Scandate-added Tungsten Dispenser Cathode Fabrication for 220 GHz Sheet Beam Traveling Wave Tube Amplifier

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Abstract

Nanocomposite Sc₂O₃-added tungsten dispenser cathodes are being developed for a 220 GHz sheet beam TWT (SBTWT) and were tested in Cathode Life Test Vehicles (CLTV) with a Pierce gun configuration under CW mode. In CLTV #1, owing to a perveance issue (there is a 100 micron gap between the focus electrode and cathode emission surface), 10 A/cm² dc current density can be achieved at practical temperature of 1120°Cₑ for more than 2000 hours. In CLTV #2 with a reduced focus electrode gap (30 μm), 45 A/cm² dc current density has been obtained. A collector pulsed current density of 56 A/cm² at 960°Cₑ at 4 kV, and up to 104 A/cm² at 1040°Cₑ was obtained in the CLTV #3 gun with a cathode out of 70 microns beyond electron focus. This CLTV is under CW life testing with 40 A/cm² current density which is the design value for the 220 GHz SBTWT.

Keywords: Sc₂O₃-added W, cathode life testing vehicles (CLTV), high current density

Introduction

As part of the Defence Advanced Research Project Agency (DARPA) initiated High Frequency Integrated Vacuum Electronics (HiFIVE) program, an effort is aimed at the development of a 220 GHz sheet beam gun for a high power travelling wave tube (TWT) amplifier, which can afford a power-bandwidth product of 1000 Watt-GHz [1]. To provide the required cathode with high electron emission current density and long life time, the University of California Davis (UCD) and Beijing Vacuum Electronics Research Institute (BVERI) have been collaborating on scandate cathode development. We have developed both nanocomposite and microcomposite scandate dispenser cathodes using Sc₂O₃-added tungsten powder made by the sol-gel method [2-3]. Using the sol-gel method, Sc₂O₃-added tungsten powders have very uniform particle distribution and nanosize Scandia dispersion. The initial powder particle sizes can be controlled by adjusting the sol-gel processing parameters from nanometers to micrometers. The densified cathode matrix fabricated from the powders has high porosity, uniform grain size and scandia distribution, and open pore distribution. The uniform cathode matrix structure makes the emission surface acquire more uniform barium, oxygen, and scandium distribution, thereby improving the emission uniformity and lowering the work function of the emission surface. This kind of cathode in which nano scandium is dispersed uniformly may be more resistive to ion bombardment.

The emission performance of scandia-added tungsten dispenser cathodes, have been tested in UHV cubes with a closely-spaced diode (CSD) configuration under pulse mode. The Sc₂O₃-added tungsten cathodes have shown excellent emission properties. A space charge limited current density of 40 A/cm² at 850°Cₑ, and 170 A/cm² at 1050°Cₑ have been obtained by using 300-500 nm Sc₂O₃-added (5.0 wt.%) W powders. Cathode life testing at a loading of 50 A/cm² has been conducted at 1050°C for 10,680 h with no sign of degradation. The microcomposite Sc₂O₃-added tungsten cathodes made from 1-2 micron size Sc₂O₃-added W powder can reach up to 160 A/cm² at 1050°Cₑ during pulsed operation, with the elliptical shape machined by conventional computerized numerical control (CNC) mills for the engineering application.

It has been found that the anode effect in diode structures impacts the cathode emission to some extent, especially during life tests. In contrast, testing cathode performances in electron gun open structures will minimize the influence from the anode. Furthermore, the testing results are useful reference for application of cathodes in VEDs. We are developing both modified UHV cubes with a real gun structure, and Pierce Cathode Life Testing Vehicles for cathode testing.

In this paper, we report the cathode testing results of nanocomposite Sc₂O₃-added tungsten dispenser cathode tested in Cathode Life Test Vehicles (CLTV) with a Pierce gun configuration under CW mode.

Experiment Results

The nanocomposite cathodes are tested in new CLTVs shown in Fig. 1 for both pulsed and CW testing. We are developing practical devices shown in Fig. 2 for test and evaluation CW in CLTVs followed by insertion into the SBTWT. The design parameters of the CLTV are: ~ 4 kV DC, 1.0 mm distance between anode and cathode, 0.2091 μF, and 40 A/cm² current emission into a water cooled collector. In CLTV #1, the emission current density was above 10 A/cm² in CW mode for more than 2,000 hours. Since there is a gap with 100 micron spacing between cathode emission surface and focus electrode, the perveance was reduced...
from the design value from 0.209 µP to 0.043 µP, and hence the emission current density was lower than the expected value. The experimental testing results matched very well with the simulation data. The second CLTV gun with reduced FE gap (30 microns) was tested with 0.135 µP perveance. The electron emission is very sensitive to vacuum pressure; when the vacuum fell to $10^{-9}$ Torr, the current emission finally rose to 47 A/cm² CW. Unfortunately, the test time at the high current density was only ~50 hrs due to a vacuum leak. From our CST simulation, it is suggested that with a cathode move of 100 microns toward the anode, this new design will allow for up to 100 A/cm² CW. The CLTV #3 gun with a cathode out of 70 microns (measured after assembly) beyond electron focus is under testing. Preliminary results in CLTV #3 show a collector current density of 104 A/cm² at 1040°Cbr at 4 kV, and up to 56 A/cm² at 960°Cbr. The CLTV is under life testing with a loading of 40 A/cm² CW which is the design value for the 220 GHz sheet beam travelling-wave tube (SBTWT) amplifier for more than 1000 hours until now.

Such Sc-type cathodes offer the promise of the development of a new class of millimeter wave and THz sources.

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**References**

