ADVANCED MATERIALS FOR ELECTRIC PROPULSION

Research and Technology Development Annual Report

JPL Task #R20108

Bryan W. McEnerney (PI), Propulsion, Thermal And Materials Engineering Section (353)
Richard R. Hofer, Propulsion, Thermal And Materials Engineering Section (353)
Celia Chari, Applied Physics & Materials Science, California Institute of Technology
Katherine Faber, Applied Physics & Materials Science, California Institute of Technology

A. OBJECTIVES

The proposal objectives are:

a) to develop an advanced ceramic solution for electric propulsion (EP) dielectric systems, specifically boron nitride (BN) grown from graphite using a powder-based carbothermic reaction process refined at Caltech,

b) to demonstrate the viability of the dielectric layer on an aerospace-grade graphite,

c) to perform thruster testing using a boron-nitride modified graphite channel, compared to that tested in FY20 to clearly demonstrate the performance benefits.

The state-of-the-art dielectric for EP systems is a boron nitride-based monolithic ceramic, which is expensive, challenging to machine and prone to significant variability in mechanical performance. The approach we are now developing is revolutionary, as it allows for the use of low-cost materials (e.g., graphite), with dielectric layers grown and deployed where needed

B. STRATEGIC FOCUS AREA

Topics:

[X] Electric propulsion

C. BRIEF BACKGROUND

Advanced electric propulsion systems, such as the Hall Thrusters that will be flown on JPL's Psyche mission, require high-performance dielectric systems to provide electrical isolation, thermal management, sputter resistance from plasma bombardment, and secondary electron emission for moderating plasma temperature. Various grades of boron nitride (BN) are typically used in Hall thrusters, but BN is expensive, difficult to fabricate at large sizes, and has poor thermal and mechanical properties. Worse still, BN procured from commercial sources for flight have recently demonstrated significant variability. These challenges increase technical risk and cost, which lead to increased margins in the thermal and mechanical design that limit performance, all of which clearly demonstrate a need for new material solutions. A second, and equally important consideration is that the incumbent material does not lend itself well to scaling to larger sizes than those that are now being used. Future systems operating at 20-50 kW will require much larger diameter discharge chambers that will make the use of BN impractical and will require new solutions.

D. APPROACH AND RESULTS

Building upon previous work, a series of graphite coupons were processed by Caltech and the Naval Research Laboratory and both vapor- and liquid-phase densified materials were created. The coupons were processed at 1700 C to achieve the thickest BN layers possible for the effort. The coupons were sized to easily fit within the Caltech and Naval Research Laboratory furnaces, but to ensure sufficient surface area for the subsequent thruster testing.

The samples were loaded into a test configuration with three samples (A, B, and C) loaded onto the front face of the H9 thruster, Figure1. A series of two samples (D and E) were loaded onto a test frame downstream of the thruster within the plume, for evaluation of erosion, Figure 2. The thruster was then operated over a range of conditions which simulated various operational environments, Figure 3. The testing demonstrated 12 thermal cycles and exposed the samples to 12 hours of total run time to simulate an operational environment. After testing, the samples were weighed and the surfaces analyzed with an optical profilometer.

The downstream samples experience significant erosion of the BN layers during thruster operation, though this is not unexpected given the impact of highly accelerated Xe ions. It should be noted that actual BN systems do not see this environment in an operational configuration, so this represents an extreme worst case scenario and was intended to gather as much data as possible with limited testing time. The erosion levels were between 4.8 - 7.0%. The samples on the face of the thruster experience erosion rates between 1.7 - 3.8%. In all cases, the vapor phase BN outperformed the liquid phase BN; further work is needed to determine the root cause in variation, though the vapor phase materials are assumed to have higher purity and a denser structure.

Sample A, Figure 4, is shown after the test series; the image on the left is the plume-facing side with the right image showing the thruster facing side. The BN showing in the left image was shieled by molybdenum, but after removing the deposited graphite, Figure 5, it shows that the BN layers remain. Vapor deposited graphite is a well-known residual side effect of ground-based testing only, due to the graphite shielding in the chambers.

E. SIGNIFICANCE OF RESULTS/BENEFITS TO NASA/JPL

The FY22 results clearly demonstrated the ability to produce thick BN layers that were acceptable for testing in H9 thruster configurations. The coupons were subjected to flight-like operational environments, with the exception of the more aggressive downstream coupons, over a range of cycles and operational parameters.

The FY22 testing of the BN/graphite on the H9 thruster is the first development of a materials system specifically designed for Hall effect electric propulsion systems. It indicated that further study is needed, but the higher processing temperatures of 1700 C+ would yield robust BN layers that, with further process refinement, could be suitable for use in the overall thruster environment. The results demonstrated a positive net benefit and with further testing and process refinement, offer a path for advanced, engineered bi-material dielectric channels.

F. NEW TECHNOLOGY

List relevant NTR numbers: 52454.

The bi-material processing approach, leveraging elevated temperatures of 1650 C+, was filed by Prof. K.T. Faber and Dr. C. Chari at Caltech, with Dr. B.W. McEnerney and Dr. R. Hofer (both JPL), and Dr. E.P. Gorzkowski and Dr. J. Wollmershauser (both NRL) as co-authors. It was pushed for a provisional patent.

G. FINANCIAL STATUS

The total funding for this task was $50,000, all of which has been expended.

H. ACKNOWLEDGEMENTS

The authors would like to acknowledge Dr. Colleen Marrese-Reading (353B) for her assistance in the measurement of the resistivity of the BN-conversion layers and thermal cycling, Dr. Dean Cheikh (3467) for his assistance in thermally processing graphite coupons and logistical support, and Dr. James Wollmershauser and Dr. Edward P. Gorzkowski of the Naval Research Laboratory for elevated temperature thermally processing testing.

I. PUBLICATIONS

[A] Chari, C., B.W. McEnerney, J. Wollmershauser, E.P. Gorzkowski, R. Hofer, and K.T. Faber, "High-temperature Carbothermal Synthesis and Characterization of Graphite/h-BN Bimaterials", Journal of the American Ceramics Society (draft submitted and undergoing edits).

[B] C. S. Chari, B. W. McEnerney, R. R. Hofer, C. M. Marrese-Reading, R. Lobbia, J. A. Wollmershauser, E. P. Gorzkowski, K. T. Faber, “Effects of Plasma Exposure on Graphite/h-BN Bimaterials for Hall-Effect Thrusters.”, in preparation.

J. REFERENCES

None

K. APPENDIX

None

L. FIGURES

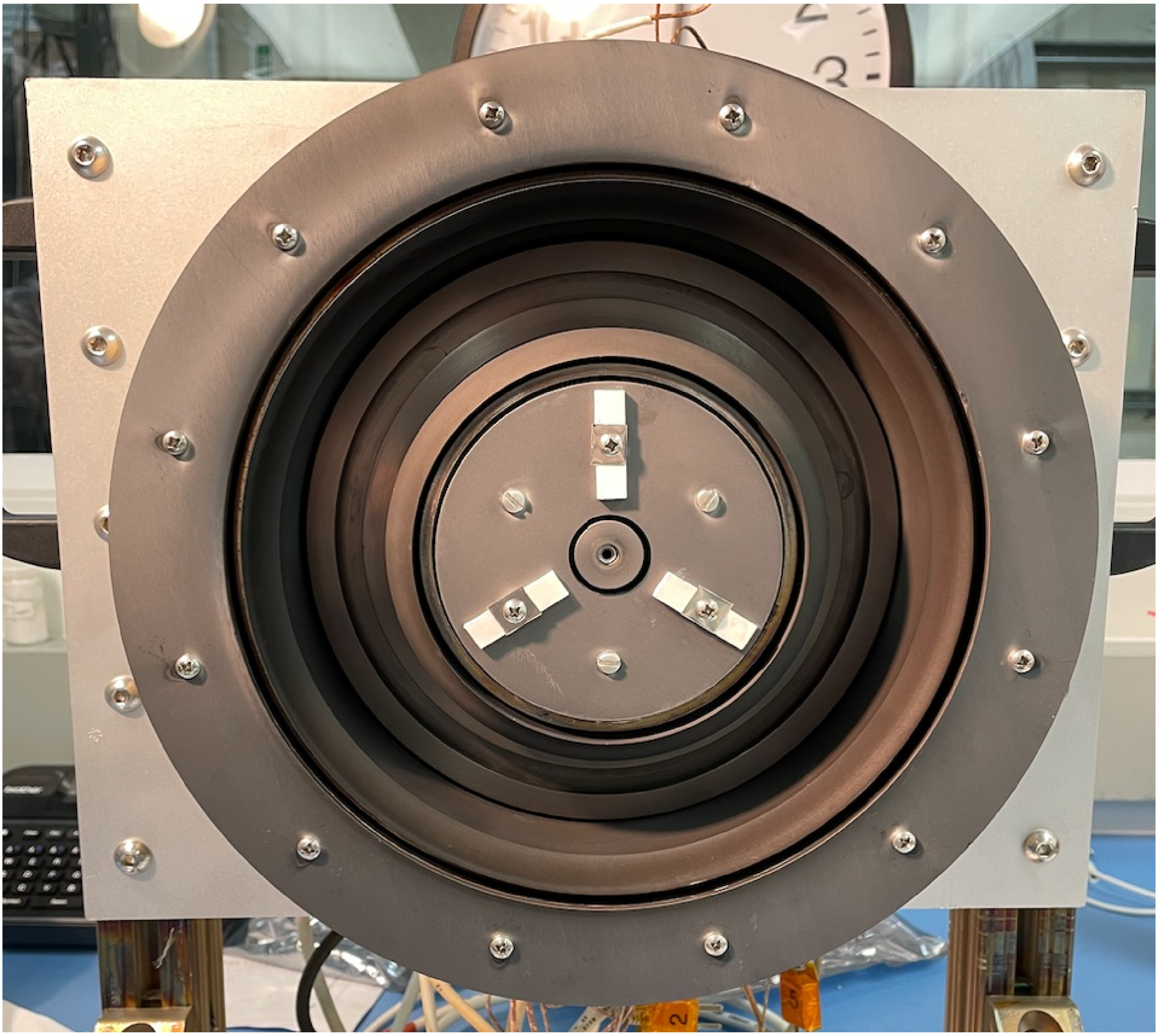

Figure 1. Figure 1: Sample configuration on the face of the H9 thruster.

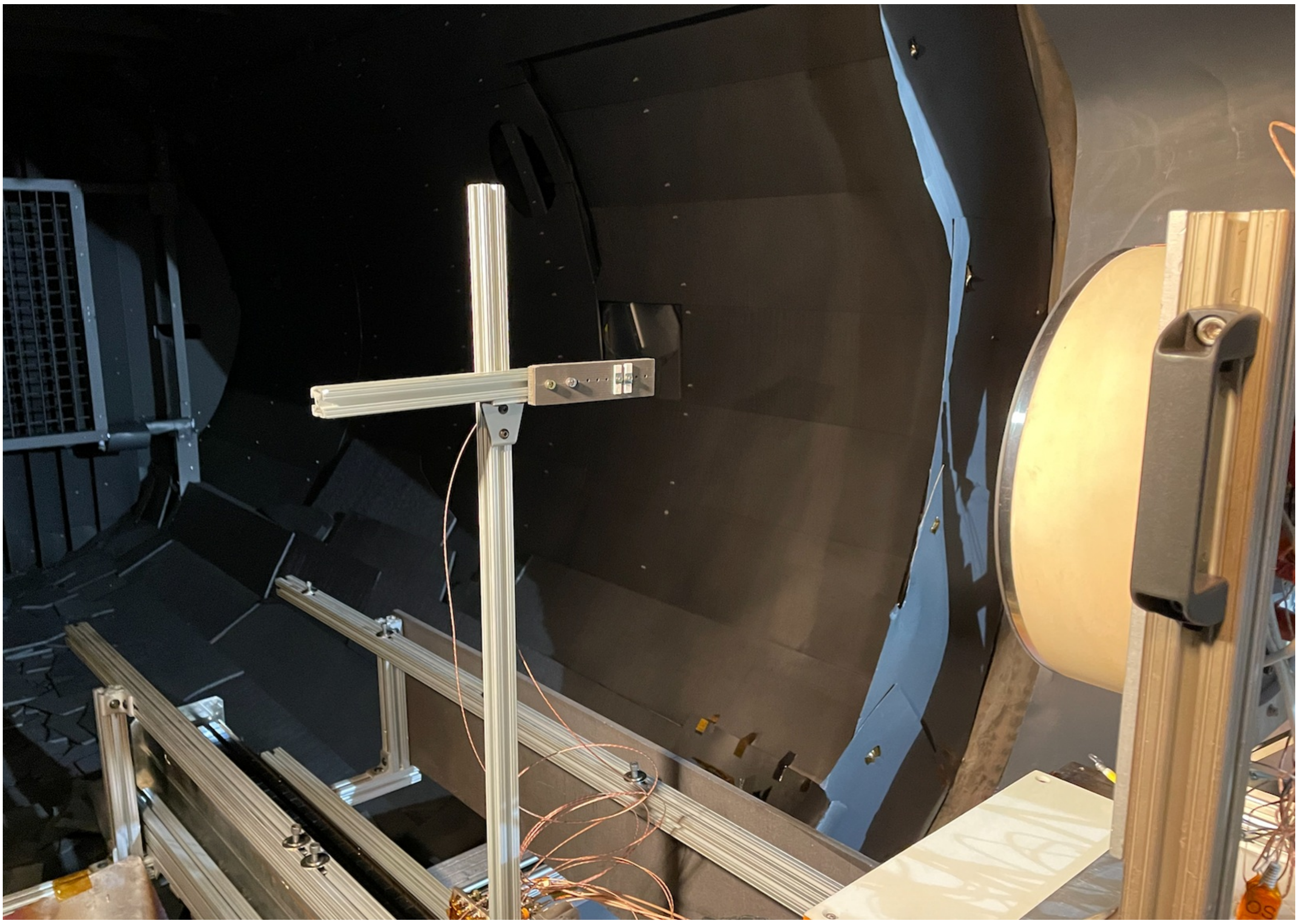

Figure 2. Figure 2: Downstream sample configuration, to be within the plasma plume.

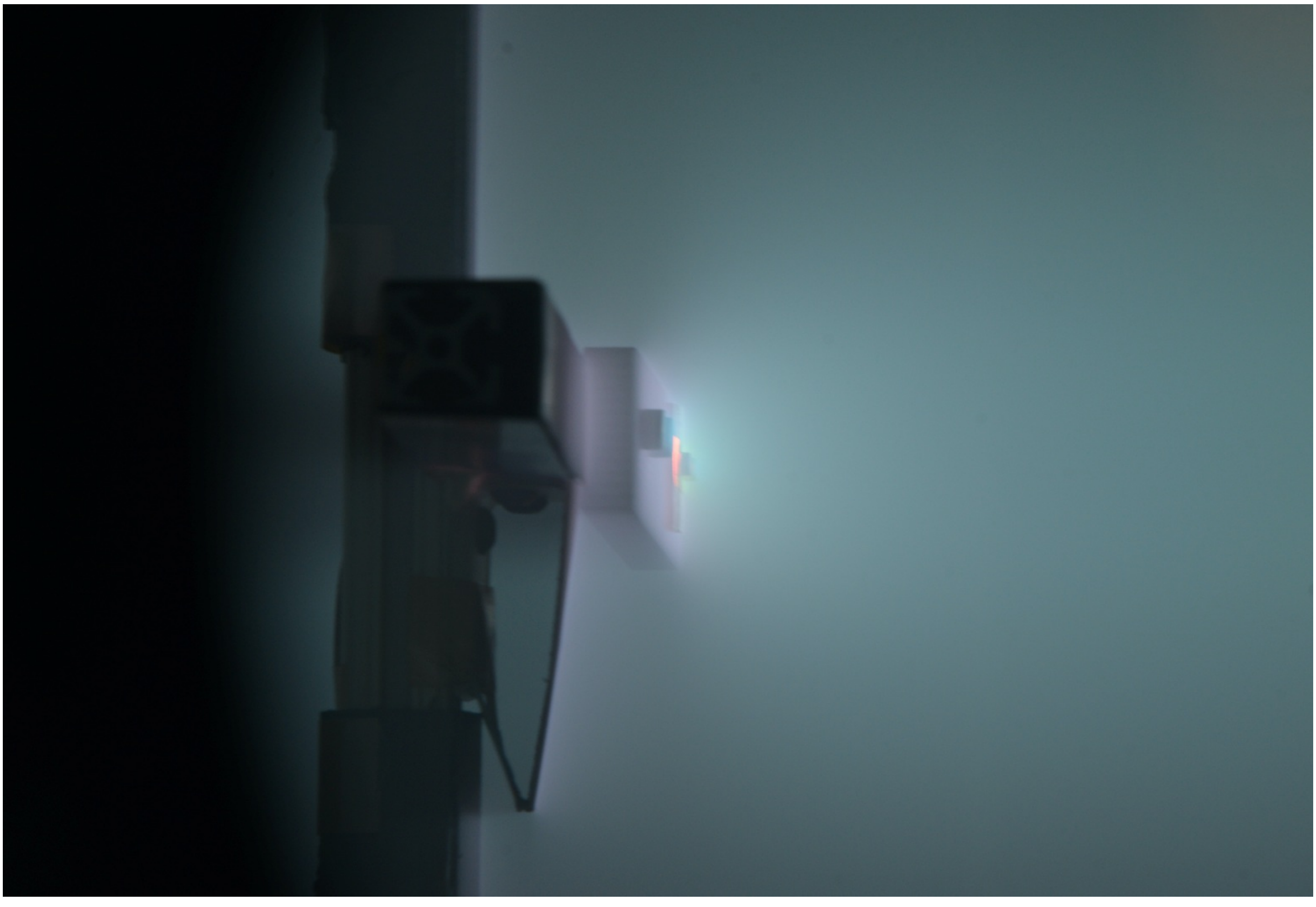

Figure 3. Figure 3: Downstream samples during thruster operation.

Figure 4. Figure 4: Sample A after the test sequences. Left image is the plume facing side, and the right image is the thruster facing side.

Figure 5. Figure 5: Sample A after cleaning to remove the deposited graphite layers.

M. COPYRIGHT STATEMENT