# Applied Ion Systems

**AIS-TR-028**
**AIS-EHT1 Micro End-Hall Thruster**
**Full System Ignition Test 1 - 03/20/2021**
**Testing Report and Summary**

**Michael Bretti – 09/01/2021**

## 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 first 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.

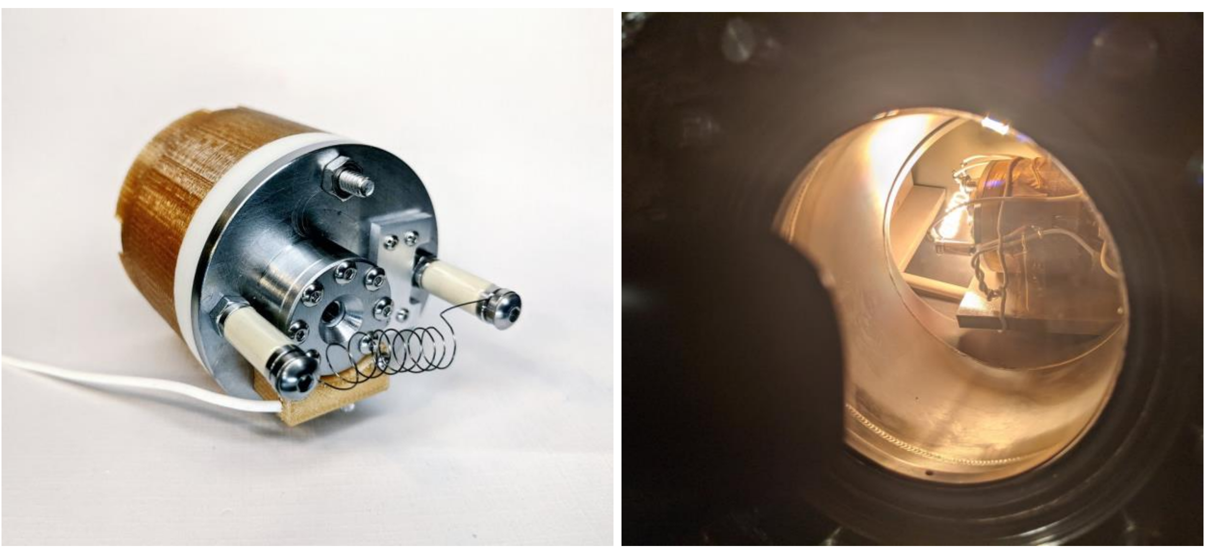

***FIGURE 1:*** *EHT1 with tungsten filament neutralizer (left) and operation in vacuum with Adamantane fuel and the tungsten neutralizer at 50W neutrzlier, 2W discharge during the first preliminary ignition test (right).*

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).*

End-hall sources are widely used in ion beam processing due to wide beam divergence, low beam energy, simplicity, and robustness. While wide beam divergence and low beam energy is undesirable for propulsion systems, the simplicity and robustness of end-hall sources makes for an ideal low-cost test platform. The EHT1 design leverages design elements from industrial end-Hall ion sources, allowing for simplified construction, and relying on only off-the-shelf ceramics.

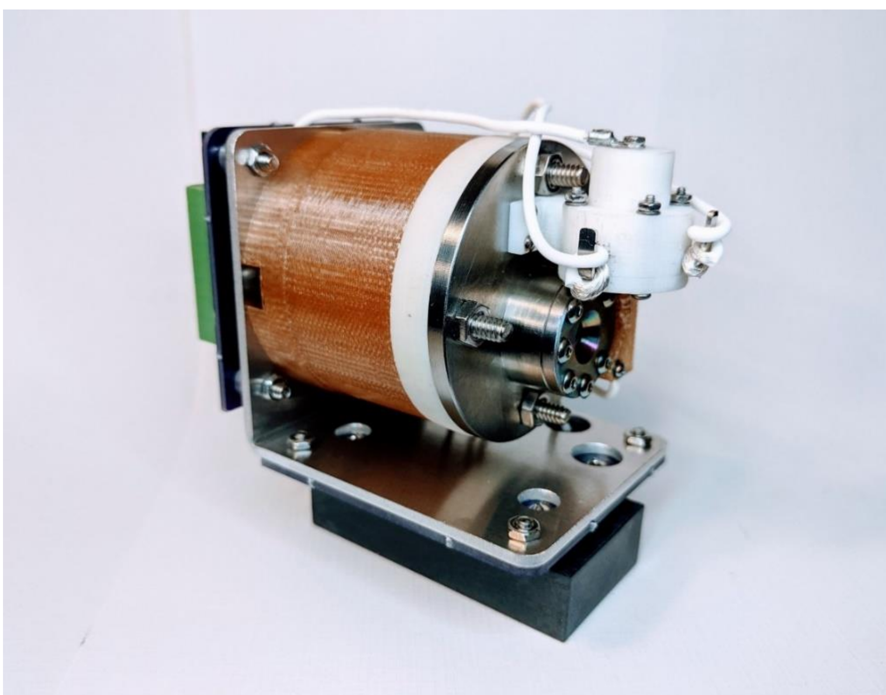

***FIGURE 3:*** *Fully assembled EHT1 with fuel system, hall thruster, GDN1 neutralizer, and power electronics.*

## III. PRELIMINARY TEST SETUP

The EHT1 thruster head itself is directly machined into the adapter flange, which allows it to be directly bolted to the fuel delivery system, eliminating any fuel lines. In addition, the adapter flange has mounting and a fuel feed port for the GDN1, located right next to the thruster head. This allows simultaneous feeding of both the thruster head and hollow cathode from a single fuel vapor source, further eliminating the need for additional feed lines, and keeps the total system volume highly compact. The proportion of fuel flow between the thruster head and the cathode is adjusted via physical dimensions of the fuel feed holes for each. In the event the hollow cathode is not used (as in the case of this test), the cathode feed port can be blanked off. The adapter flange measures only 50mm in diameter, with the thruster head offset to one side, measuring only 20mm in diameter and 10mm in height fully assembled.

***FIGURE 4:*** *Fully assembled EHT1 thruster head with GDN1 neutralizer.*

The full EHT1 assembly consists of three major subsystems tightly integrated together as one unit – the sublimation fuel delivery system (SFDS), fuel valve, and Hall thruster head assembly. Currently, valve development is still underway, and as such, only the valve housing is used without a valve, meaning fuel is continuously sublimated from the start to the end of the test. Rate of flow however is still controlled via sublimation heater.

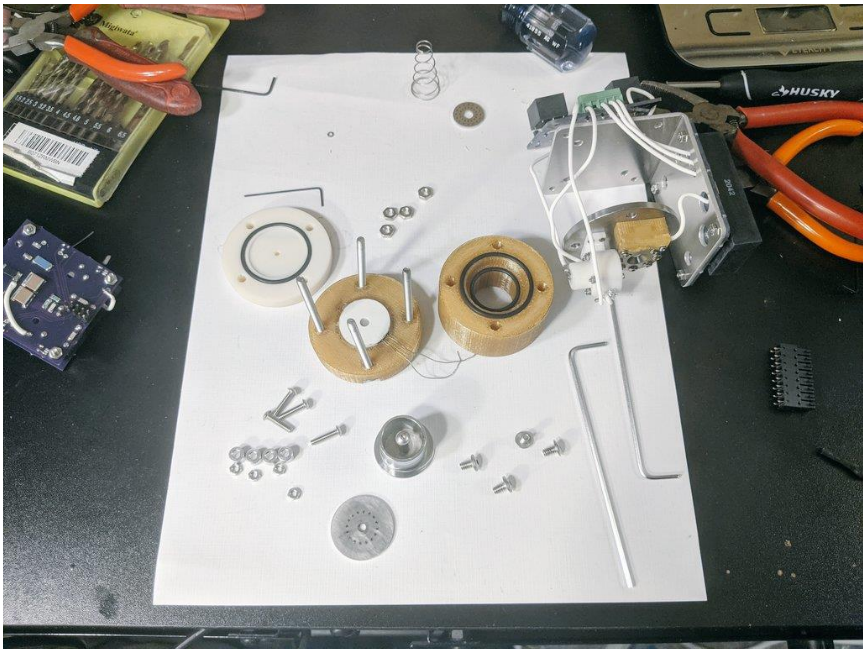


***FIGURE 5:*** *Complete parts for assembly. Left: fuel system, Center: valve housing, Right: Hall thruster head assembly*

Prior to final assembly, the thruster must be fueled with Adamantane. Adamantane has the consistency of coarse table salt, which is poured directly into the fuel heater cartridge and packed down. A presser plate is placed over the fuel charge, preventing fuel from escaping, while allowing vapors to rise up from sublimation through holes drilled around the plate. After filling the heater cartridge with about 3 grams of Adamantane, the cartridge is inserted into the 3D printed Ultem housing. A conical spring presses the plate into the Adamantane, providing continuous contact with the bottom heated portion of the cartridge, which is heated by a ceramic-metal heater in direct contact with it. A top fuel plate completes the assembly, locking the cartridge into the fuel tank housing and compressing the spring into the fuel presser plate.

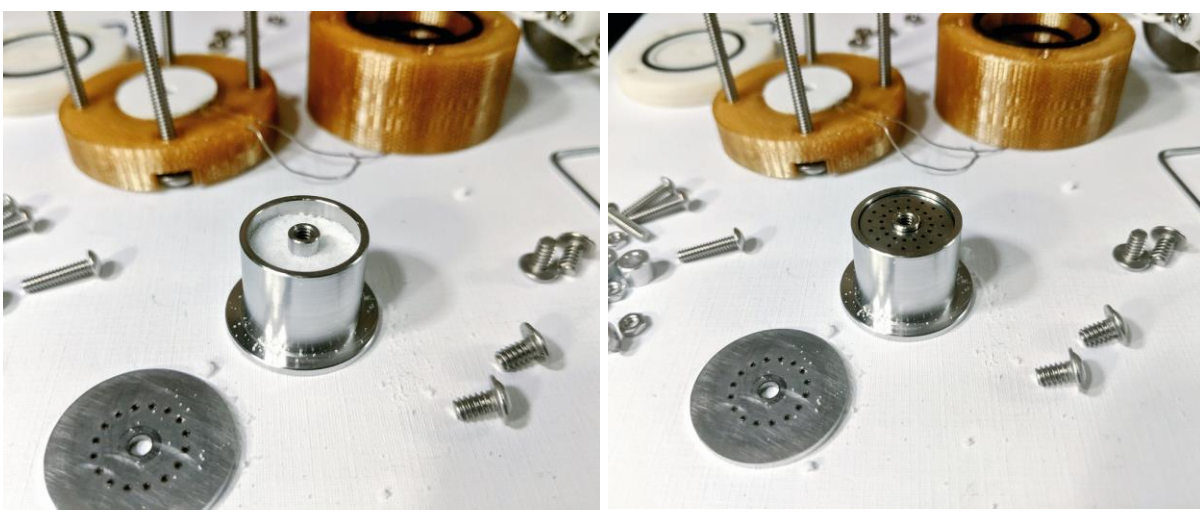

***FIGURE 6:*** *Fueling of the fuel heater cartidge with Adamantane.*

After fueling, the thruster is fully assembled and bolted together, and the power supplies wired for the Hall thruster head, neutralizer, and sublimation heater. An aluminum bracket allows for electronics mounting to the thruster body assembly.

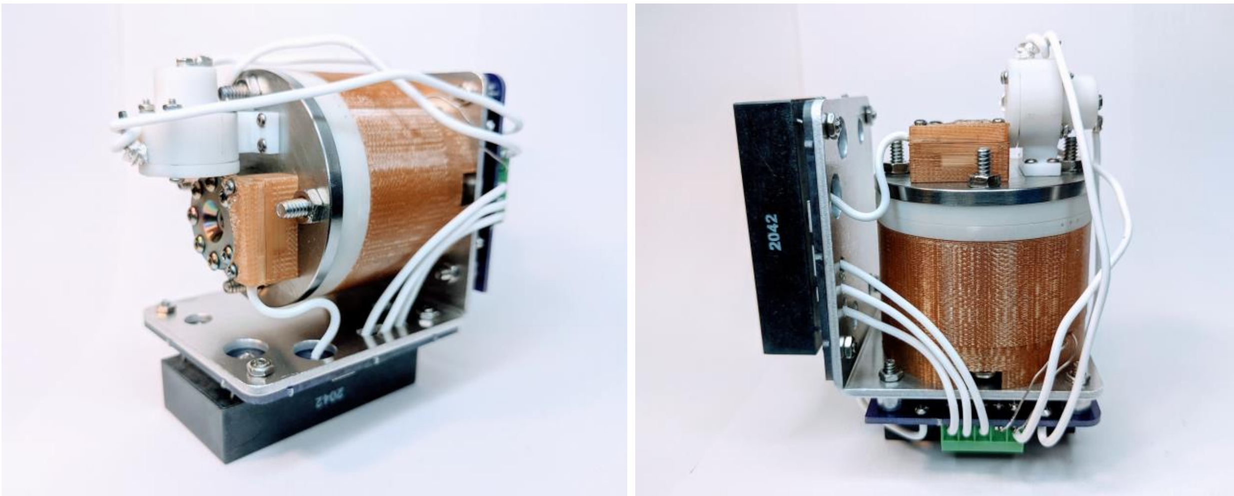


***FIGURE 7:*** *Completely assembled and wired EHT1 End Hall Thruster system.*

## 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.

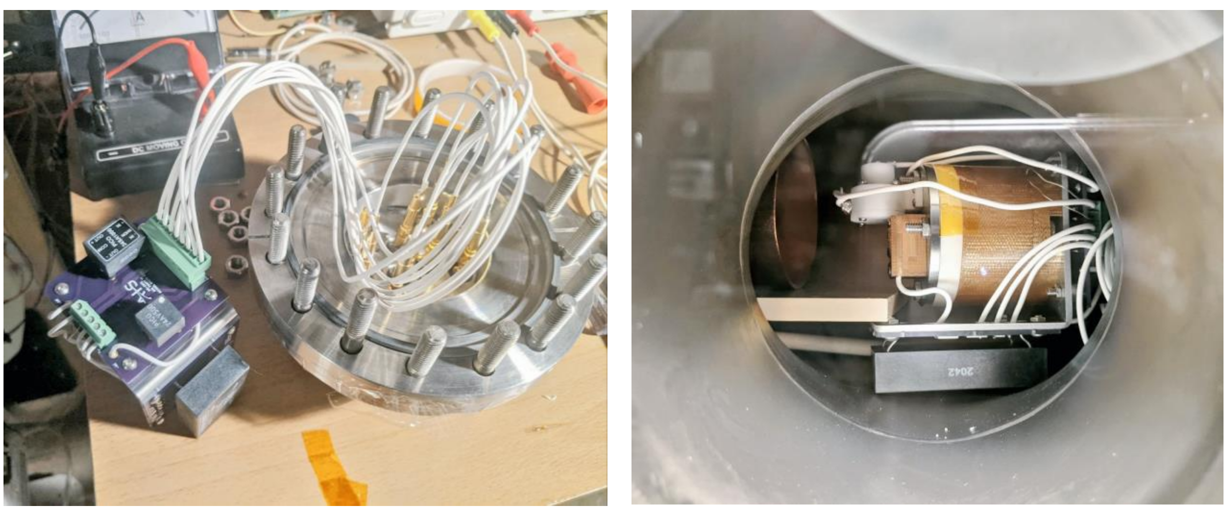

***FIGURE 8:*** *Wiring the EHT1 to the conflat feedthrough (left) and mounting in the vacuum chamber (right).*

Heater power was first applied, and discharge power was brought up to a few hundred volts. After pressure rise was observed in the chamber, the cathode discharge supply was turned on, and discharge power further increased, until finally a light glow from both the thruster head and neutralizer was established. After this light glow was established, the extractor voltage was brought up, and all the supplies were adjusted to increase output from the neutralizer. A few minutes after, a large plasma flashover occurred along the outside of the thruster, resulting in catastrophic failure with a shower of sparks and termination of the thruster glow.

Upon further examination of test video after the test, it was discovered that the cascading failure event was initiated by a sudden e-beam burst from the neutralizer. While most of the beam was bent into the Hall thruster head at 90 degrees, a small fraction of the beam traveled past the head and continued straight, hitting the PEEK baseplate that held the Faraday cup. This triggered an immediate outgassing burst, which raised the local pressure enough for ionization to occur, causing a cascading plasma flashover.

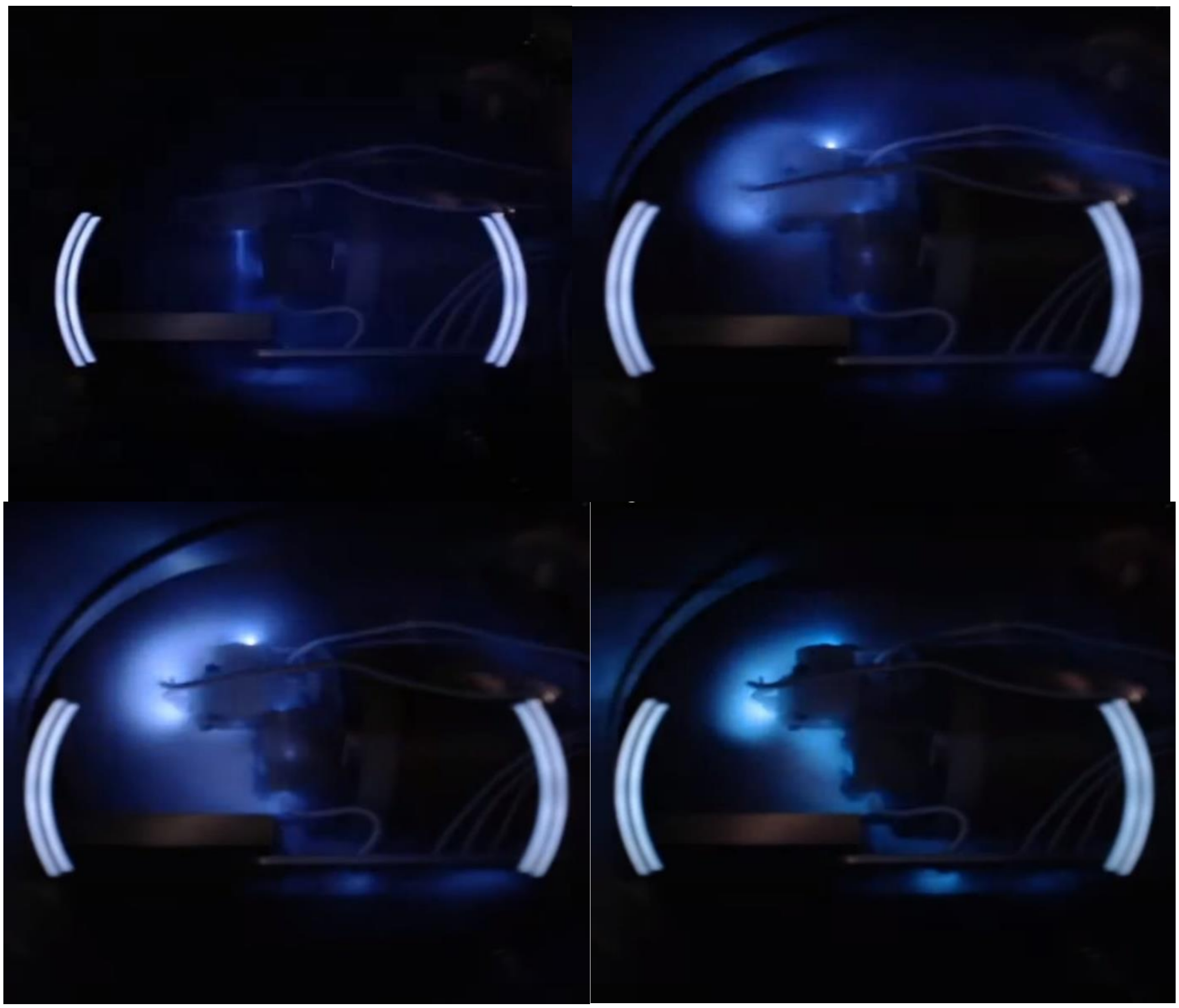

***FIGURE 9:*** *Initial outgassing and plasma flashover event, starting with an extracted e-beam from the neutralizer impinging upon the PEEK baseplate, followed by evolution of the flashover traveling around the cathode and bridging across the Hall thruster head and to the main discharge power supply board.*

Almost immediately after the initial ionization events due to localized outgassing from e-beam impingement, the plasma intensity increased significantly, followed by a yellow flash at the rear of the thruster, resulting in a shower of sparks. The entire sequence happened within a fraction of a second. After this explosive failure, the thruster supplies were immediately shut down.

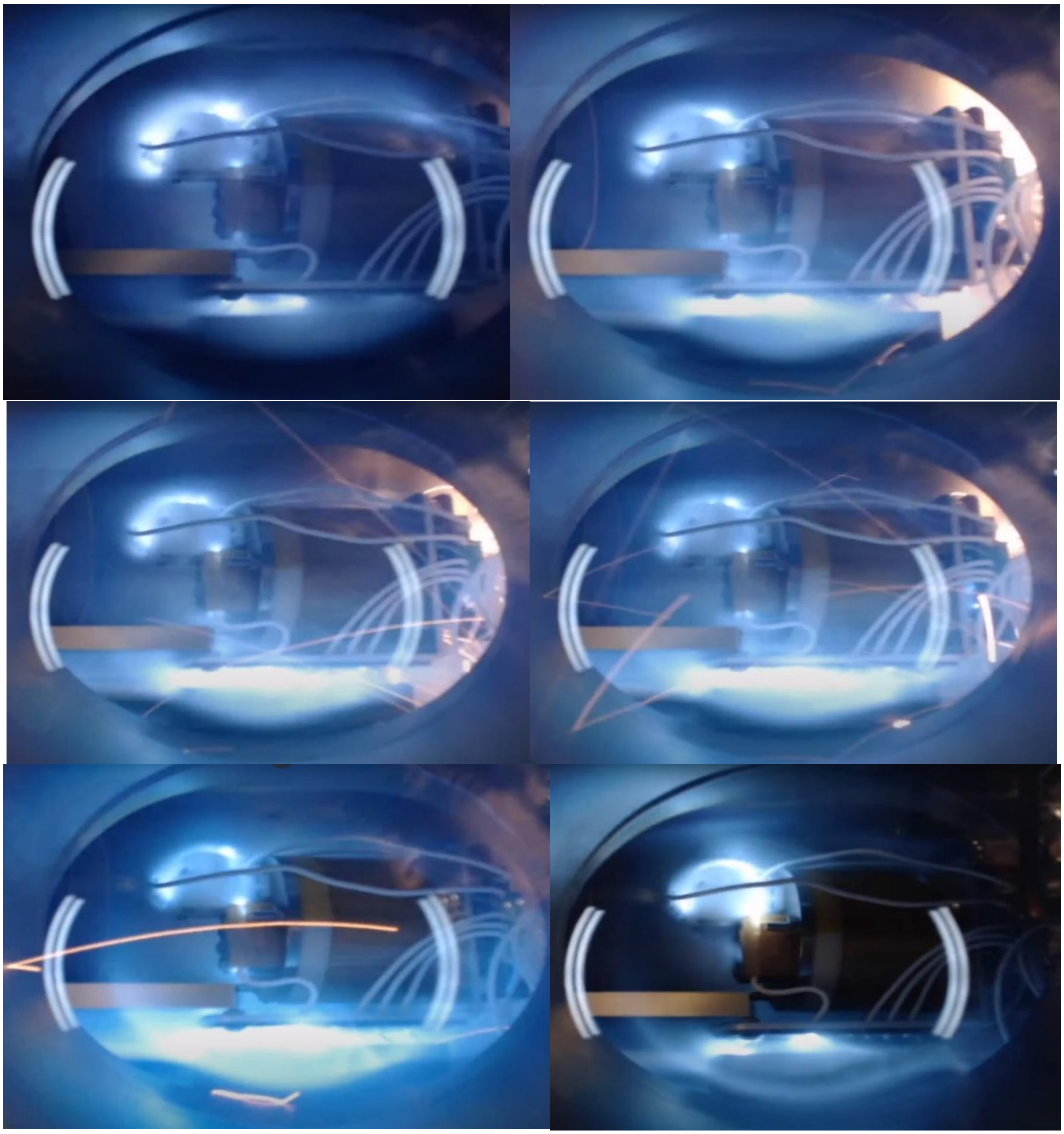

***FIGURE 10:*** *Catastrophic failure sequence of the high voltage neutralizer power supply.*

After the failure, each of the supplies were carefully tested while still in the vacuum chamber to assess the damage. It was found that the main Hall thruster discharge and neutralizer discharge supplies were functional, however the neutralizer extractor supply was no longer functional. Despite this failure, it was decided to resume testing.

Both main discharge and neutralizer discharge supplies were carefully turned up and adjusted. Eventually, the discharge grew brighter, and stable plasma bridging was established between the cathode and Hall thruster head. No beam current was measured on the Faraday cup, and despite the successful plasma bridging, a true exhaust plume was not observed, indicating failure to fully ignite the thruster. Despite this, plasma bridging between the cathode and thruster was achieved, marking the first step towards ignition.

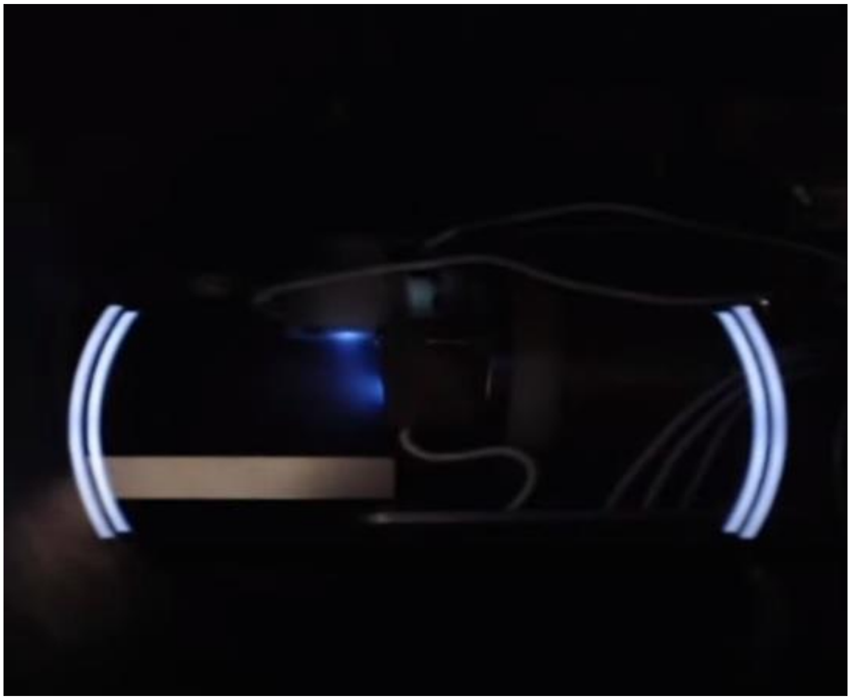

***FIGURE 11:*** *Formation of plasma bridging between the EHT1 and GDN1.*

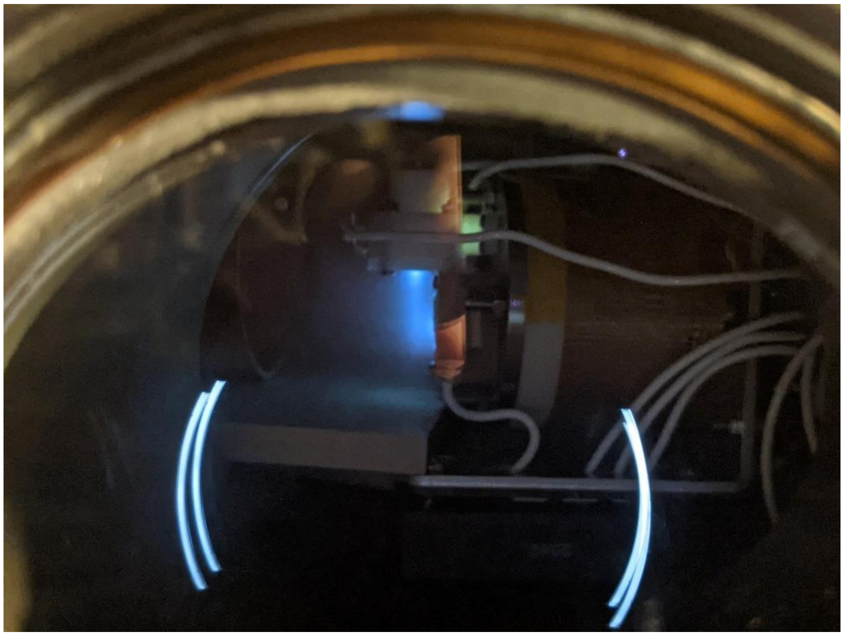

***FIGURE 12:*** *Formation of stable plasma bridging between the EHT1 and GDN1.*

The system was operated for several minutes, until the plasma suddenly cut out. After further power checks and inspections, it was determined that the cathode discharge supply had failed, ending the test.

## V. POST TEST ANALYSIS

After the conclusion of the test, the thruster was removed from the chamber for inspection. Immediately, it was observed that the neutralizer extractor supply was the source of the explosive catastrophic failure during the first phase of the test.

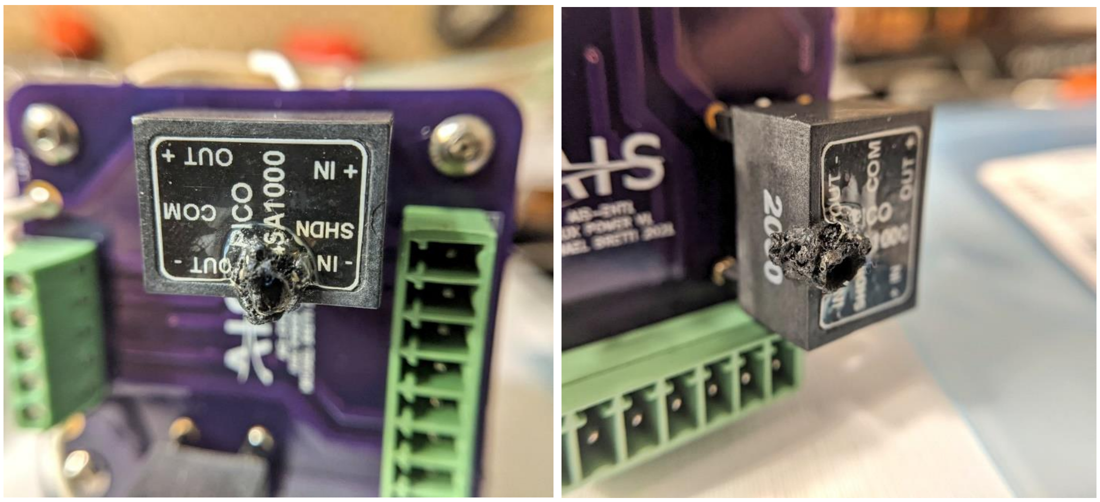


***FIGURE 13:*** *Catastrophically failed +HV supply for the neutralizer extractor*

Inspection of the Hall thruster head itself showed evidence of minor discoloration due to the hydrocarbon plasma output, but no major erosion or heating damage to any of the components otherwise.

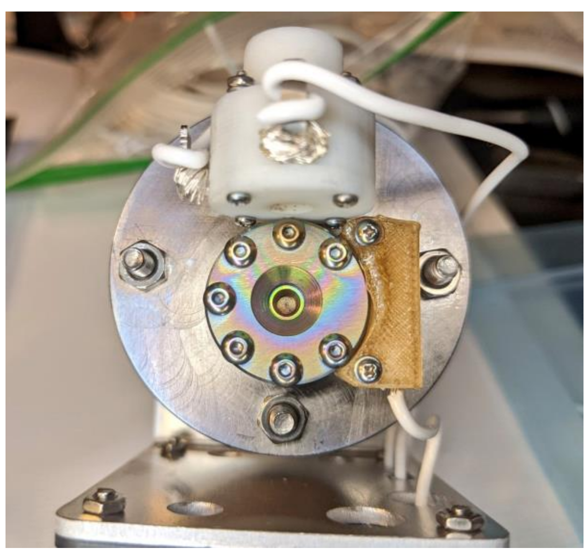

***FIGURE 14:*** *Inspection of the thruster post-test. More visible discoloration due to deposition from the hydrocarbon plasma during operation.*

## VI. CONCLUSION

The first 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 there was a catastrophic flashover early on in the test, leading to failure of one of the hollow cathode power supplies, stable plasma bridging was eventually established and maintained between the Hall thruster head and cathode, marking the first step towards ignition with the full system. Interestingly, stable plasma bridging was able to be achieved from just the neutralizer discharge power alone, without the need of the extractor supply. However, it is expected that some positive bias on the cathode extractor would allow for increased neutralizer plume output, resulting in increased electron emission for ionization and neutralization. Moving forward, the thruster will be repaired and modified for the next round of ignition testing. Care will also be taken to prevent any plastics for thruster mounting in the chamber from getting in the way of both the neutralizer plume and main output plume to prevent potential flashovers due to outgassing from beam bombardment.