National Aeronautics and Space Administration

Alternative-Propellant Electric Thruster Cathodes

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Program: Topical

Project Objective:

Background: JPL is the only NASA center to fly electric propulsion (EP) missions to date, and continues to propose new electric propulsion missions for competed and flagship class missions. Emerging missions outside conventional planetary or small body concepts include interstellar precursor and outer planet missions that required extremely high Isp missions. These emerging missions require alternative propellants than the conventional xenon be used.

Objectives: The objective was to design, build and test a lithium hollow cathode capable of up to 50 A of discharge current. Specifically:

1. Develop a hollow cathode capable of operating in alterative propellants (such as lithium, iodine, and sulfur)
2. Develop lithium-oven based feed system capable of providing cathode operation of 50-200 hours
3. Demonstrate operation of the first-generation hollow cathode in lithium in the test facility at UCLA
4. Validate materials compatibility through inspection and DPA of the first-generation cathode after testing

Benefits to NASA and JPL:

Existing EP missions (DS1, Dawn, Psyche), and all of the recently proposed science missions to NASA, use xenon for propellant due to its inert nature, ease of ionization, and good storability (≈1 gm/cc). Alternative propellants, such as those shown in Table 1, can provide additional capability. However, there are significant advantages to using other propellants for some missions. For example, a very high Isp ion thruster can potentially be used in interstellar precursor missions capable of delivering a New Horizons-sized-sized spacecraft in a flight time of about 12 years to over 500 AU; a location where solar gravity lensing can be used to image exoplanets, as illustrated in Figure 1. This propulsion system may also enable rapid transportation throughout the solar system.

In order to achieve such high values of Isp without inordinately high voltages, the ion thruster must run on lithium as the propellant. Using acceleration voltages between 5 and 10 kV, which have been previously demonstrated in high power ion thrusters, the thruster can accelerate the light lithium ions to very high exhaust velocities and thereby achieve high Isp. The demonstration model thruster in development is a sub-scale, 50,000-s, lithium fueled gridded ion thruster that will be tested at up to 50 kW input power. However, there is no long-life hollow cathode for this thruster that will work in lithium. This R&TD program solves that problem by developing a lithium hollow cathode. The cathode technology is also compatible with most of the propellants in Table 1, enabling other types of missions such as cubesats/smallsats with high propellant storage density.

FY18/19 Results:

The technical approach is to design a hollow cathode that uses a thermionic electron emitter and supporting materials specifically selected to be compatible with liquid and vapor-phase lithium. The thermionic electron emitter is lanthanum hexaboride (LaB6), which is a low work function crystal that we have found is compatible with lithium propellant (does not chemically react with most alternative propellants). Testing will be done at UCLA in a dedicated lithium compatible vacuum facility controlled by the partners there in this research.

The innovation is to remove the materials conventionally used to support and heat the thermionic cathode material, and replace them with refractory metals and ceramics that don't react with the alternative propellants. The thermionic electron emitter is lanthanum hexaboride (LaB6), which we have found is compatible with lithium and other alternative propellants. The other parts of the cathode must be compatible with lithium, which is a significant challenge at the temperatures of over 800 ˚C found throughout the cathode construction because lithium is very reactive with nearly all carbon and oxygen containing materials. The prototype version of this cathode uses only molybdenum, tungsten, tantalum and boron nitride in its construction, which is shown in Fig. 2. The lithium reservoir design is based on lithium oven technology where the solid lithium is loaded into the reservoir and is melted into a molybdenum mesh lining the walls where it is vaporized at temperatures above 500 ˚C. The assembly is shown in Fig. 3. The cathode has successfully operated in a special lithium test facility at UCLA at up to 50 A of discharge current in argon and 25 A of discharge current in lithium to date. Operation in lithium in the test facility at UCLA shown in Fig. 4 is seen in Fig.5, where the bright red glow of lithium plasma is shown. Issues with lithium include the build up of lithium on the anode and windows, leading to insulating Li-oxide layers.

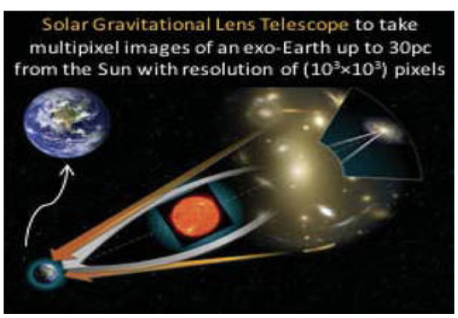

Figure 1. Interstellar precursor mission to 500 AU to use the sun as a Gravitational Lens. Requires Li ion thruster to get there in <12 yrs.

Element	Mass (AMU)	Ionization potential	Isp Relative to Xe	Melting Temperature C	Density (g/cc)
Lithium	6.9	5.4	4.3	180.5	0.53
Krypton	83.8	14.0	1.3	-	<0.9
Tin	118.7	7.3	1.05	232.9	7.3
Iodine	126.9	10.4	1.02	113.7	4.9
Xenon	131.3	12.1	1.00	-	≈1
Cesium	132.9	3.9	0.99	28.4	1.9
Mercury	200.6	10.4	0.81	-38.8	13.7
Lead	207.2	7.4	0.80	327.5	11.3
Bizmuth	209.0	7.3	0.79	271.4	9.8

Table 1. Propellants of interest and their properties.

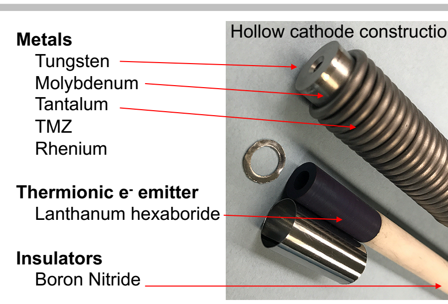

Figure 2. Only materials compatible with lithium used in cathode construction.

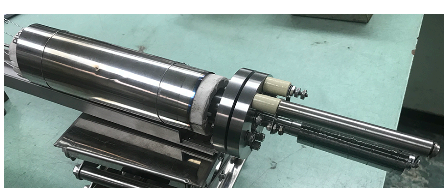

Figure 3. Cathode assembly with lithium reservoir and heater on the left and cathode on the right.

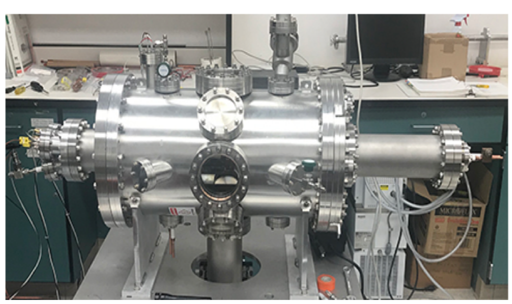

Figure 4. Li test facility at UCLA.

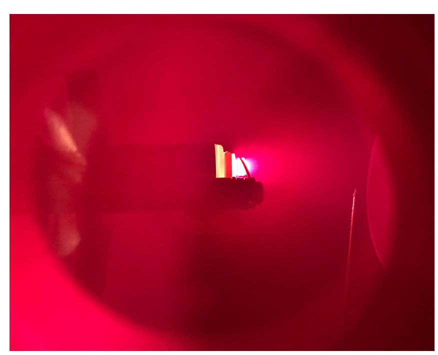

Figure 5. Li plasma discharge at 25 A and 12 V.

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Figure 6. Anode coated with lithium oxide after testing

Publications:

D.M. Goebel, G. Becatti, R.W. Conversano, K.W. Marsh and C. Joshi, "Lithium Hollow Cathode for a Very High Isp Interstellar Precursor Ion Thruster", IEPC-2019-369, 36th International Electric Propulsion Conference, Vienna, Austria September 15-20, 2019.

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