Microcracks in Hall Thrusters

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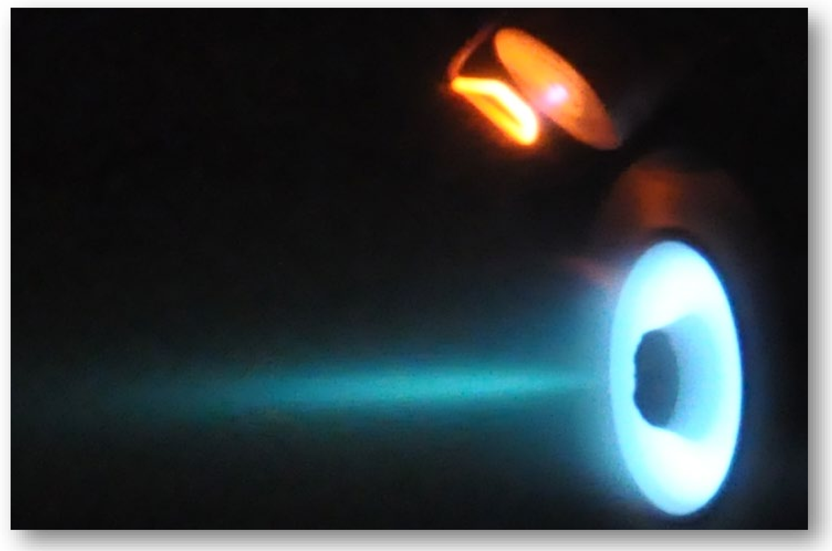
Background

Hall Thruster

- Hall thrusters (HET) are widely used to maneuver satellites in space.
- They produce thrust by accelerating ions to high exit velocities by an applied electric field.
- Plasma is formed as a result of the collision between magnetically trapped electrons in a Hall current and neutral inert gas propellant.



Aerojet Rocketdyne T-40

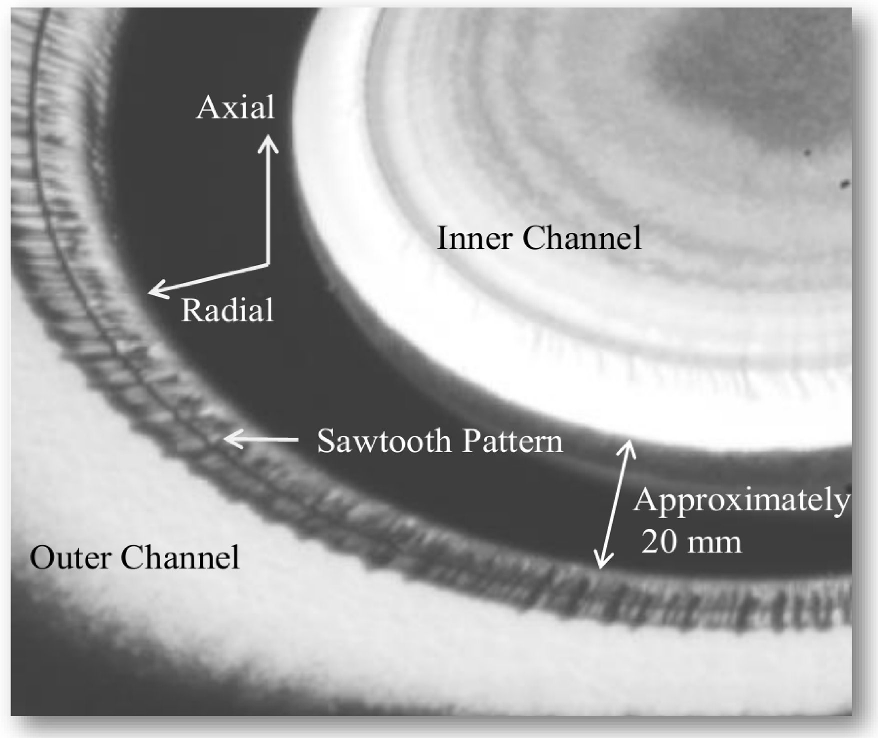
SMART-1 Satellite [1]

Operational Lifetime

- The discharge channel wall protects the magnetic circuitry from exposure plasma.
- Erosion of the wall, made from borosil composite (BN + SiO_2), is the primary cause of thruster failure.
- The average lifetime of a Hall thruster is 7,000 hours.

Erosion Models

- Current erosion models fail to explain observed features, shown to the right.
- Differences in the borosil composite may explain microcracking observed during thermal cycling caused by differences in coefficient of thermal expansion (CTE).



Lockheed Martin BPT-4000 anomalous erosion ridges[2]

Objectives

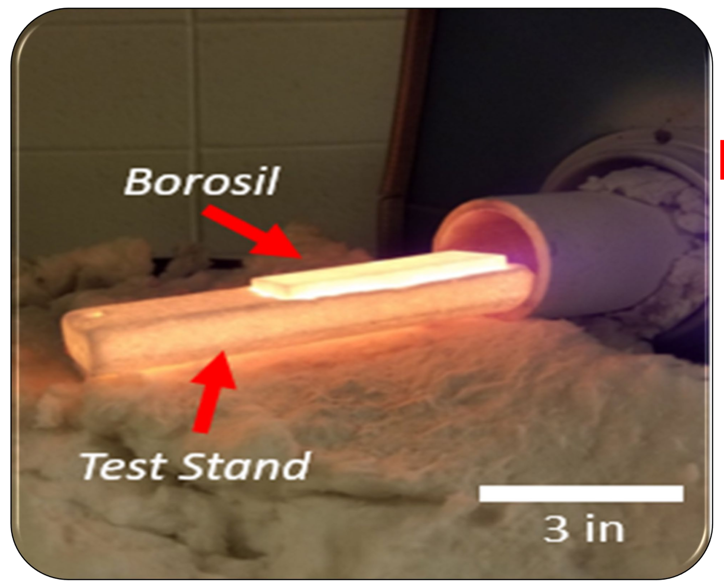
1) **Determine the effect of CTE difference between BN and SiO_2 on crack formation.**
2) **Determine the effect of microcracks on plasma erosion.**
3) **Determine the effect of microcracks on element composition.**

Methods

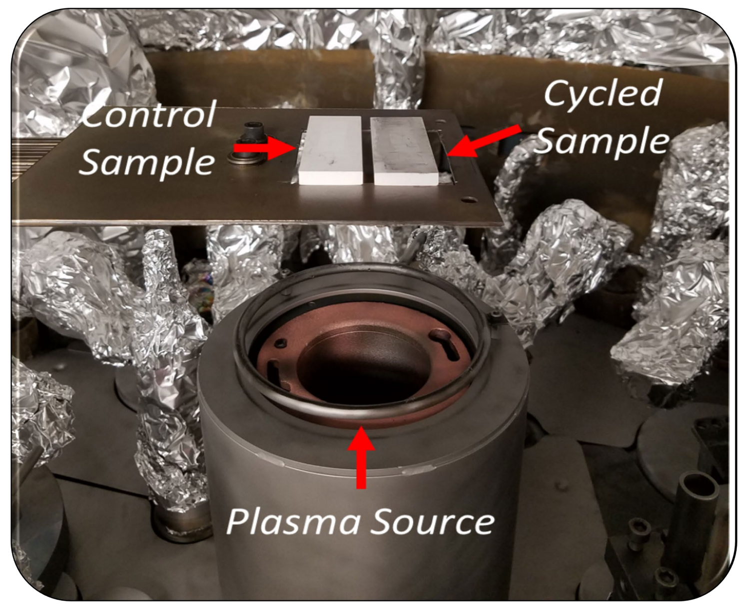
Experiment

- Polish four borosil samples to 0.2 µm surface roughness.
  - Two are thermally cycled.
  - Two are not cycled (control)
- Expose all samples to plasma.

20 thermal cycles at Hall thruster wall temperatures (800°C)



Thermal Cycle Set-Up



Plasma for 5 hours

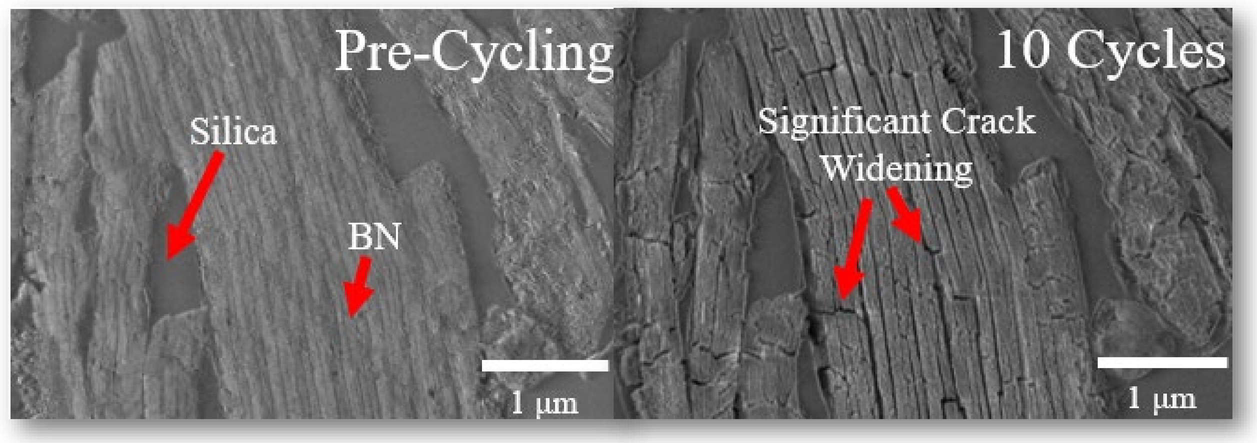
Plasma Set- Up

Results

Quantify Microcracking

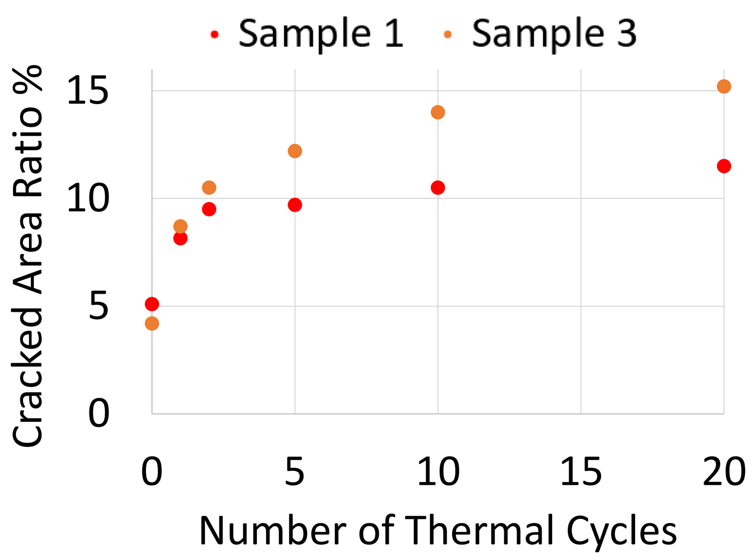
- Cracks were identified using customized software.
- Cracking quantified as a cracked area ratio (CAR).

Obj. 1 : Identification of Cracks



Pre and Post SEM images

Thermal shock causes BN to expand and contract more quickly than silica, leading to stresses strong enough to induce cracking – mostly in the BN phase.

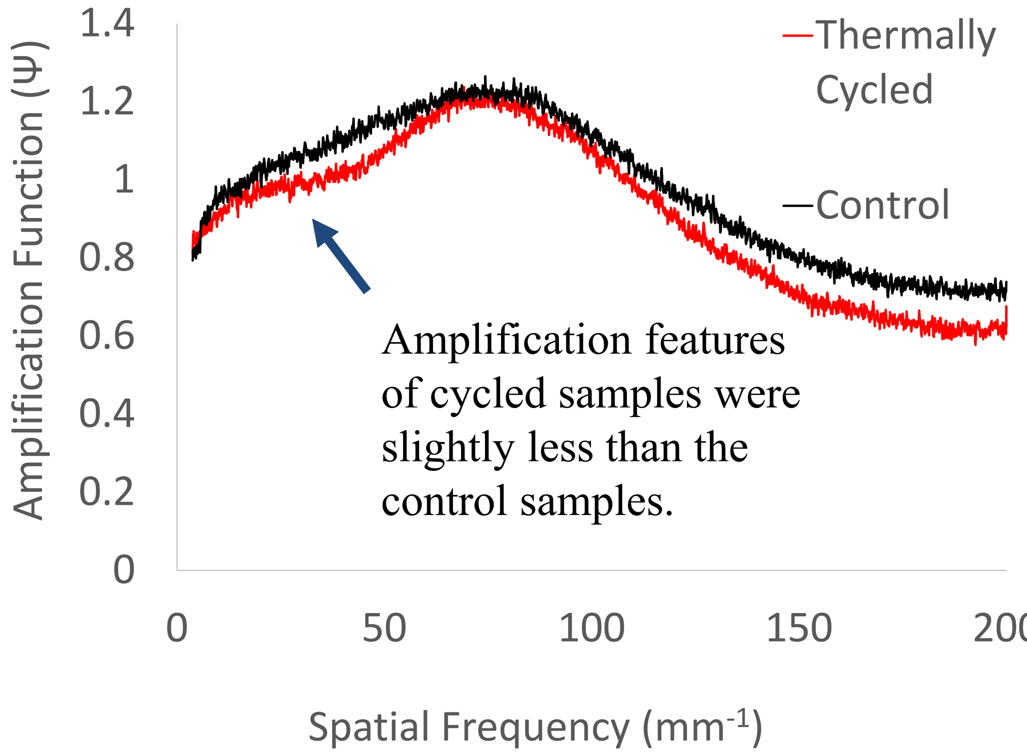


$$CAR = \frac{Total\ Crack\ Area}{Total\ Image\ Area}$$

Crack trend is similar to that found in other works with ceramic composites.

Results

Obj. 2 : Surface Feature Growth



$$\Psi = \log_{10}\left(\frac{\hat{h}_{post}(\omega)}{\hat{h}_{pre}(\omega)}\right)$$

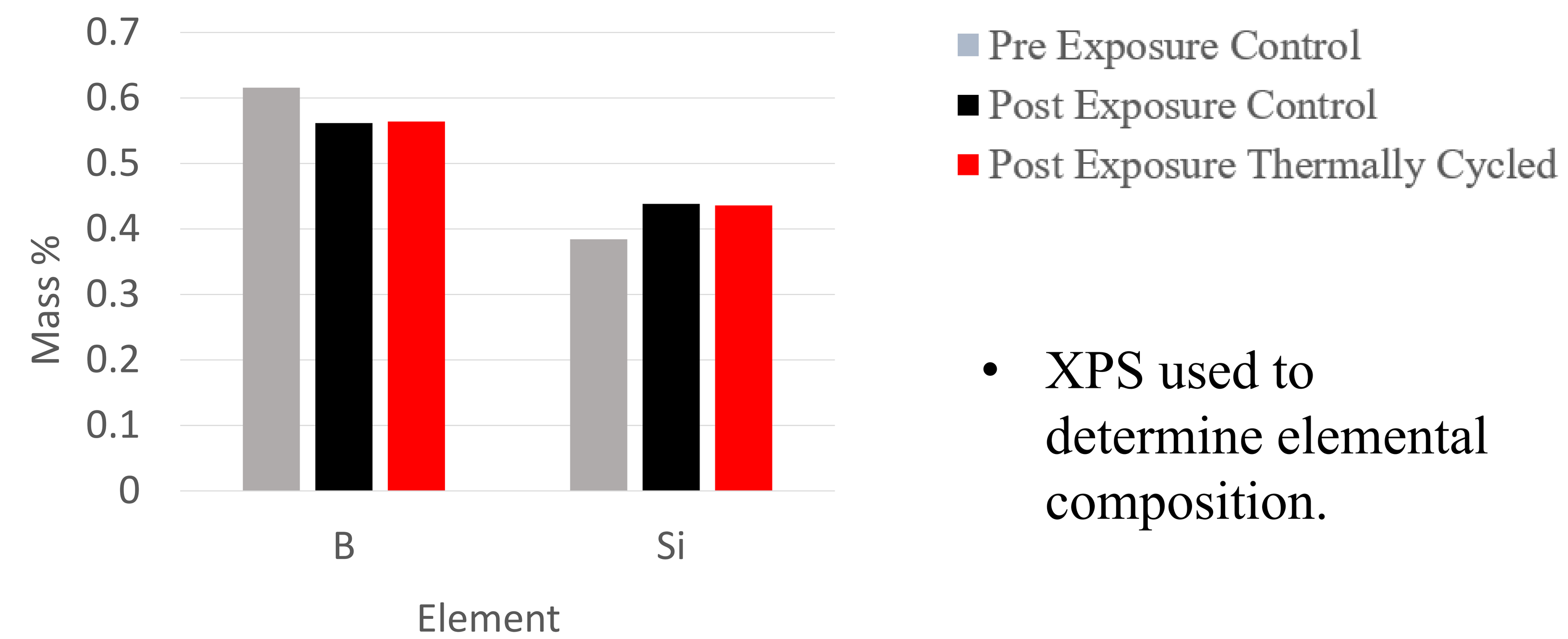
$\Psi = Amplification\ Function$

$\hat{h}(\omega) = Fourier\ Transformed\ Height\ Profile$

$\omega = Spatial\ Frequency$

- Contact profilometry used to analyze surface feature growth.
- Surface roughness in control and thermally cycled samples increased similarly.

Obj. 3 : Elemental Composition



- XPS used to determine elemental composition.

- Boron mass % decreased similarly and Silica mass % increased similarly for the control and thermally cycled samples after exposure to plasma.

Conclusions

- Cracks are induced by thermal cycling in Hall thrusters.
- Cracks have no demonstrated impact on plasma erosion
- Cracks have no demonstrated impact on elemental composition.

Acknowledgements

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References

[1] Solar System Exploration. (2008, June 15). Retrieved January 14, 2015, from http://climate.nasa.gov/evidence/
[2] Grys, K., Mathers, A., Welander, B., Khayms, V. (2010). Demonstration of 10,400 Hours of Operation on a 4.5 kW Qualification Model Hall Thruster. *AIAA/ASME/SAE/ASSE Joint Propulsion Conference*.