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Understanding electrode plasma formation on wires and thin foils via vacuum ultraviolet spectroscopy of desorbed surface contaminants

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1: Plasmas, Pulsed Power, & Microwave Laboratory, University of Michigan

2: Sandia National Laboratories

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Sandia National Laboratories

National Nuclear Security Administration

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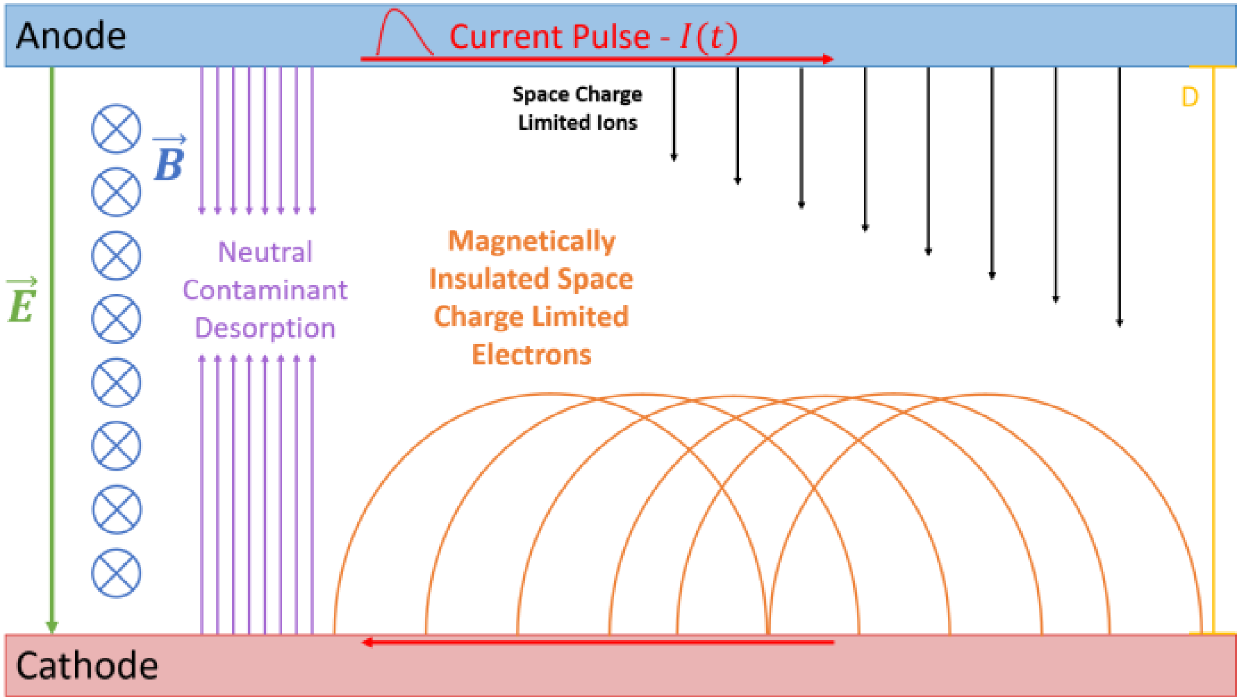
What is Power Flow for Current Delivery?

- The study of how power is delivered from the capacitor banks to the load region
  - Specifically, the magnetically insulated transmission lines in the vacuum section of a pulsed power driver
- Electrodes heat due to ohmic heating, charged particle bombardment, etc.
- This heating liberates contaminants from surface/bulk and ionize
- A strong magnetic field insulates the plasma from crossing the gap
- Plasma drifts along electrodes
- Current loss occurs when a weak or no magnetic field is present to insulate the plasma

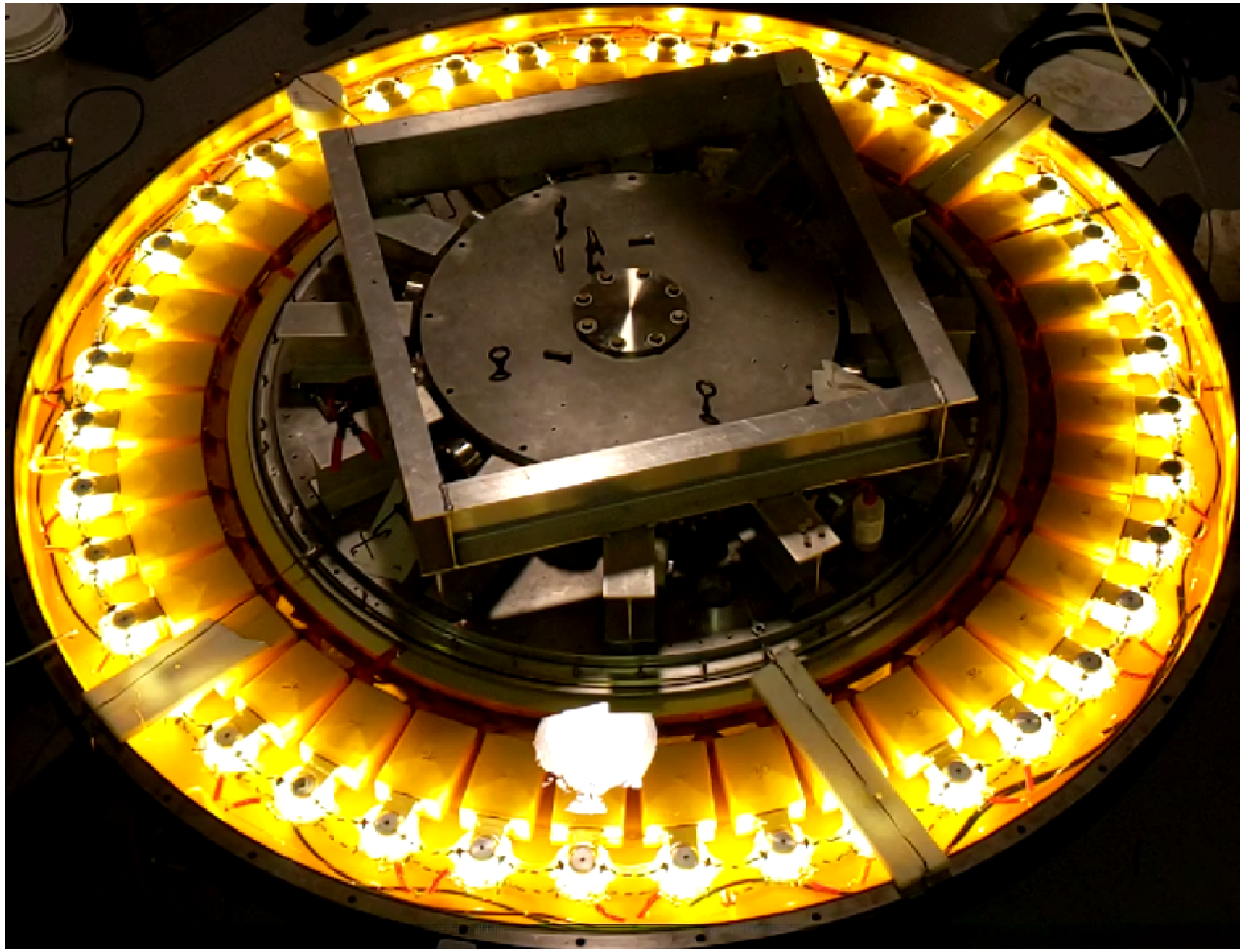
M.R. Gomez *et al.* **PRAB** (2017) [10.1103/PhysRevAccelBeams.20.010401](https://doi.org/10.1103/PhysRevAccelBeams.20.010401)



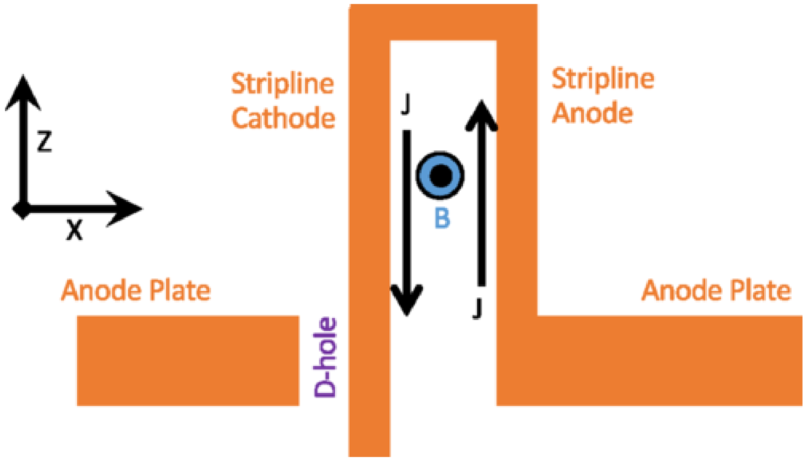
University of Michigan MAIZE Facility

- Michigan Accelerator for Inductive Z-pinch Experiments (MAIZE) at the University of Michigan
- Delivers up to 1 MA (at full charge) for a matched load with a rise time of 100 ns
- 40 bricks comprised of two oppositely charged 40 nF capacitors and a spark gap switch
- Charges and Discharges in parallel to add current

P.C. Campbell *et al.* IEEE Trans. **46** (2018)



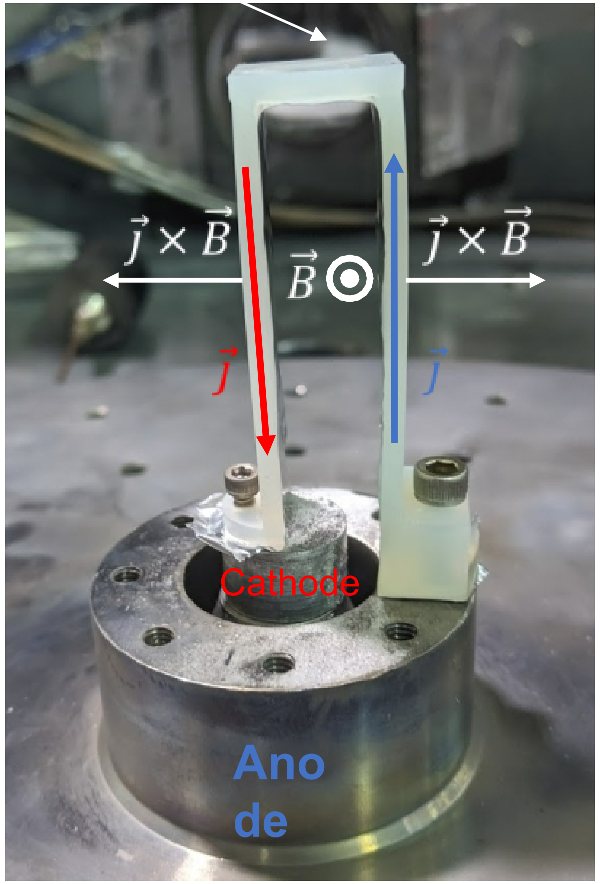
New Power Flow Platform at the University of Michigan



Strip-line flyer plate geometry used on the Z-machine for dynamic material property experiments

A. Porwitzky *et al.* **PRAB** (2019)

laser entrance window

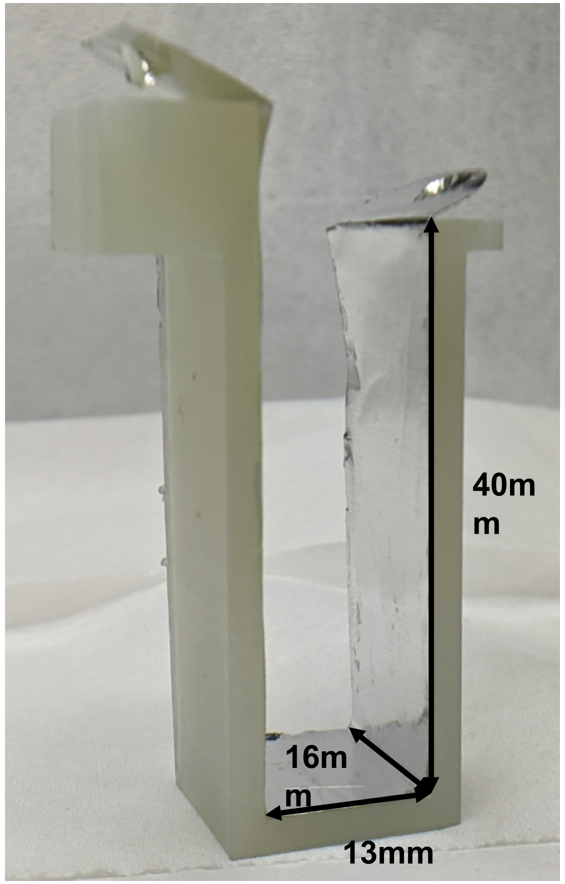


Target in situ inside MAIZE vacuum chamber

50 µm Aluminum Planar Foil

R = 3.6 mΩ

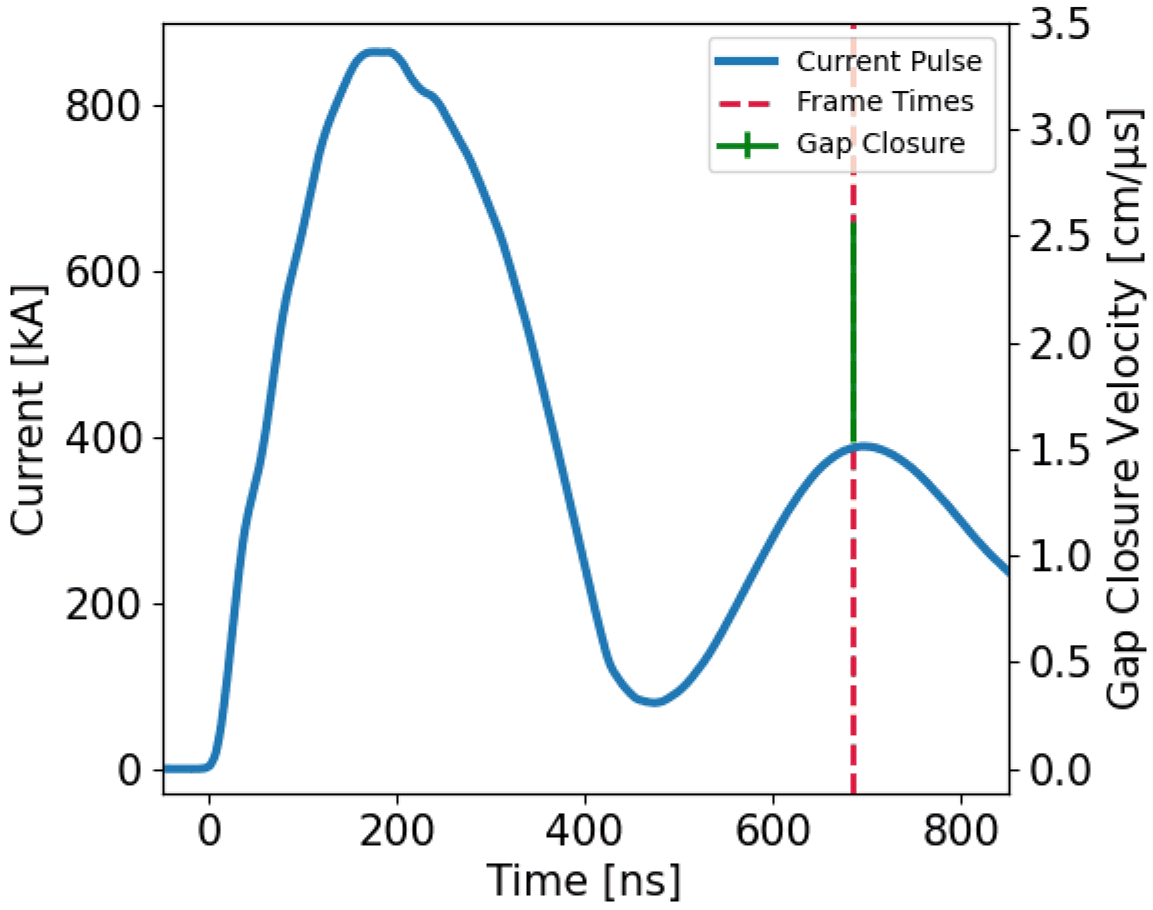
L = 20-50 nH

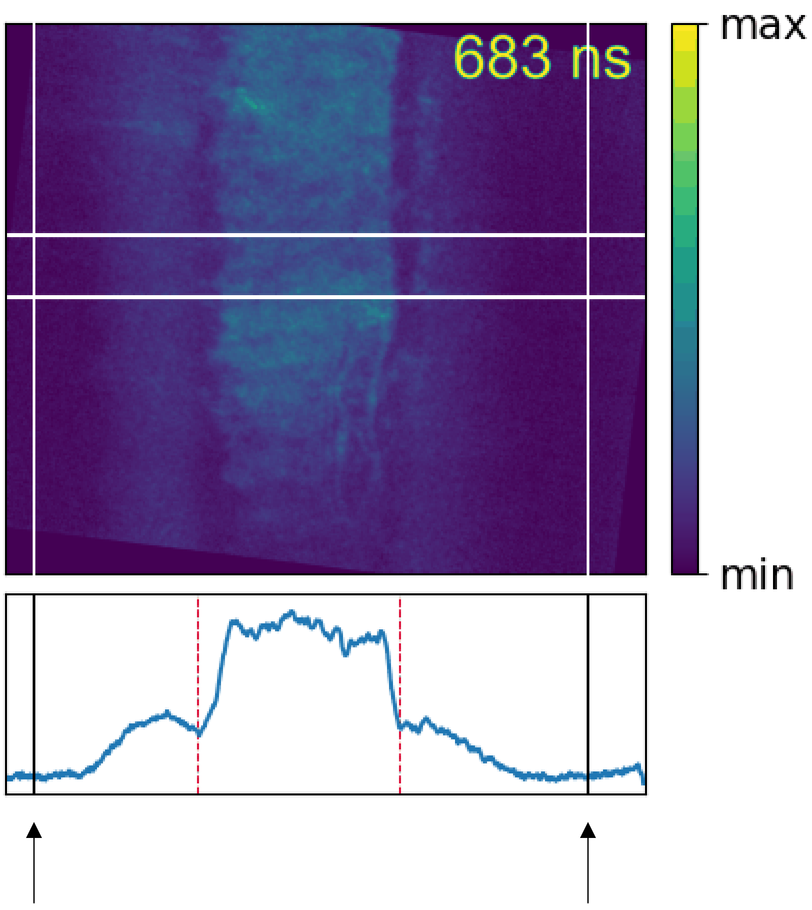


- 3D Printed Support Structure
- Uses Form 2 SLA printer Durable Resin
- 31.8 MPa tensile strength

T.J. Smith *et al.* **RSI** (2021) 10.1063/5.0043856

Thin Foil Planar Tab Experiments – Large Gap Size (13 mm)





Starting Foil Locations (13 mm)

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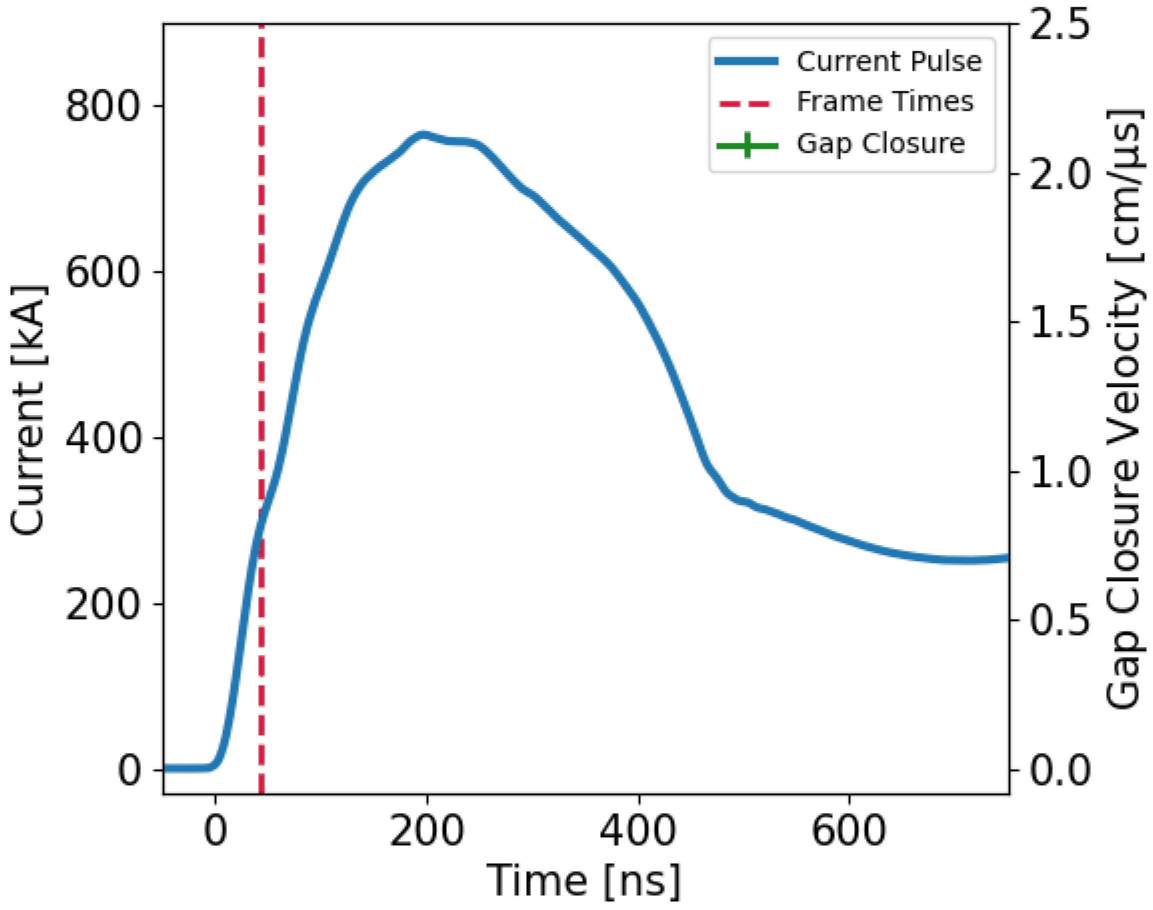
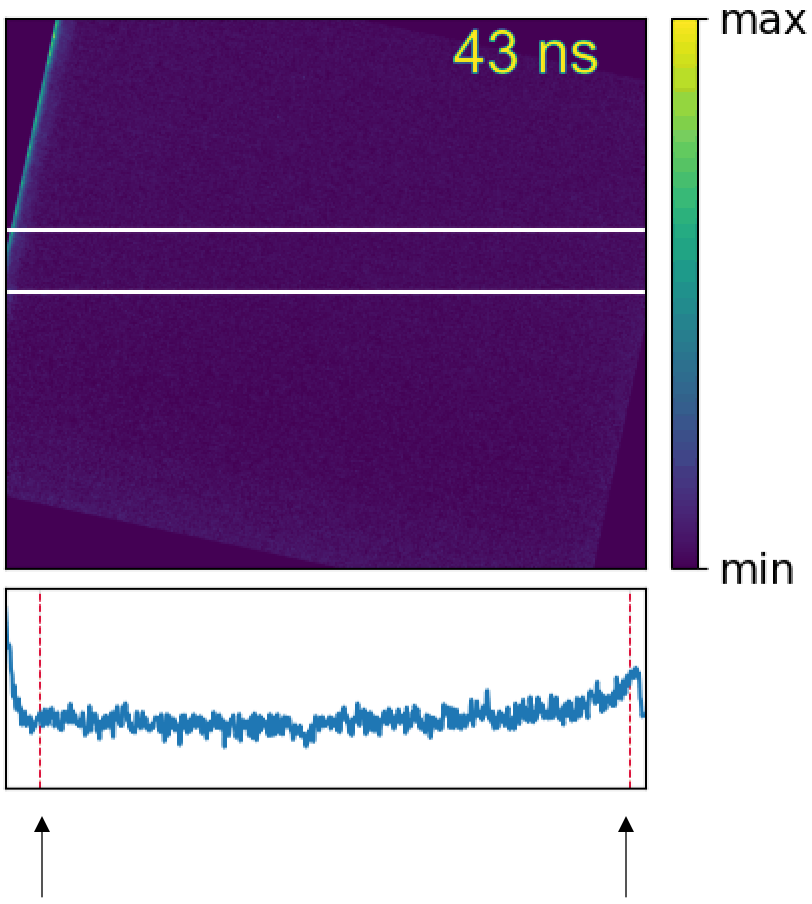
T.J. Smith *et al.* **RSI** (2021) 10.1063/5.0043856

Thin Foil Planar Tab Experiments – Large Gap Size (13 mm)

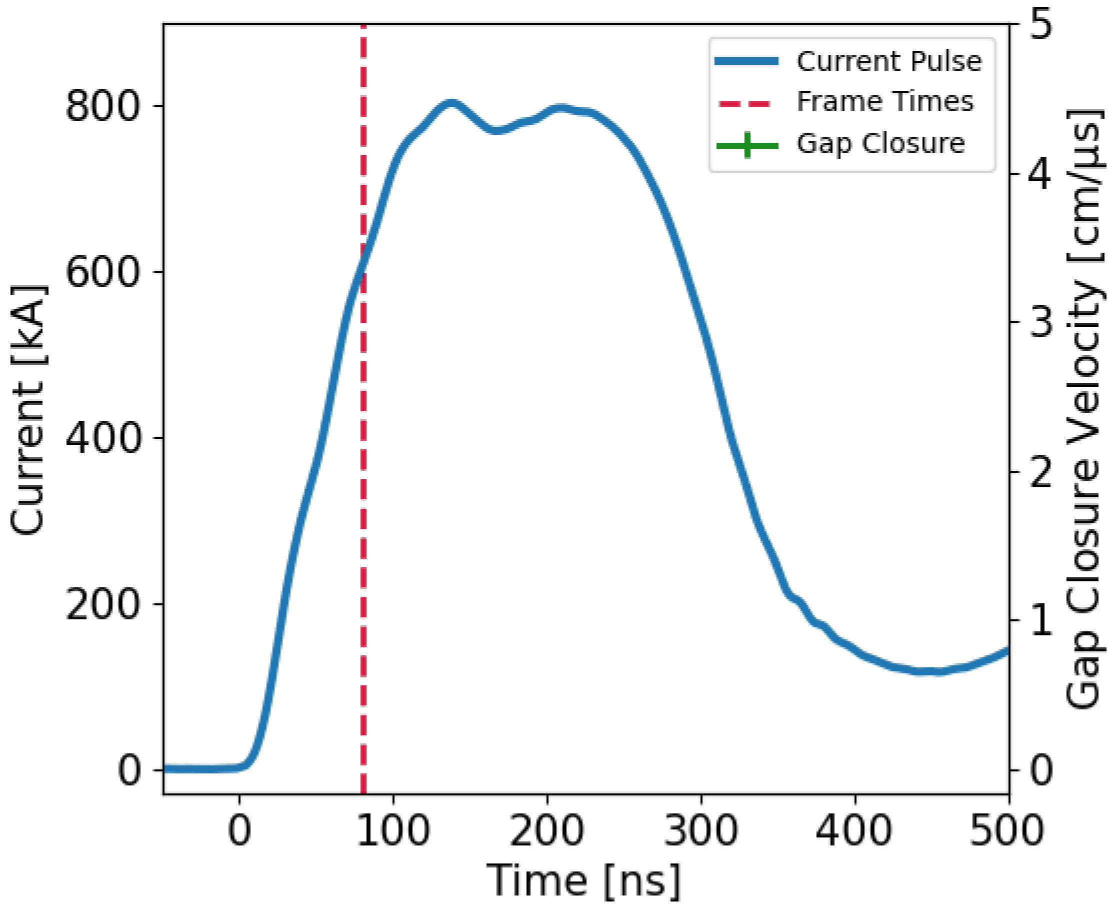


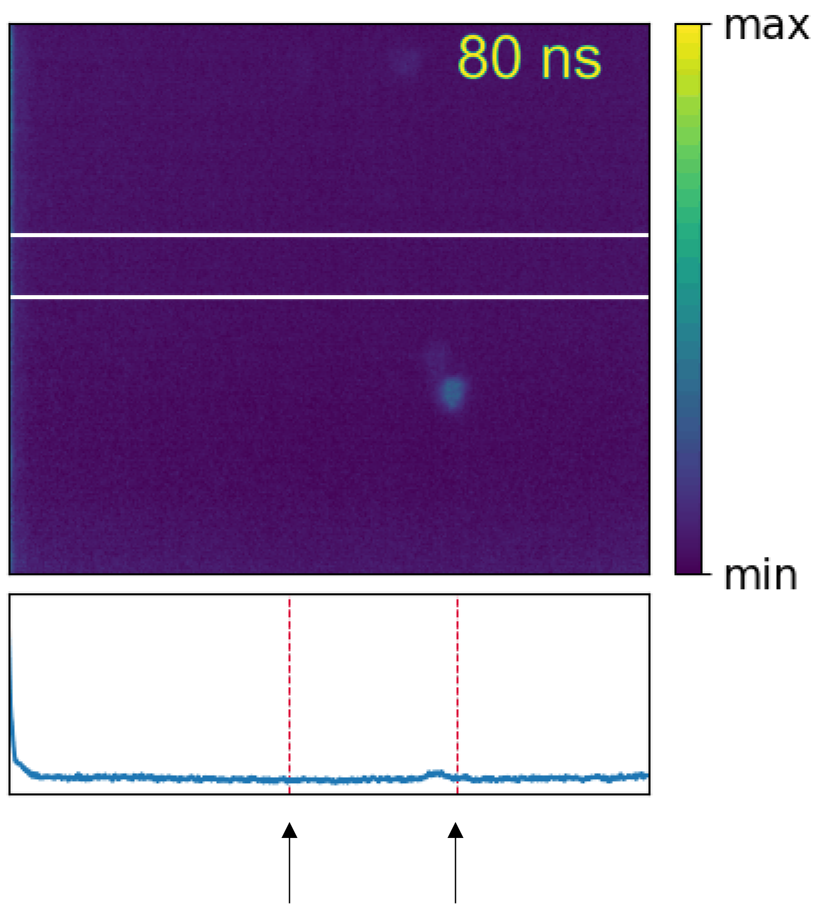


Starting Foil Locations (13 mm)

T.J. Smith *et al.* **RSI** (2021) [10.1063/5.0043856](https://doi.org/10.1063/5.0043856)

Thin Foil Planar Tab Experiments – Small Gap Size (4.8 mm)

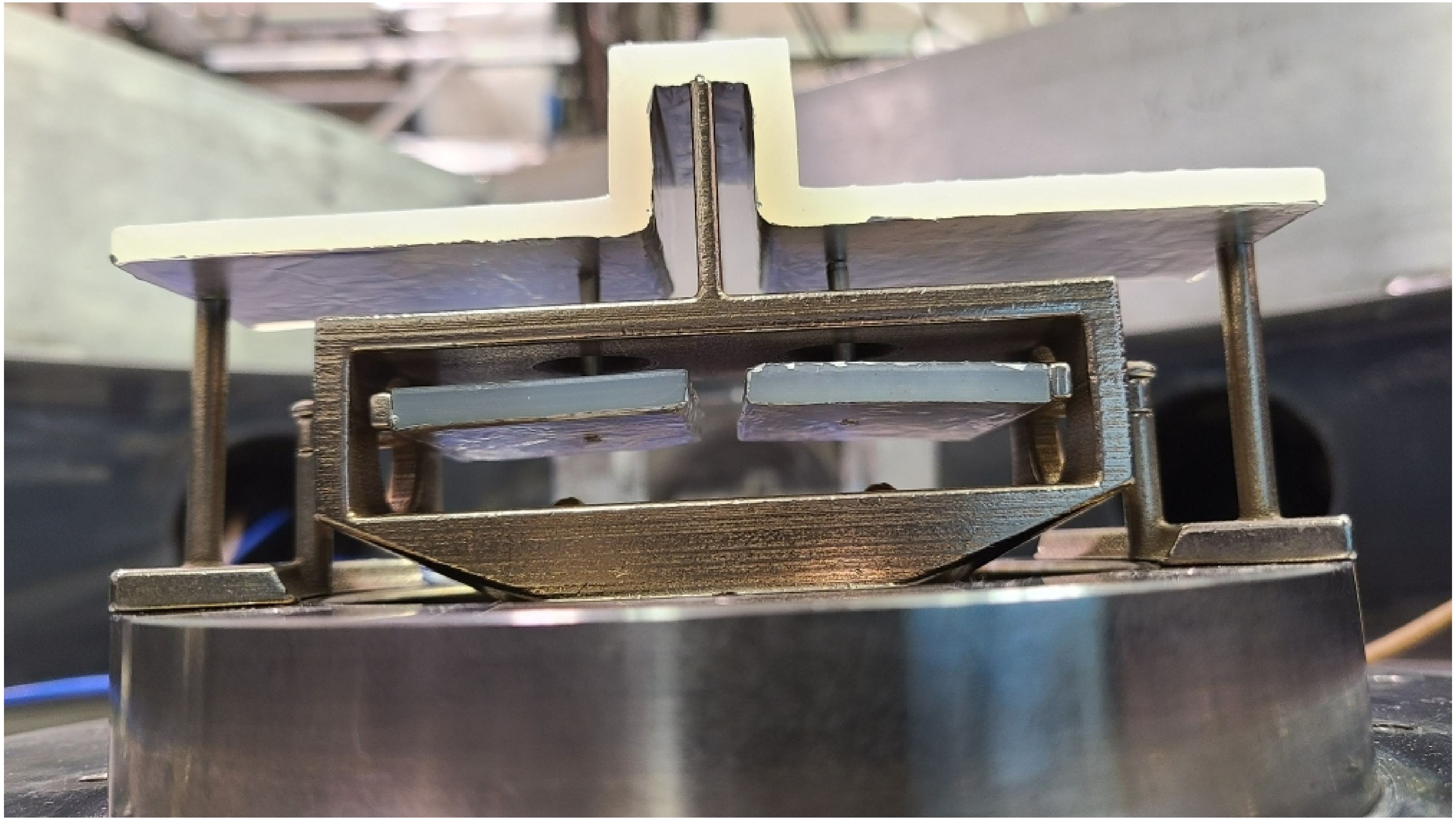




Starting Foil Locations (4.8 mm)

T.J. Smith *et al.* **RSI** (2021) [10.1063/5.0043856](https://doi.org/10.1063/5.0043856)

Print-A-Lute - Pre Shot – Anode Foils



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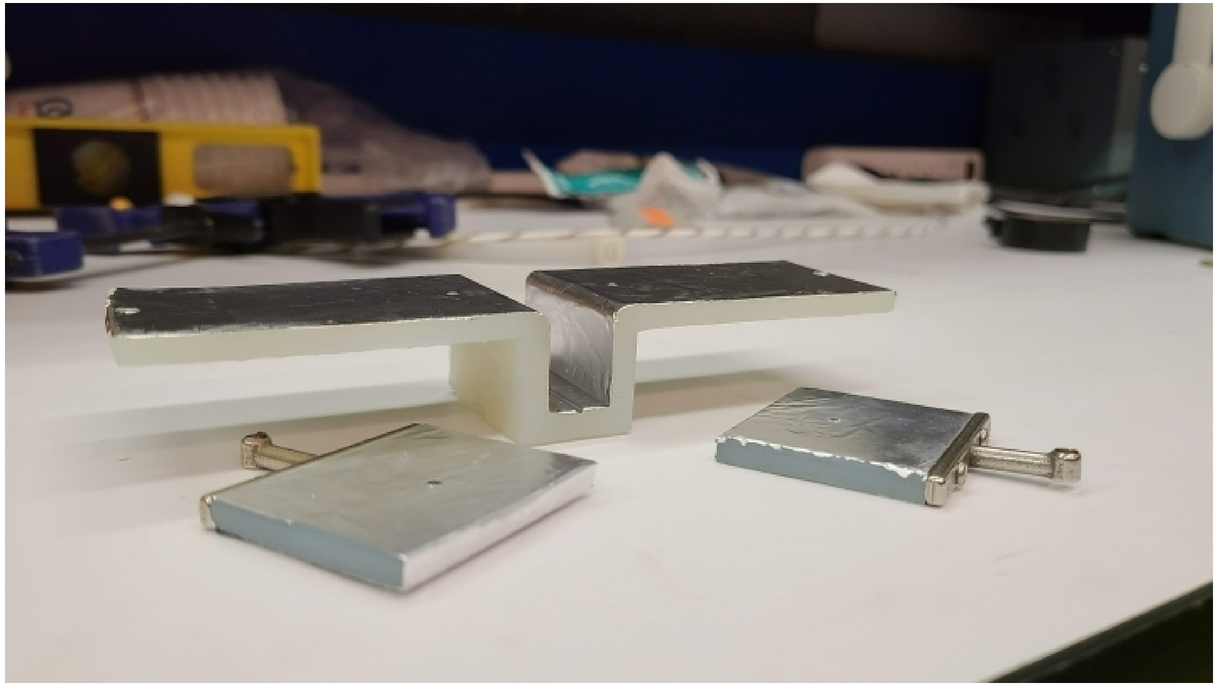

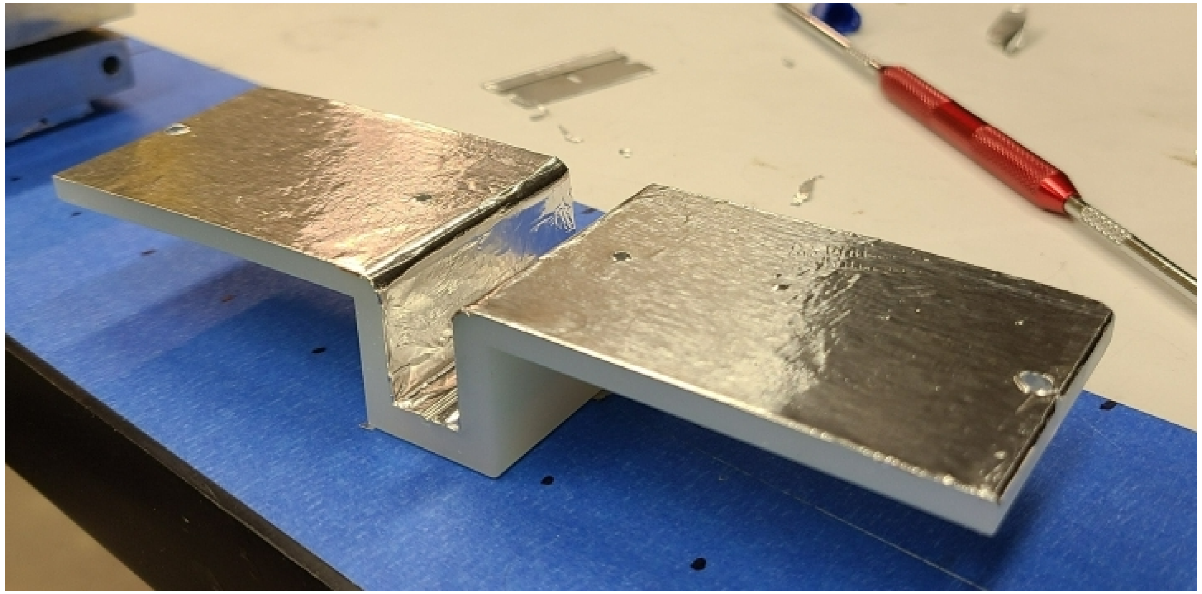

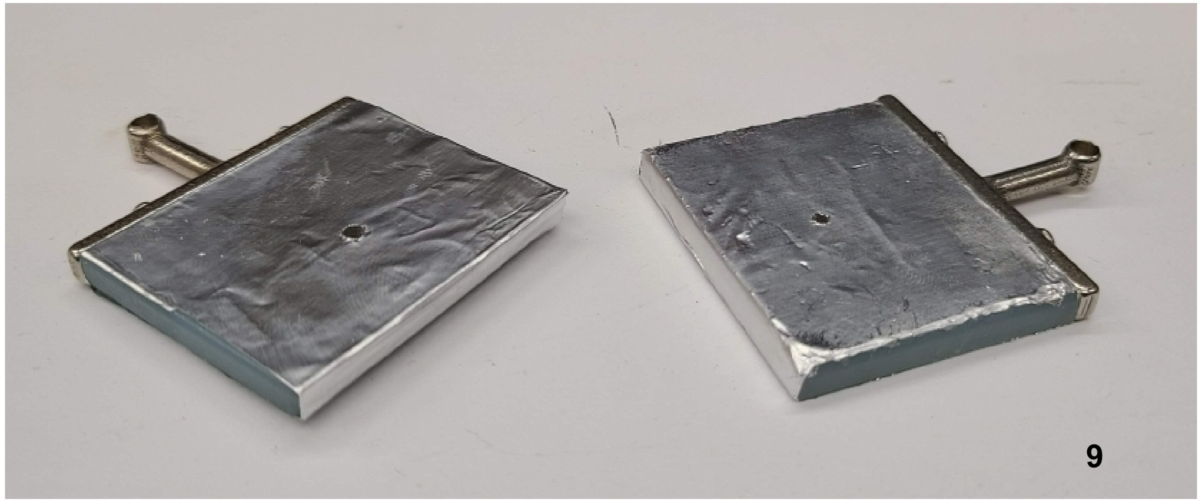

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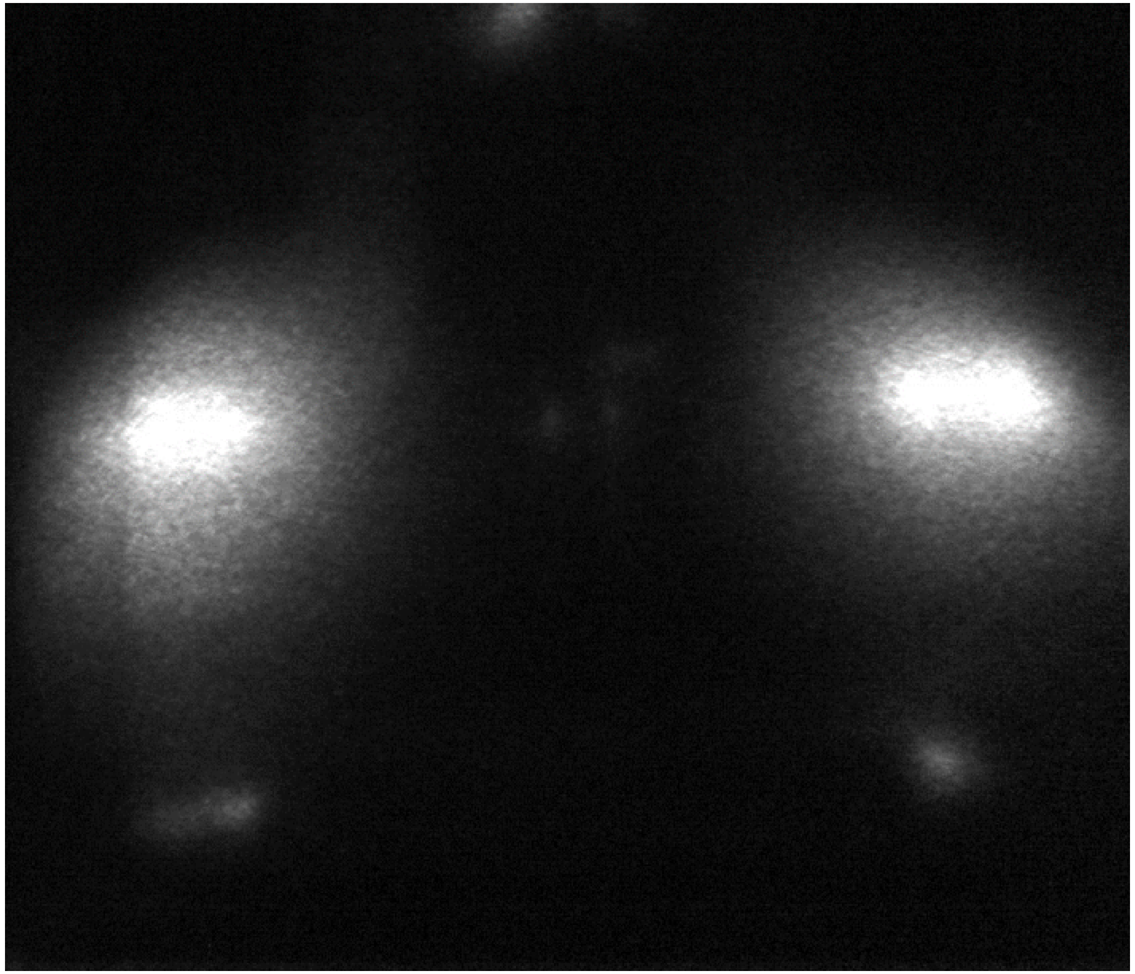
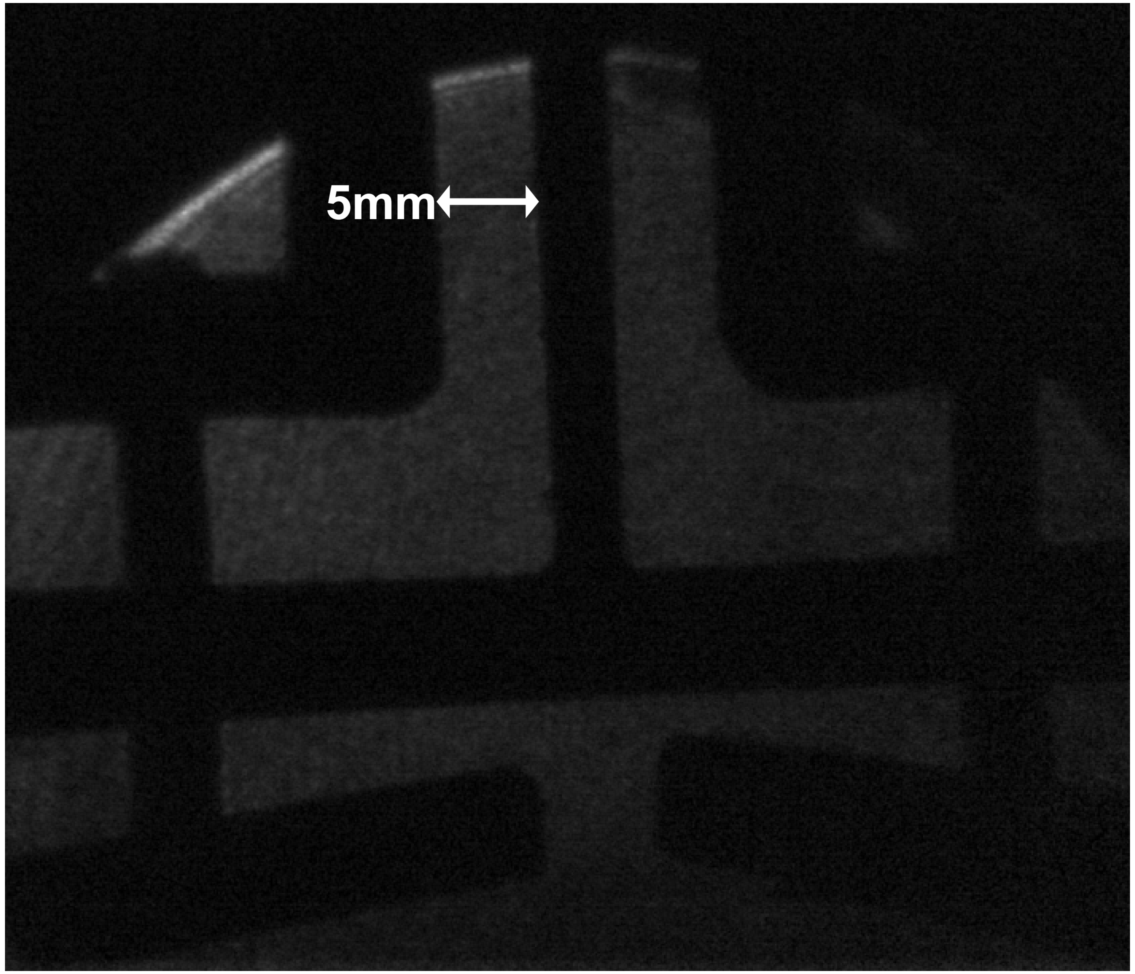
Print-a-Lute – Visible Self-Emission - 01762





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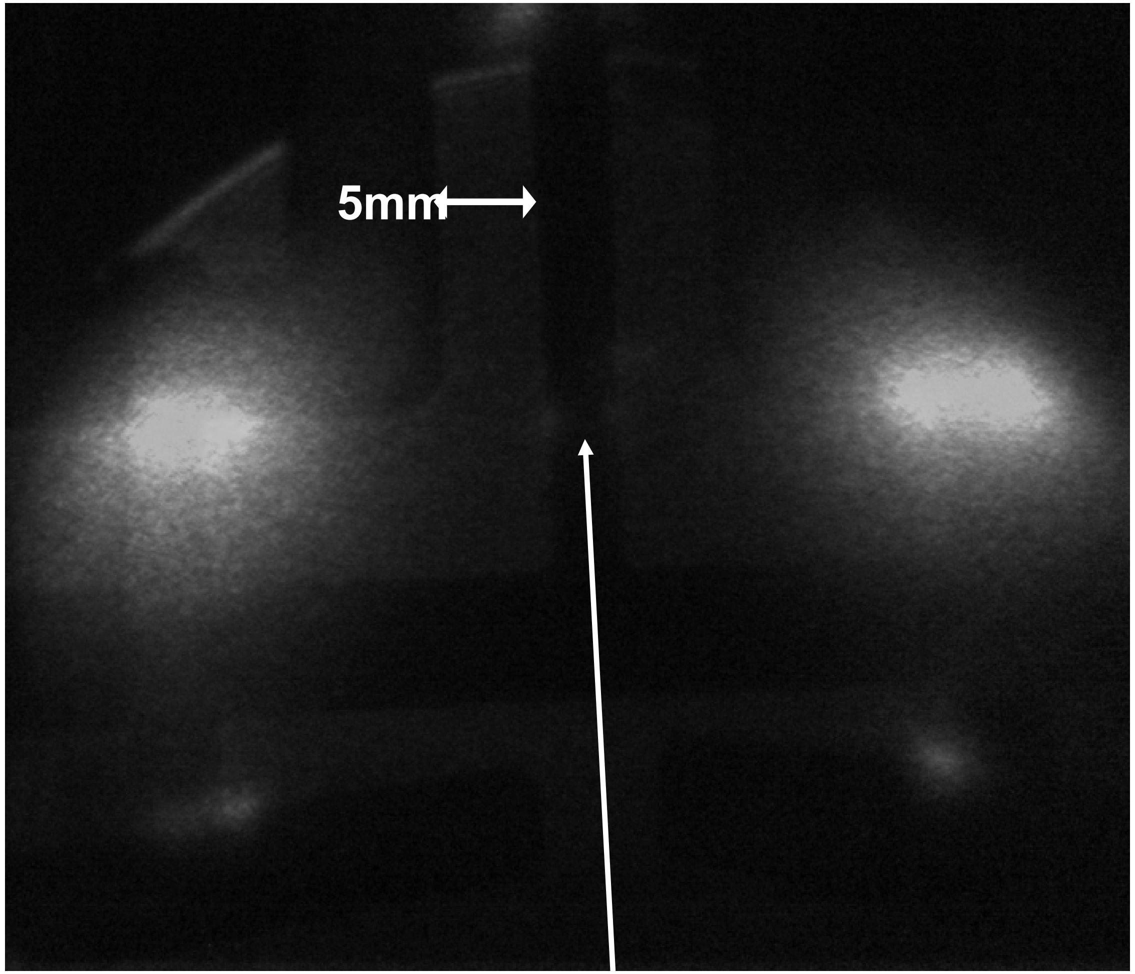
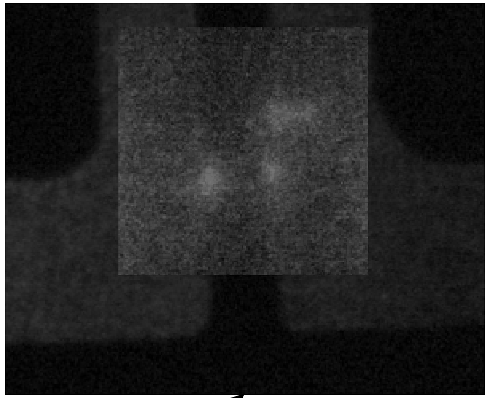
Print-a-Lute – Visible Self-Emission – Composite Image

Main bright spots seen at where the posts attach to the anode levels

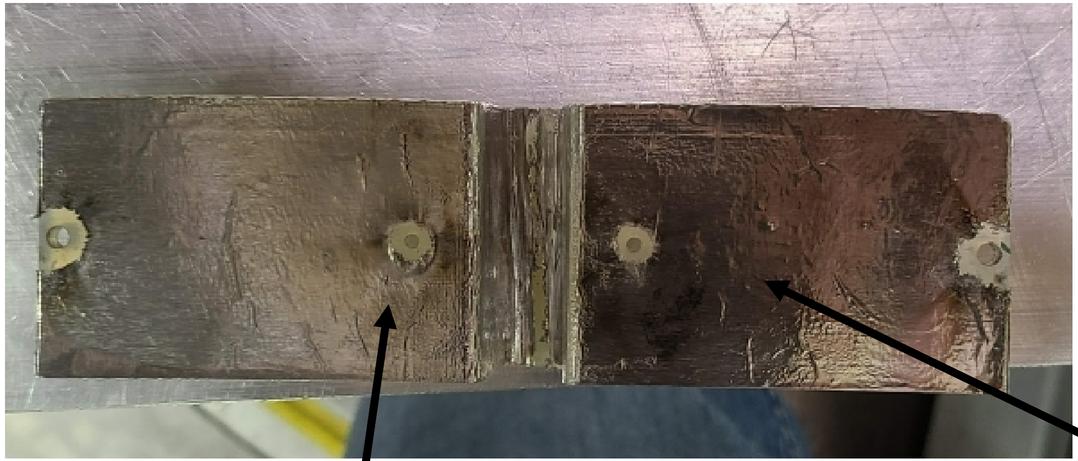


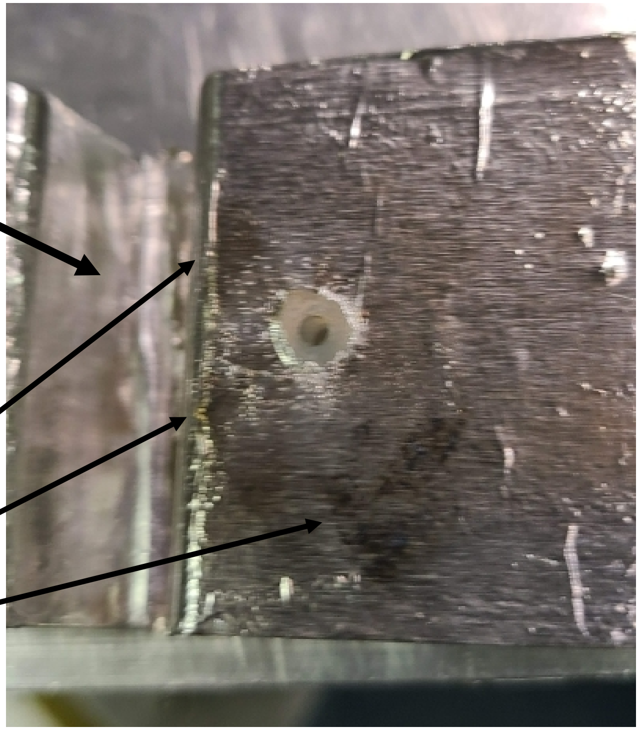
“Bright” wisps on cathode at rough height of upper anode level

Higher brightness



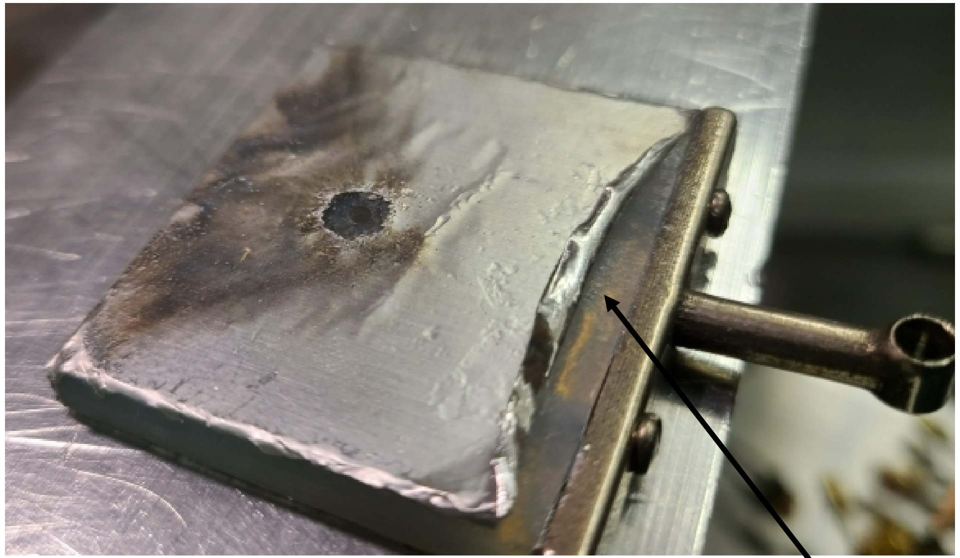
Print-a-Lute – Post Shot – Upper Anode Level

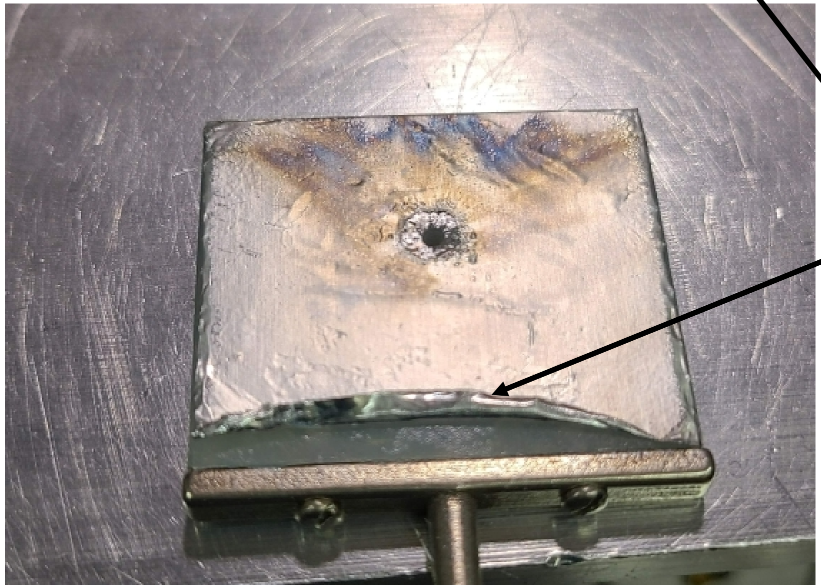




Scorch marks

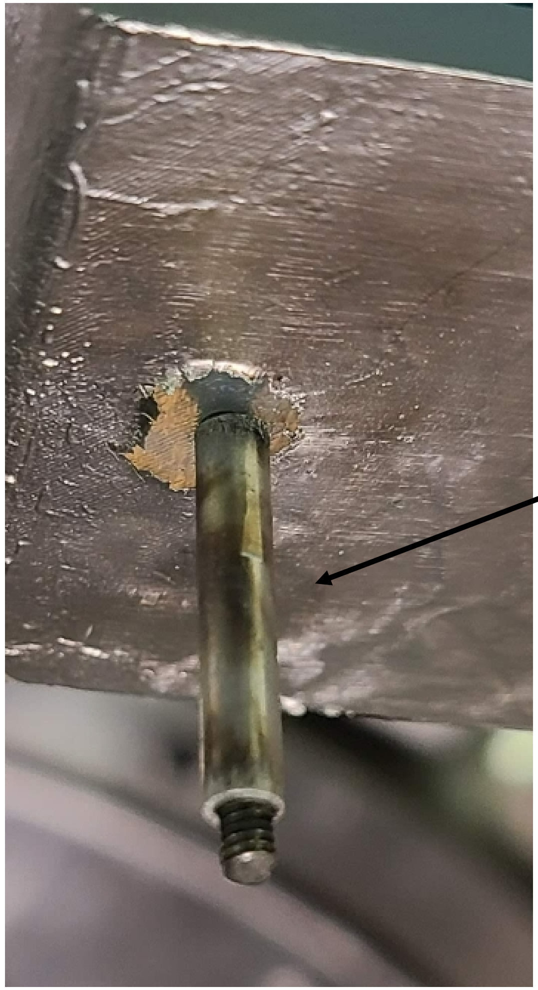
Print-a-Lute – Post Shot – Lower Anode Level





Foil "cut" from heating up at metal contact

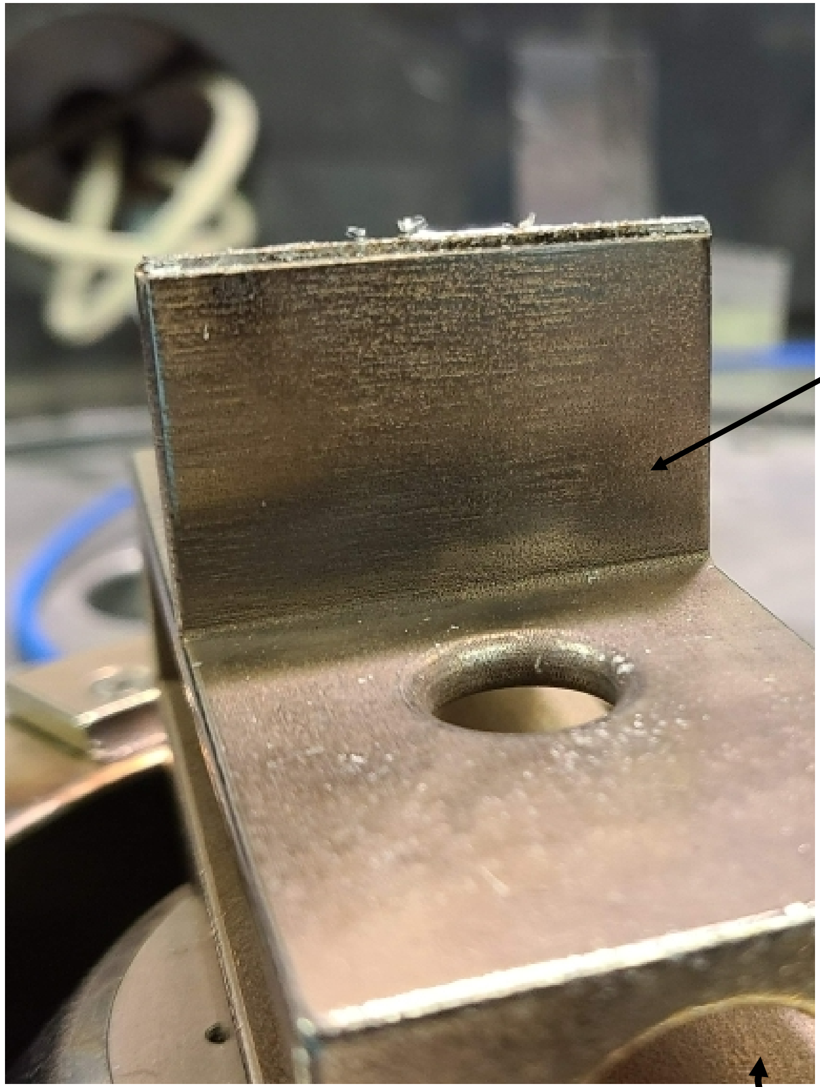
Print-a-Lute – Post Shot – Anode Post

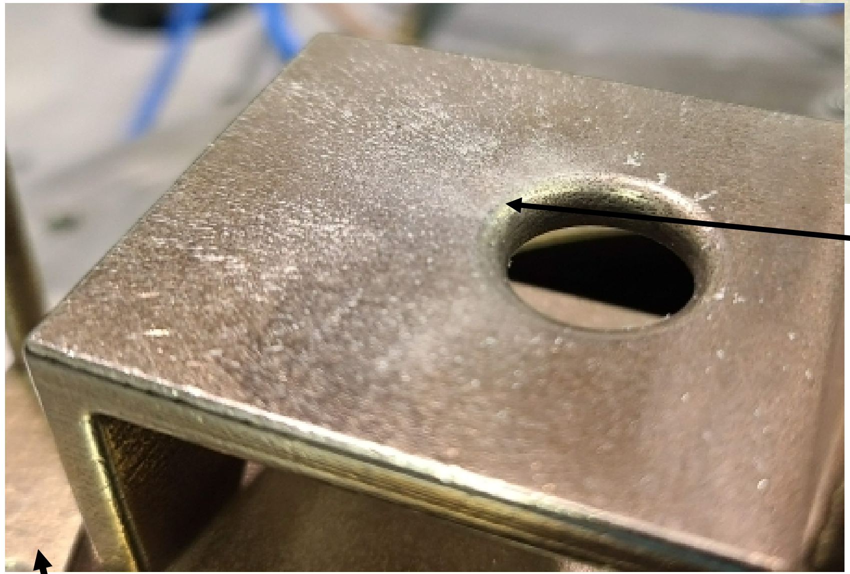


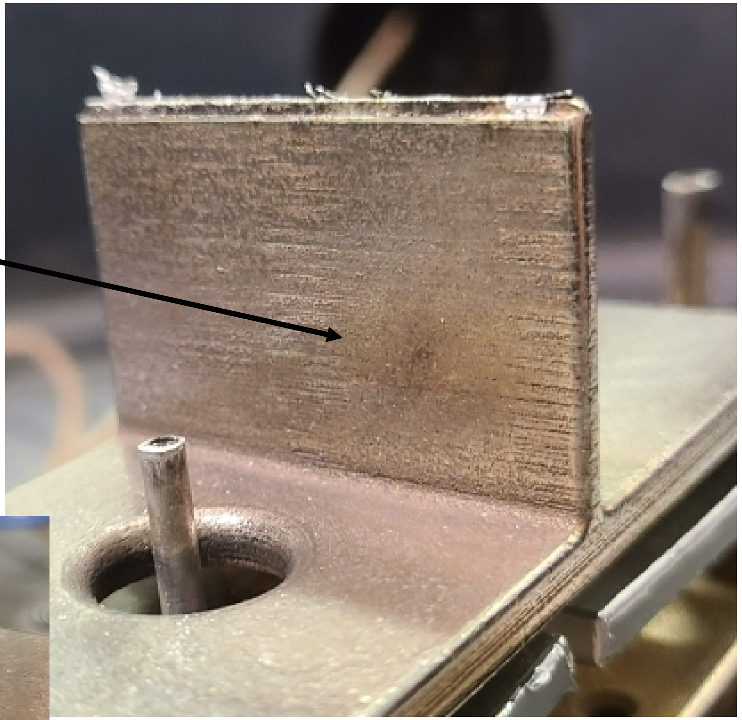
Scorching on posts concentric to cathode hole

Print-a-Lute – Post Shot – Cathode

Scorch marks (opposite sides)







Looks to be from plasma generated at post connection locations as it sometimes appears after the all-metal print-a-lute shots

Sandia Internship - Organization/Manager/Mentor

- Organization: 1659 – Advanced Capabilities for Pulsed Power
- Manager: George R. Laity
- Mentor: Mark D. Johnston

“Department 1659 develops new capabilities and diagnostics for state-of-the-art pulsed-power facilities. We conduct experiments on Z and other pulsed power facilities in support of multiple programs, including **power flow physics**. We develop and support emission **spectroscopy** on Z, which is fielded on ~50% of experiments on Z. We maintain and operate SITF (Systems Integration Testing Facility) to develop subsystems for Z to a TRL of 6 prior to fielding on Z, including **magnetic field coils**, **gas puff z-pinches** and other capabilities. We are developing new systems for Z to provide in-situ **electrode cleaning** to mitigate or eliminate contaminant plasma formation on electrodes which limit current coupling efficiency.”

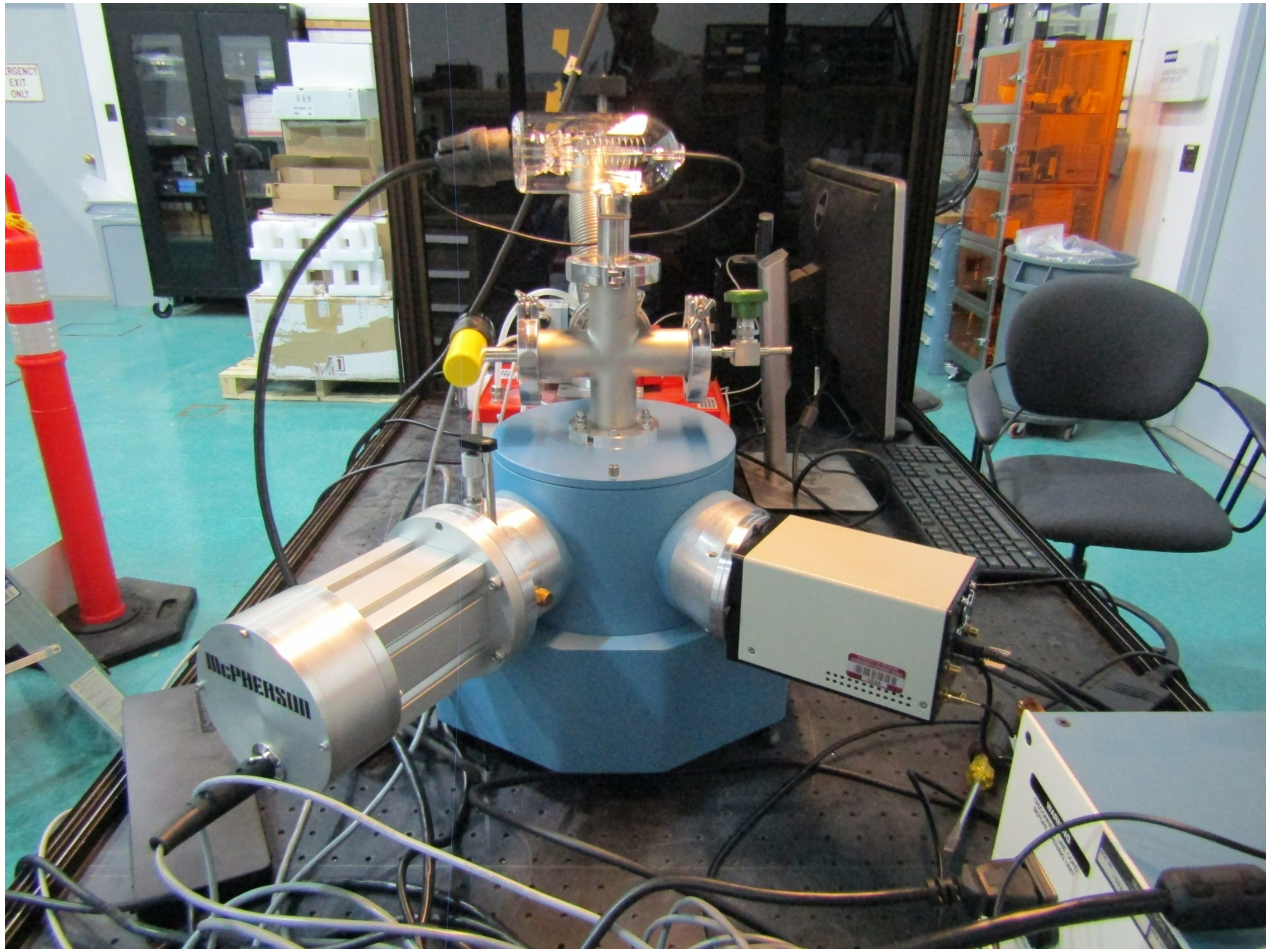
VUV Spectrometer - McPherson 234/302

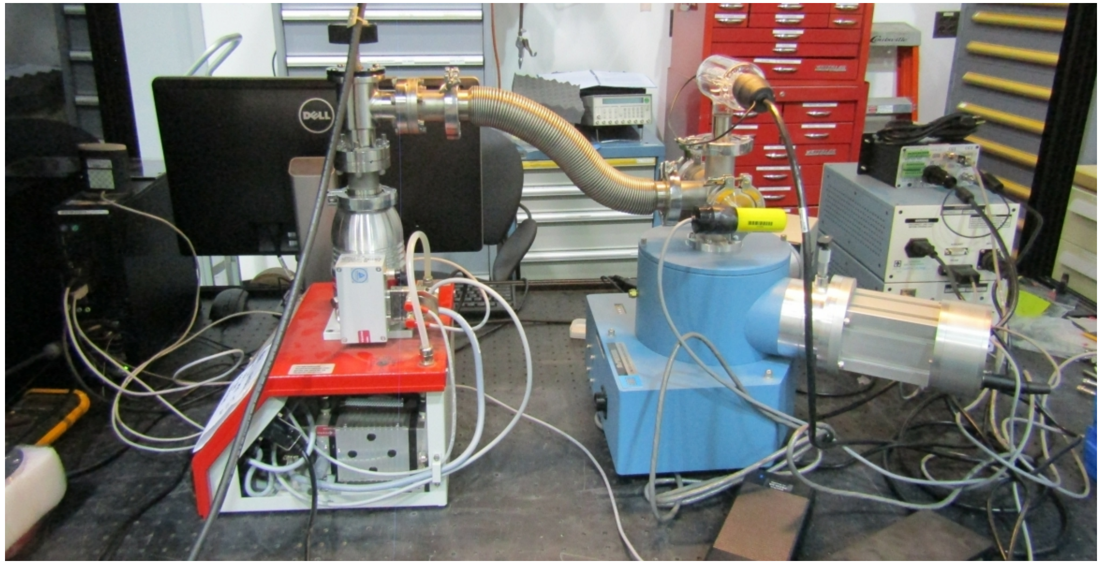
- **Optical Design:** Abberation Corrected Seya-Namioka
- **f/#:** f/4.5
- **Focal Length:** 0.2 m
- **Gratings:** 600, 1200, 2400 g/mm
- **Grating Coatings:** Al + MgF_2
  - PI for 2400 g/mm
- **Operating Wavelengths:** > 40 nm
- **Required Vacuum:** ~10^{-5} Torr
- **Linear Dispersion:** 4 nm/mm
- **Slit Width:** 0.1-3 mm

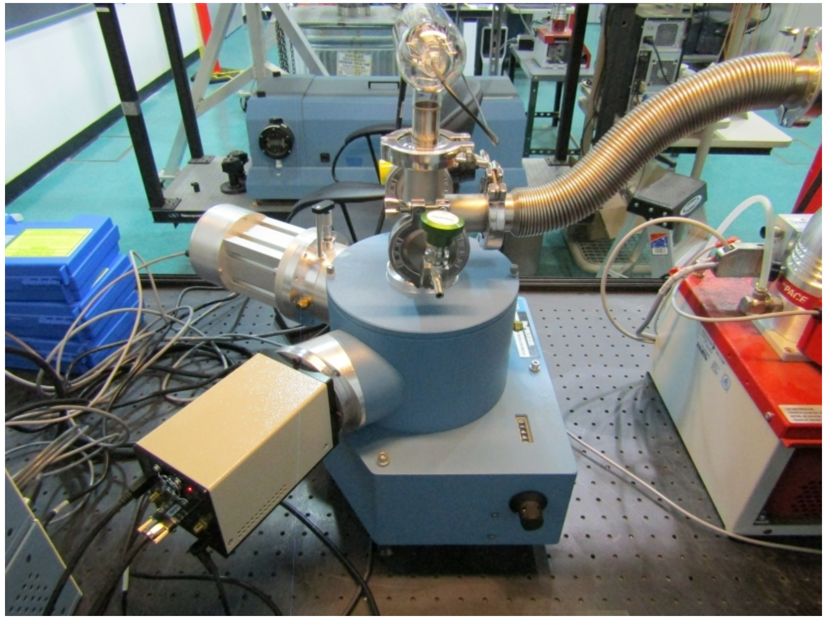
Camera - Photek iCMOS 160

- **Quantum Efficiency:** 20-25% (100 -300 nm)
- **Gate Width:** > 3 ns
- **Window Size:** 25mm, 1920x1200 pixels
- **Pixel Size:** 13.3 μm
- **Window Material:** MgF_2

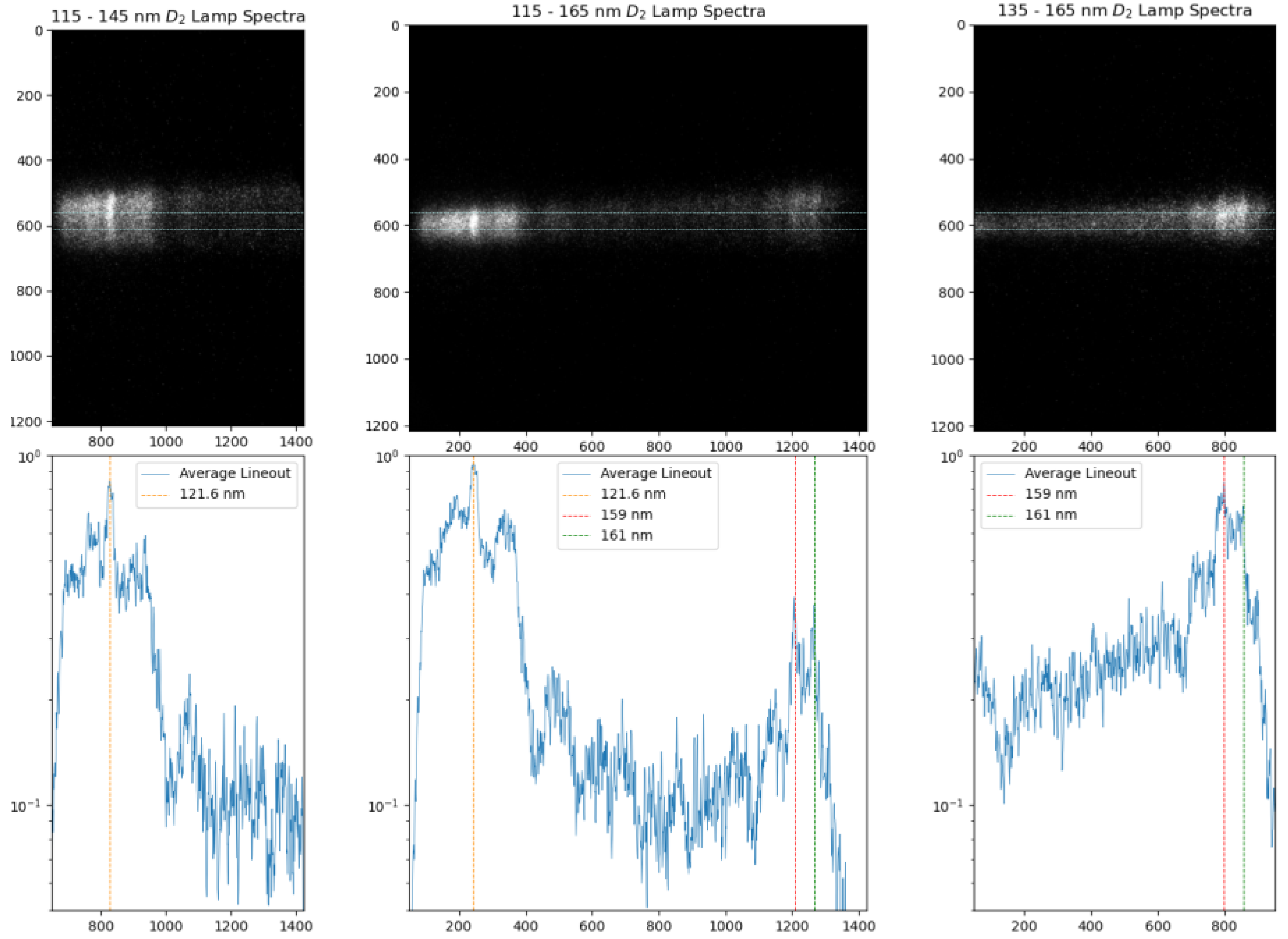
Spectrometer Calibration Setup







First Collected Spectra Using Deuterium Lamp Source

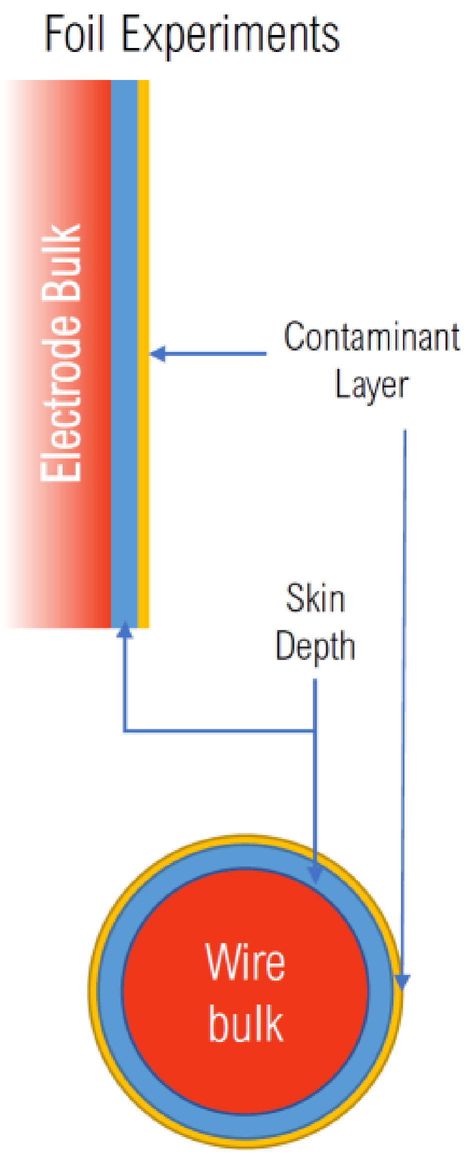


- 1200 g/mm Grating – 1400 Å Blazed
- 2 µs Gate Width
- 70/100 Gain (Photek Camera)
- 50 µm slit width
- Centered @ 1216 Å (left), 1440 Å (center), & 1600 Å (right)
  - Left and Right images are cropped

VUV Spectrometer Slit Focusing Optics

- MgF_2 is standard coating and lens material for optics operating at wavelengths in VUV near Lyman-α
- Lens
  - Transmission near 50% @ 121.6 nm
  - MgF2 is a birefringent material – refracts polarizations differently & has to be oriented correctly to light ($\hat{k}$)
  - Refractive Index (n) is variable and non-linear with wavelength (λ) (larger n for smaller λ)
  - Useful only for measuring a specific line – focal length changes vs λ – move lens to measure different line
- Mirrors
  - High reflectance (78-83% @ 121.6 nm)
  - Use of focusing mirrors should achieve same thing as lens, with higher efficiency in VUV
- Optical surface damage
  - Films/surface coatings form from general exposure to oxygen, humidity
  - Over time, VUV interaction can damage by interacting with these films
  - Storage in general humidity can also further degrade optical reflectivity/transmission

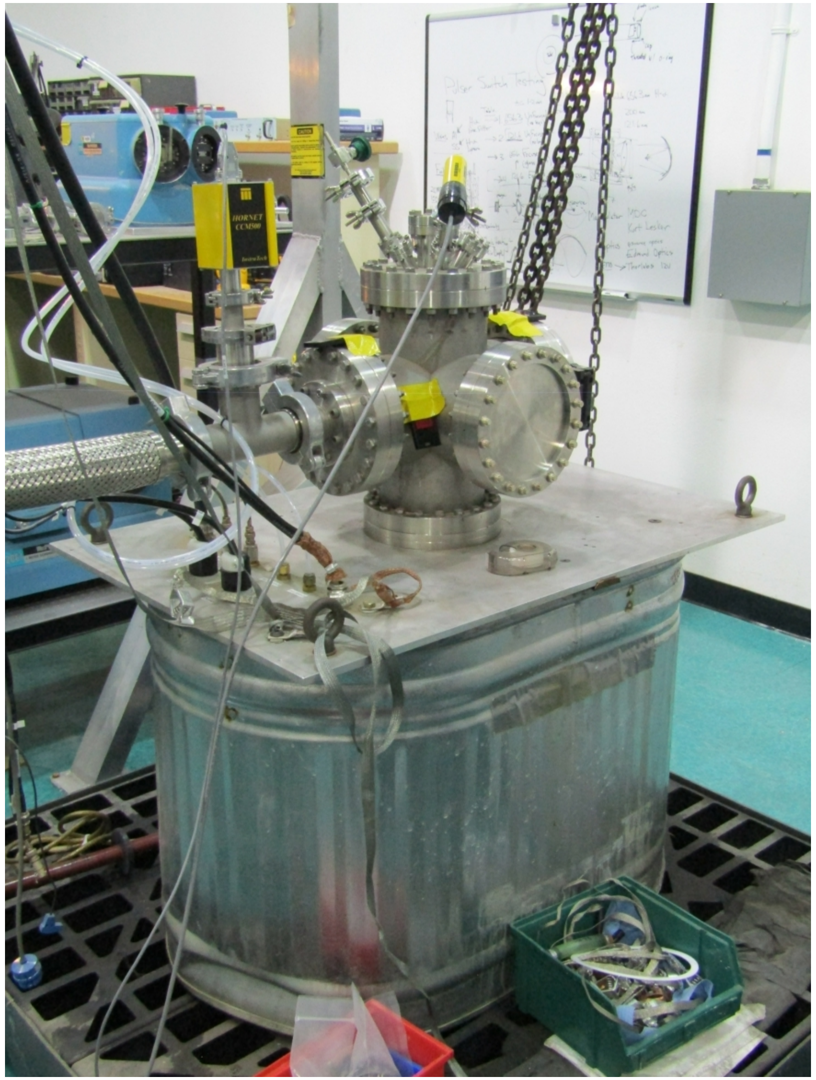
Electrode Surface Science – Upcoming Experiments

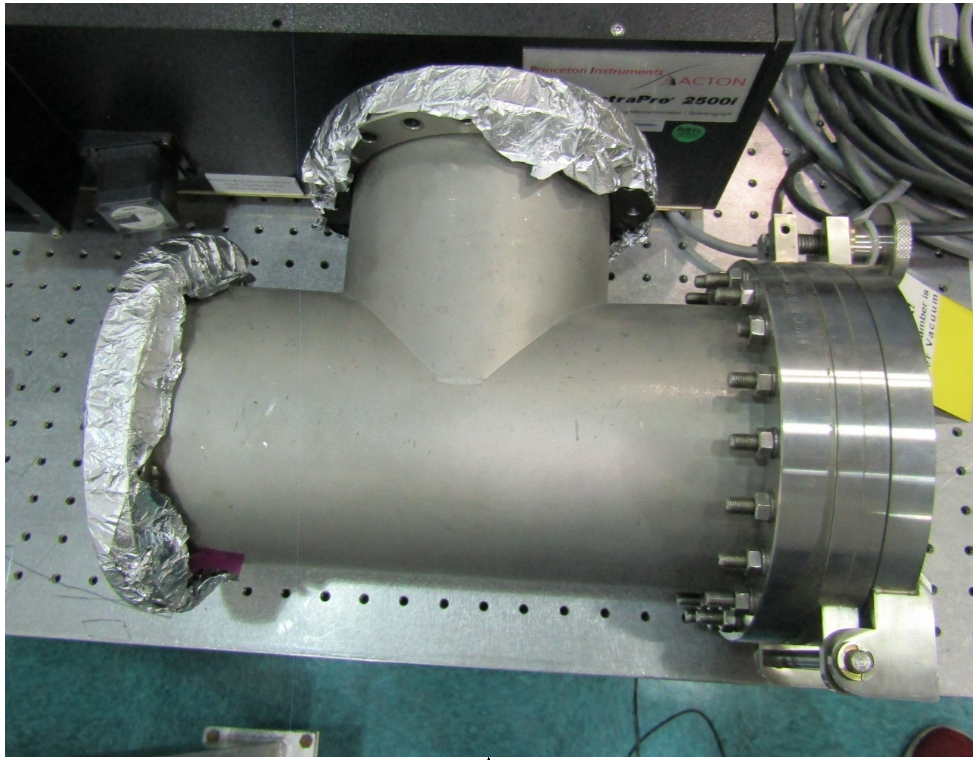


- Ohmic Heating occurs at skin depth of conductor
  - Heat transfers to foil/wire bulk and surface contaminant monolayers
- As bulk thickness decreases, how does the rate of contaminant layer desorption react?
  - Should be directly proportional to ohmic heating rather than other heating methods like ion/electron deposition
  - Finite energy in a current pulse. Thermal Energy scales from current density at skin depth layer (for planar geometry)
  - Heat transfer should take place from skin depth layer to bulk material and contaminant layer
  - Shot-to-shot, increasing bulk thickness in relation to skin depth of current pulse should increase the thermal energy deposited there rather in the contaminant layers (should act as a heat sink).
  - Conversely, shrinking the bulk material thickness should see more heat transferred to the contaminant layer, increasing the rate of material desorbed from the surface (and possibly electrode material melt)
  - Using spectroscopy, we should be able to measure the plasma density and thus the contaminant inventory from the wire/foil

Electrode Surface Science – Upcoming Experiments

Sandia Light Lab pulser for wire experiments





VUV optics chamber before spectrometer

Conclusions & Future Work

- Expand the platform to more complex geometries relevant to pulsed power accelerator architecture
  - Post-hole Convolute
- Use the platform to develop more diagnostics for power flow experiments
  - VUV Spectroscopy
- Use of advanced computational techniques to further investigate underlying physics

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