Reservoir Hollow Cathodes for High Power Ion Engines

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Advanced ion propulsion technologies for use in Nuclear Electric Propulsion (NEP) systems for outer planet exploration are being developed under the Nuclear Electric Xenon Ion System (NEXIS) program. The very high propellant throughput required for NEP applications demands a revolutionary approach to assure adequate cathode performance and commensurate life. In conventional hollow cathodes, the life is limited by degradation of the emitting surface morphology and/or surface coverage. There are four main processes that degrade the surface and the barium adsorbate layer and can lead to insert failure:

1. Depletion of the barium source material.
2. Insufficient production of Ba and BaO because of reaction product buildup at the interface between the impregnant and the tungsten matrix.
3. Inadequate transport of Ba and BaO from impregnant deep in the matrix through the pores to the surface.
4. Closure of the surface pores by deposition of tungsten. The tungsten is likely transported as tungsten oxide vapor, which then dissociates in the emission zone.

A reservoir-type dispenser hollow cathode is being developed to address each of these failure mechanisms, replacing the impregnated-type dispenser cathodes currently used in electric thrusters. This approach exploits four design variables to essentially eliminate these failure modes: matrix material, source material, geometry, and thermal design. The cylindrical porous emitter is made from a W-Ir alloy which has a lower work function than tungsten when covered with a barium and oxygen layer, but is not impregnated with the source material as in conventional impregnated dispenser cathodes. The barium source material is contained in a reservoir surrounding the central emitter. The porous emitter serves as the emission substrate and to provide controlled passage of Ba and BaO liberated from the enclosed source material to the emitting surface. A fine tungsten powder mixed with the source material serves as the required reducing agent to liberate Ba and BaO, so the porous emitter structure does not need to react with the source material as it does in the impregnated cathode.

Decoupling the source material from the emitter surface in the reservoir device addresses all four insert failure modes. W-Ir cathodes have a lower work function than impregnated tungsten, which reduces the emitter temperature required to deliver a specific current density. Impregnated inserts actually oversupply barium for most of their lifetime because the emitter temperature required to deliver the emission current is higher than that necessary for production of adequate quantities of adsorbates. The excess barium does not improve performance, but does more rapidly deplete the finite supply. In a reservoir cathode, the barium supply can be made sufficiently large by design to satisfy the mission life requirements, rather than being limited to the approximately five weight percent of barium calcium aluminate impregnant incorporated into impregnated inserts.

Reaction product buildup on the pore walls of the impregnated matrix, which increasingly inhibits production of barium over life, is avoided in the reservoir cathode. The finely divided tungsten powder provides much more surface area than the interior surface area of the porous impregnated insert. Limitations in the transport of Ba and BaO are also avoided. The loosely packed, highly porous source powder offers much less resistance to vapor flow than the tortuous, impregnant-filled porosity of the impregnated insert.

The porous W-Ir emitter is much less reactive than pure tungsten, so the pores in the emitter do not become clogged with reaction products. This provides a fixed flow resistance, which allows the supply rate to be constant, whereas the supply rate of conventional dispenser cathodes diminishes monotonically over life because the barium must flow from deeper and deeper in the porous insert through pores that become increasingly clogged by reaction products. Deposition of tungsten, hypothesized to occur by dissociation of tungsten oxides, is foreseen to also be reduced. W-Ir has enhanced oxidation resistance compared to pure tungsten and the lower operating temperature will reduce the oxidation rate.

This paper summarizes the development of reservoir cathodes for the 20 kWe NEXIS ion thruster. It includes results of performance testing, thermal characterization and preliminary wear testing.