Metal Vapor Hall Thruster Research

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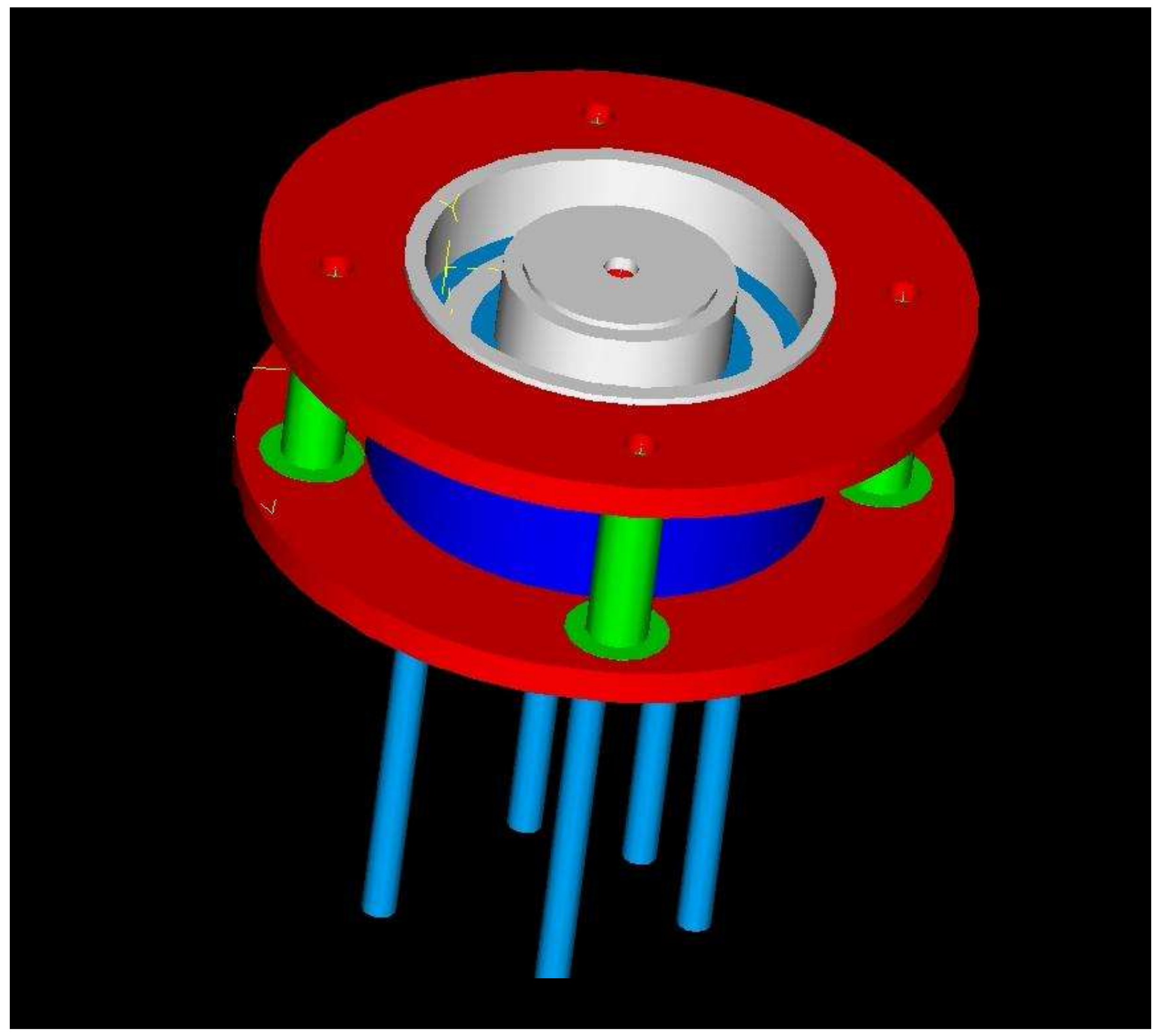
Overview

Hall thrusters use magnetic and electric fields to accelerate and expel ionized gas thereby generating thrust. Typical hall thrusters use a propellent which is gaseous at ambient conditions. Xenon is typically used because it has a low ionization potential and a high atomic weight. A propellent species with a low ionization potential requires less power to prepare, and one with a high atomic weight generates more momentum per expelled ion. Both factors are important in creating an efficient thruster.

Certain metal vapors may offer superior performance when compared to xenon. Bismuth, for example, offers both a lower ionization potential as well as a higher atomic weight. In addition, bismuth costs significantly less than xenon, which reduces the cost of both flight as well as research and development. The primary drawback of using metal vapors as the propellent is that a mechanism to vaporize the solid metal must be included in the design of the thruster.

We propose to build a thruster that uses the waste heat generated by the thruster to maintain the bismuth in the mixed liquid-vapor state. Vapors escaping from the anode will fuel the thruster. The primary method of heat generation is through backstreaming electrons incident upon the anode itself. By using a segmented anode a fraction of the electrons can be deflected from the primary anode thus allowing control over the amount of heat generated in the anode. This, in turn, controls the amount of heat added to the liquid-vapor, thereby controlling the vapor pressure of the bismuth.



Solid model of the proposed thruster. Segmented anode is visible as the blue rings at the base of the chamber.

Plan of Action

Our research currently has three stages that should produce a working laboratory thruster.

1. Analyze the thermal characteristics of the thruster, both in simulation and experiment

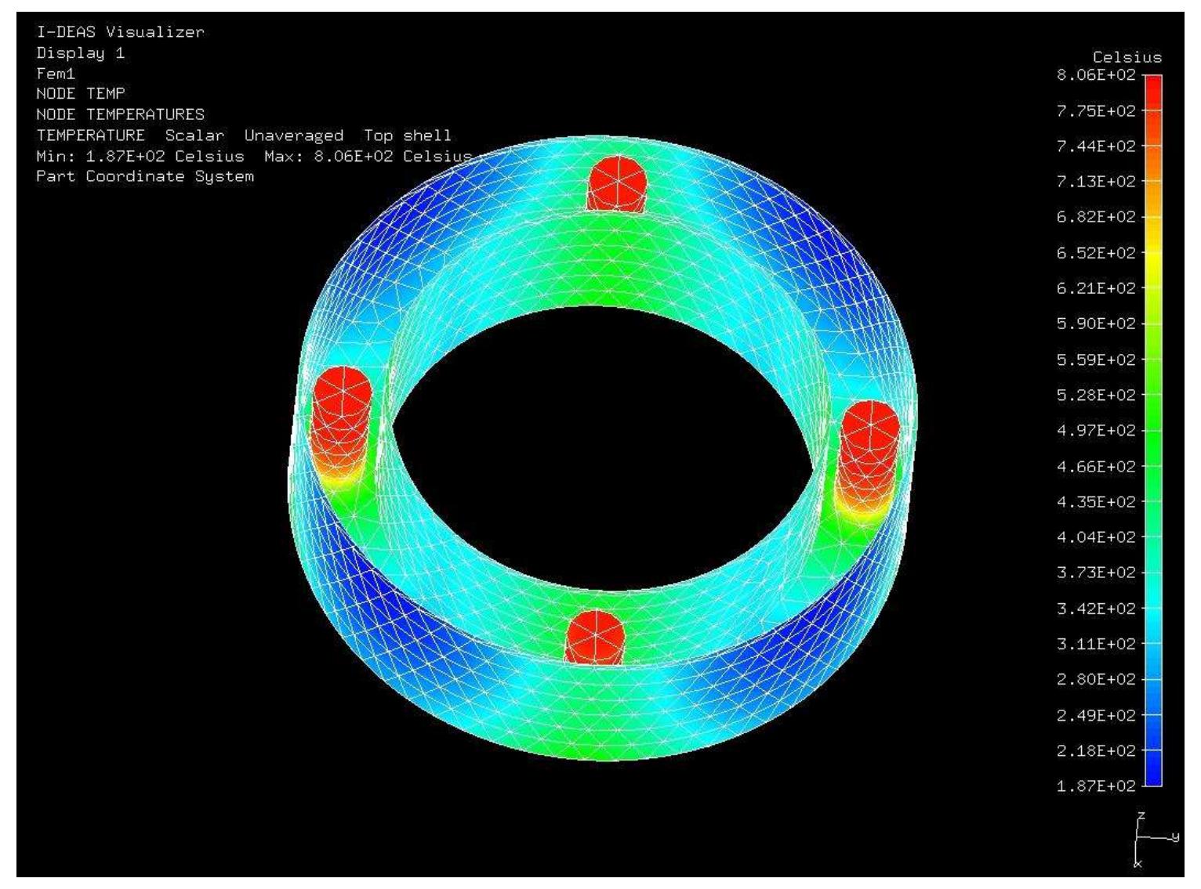
2. Determine the optimal mass flow control mechanism

3. Build the thruster

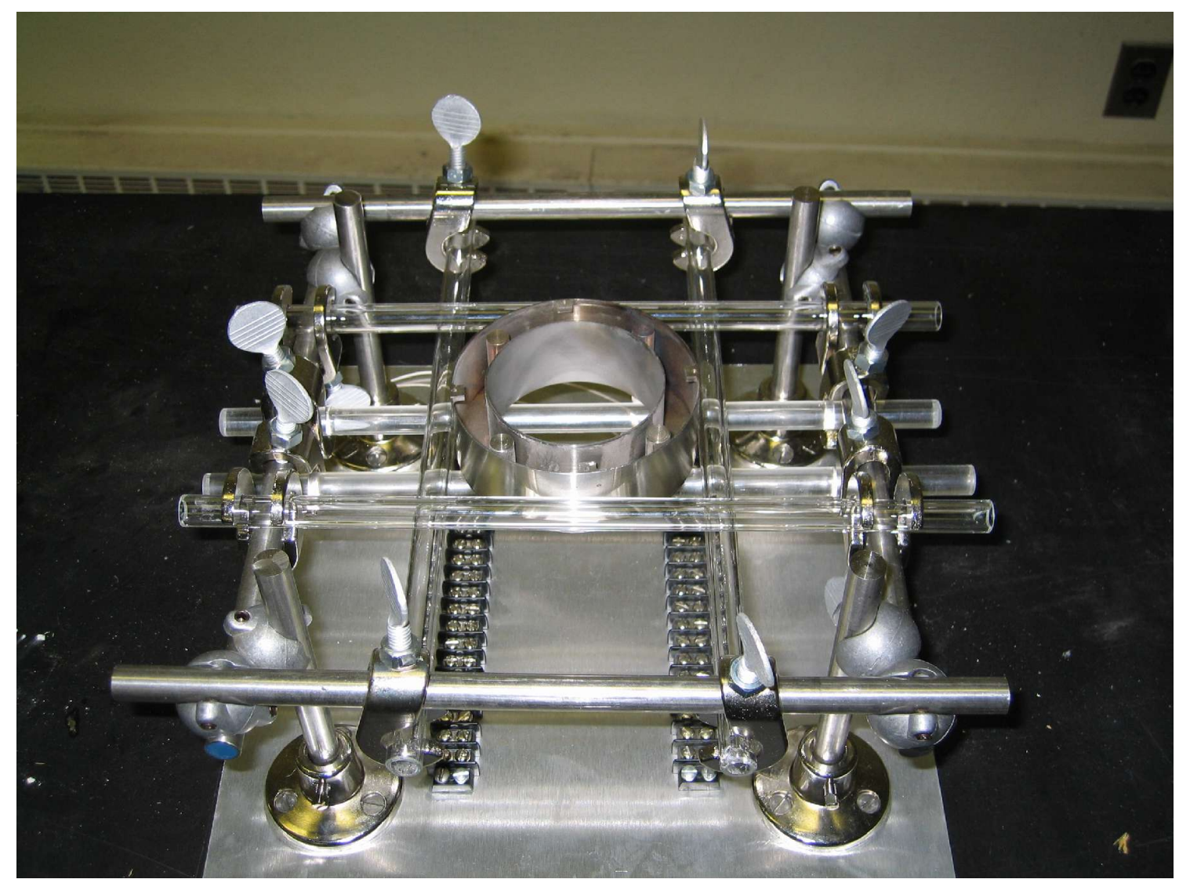
Thermal Modeling

Maintaining thermal control of the thruster is necessary to maintain the bismuth vapors at the correct pressure. The segmented anode should enable this control. In theory, by adjusting the bias voltage between the different anode sections, spatial control over power deposition is gained. We will create a thruster in which one part of the anode is able to retain heat, and the other conducts it away. By adjusting the voltages between the anodes power control, and therefore thermal control, may be achieved.

Practically speaking, the anode assembly must be able to maintain a thermal gradient between the anode segments. To ensure the most efficient functioning, a comprehensive thermal model must be developed. Using the TMG module of I-DEAS 9, work has commenced on the exploration of the conductive and more importantly radiative heat transfer mechanisms within the thruster body.



Thermal model of the mock-up anode



Mock-up anode being prepared for thermal testing.

Thermal Characterization

To fully understand the thermal characteristics of the anode, the thermal model must be checked against real-world data. However, measuring the thermal characteristics of an operating thruster is impractical due to physical and temperature limitations. Therefore, we are validating a mock-up of the anode, which is easier to test. By tweaking the thermal simulation of the mock-up to match the real-world data from the mock-up, we can validate our thermal modelling capabilities and the validity of the thermal model of the actual thruster.

In order to acquire real temperature data from the mock-up anode, we will attach several thermocouples to its various surfaces. The heat will be applied from built-in electric heaters, simulating the effect of backstreaming electrons. All experiments must be conducted within the vacuum environment provided by the space simulation chamber so that convective heat transfer is negated.

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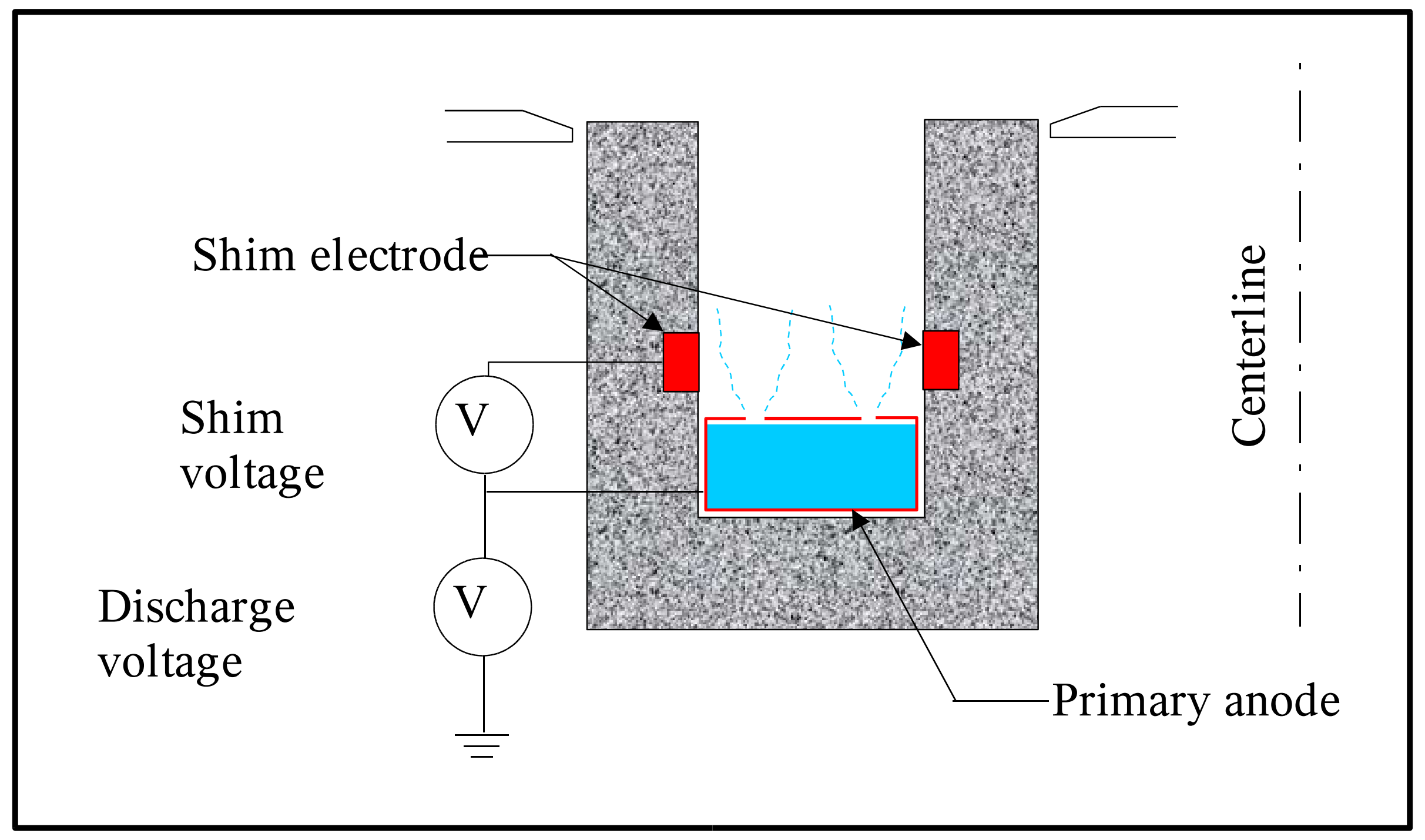
Mass Flow Control

Once the thermal characteristics of the anode are understood, work can begin on appropriate mass flow control. The basic design of the system requires that only a portion of the metal vapors be allowed to pass from the base of the anode into the acceleration chamber. A simple solution to this problem is to introduce a plate permeated with holes that allow the vapor to pass. However, the correct number and size of holes must be determined.

We will heat the mock anode by electric heaters to simulate heating from backstreaming ions. Using this heat we will maintain the bismuth in the liquid metal state. The whole apparatus will be kept inside the space simulation chamber. By collecting the bismuth vapors, which will condense on the first ambient temperature surfaces they contact, we can determine the mass flow rate for a given plate configuration. Through an iterative process, we should be able to arrive at an ideal combination of hole size and coverage for the mass flow control plate.



Cross-section of proposed segmented anode Hall thruster

Space simulation chamber at the Ion Space Propulsion Laboratory