-S) scandia-doped tungsten matrix impregnated (SDI) cathode, and the liquid-liquid (L-L) SDI cathode. The widespread commercialization of these cathodes has primarily been hindered by the nonuniform emission from the cathode surface. A secondary concern is that certain of these processes, such as the sol-gel method used to prepare material for the L-L SDI cathodes, cannot be scaled up to commercial volumes in a cost-effective manner.

Herein, we report on the production of scandia nanopowder and the resulting nano-scandia/tungsten composite mixtures, processing into emitters for cathode assemblies, emission testing, and analytical characterization of work function.

Experimental Procedure

The scandia (Sc_2O_3) nanopowder was produced by Engi-Mat using the Nanomiser® atomization device which is utilized in a combustion-based, chemical process. Trial batches on the order of tens of grams are routinely produced with consistent particle characteristics. Larger production units at Engi-Mat have the capability to produce kilograms of nanopowder per day. The nano-scandia/tungsten composite powder was also made at Engi-Mat via a proprietary mixing technique.

Powder processing and cathode fabrication was performed at Ceradyne. The nano-scandia/tungsten composite powder was pressed into low green density billets, and then sintered to higher targeted densities. The billets were infiltrated with impregnant materials. The processing parameters (pressure, temperature, time) were modified from those used for standard M-type cathodes. Impregnated billets were machined into emitters with the same geometry as emitters used in the manufacturing of the Northrop Grumman M-type cathode. The emitters were installed in cathode assemblies, which underwent emission testing in a Pierce-gun set-up at Northop Grumman.

Analytical characterization was performed at the University of Kentucky. Single cathode pellets (Fig. 1) can be activated in a Cathode Characterization Chamber (CCC), where the work function can be measured before and after activation without removing the cathode from an ultra-high vacuum system. The

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CCC is equipped with the following: heater, pyrometer, residual gas analyzer (RGA), ambient pressure spectroscopy (APS), surface photovoltage spectroscopy (SPS), and contact potential difference (CPD). With the heater and the use of the disappearing filament pyrometer, the cathode can be activated at temperatures up to 1200°C.

Fig. 1. Single cathode heater inside the Cathode Characterization Chamber.

Results and Discussion

Difficulties were encountered when manufacturing emitters from varied nano-scandia/tungsten composite powders. For example, from two powders processed identically, one emitter exhibited an ideally uniform surface, whereas the other displayed catastrophic surface fracturing (Fig. 2). The only difference between the two composite powders was in the average particle size of the scandia nanopowder. To account for the varied material properties, a novel die pressing method was implemented in the manufacturing process.

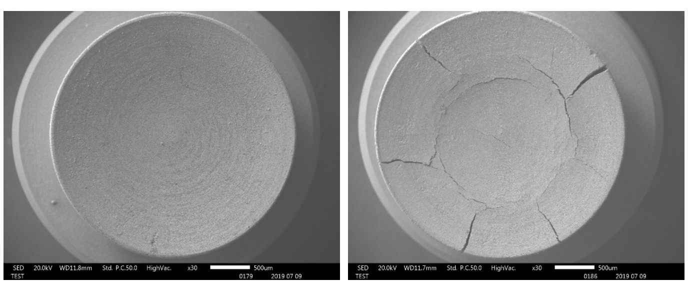

Fig. 2. Scanning electron micrographs of ideal (left) and fractured (right) emitter surfaces.

One of the scandate cathodes demonstrated excellent emission behavior during testing in the Pierce-gun set-up at Northrop Grumman (Fig. 3). A standard M-type cathode, serving as a baseline for the measurement, exhibited a knee temperature at 1100°C. The knee temperature for the scandate cathode was significantly reduced, displaying a value approaching 870°C. Further testing of scandate cathodes at Northrop Grumman is on-going, with results forthcoming.

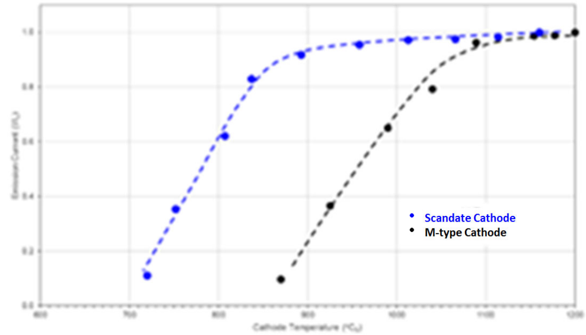

Fig. 3. Plot of knee temperatures for scandate (blue) and M-type (black) cathodes, derived from emission testing in a Pierce-gun set-up.

Prior to activation, the work function of the unactivated cathode will be measured by CPD and APS. CPD can measure the relative work function compared to a known Kelvin probe tip value, whereas APS measures the absolute work function. APS determines the work function by measuring the photoemission in response to illumination of the cathode surface by different ultraviolet (UV) wavelengths.

During the cathode activation sequence, the RGA will collect data on any molecules which are degassed or desorbed from the cathode surface. Following activation, the work function of the cathode should be lower than that of the unactivated cathode. The work function of the activated cathode will be measured by CPD and SPS. Similar to APS, SPS determines absolute work function. The difference is that SPS is effective for measuring work functions below ~ 3.1 eV, while APS is applicable for work functions above that value.

Conclusions

Scandate cathodes were prepared from composite mixtures of scandia nanopowder and tungsten. Novel processing techniques were developed to ensure highly uniform emitter surfaces. Testing of a scandate cathode revealed a considerable reduction in knee temperature versus the conventional M-type cathode. An investigation is underway to characterize the work function of the scandate cathode surface before and after cathode activation.

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