Applied Ion Systems

AIS-TR-029

AIS-EHT1 Micro End-Hall Thruster
Full System Ignition Test 2 - 03/27/2021
Testing Report and Summary

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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 second 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*).

Throughout the first four preliminary tests, AIS demonstrated the ability of Adamantane to be sublimated at extremely low background temperatures in vacuum, as low as 11C. Adamantane was also successfully sublimated with very low heater power of 3.5W and less for these tests. In addition, the first instances of ultra-low power ionization of Adamantane for propulsion use was demonstrated, with successful glow-discharge ionization of both passively and actively sublimated fuel from less than 1W to 2W. In these ionization tests, the ionization test cell was configured and successfully operated for a variety of conditions, including general ionization, operation as a glow-discharge hollow-cathode plasma source, as well as both positive and negative charge extraction from the same plasma.

In the first preliminary ignition test, the EHT1 was operated with a simple tungsten filament neutralizer with Adamantane fuel, operating at 50W for the filament and 2W for the primary discharge. During the test, successful beam was established and measured from the thruster, marking the first time a Hall thruster has been demonstrated operating on Adamantane fuel in the field.

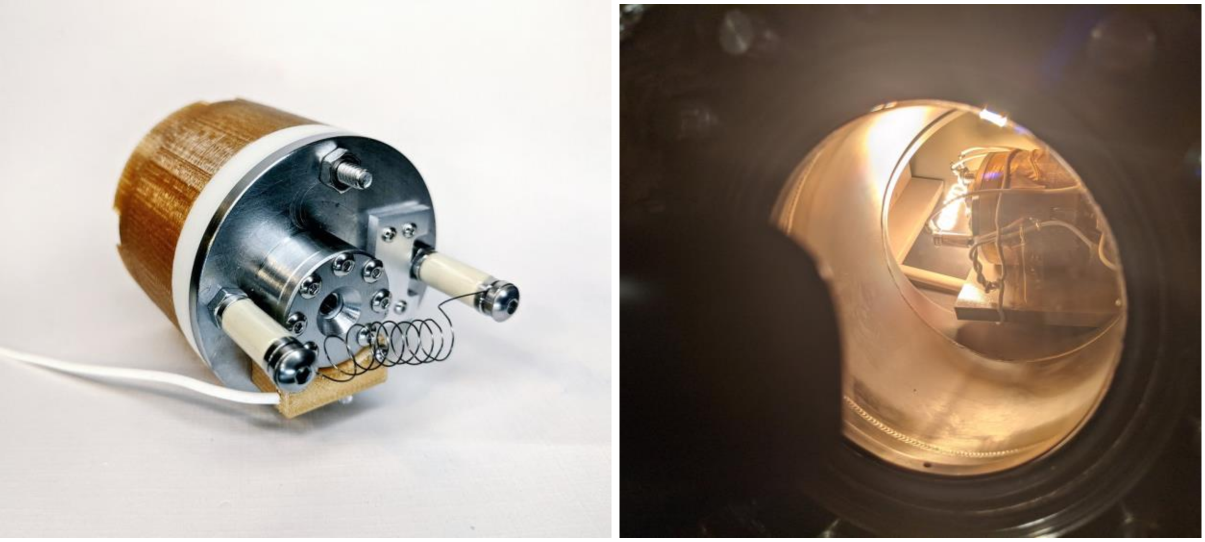

FIGURE 1: *EHT1 with tungsten filament neutralizer (left) and operation in vacuum with Adamantane fuel and the tungsten neutralizer at 50W neutrzlier, 2W discharge during the first preliminary ignition test (right).*

In the next test, the GDN1 was operated by itself to verify use with Adamantane fuel. During this test, a stable neutralizer plasma plume was extracted, operating on only 2W of power for the neutralizer. This was the first time such a neutralizer has been reported in the field.

FIGURE 2: *GDN1 full assembly (left) and operation of the GDN1 with Adamantane fuel on 2W neutralizer power (right).*

Finally, 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.

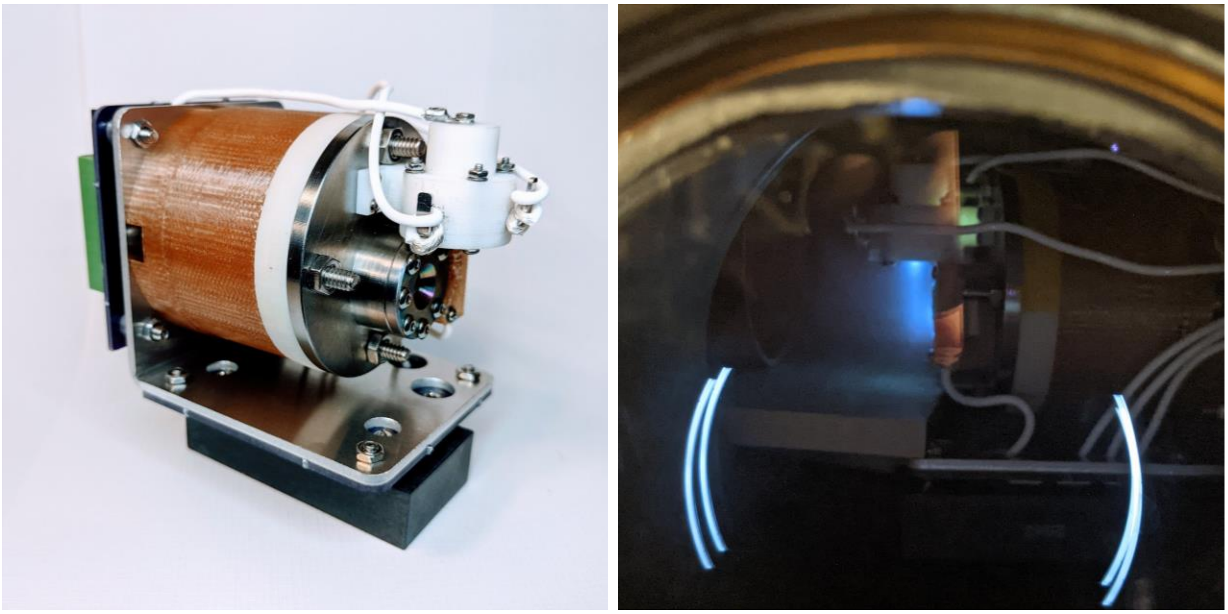

FIGURE 3: *Fully assembled EHT1 with fuel system, hall thruster, GDN1 neutralizer, and power electronics (left) and stable plasma bridging between Hall head and cathode (right).*

III. PRELIMINARY TEST SETUP

During the prior full system ignition test, a catastrophic plasma flashover as a result of excessive outgassing from neutralizer beam bombardment of a PEEK plate used for fixturing the thruster in the chamber caused the cathode supplies to fail. In order to run the hollow-cathode, the makeshift power board used in the prior hollow cathode ignition test (*see AIS-TR-027 for further details*) was utilized and jumpered to the neutralizer auxiliary supply board. All other thruster preparations remained the same as prior testing (*see AIS-TR-028 for further setup details*).

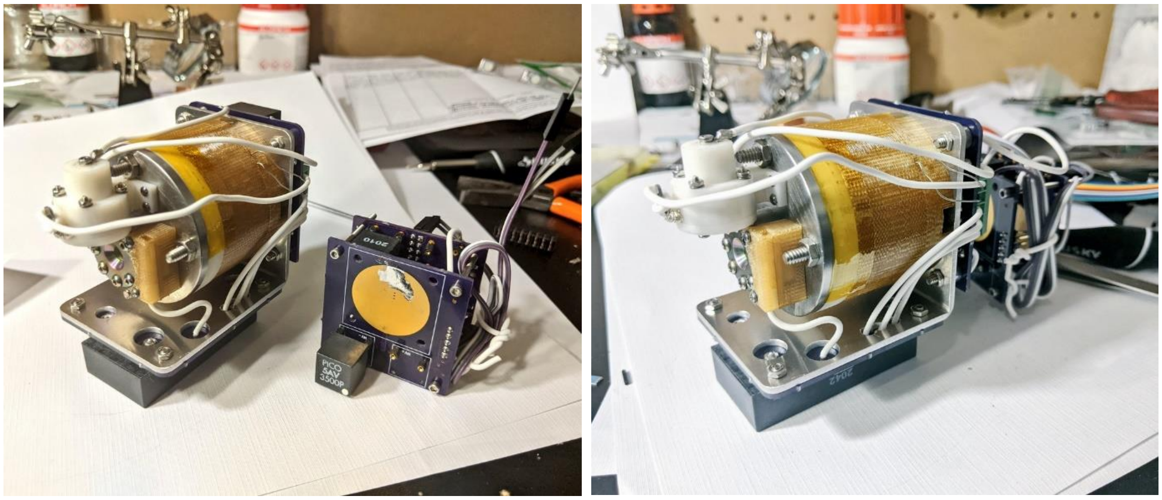

FIGURE 4: *Modifications for the makeshift neutralizer supply.*

IV. TESTING

The thruster was then 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.

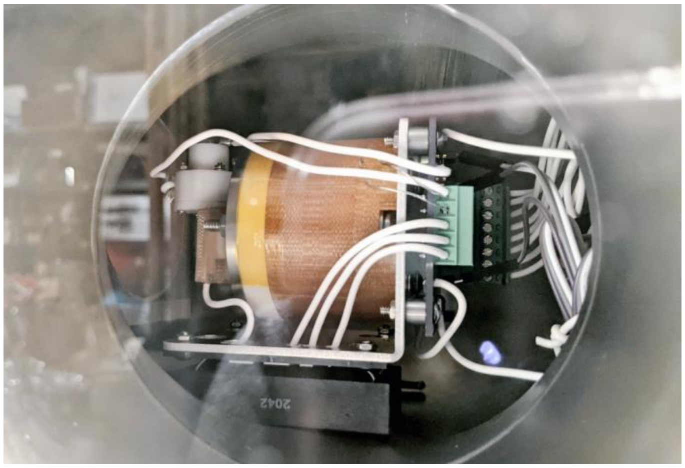

FIGURE 5: *AIS-EHT1 Hall system with modified GDN1 cathode supply mounted into the high vacuum chamber for testing.*

Once vacuum was established, heater power was first turned on and slowly increased to 5.5W of input power. After fuel flow was verified by the increase of pressure in the chamber, Hall thruster discharge power was turned on and brought up. Next, the neutralizer supplies were turned on and adjusted until a plasma glow was formed between the neutralizer and the thruster head. The supplies were continuously adjusted and main discharge power increased until the plasma glow was increased in brightness.

For this test, the plasma bridging was much more stable and brighter than the prior ignition test. In addition, no flashovers occurred on the boards or around the thruster. Despite this improvement, there was noticeable background plasma formation, and chamber pressure was higher than prior tests. Chamber breakdowns began to occur more and more frequently, although the thruster operated in this diffuse plasma background without much issue.

FIGURE 6: *Stable plasma bridging between the neutralizer and Hall thruster head. Due to the high background plasma affecting Faraday cup readings, full ignition could not be verified.*

FIGURE 7: *Second view of the plasma bridging between the neutralizer and Hall thruster head.*

The thruster was operated for a total of about 25 minutes before the test was ended due to excessively high chamber pressures and background plasma. While current was read on the Faraday cup, because of the background plasma, complete ignition could not be verified.

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 compared to the prior test.

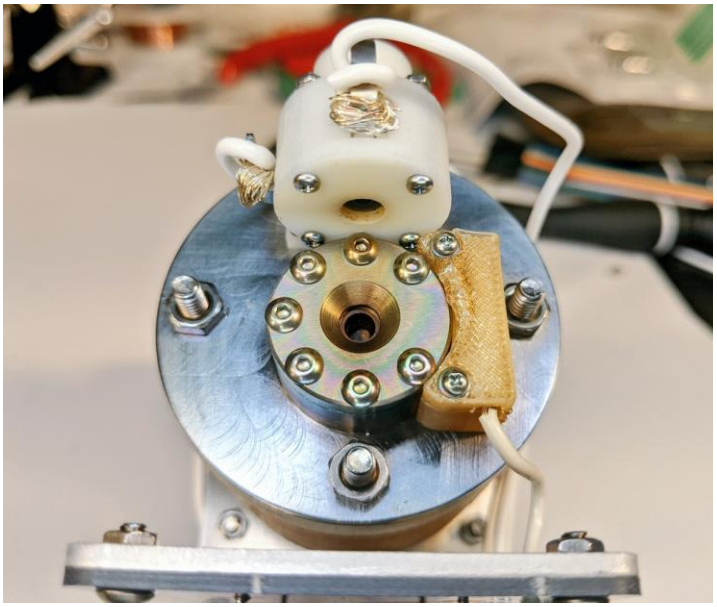

FIGURE 8: *Inspection of the thruster post-test. Significant discoloration is present on the thruster head due to deposition from the hydrocarbon plasma.*

Removing the thruster head from the assembly, visible discoloration was also observed around the neutralizer fuel feed hole and fuel feed hole for the Hall thruster head closest to the neutralizer feed. This is indicative of plasma leakage back into the fuel feed.

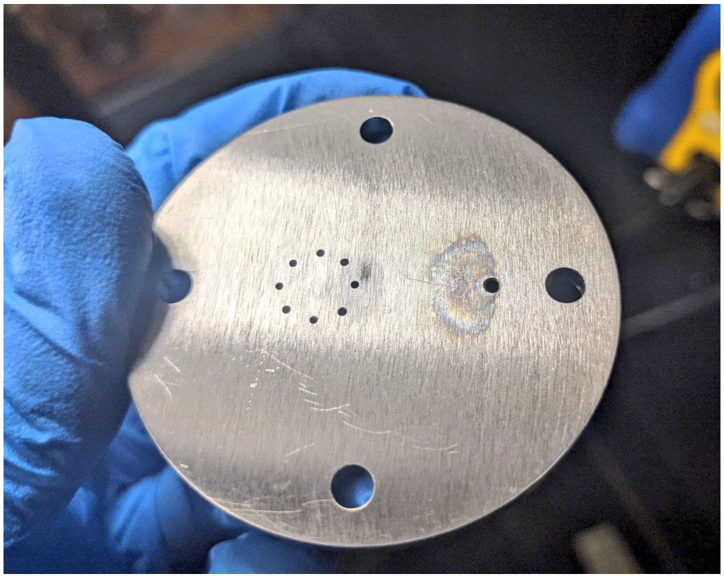

FIGURE 9: *Evidence of slight plasma bridging and leakage through the fuel feed apertures for both the thruster head and neutralizer.*

Disassembling the neutralizer, it was immediately observed that the anode aperture for the hollow cathode assembly was completely clogged due to carbon buildup. It is suspected that this was more severe than prior tests due to the longer run time of the cathode, as well as the higher overall background test pressures seen.

FIGURE 10: *Significant amorphous carbon deposit on the anode plate of the neutralizer, clogging the neutralizer output.*

A large amount of carbon deposit was further observed inside the hollow cathode itself.

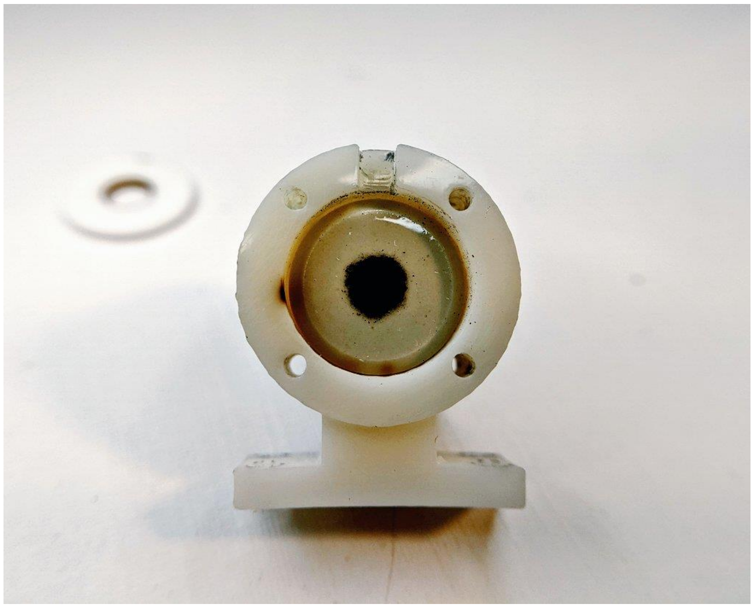

FIGURE 11: *Significant amorphous carbon deposit in the ceramic spacer and hollow cathode insert.*

Removing the hollow cathode insert, noticeable buildup was present in the fuel feed channel, as well as discoloration due to plasma exposure from the increased backpressure due to the anode aperture clogging. However, despite the discoloration, no evidence of heat damage was present, and the carbon buildip and discoloration could easily be scraped off the surface.

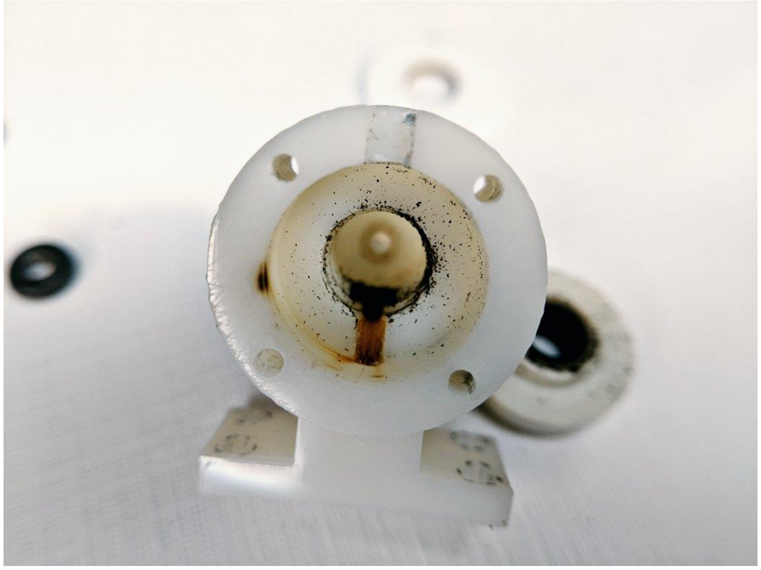

FIGURE 12: *Amorphous carbon deposit in the fuel feed channel in the neutralizer housing, as well as evidence of plasma leakage into the fuel feed channel due to clogging of the anode aperture.*

VI. CONCLUSION

The second full system ignition test of the EHT1 Micro End Hall Thruster using the GDN1 Glow Discharge Hollow Cathode Neutralizer has been completed, with both systems operating on sublimated Adamantane fuel. Although ignition could not be confirmed due to the excessive levels of background plasma, stable plasma bridging was achieved, with much higher intensity than the prior first full system ignition test. Using the modified hollow cathode power supply, only 2W was needed for the cathode, and with both main discharge and extractor supplies operating, plasma intensity was improved over just the discharge supply operating. It was found that unlike the stand-alone test with the GDN1, when operating with the Hall thruster head itself, cathode discharge voltage had to be increased to a maximum of -3.5kV, while cathode extractor bias voltage was at a minimum of a couple hundred volts for the best plasma bridging conditions to occur. The main Hall thruster discharge was operated around 1-1.5kV, however due to the lack of complete ignition and beam formation, power draw on the supply was minimal.

In addition, more work is needed to determine the effects of long term operation on amorphous carbon buildup and the resulting aperture clogging for the neutralizer, which has detrimental effects to output and use. The GDN1 will ultimately have to be re-designed in order to address these issues, with modified internal geometry, electrode spacing, operational pressure, and output aperture size adjusted to maximize lifetime and minimize carbon buildup in the anode aperture, particularly at increased output power levels and fuel flow rates for scaling up to larger systems.

Moving forward, the thruster will be refurbished for the next round of testing, and additional modifications will be made to reduce the probability of background plasma formation, as well as increasing the Hall thruster head magnetic field strength to improve ionization for better chances of full ignition.