FIELD EMISSION ARRAY CATHODE MATERIAL SELECTION FOR COMPATIBILITY WITH ELECTRIC PROPULSION APPLICATIONS

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ABSTRACT

Field emission (FE) cathodes are under development for electric propulsion systems because of their superiority over thermionic cathodes in power, mass, and expellant consumption. The electric propulsion systems which could benefit from the field emission cathode technology operate at relatively low power levels which are comparable to thermionic cathode power levels. These systems include low power Hall (<200 W), ion (<200 W), colloid (<5 W) and field emission electric propulsion (FEEP) thrusters (<5 W) and electrodynamic tethers. Hall and ion thrusters require the electron source to ionize the propellant and neutralize the ion beam and thruster charge. Colloid and FEEP thrusters require electron sources to neutralize the thruster charge. Electrodynamic tethers (EDT) require the electron source to drive the electrons out of the tether and through the ionospheric plasma.

Field emission cathodes have already demonstrated compatibility with indium-FEEPs and colloid thrusters. Although the compatibility experiments conducted were only preliminary because of their short durations, the results were remarkably promising. The Mo field emission array (FEA) cathode from SRI International improved the performance of the thruster by >50% with respect to the performance with a state-of-the-art thermionic cathode. This experiment was conducted at a thruster operating point of ~8 μN and 66 μA , which is near to the target operating point for the Laser Interferometry Space Antenna mission. The environment during these missions was not favorable for Spindt-type field emission cathode operation. While the chamber was UHV compatible, the cathode was susceptible to contamination by the partial pressures of oxygen in 10^{-7}-10^{-6} Torr of air and back sputtered indium and aluminum from the ion beam target which was positioned only 1-6 cm from the ion and electron sources. The cathode successfully demonstrated that it could be used to neutralize the thruster charge with remarkable stability while operating at 66 μA and 52 V for approximately 30 min. This cathode consisted of 50,000 tips with 0.9 μm gate aperture diameters. Longer duration testing is required to further substantiate these results and cathode ruggedization will required to achieve mission lifetime requirements of >6000 hours in the spacecraft environment.

Other electric propulsion systems require more advanced field emission cathode configurations and materials for compatibility because of their hostile environments, voltage limitations, and current densities required. EDTs will require 10-20 mA/cm^2 in a low Earth orbit environment, which is predominantly atomic oxygen at 10^{-7} Torr. Field emission cathode materials traditionally used are very sensitive to oxygen. This environment affects the cathode performance with work function and conductivity changes. Experimental results have shown that limited exposure to oxygen during operation produces reversible cathode performance changes. The cathode performance is not affected by the same exposures with the cathode not operating. Prolonged exposure to oxygen during operation does result in irreversible performance changes. Oxygen ionized locally can contribute to tip blunting from ion bombardment if the ion energies exceed the energy threshold for sputtering. Experimental results suggest that this operating voltage limitation exceeds 60 V. For this application, a FEA cathode material is required which is compatible with the cathode fabrication process, has low work function and forms a conductive and low work function oxide in atomic oxygen. The work function required depends on the cathode geometry, fabrication uniformity, and operating voltage limitations. Many materials have been identified for this application and are currently under investigation. Some of these include MgO, NbC, NbNi, ZrC and Pt. These materials have been investigated for their chemical and work function stability in oxidizing environments. The results will be presented in the final paper and presentation.

Even more challenging compatibility issues exist with other electric propulsion applications. Small scale ion thrusters which generate a few millinewtons of thrust require cathodes capable of 10-200 mA/cm^2 in a highly ionized environment. Because these thrusters primarily operate with xenon propellant, the cathodes must operate in a predominantly xenon environment. The low ionization potential of xenon results in a significant population of xenon ions which can sputter the tip material if their energies exceed the energy threshold for sputtering, which has been estimated to be ~36 eV. Therefore the cathode must be operated so that the energy of self-generated and thruster ions bombarding the tips does not exceed 36 eV. Because the testing environment of the thrusters is not UHV, the cathode must also be fairly resistant to contamination by background oxygen. Experimental results have shown that FEA cathodes can be operated in xenon environments similar to the thruster environments without permanent performance degradation, however, temporary performance degradation observed may be attributable to contamination by background oxygen. In this case, the cathode under development for the EDT application should also benefit the Hall and ion thruster applications.

Small scale Hall thrusters could also benefit from a compatible FEA cathode although the hollow cathodes developed for these applications are fairly competitive. A FEA cathode will be absolutely necessary for this thruster to be considered to operate on oxygen when utilizing space resources for the propulsion system propellant on a lunar or Mars cargo vehicle.

As discussed, several electric propulsion systems are under development which could benefit from compatible FEA cathodes. The required material characteristics, material chemical stability and materials to meet the performance demands of the electric propulsion applications will be the focus of this paper and presentation. Experimental results from the materials investigations will be presented.