National Aeronautics and Space Administration

Lithium Plasma Sources for High Specific Impulse Ion Thrusters

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Program: SURP

Project Objective: To design and build a lithium plasma source and study the efficiency of lithium plasma generation to support the development of very high specific impulse (Isp) ion thrusters for rapid transportation in the solar system.

FY18/19 Results: Figure 1 shows the calculated performance of the conceptual lithium thruster design (Fig. 2). The magnet sizes and locations were chosen to produce the magnetic field (Fig. 3), which confines the plasma and determines to a large extent the engine efficiency. A lithium vaporizer based on an open heat pipe design (Fig. 4) was developed to feed lithium vapor to an inner stainless steel shell which forms the anode. The lithium is ionized by electrons emitted by a high temperature, resistively-heated tungsten filament cathode (Fig. 5) mounted at the back of the anode. An outer shell of mild steel with rings of samarium-cobalt magnets generates the magnetic field (Fig. 6). The plasma generator performance can be simulated without extracting an ion beam, so this source does not need the two grids and high voltage normally required for an ion thruster. A single grid at the downstream end (Fig. 7) produces the same neutral density an ion engine would have. Designing and building the source proved more challenging than anticipated, so we were not able to test the source. Princeton was able to prepare the test chamber, however (Fig. 8).

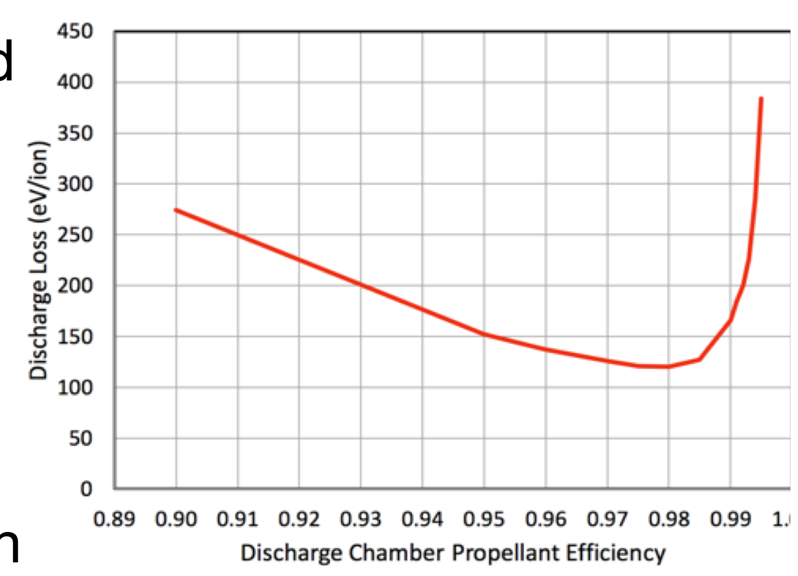

Fig. 1: Plasma source performance curve—energy input per ion expelled in the thruster beam as a function of the fraction of injected propellant that leaves as ions.

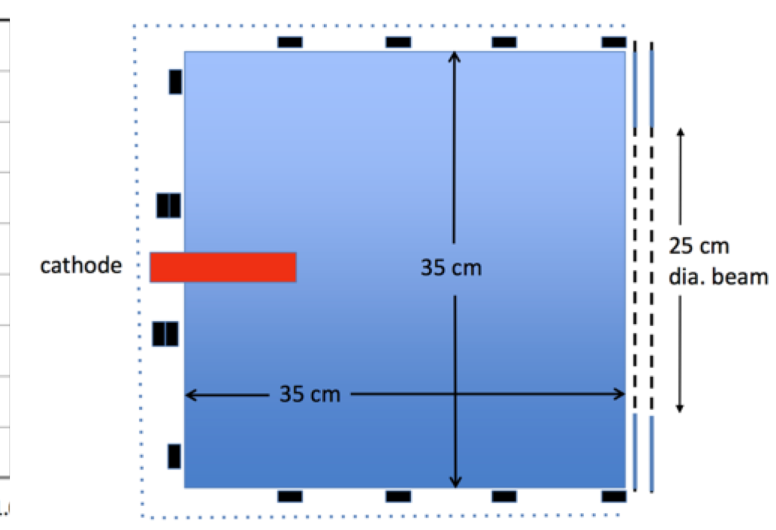

Fig. 2: Conceptual lithium ion thruster design. Lithium vapor injected at the upstream end is ionized by electrons emitted from the cathode. Magnet rings (shown as black rectangles) generate fields that confine the plasma.

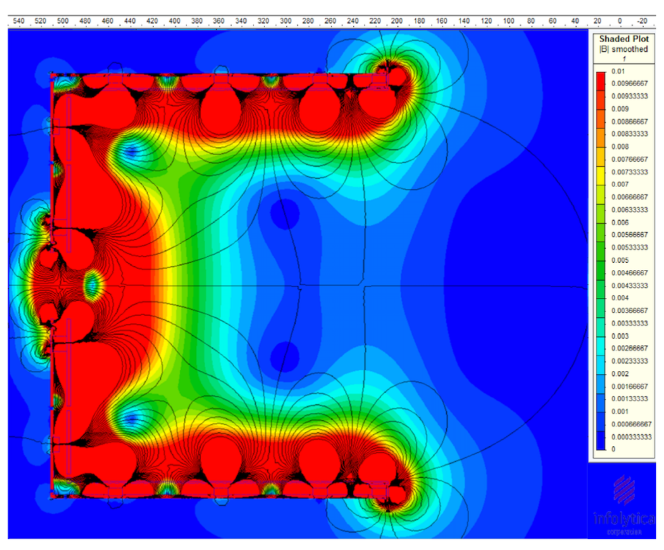

Fig. 3: Cross section of the thruster showing the magnet locations and magnetic field design. Black lines are magnetic field lines; colored contours show magnetic field strength.

Fig. 4: Tantalum vaporizer assembly. Open-ended heat pipe design efficiently vaporizes lithium.

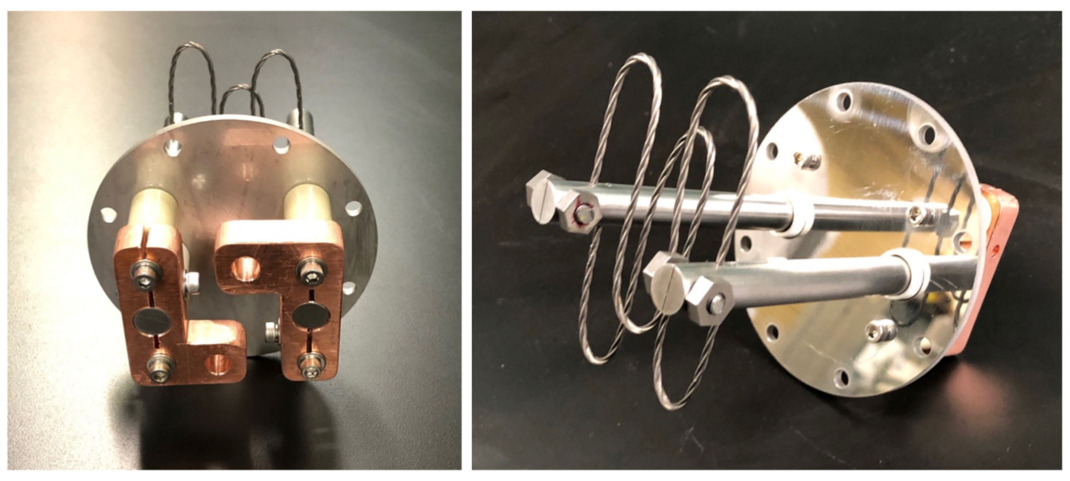

Fig. 5: Tungsten filament cathode assembly

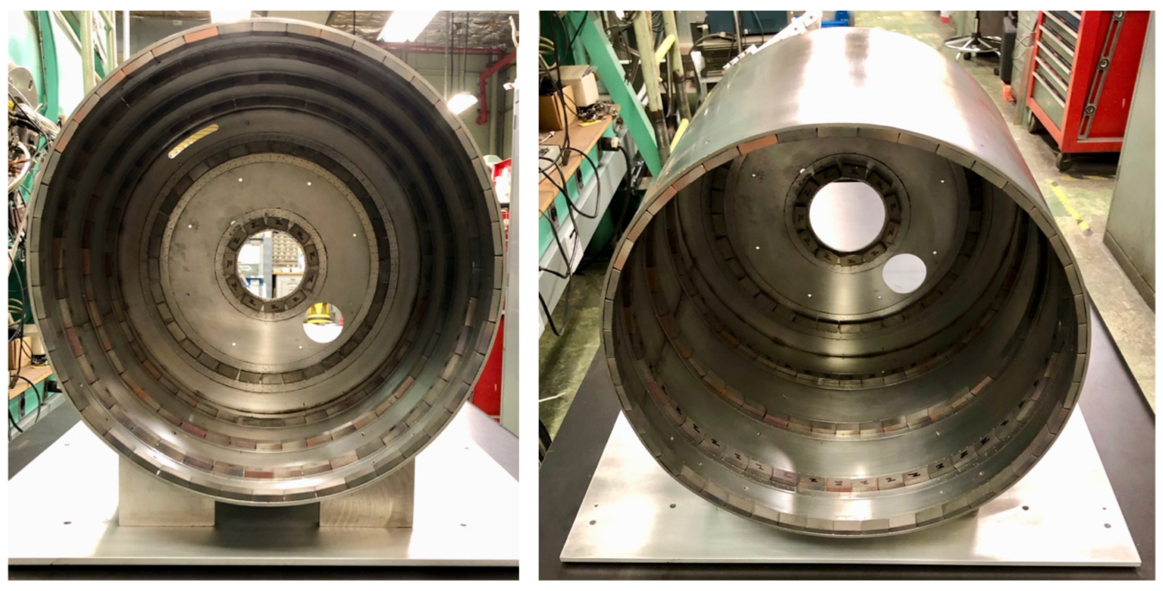

Fig. 6: Outer shell with magnet rings.

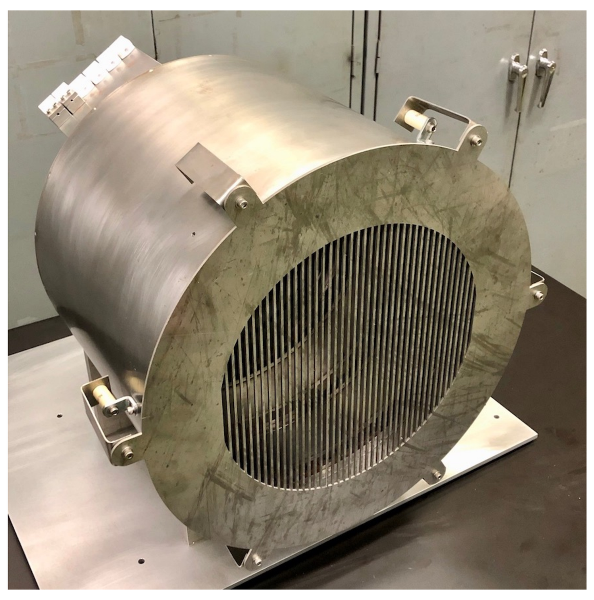

Fig. 7: Assembled plasma source with slotted grid on downstream end.

Fig. 8: Princeton's lithium test chamber—specifically designed to test high power lithium-fed engines. The feed system was modified to deliver the low flow rates required for the ion source.

Benefits to NASA and JPL: The Dawn mission to Vesta and Ceres was enabled by its ion propulsion system, which provided more than 11 km/s ΔV. Although this is by far the largest ΔV ever delivered by an onboard propulsion system, there are possible future missions with even higher ΔVs, in the range of 100 km/s to 200 km/s. Such missions include traveling out to 550 AU from the sun—the distance at which solar gravity lensing could be used to image exoplanets—in less than 15 years; a Pluto orbiter mission with a flight time of less than 4 years; or even human missions to the Jovian system. Such extremely high ΔV missions require a corresponding increase in Isp. A thruster that can provide an Isp of 40,000 s, roughly an order of magnitude greater than the state-of-the-art, would enable missions like these that are currently impossible.

To achieve such a high Isp, lithium is used as the propellant in a gridded ion thruster. Lithium's low atomic mass enables very high Isp at reasonable accelerating voltages. For example, with lithium a voltage of about 6 kV will produce an Isp of about 40,000 s. To achieve the same Isp with xenon (the propellant used in the Dawn engines) would require a voltage of roughly 110 kV. In addition, lithium may be stored as a solid, is easily ionized, and is very difficult to doubly ionize. Lithium's ionization properties should enable thruster operation at nearly 100% discharge chamber propellant efficiency, minimizing neutral gas leakage from the thruster. This minimizes production of the charge-exchange plasma that is responsible for erosion of the ion engine grids and current collection on the spacecraft's photovoltaic arrays, key issues in thruster lifetime and spacecraft accommodation. The work completed under this SURP positions the team to respond to anticipated opportunities at NASA to develop the key technology for this architecture.

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