Applied Ion Systems

AIS-TR-030
AIS-EHT1 Micro End-Hall Thruster
Full System Ignition Test 3 - 04/03/2021
Testing Report and Summary
Michael Bretti – 06/26/2022

I. BACKGROUND

The AIS ADAMANT Series thrusters leverages Adamantane, a diamandoid hydrocarbon which exhibits many unique properties allowing for the potential of extreme power and size miniaturization of conventional gas-fed electric propulsion systems, with significantly reduced toxicity and no known corrosion issues like its similar and highly explored cousin Iodine. Currently, the ADAMANT Series is focusing on the development of highly integrated and modular micro-Hall thrusters run purely on sublimated Adamantane fuel. Total system power depending on the thruster is currently aimed from 5W up to 20W for the smallest class systems, with the ability to scale up to more conventional 50W class systems. Despite its unique potential as an alternative molecular propellant for conventional gas-fed EP, little work has been done on Adamantane for use as a fuel in the field.

While Adamantane has been tested a couple of times in literature, this has only been done at much higher power levels in larger gridded ion thrusters at hundreds of watts to kW class systems. Despite successful operation at higher power levels, with performance similar to Xenon, Krypton, and Iodine, Adamantane has been largely dismissed in literature without custom modifications to the chemical composition to overcome some of the inefficiencies inherent to the fuel, and overall testing in the field has been practically non-existent otherwise. Due to its many attractive properties however, such as solid storage, ease of sublimation, high ionization cross-section, high molecular weight, low cost, non-corrosiveness, and low-toxicity, Adamantane has been identified as a key technical enabler in meeting the unique challenges being addressed and inherent limitations in funding and infrastructure at AIS, and fully embraced as the central focus of new development efforts at AIS through the ADAMANT Series, which leveraging the unique properties of Adamantane to overcome conventional scaling limitations in EP technology such as Hall thrusters.

Looking at currently available limited data, and drawing extrapolations from these test results and basic principles of related EP systems and other alternative fuels, AIS proposes that Adamantane can allow for unprecedented scaling of conventional gas-fed EP technologies, allowing for low-power operation and unpressurized feed for the smallest class of satellites in the field. With significantly less toxicity, and no corrosion issues like Iodine, Adamantane has further potential for much greater total system cost reduction using conventional materials in the design of the Hall thruster, neutralizer, and propellant feed system. AIS is also taking a radically unconventional approach towards cathode design to leverage these advantages to create the smallest fully integrated Hall thruster systems ever developed in the field. AIS is currently the leading developer of Adamantane research for micro-EP, and the first and only company in the world to exclusively develop Adamantane for use with micro ion and plasma thrusters.

II. OVERVIEW

This test represents the third full system ignition test of the EHT1 using both the Hall thruster head and GDN1 Glow Discharge Hollow Cathode Neutralizer together with full power electronics. This test builds off of the prior four preliminary ionization and sublimation tests performed using Adamantane fuel and a simple test cell in vacuum (*see AIS-TR-022*, *AIS-TR-*

023, AIS-TR-024, and AIS-TR-025 for further details), as well as the prior preliminary ignition test with a tungsten filament neutralizer (*AIS-TR-026*) and the stand-alone test of the GDN1 neutralizer (*AIS-TR-027*), and first two full system ignition tests (*AIS-TR-028* and *AIS-TR-029*).

In the prior first full system ignition test (*AIS-TR-028*), the full Hall system was run for the first time with both the EHT1 Hall thruster head and GDN1 neutralizer together on Adamantane fuel with full power supplies. During the test a catastrophic plasma flashover caused the extractor supply of the cathode to fail, however stable plasma bridging was still established between the Hall head and neutralizer.

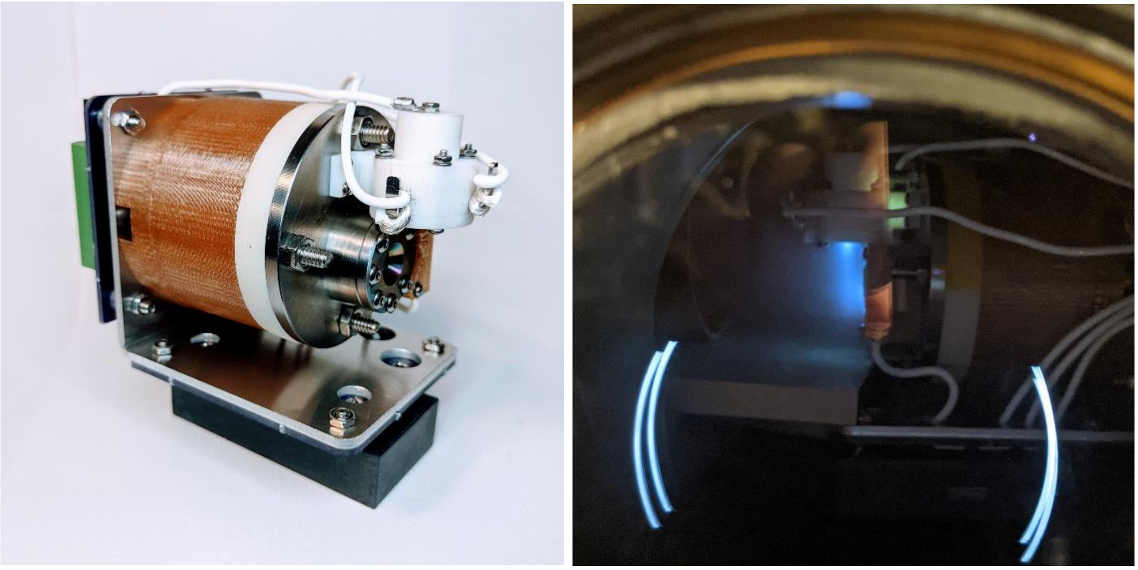

***FIGURE 1:** Fully assembled EHT1 with fuel system, hall thruster, GDN1 neutralizer, and power electronics (left) and stable plasma bridging between Hall head and cathode (right).*

In the second full system ignition attempt, the neutralizer electronics were modified, and more intense plasma bridging was established between the anode and cathode. However, full ignition and beam was not established.

***FIGURE 2:** Stable plasma bridging between the EHT1 head and GDN1 neutralizer during the second ignition test.*

III. PRELIMINARY TEST SETUP

In order to prevent arcing or flashovers seen in prior testing, the aluminum mounting bracket was modified to completely cut out areas around the high voltage points of the main discharge supply.

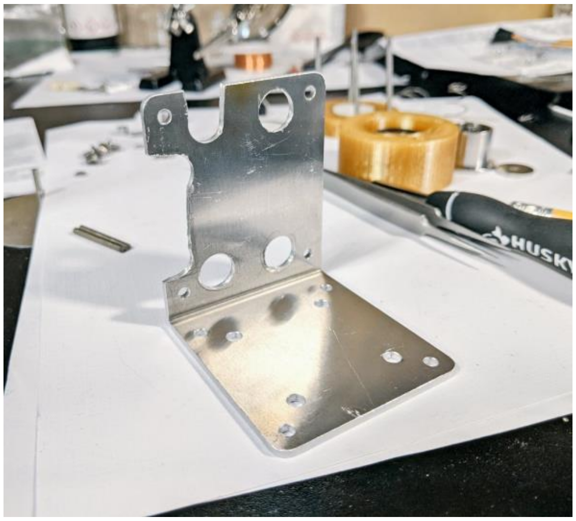

FIGURE 3: *Modified aluminum bracket for electronics mounting.*

In addition, the magnetic field strength was further increased by adding another set of magnets around the Hall thruster casing.

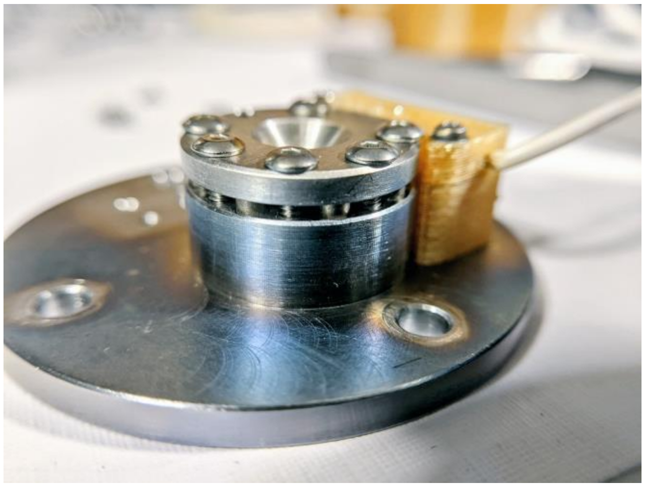

FIGURE 4: *Additional added magnets for increased field strength.*

Finally, the apertures for both the extractor and anodes in the GDN1 neutralizer were increased in diameter to prevent clogging due to amorphous carbon buildup, which casue the prior test to end earlier than expected.

IV. TESTING

The thruster was mounted into the vacuum chamber, electronic connections checked, and the system pumped down. Since no control system had been designed yet, the discharge supplies would be manually controlled via low-voltage external power supplies like prior tests.

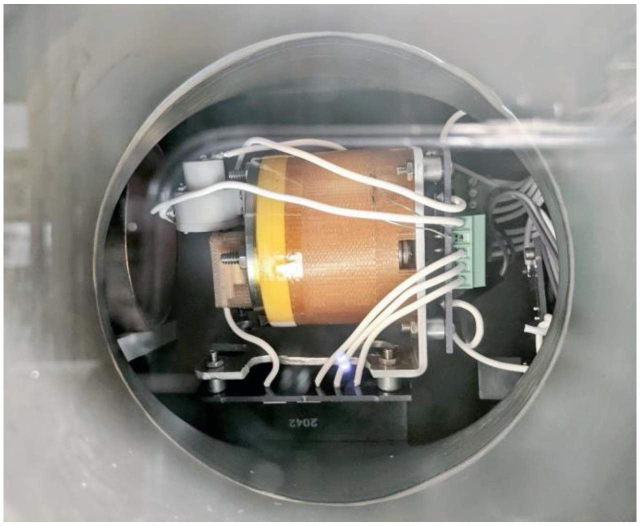

FIGURE 5: *AIS-EHT1 Hall system with modified GDN1 cathode supply mounted into the high vacuum chamber for testing.*

Once vacuum was established, heater power was first turned on and slowly increased to 6.6W of input power. After fuel flow was verified by the increase of pressure in the chamber, the cathode supply was powered on, and brought up to -3kV on the cathode and 500V on the extractor. Glow was established, and eventually stable plume output was initiated. Hall thruster discharge power was turned on and slowly brought up. The supplies were continuously adjusted and main discharge power increased until stable plasma bridging was formed between the anode and cathode.

FIGURE 6: *Stable plasma bridging established between anode and cathode.*

As the main discharge voltage was further increased, the plasma bridge began expanding outwards, and at max power achieved full plume expansion. Discharge power was 15W, and beam current on the Faraday cup was maxing out at over 500uA of beam. Total power on the system was 26W, with 15W discharge, 2W neutralizer, and the rest for sublimation heater power.

FIGURE 7: *Transition from plasma bridging to ignition plume.*

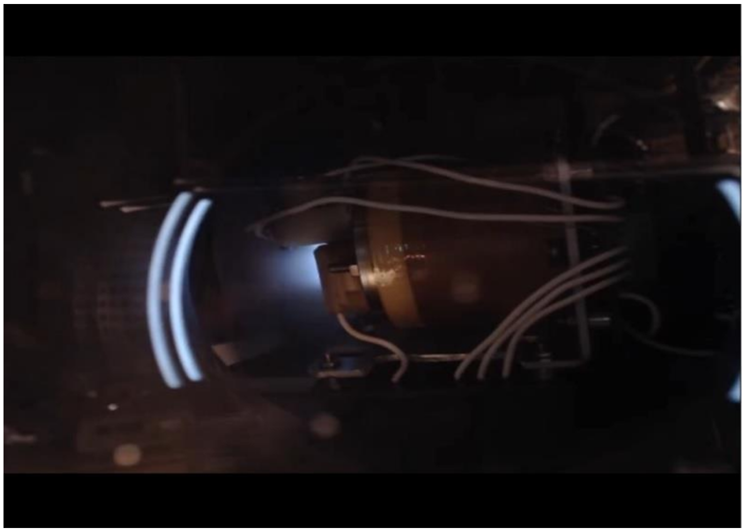

FIGURE 8: *Fully expanded exhaust plume during successful ignition. Discharge power at 15W, cathode power at 2W, total system power at 26W.*

The test was run for about 10 minutes at full power before pressure rise in the chamber increased to significant levels. Thruster power was throttled back to 50% on the discharge, however chamber pressure remained too high to continue safely, and the test was terminated as a result. While plasma background did increase towards the end of the test, no failures or flashovers occurred, and the exhaust plume remained stable. Breakdown was seen around the edges of the Faraday cup during beam bombardment.

V. POST TEST ANALYSIS

After the test, the thruster was removed from the chamber for inspection. Like the prior test, discoloration was present from the hydrocarbon plasma, however the deposit was significantly more noticeable.

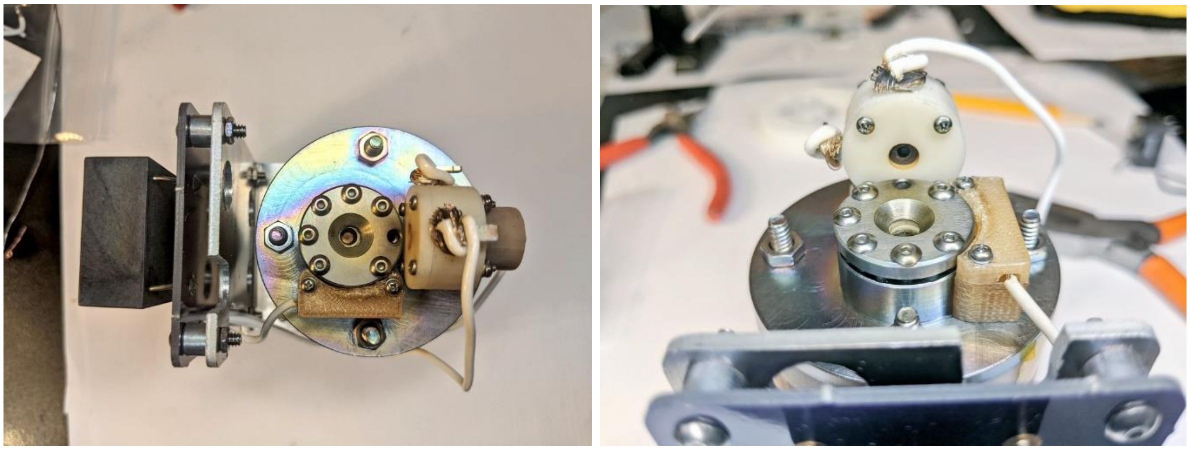

FIGURE 9: *EHT1 inspection after testing. Noticeable discoloration due to hydrocarbon plasma on exposed surfaces.*

Upon examining the thruster more carefully, it was first discovered that the back of the cathode suffered from extreme discoloration. A closer look revealed what appeared to be thermal stress fractures in the Somos PerFORM 3D printed casing. This thermal stress was not present in the prior tests with the GDN1.

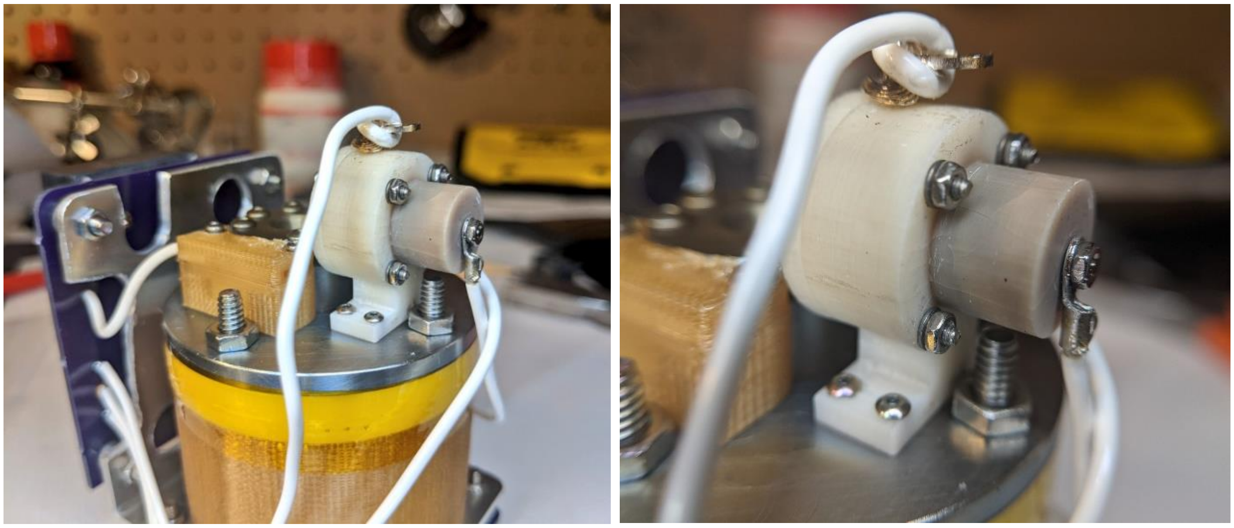

FIGURE 10: *Significant discoloration at the back of the GDN1 Somos PerFORM 3D printed housing due to thermal stresses.*

The cathode was then removed for further inspection and disassembly. Along the full front face, significant discoloration from the hydrocarbon plasma was present. Looking closer at the back, the thermal stress fractures were more significant than anticipated. However, this did not seem to affect cathode performance during the thruster run.

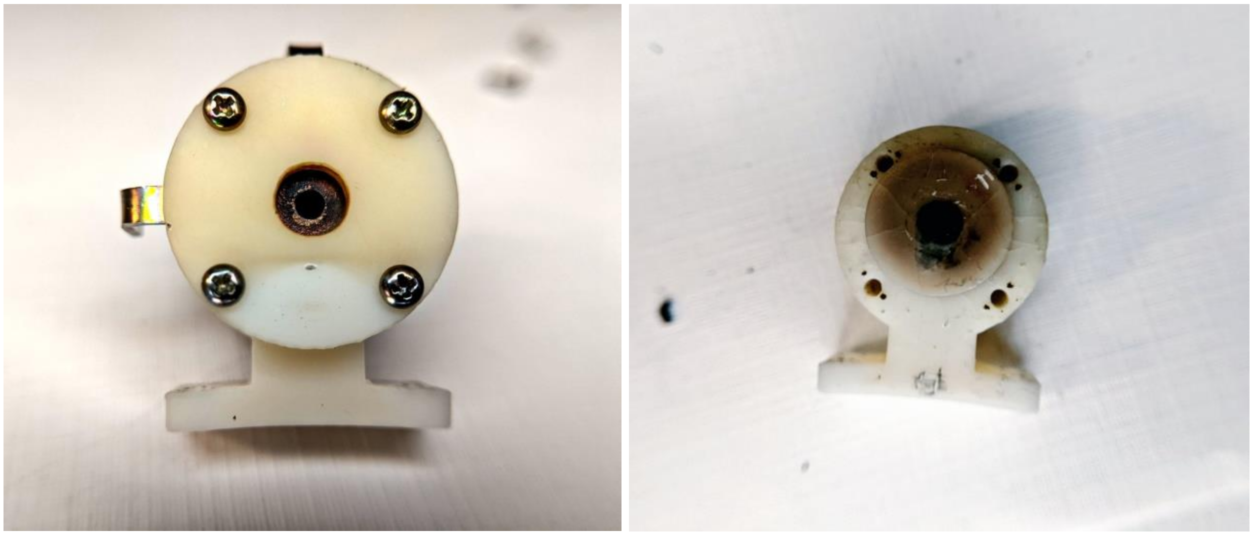

FIGURE 11: *Front of the GDN1 post-test with hydrocarbon discoloration (left), back of the GDN1 with signs of discoloration and thermal stress fractures (right).*

Taking the cover and extractor out first, significant buildup of amorphous carbon deposit was seen on all surfaces in the cathode assembly. Large amounts of buildup occurred during the short run. However, with the increased aperture diameters on the extractor and anode, complete clogging did not occur like the prior test. Unfortunately, this came at a cost of significantly increased fuel flow rate to compensate.

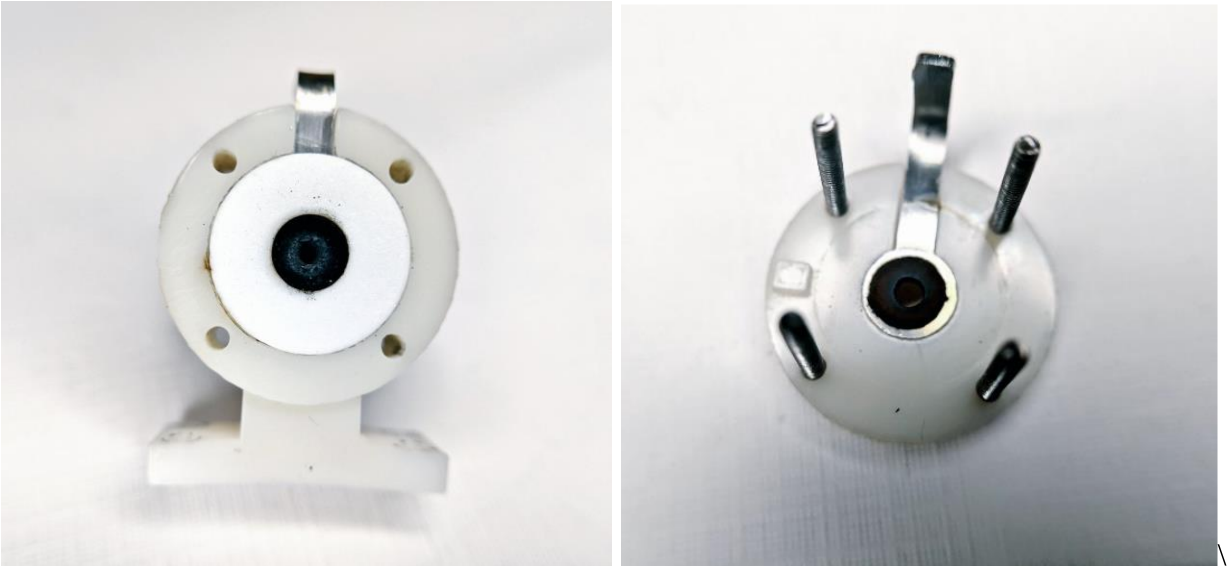

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FIGURE 12: *First insulating washer between the extractor and anode with significant amorphous carbon deposits (left), back of the extractor electrode with amorphous carbon deposits around the aperture (right).*

FIGURE 13: *Front of the anode electrode with amorphous carbon deposits around the aperture (left), back of the anode electrode with amorphous carbon deposits around the aperture (right).*

Looking into the cathode, large amounts of amorphous carbon were also observed. Despite the inlet aperture being relatively small, complete clogging did not seem to occur. However, this could present significant challenges for longer duration runs. Removing the cathode and looking into the back of the housing, severe discoloration and thermal degradation can be seen.

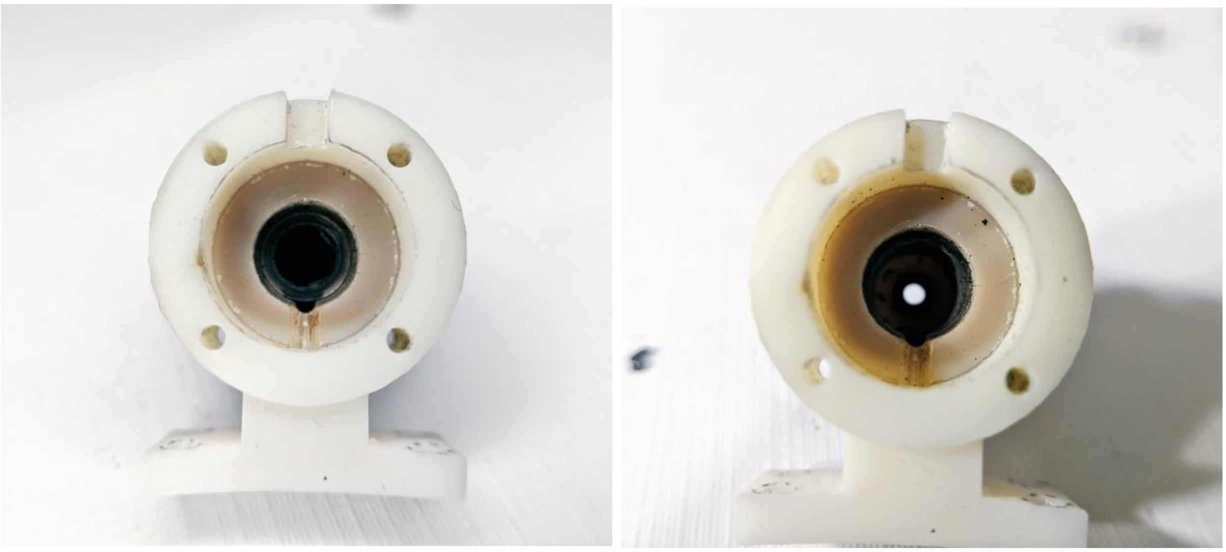

FIGURE 14: *Looking into the GDN1 housing with the stainless steel hollow cathode (left), hollow cathode removed, revealing significant discoloration and thermal damage to the back of the housing (right).*

VI. CONCLUSION

This test marks the third full system ignition test of the EHT1 Micro End Hall Thruster, and the first time the EHT1 and GDN1 have successfully demonstrated full ignition at full power running on purely sublimated Adamantane fuel. Both stable plasma bridging and full ignition was observed, indicated by the shift and expansion of the exhaust plume as power was increased, as well as beam current being read on the Faraday cup. All modifications to the system were successful and resulted in improvements over prior tests, including cutouts around high voltage points on the electronics mounting bracket, increasing the magnetic field strength of the thruster head, and increasing the aperture diameters in the electrodes used in the hollow cathode. During the test, a max power of 26W on the system was achieved during the peak of thruster output, including 15W for the main discharge, 2W for the hollow cathode, and the remaining power for the sublimation heater.

While overall lower performance than other types of Hall thrusters, end Hall has proven a simple, low-cost, scaleable, and reliable topology for low power ignition. Over the course of a number of tests, ignition has been demonstrated across a range of discharge power levels with both a tungsten filament neutralizer and a novel low-power DC cathode. Moving forward, there are a number of key issues that need to be addressed. First, while amorphous carbon deposits have not been seen inside the Hall thruster head, significant deposits have occurred in the cathode, posing serious challenges for long term operation. While increasing the output apertures have resulted in reduced clogging, this comes at the cost of increased fuel flow rates. Second, the GDN1 cathode design needs to be reevaluated for improved thermal handling. This includes increasing the size and mass of the hollow cathode itself, as well as improving the housing design to mitigate thermal issues. For the next iteration of the development, additional thruster topologies such as anode layer Hall can be explored, as well as improved fuel capacity, and implementing an onboard valve for better fuel flow control