NASA SBIR 2020 Phase I Solicitation

Z10.04 Manufacturing processes enabling lower-cost, in-space electric propulsion thrusters

Lead Center: GRC

Technology Area: TA2 In-Space Propulsion Technologies

Electric propulsion for space applications has demonstrated tremendous benefit to a variety of NASA, military, and commercial missions. During recent flight thruster development projects, NASA has identified manufacturing issues that have resulted in significant costs to achieve performance repeatability and hardware reliability. Without addressing the process and materials issues, both the production of existing thrusters and the development of new thrusters will continue to face the prospect of high costs that limit the commercial viability of these technologies. NASA thus seeks proposals that address improved fabrication processes or materials to reduce the total life cycle cost of electric propulsion thrusters. For example, a proposed component or assembly manufacturing process that improves fabrication reliability could permit reductions in the scope of acceptance testing and thus lower the overall cost of the technology.

Critical NASA needs have been identified in the scope areas detailed below. Proposals outside the described scope shall not be considered. Proposers are expected to show an understanding of the current state-of-the-art (SOA) and quantitatively (not just qualitatively) describe improvements over relevant SOA processes and materials that substantiate NASA investment. Prospective proposers in fields outside of electric propulsion are highly encouraged to apply if they have experiences with manufacturing processes that may be suitable for this solicitation.

Scope Title

Material joining in hollow cathodes

Scope Description

SOA hollow cathodes in thrusters are complex assemblies with metal-to-ceramic (e.g., alumina, magnesium oxide, etc.) and metal-to-metal joints where dissimilar materials may have large thermal expansion mismatches. In such cathodes, operating temperatures can range from 1000 - 1700 Â°C (necessitating the use of refractory metals such as molybdenum, rhenium, tantalum, tungsten, etc.), and material joints must be able to survive in excess of 10,000 thermal on-off cycles without failure. Existing material joining processes used to construct Hall-effect and ion thruster cathodes have demonstrated inconsistencies in joint strength and the presence of impurities that may degrade cathode performance during vacuum operations. Efforts to mitigate these issues have to date contributed to the high cost for the integrated cathode assembly and thruster; thus, making them less attractive for commercial usage, particularly for small satellite propulsion applications. Proposed material joining processes to this area must be compatible with critical high-temperature materials; be performed readily, reliably, and with some economy; demonstrate structural integrity at typical cathode operating conditions; and avoid contaminant release that could degrade the performance of common cathode emitter materials such as barium oxide (BaO) and lanthanum hexaboride (LaB_6).

References:

- M.J. Patterson, "Robust Low-Cost Cathode for Commercial Applications", NASA/TM 2007-214984.
- AWS C3.2M/C3.2:2008, "Standard Method for Evaluating the Strength of Brazed Joints".

Scope Title

High-temperature electromagnets

Scope Description

Thermal management of integrated electric propulsion systems is often challenging, especially for compact micro-propulsion devices or high-power-density systems. For thrusters with electromagnetic coils, such as Hall-effect thrusters or plasma thrusters utilizing magnetic nozzles, these magnetic circuits may experience operational temperatures in excess of 500 ÂºC due to coil self-heating and close proximity to plasma-wetted surfaces; such magnetic circuits, may also need to survive in excess of 10,000 thermal on-off cycles without failure. High wire packing density is frequently desirable to achieve high magnetomotive forces (i.e., high ampere-turns). This is facilitated by small wire diameters with thin insulation, with the drawback of being more susceptible to heating and insulation failure. Existing processes for manufacturing and potting magnetic wire have exhibited instances of insulation and potting degradation during thruster operations that can lead to early thruster failure; however, the associated extensive acceptance testing required to ensure high reliability contributes to the current high cost of thrusters. Proposed solutions to this scope area must be compatible with high ampere-turn, multi-layer electromagnets; be fray-resistant; and avoid performance degradation at the operational conditions indicated above. Any formation of volatile materials under operational conditions, particularly if binders or potting materials are used (e.g., for electrical insulation between wire layers or for thermal management), must be limited so as to preserve the insulating materials' dielectric strength and to remain compliant with general NASA material outgassing guidelines (i.e., < 1% total mass loss and < 0.1% collected volatile condensable material).

References:

- J. Myers et al., "Hall Thruster Thermal Modeling and Test Data Correlation", AIAA 2016-4535.
- ASTM E595-15, "Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment".

Scope Title

Robust ceramics for Hall-effect thruster discharge channels

Scope Description

State-of-the-art Hall-effect thrusters make use of hot-pressed, hexagonal boron nitride (BN) or derivative ceramics, for the machined discharge channel in which plasma is generated and accelerated. The discharge channel (typically with outer diameters between 2 and 14 inches depending on the thruster's power level) must maintain electrical isolation between the thruster electrodes while being subjected to an energetic plasma environment, large thermal gradients and transients, and back-sputtered material from other thruster components or the vacuum test facility. To date, these materials have exhibited substantial lot-to-lot variability in key material properties (including mechanical strength, moisture sensitivity, and thermal conductivity and emissivity) that have resulted in discharge channel damage during vibration, shock, and thermal testing of the assembled thruster. Such material property inconsistencies have thus necessitated costly thruster design features to improve survivability margins against mechanical and thermal shock. Proposed processes to improve the lot-to-lot consistency should focus on the BN family of materials or similar ceramics compatible (i.e., exhibiting low ion-bombardment sputtering yields) with a Hall-effect thruster's discharge plasma.

References

H. Kamhawi et al., "Performance, Stability, and Plume Characterization of the HERMeS Thruster with Boron Nitride Silica Composite Discharge Channel", IEPC-2017-392.

ASTM C1424-04, "Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature".

ASTM E1461-13, "Standard Test Method for Thermal Diffusivity by the Flash Method".

ASTM E1933-14, "Standard Practice for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers".

Desired Deliverables

Phase I: In addition to a final report with supporting analysis, awardees shall deliver NASA material samples from the effort that can be utilized for independent verification of claimed improvements over SOA technologies.

Phase II: In addition to a final report with supporting analysis, awardees shall demonstrate functionality of components derived from the effort when integrated with operating thruster hardware. Partnering with electric propulsion developers may be required.

Expected TRL or TRL range at completion of the project: 2 to 6

Relevance / Science Traceability

Both NASA's Science Mission Directorate (SMD) and Human Exploration and Operations Mission Directorate (HEOMD) need spacecraft with demanding propulsive performance and greater flexibility for more ambitious missions requiring high duty cycles and extended operations under challenging environmental conditions. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct *in situ* exploration of planets, moons, and other small bodies (i.e., comets, asteroids, near-Earth objects, etc.) in the solar system; furthermore, mission priorities are outlined in the decadal surveys for each of the SMD divisions (https://science.nasa.gov/about-us/science-strategy/decadal-surveys). For HEOMD, higher-power electric propulsion is a key element (e.g., the Power and Propulsion Element of the Lunar Gateway) in supporting sustained human exploration of cis-lunar space.

This subtopic seeks innovations to meet future SMD and HEOMD propulsion requirements in electric propulsion systems related to such missions. The innovations would enable lower-cost electric propulsion systems for small spacecraft, Discovery-class missions, and low-power NEP (nuclear electric propulsion) missions while improving the reliability and robustness of higher-power electric propulsion systems to support human missions. The roadmap for such in-space propulsion technologies is covered under the 2015 NASA Technology Roadmap TA-2 (In-Space Propulsion Technologies).