Hollow Cathode Assembly Development for the HERMeS Hall Thruster

Timothy R. Sarver-Verhey (presenter) and Hani Kamhawi
NASA Glenn Research Center, Cleveland, OH, 44135

Dan M. Goebel and James E. Polk
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA,

Peter Y. Peterson  and Dale A. Robinson
Vantage Partners, LLC
NASA Glenn Research Center, Cleveland, OH, 44135

Presented at Propulsion & Energy 2019
52nd AIAA/SAE/ASEE Joint Propulsion Conference
Salt Palace Convention Center, Salt Lake City, UT
25-27 July, 2016
Presentation Outline

• Introduction
• Cathode Development Approach
• Cathode Characterization Test Results
• BaO Cathode Wear-Test:
  – Cathode Configuration
  – Wear-test Configuration
  – Wear-test Performance Results
Introduction

• **HERMeS Thruster Development for Asteroid Redirect Robotic Mission (ARRM)**
  – Each 12.5 kW HERMeS Hall thruster on spacecraft will be required to process ~1800 kg of Xenon
  – Hollow cathode required to provide 8 – 32 ADC for 34,000 hours
  – Two emitter technologies are being investigated
    • Lanthanum Hexaboride (LaB6)
    • Barium-based impregnated (411, BaO)
Hollow Cathode Emitter Technology Assessment

- Hollow Cathode capability assessed through three activities
  - Cathode Testing
    - Characterization testing to determine temperature & plasma properties to identify cathode configuration to support thruster testing
    - Wear-testing of hollow cathodes at thruster operating conditions
    - LaB6 heater life testing to validate heater reliability
  - Develop mature cathode assembly design for HERMeS thruster
    - Detailed design of hollow cathodes compatible with HERMeS completed
      - Analyzed structural and thermal behavior
      - Prepared for environmental testing of completed units
  - Assess systemic benefits and consequences of use of emitter options
    - Quantify benefits of LaB6 emitter resistance to propellant oxygen contamination
- Cathode emitter option down-select & recommendations expected to be completed by end of Summer 2016
Characterization Testing – BaO cathode results

- **Cathode operating behavior measured:**
  - Emitter temperature measured with internal optical probes
  - Cathode plasma properties measured with probes internally installed
- **Cathode Orifice Size options investigated**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>BaO</th>
<th>LaB6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>83%</td>
<td>158%</td>
</tr>
<tr>
<td>3</td>
<td>58%</td>
<td></td>
</tr>
</tbody>
</table>

- **Results:**
  - Configuration 1 temperature behavior represented best match for stable operation and margin
  - Plasma measurements showed broad plasma distribution on emitter interior
Cathode Configuration for Wear-test

- Cathode Assembly Breakdown:

- Development cathode allowed rapid changes for characterization testing while being compatible with HERMeS TDU thrusters
Thruster Simulator Anode

- Anode incorporates magnetic coil to simulate the equivalent field magnitude imposed by HERMeS thruster magnet coils when operating at nominal run condition
- Mikellides & Goebel have verified simulator design represents HERMeS thruster
Cathode West-Test Set-up

- **Electrical Configuration**
  
- **Data Acquisition System**
  - Data logger connected to software on computer for data monitoring and display
  - Interlocks enabled in software that disables power supply operation in event of limit trip
Wear-test Facility

- VF-56 Test Facility
  - 1.0 m dia X 1.0 m L
  - Cryo-pumped – 2 x 10^{-6} Torr base,
    10^{-4} Torr at run condition
Xenon Feed-system

- **Cleanliness Requirements:**
  - 99.9995% purity xenon
  - Feed-system integrity verified by bake-out & leak-rate testing
    - Per GRC procedures developed for past qual-flight programs
  - Point-of-Use Purity test
    - Collected xenon gas sample for verification by commercial vendor
    - Feed-system passed for all contaminants
Cathode Operating Conditions

• **Steady State:**
  – Discharge Current = 24.8 ADC
    – Incorporating corrections for thruster effects
  – Mass Flow Rate = 1.45 mg/s (14.7 sccm) (7% condition)
  – Keeper current = floating
  – Magnet Current sufficient to generate 180 G field on anode centerline

• Similar conditions as cathode operating in TDU-1 2000 wear-test

• **Data measured**
  – Voltages – discharge, keeper (powered/floating), magnet coil
  – Currents – discharge, magnetic, keeper
  – Mass flow rate
  – Cathode orifice plate temperature
  – AC behavior: discharge voltage, keeper voltage, discharge current
  – Facility Pressure
Wear Test Timeline & Progress

• Wear-test initiated 5/20/2016

Legend:
X = unplanned interruptions
✓ = performance characterizations completed
Green arrow = planned characterizations
Cathode Performance Characterizations

- Parametric Sweep to check cathode operation over entire range
  - Limited operation where necessary – discharge voltage ≤ 30 V
  - Keeper-only operation to provide common check points with cathode performance in thruster
- Characterizations performed every 500 hours
Cathode Operation to Date

• Discharge voltage, cathode tip temperature have been stable
  – Voltage = 14.3 V nominally
  – Temperature = 962 °C
    • Temperature measured with type thermocouple spot-welded to cathode tube at orifice plate weld
    • Decaying temperature may be attributable to changing contact conditions
Cathode Operation to Date (cont’d)

- Keeper Voltage measurements showing variation
  - Changes with test interruptions suggest changes in keeper surface conditions may be factor
    - Facility regeneration at hour 430 may have lead to oxide coating
    - Recovery after performance characterization may indicate removal of coating
Performance Characterization Results

- Discharge voltage exhibited agreement between characterization checks
Performance Characterization Results (cont’d)

• Cathode tip temperature exhibited agreement between characterizations
• Insensitive over flow range
Performance Characterization Results (cont’d)

• Periodic checks over operating range showing consistent behavior
Summary Remarks

- Cathode assembly assessment and development activities are underway to support long-life operation for HERMeS thruster
- Combination of testing, high fidelity cathode assembly design, and system-level integration assessments is being pursued to determine emitter option for use in HERMeS thruster
  - Down-select to be completed by end of this summer
- BaO Cathode Assembly is being wear-tested in dedicated facility at VF56
  - Same conditions as cathode operating in HERMeS TDU-1 thruster being wear-tested at GRC
- Cathode operating parameters have been stable
  - Keeper voltage variation appears related to test interruptions (coating possible culprit)
- Upon completion of 2,000 hour test, cathode condition will be assessed for any thruster-specific wear mechanisms
  - TDU-1 hollow cathode will also be examined