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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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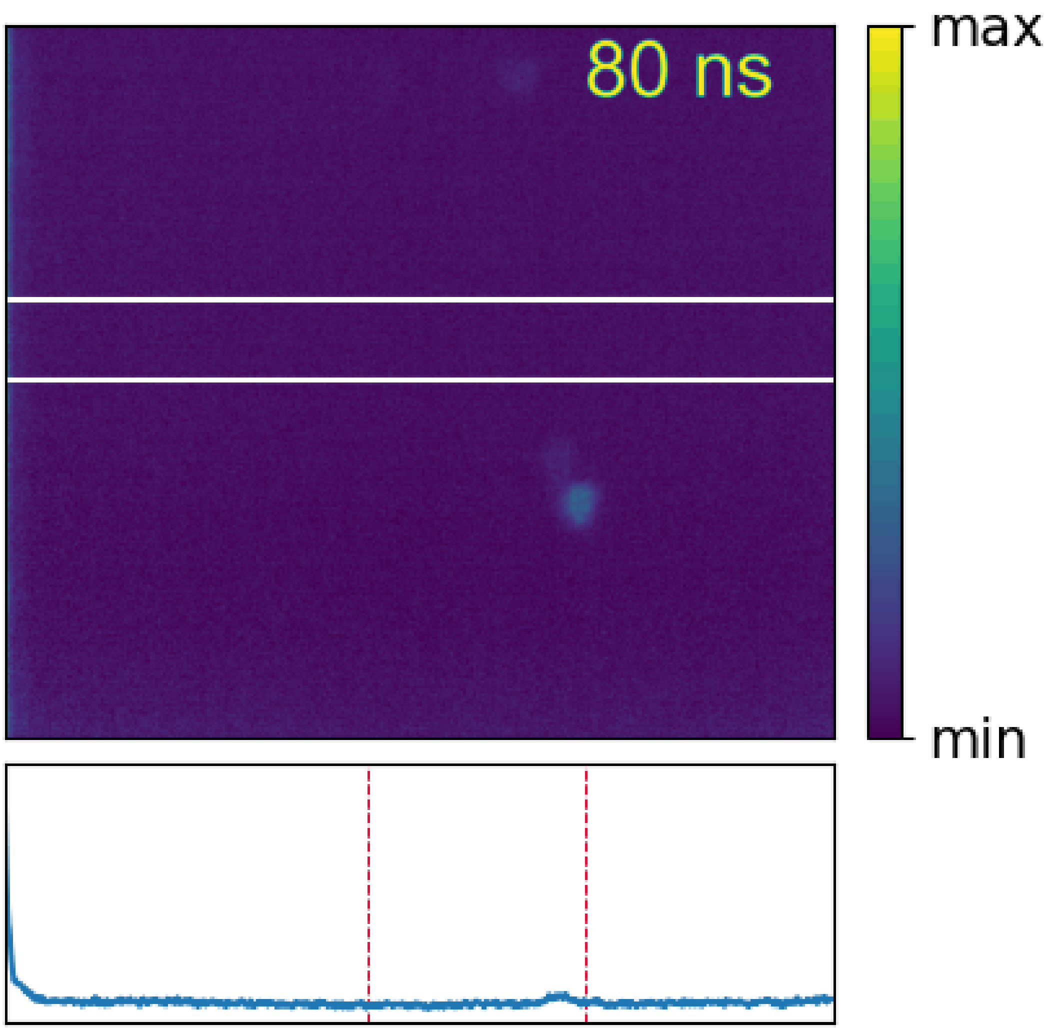
Project Overview

Power Flow Plasmas

- I have previously demonstrated (@ UMich) how to generate plasmas to study dynamics in relevant pulsed-power geometries on university scaled drivers (T.J. Smith *et al.* RSI 2021)
- Using this platform, we can study electrode surface science looking at mechanisms for initial plasma formation
- Inventory measurements of contaminant desorption off high-power magnetically insulated transmission line (MITL) electrode surfaces/bulk
- Using vacuum ultraviolet (VUV) spectroscopy to measure hydrogen Lyman-α line (121.6 nm) to determine inventory



Semi-Analytic Model for Foil Heating & Contaminant Desorption

Python ODE solver solves RLC voltage driven/user defined current trace to determine solid foil temperature and rate of neutral contaminant desorption

Knoepfel model defines rate of heat entering through resistive Joule heating

- $\frac{\partial Q}{\partial t} = \frac{j^2}{\sigma} + k\Delta T$

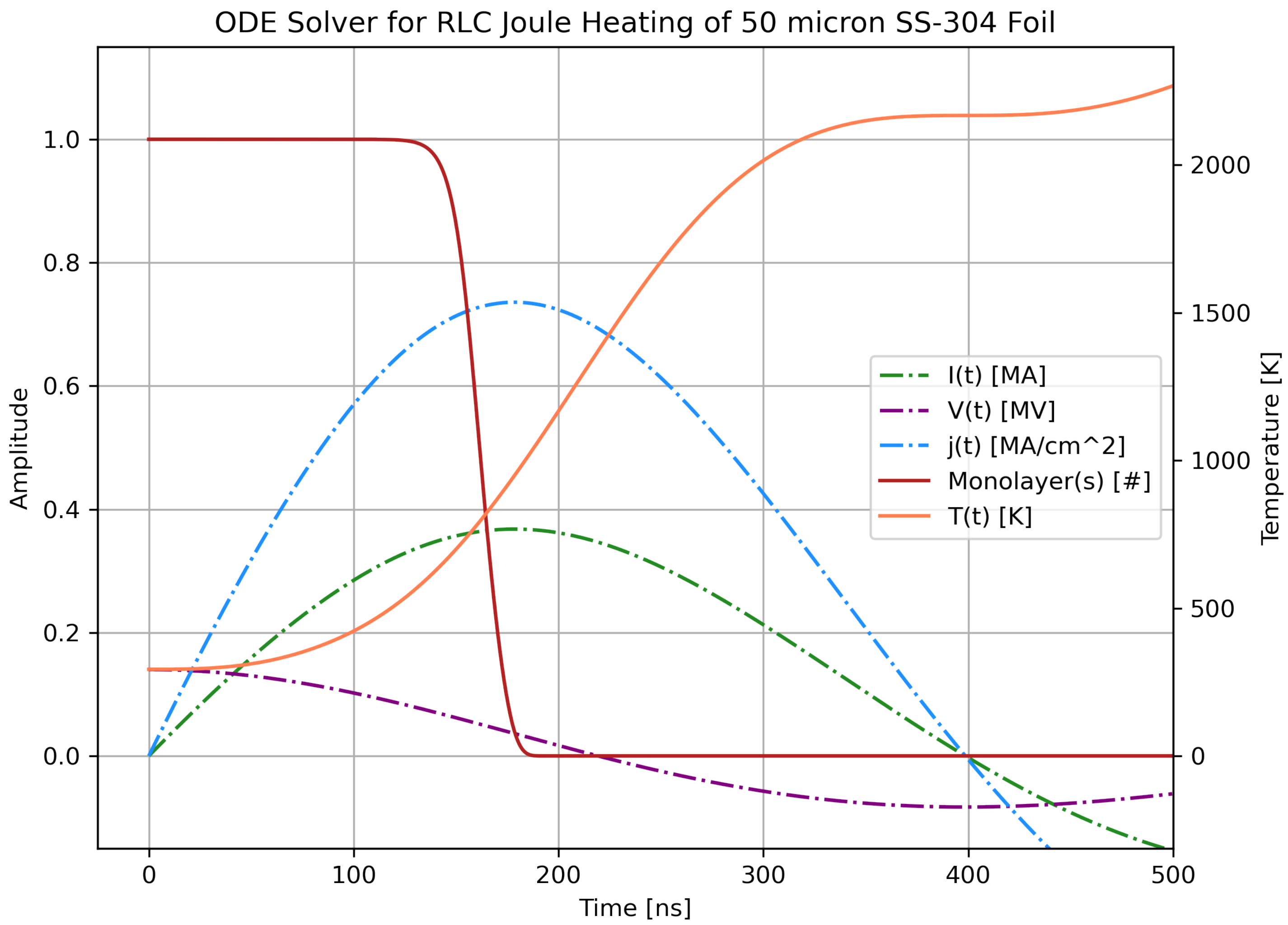
Modified Temkin Isotherm, E', determines rate of desorption of contaminant surface layers

- $\frac{dn}{dt} = k_0 n_m \theta e^{-E'/k_B T}$

Solver gives semi-analytic solution in a matter of seconds

Currently working to add

- heat transfer from skin depth to foil bulk
- bulk hydrogen desorption
- metal vaporization
- ionization



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
- Pl for 2400 g/mm

Operating Wavelengths: > 40 nm

Required Vacuum: $\sim 10^{-5}$ Torr

Linear Dispersion: 4 nm/mm

Slit Width: 0.1-3 mm

Camera - Photek iCMOS 160

Quantum Efficiency: 20-25% (100-300 nm)

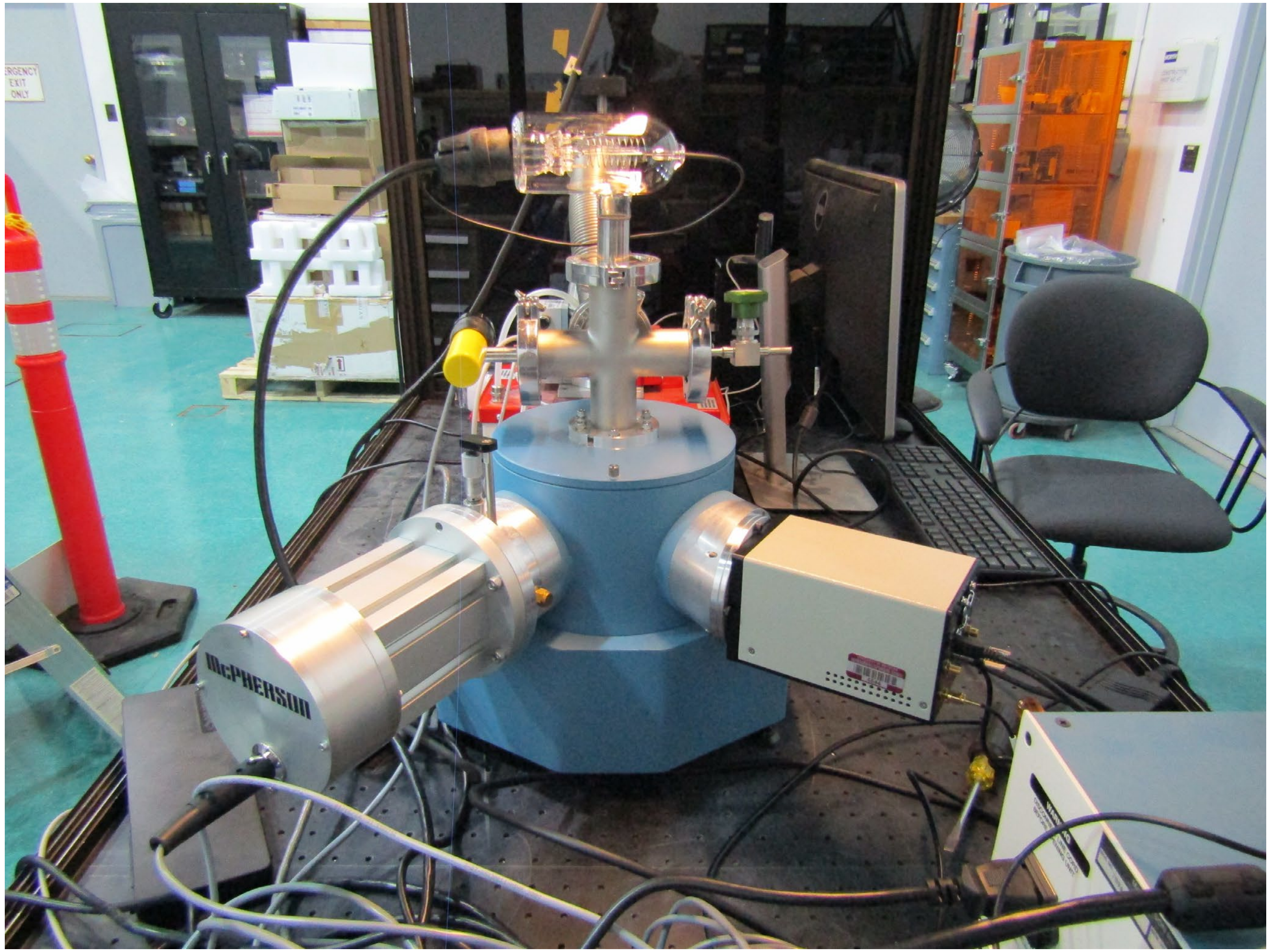
Gate Width: > 3 ns

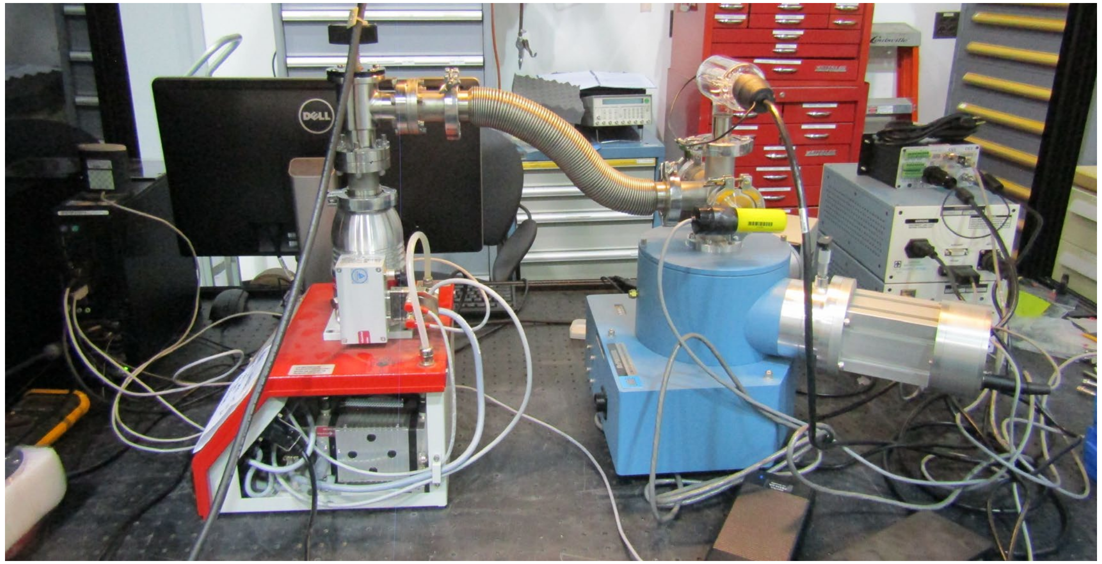
Window Size: 25mm, 1920x1200 pixels

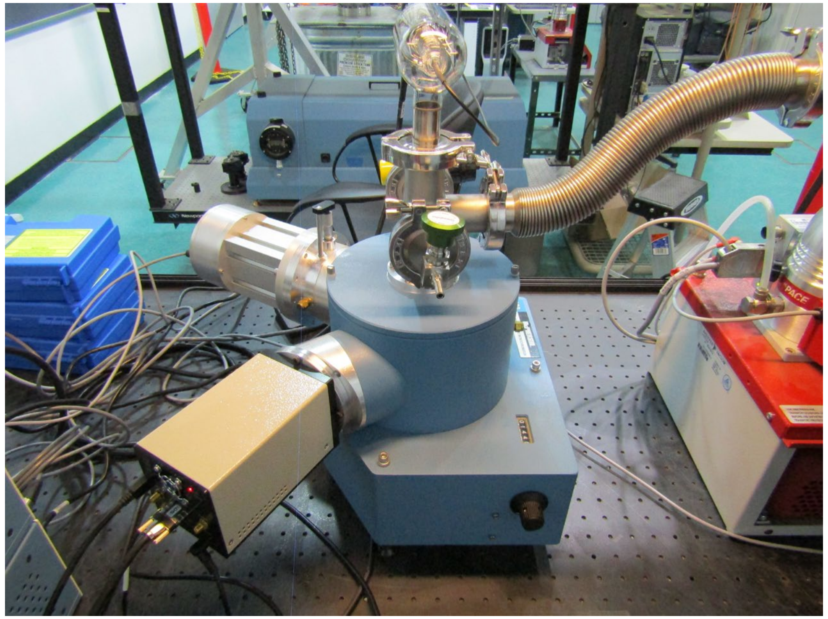
Pixel Size: 13.3 μm

Window Material: MgF_2

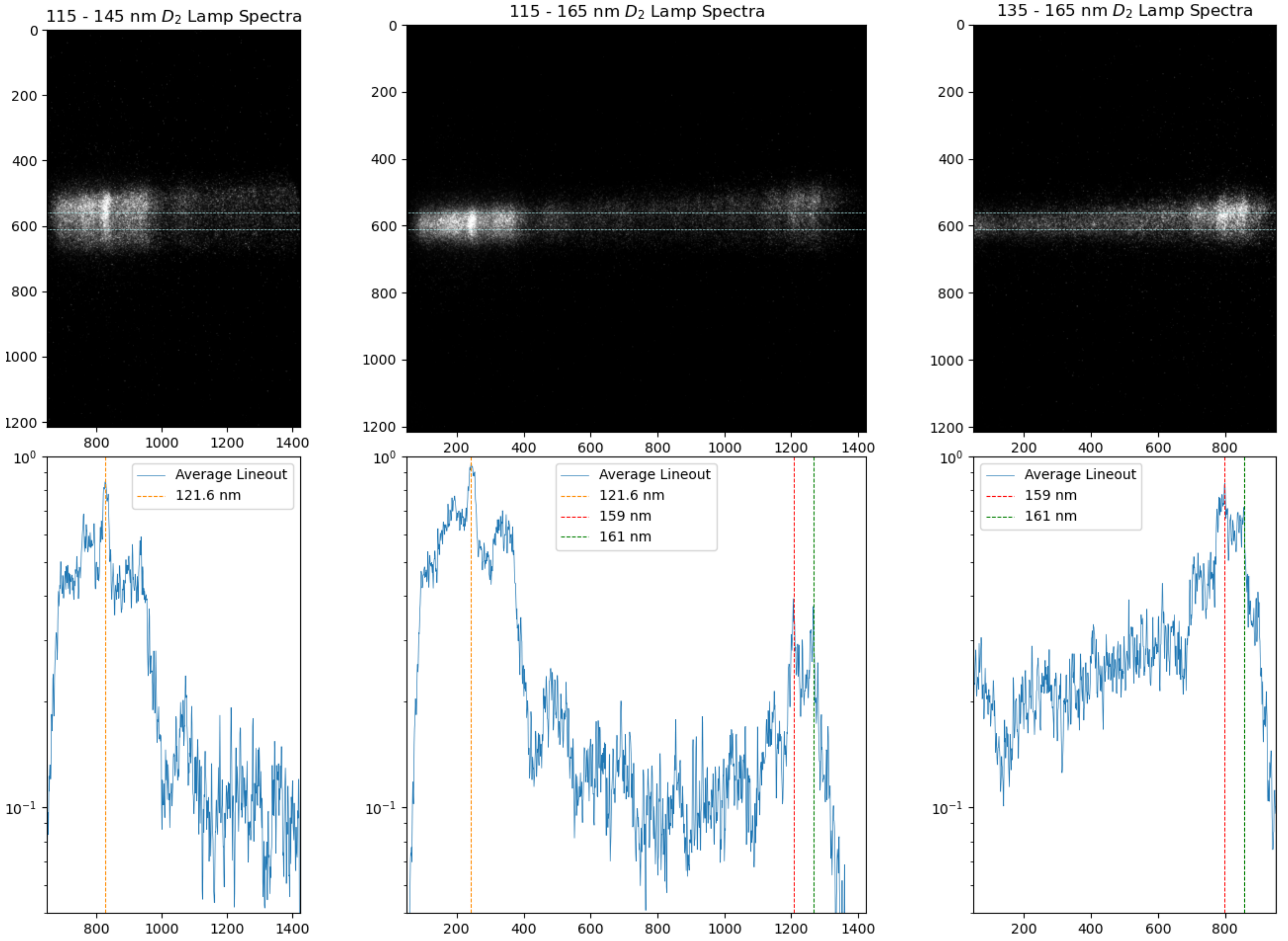
Spectrometer Calibration Setup







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

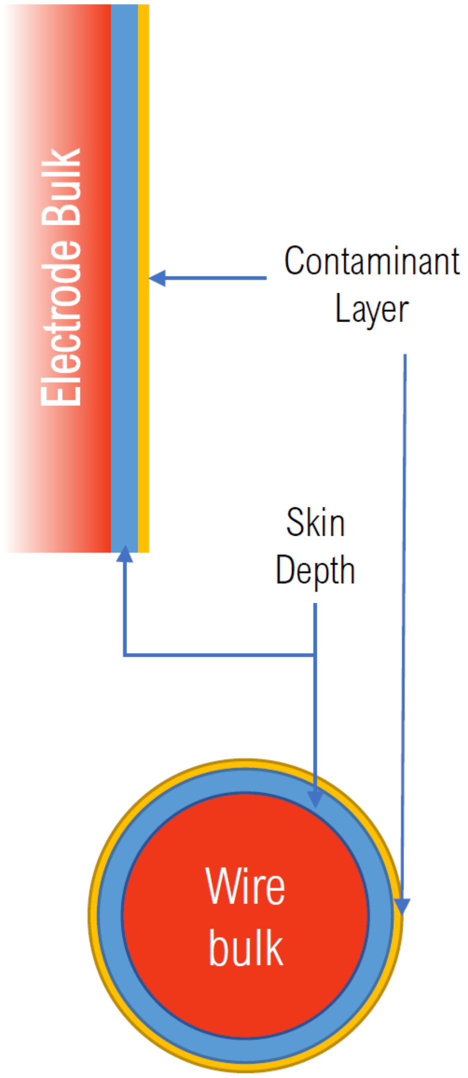
- Films/surface coatings form from general exposure to oxygen, humidity
- Over time, VUV interaction can damage by interacting with these films
- Storage in general humidity can also further degrade optical reflectivity/transmission

Sandia Summer Internship 2021

- Design and setup of McPherson 234/302 Vacuum Ultraviolet spectrometer
  - Vacuum system (pump, chamber, camera adapter, gauges, etc.)
- Optical Design for focusing light onto spectrometer – use of focusing mirrors instead of lenses due to material-photon interactions in VUV
- Updating my Semi-Analytic Model for MagLIF (SAMM) code to calculate foil heating using a simple EoS model

Electrode Surface Science – Upcoming Experiments

Foil 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

Questions?

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