An Investigation of Debris Production by Various EUV Sources

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Outline

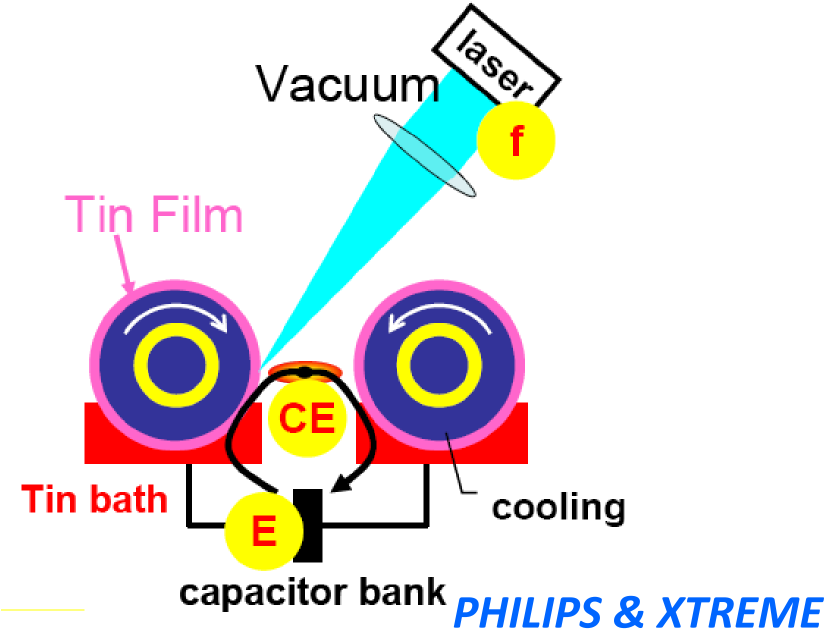
- **Introduction**
  - LADPP and Sn splats debris
  - Modified LADPP at CPMI
- **Direct EUV Source Measurements**
  - SEM (witness plate)
  - ESA (ion flux)
  - Neutral detector
  - EUV power
  - Cleaning
- **Intermediate Focus Measurements**
- **Summary**

LADPP

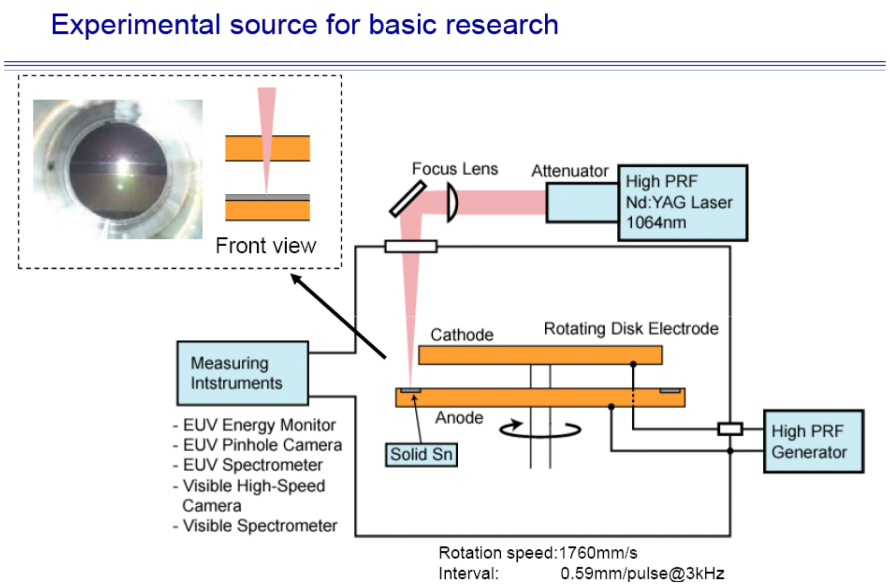
A **l**aser **a**ssisted **d**ischarge **p**roduced **p**lasma (LADPP) is a hybrid method to achieve a high power EUV light source for high volume manufacturing (HVM).

- **Advantages**
  - Small, stable, bright plasma
  - Low thermal load
  - EUV output improvement

- **Disadvantages**
  - Micro-particles or splats



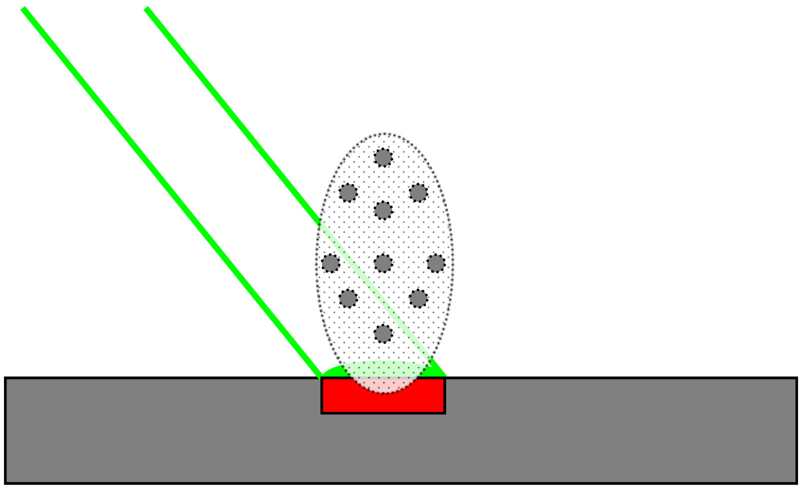
PHILIPS & XTREME



EUVA, SPIE 2008

Ablation process

Where are those Sn splats or micro-particles coming from?



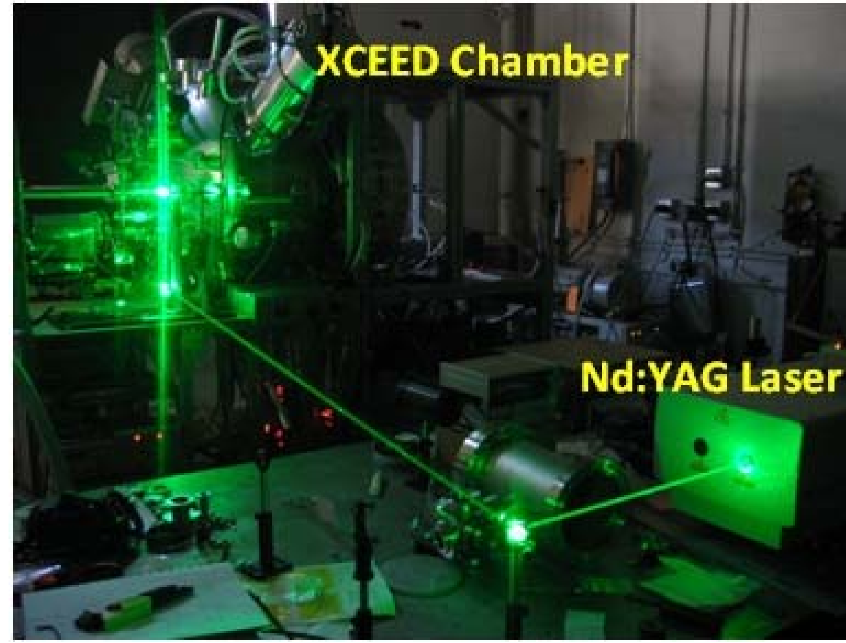
Concept of the ablation process

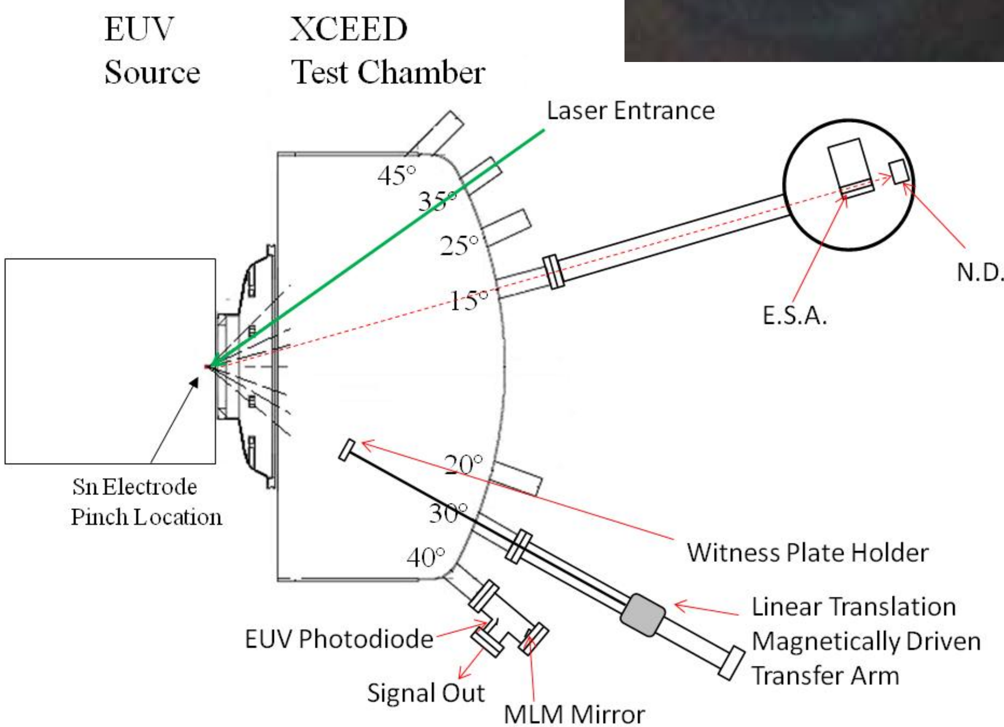
- Laser hits the surface
- Energy is absorbed on the surface
- Material within the heated volume is melted and excess energy leads to evaporation
- Poorly connected particles are ejected without being vaporized

  (Origin of micro-sized solid particles and liquid droplets)

Modified LADPP

Laser Ablation Holes



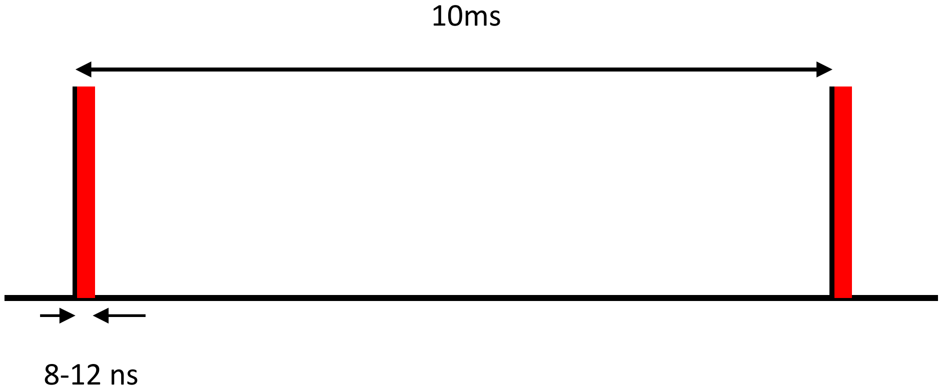


- The Sn electrode is ablated and a z-pinch is achieved across the plume to create an LADPP.
- SEM, Ion flux, Neutral flux, EUV power, and Sn splats removal through a plasma based cleaning method are analyzed.

Nd:YAG Laser

- Repetition rate : 100Hz
- Pulse width 8-12ns (δt)
- Harmonic separation crystals
  - 1064nm (325mJ)
  - 532nm (120mJ)
  - 266nm (20mJ)
- Focused onto a 1mm D spot (δA)
- Power density ($j=J/(\delta t\ \delta A)$) : 1.2×10^{9} W/cm^2
- Fluence ($j\ \delta t$) : 12 J/cm^2
- Incident energy per pulse : 120mJ
- Instantaneous power : 1.2×10^{7} W
- Average power : 12W

Laser Pulse

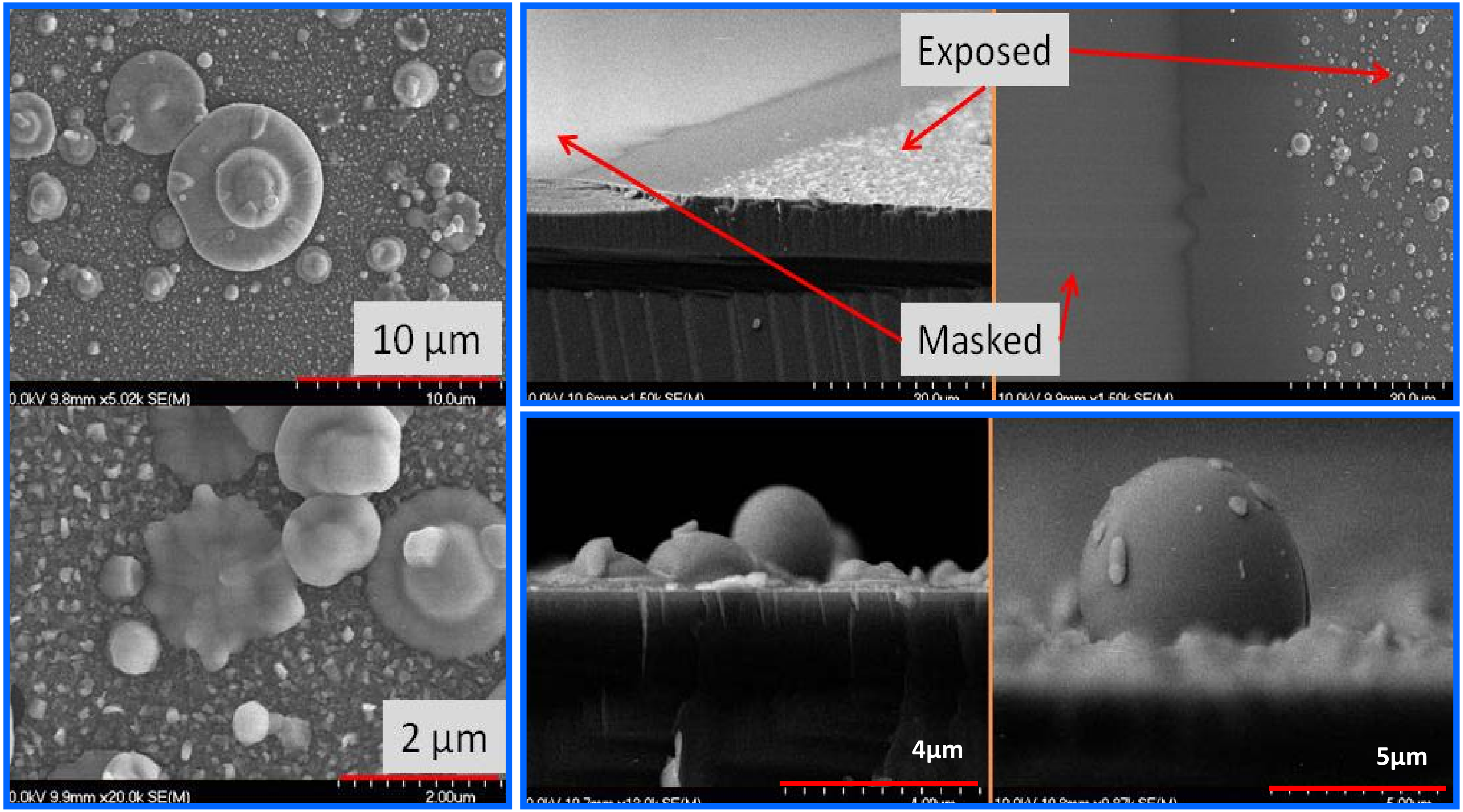


Spectra Physics

We lowered the power density for LADPP study.

SEM at 6 cm from Target, Laser Only

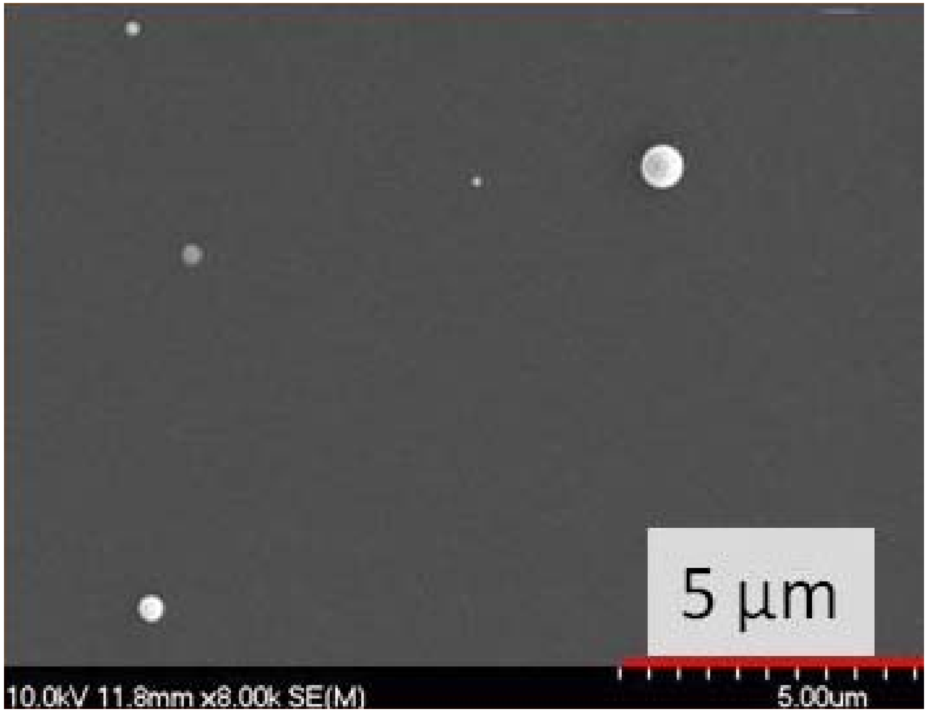
After Sn ablation by laser alone at **near-field** (6cm from the electrode)
No debris mitigation tool present & 10 min (60k shots) @ 1.2x10-5 Torr

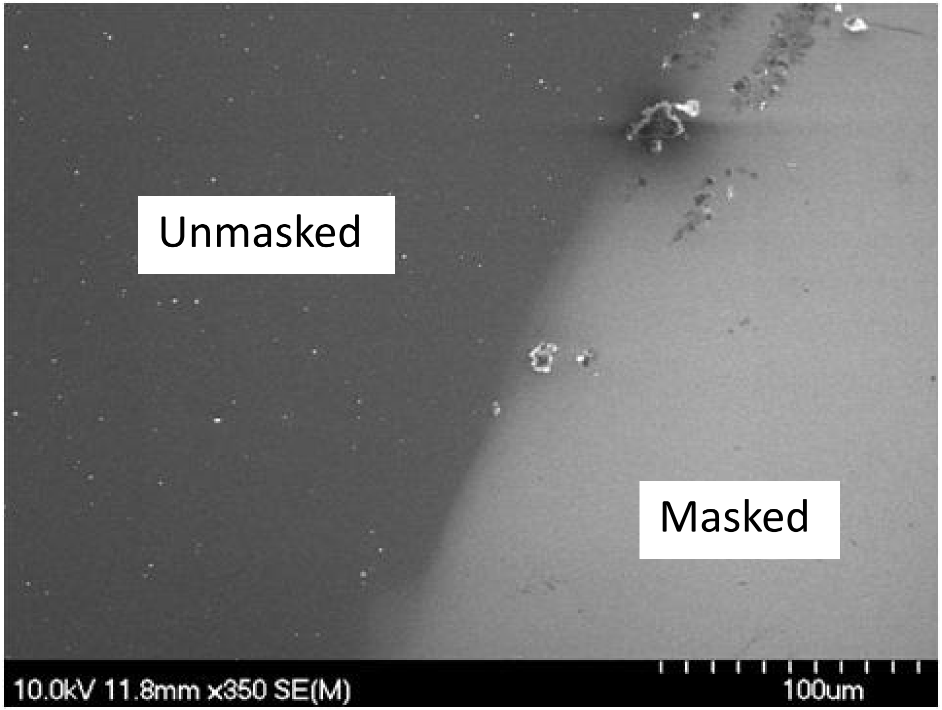


- There is substantial contamination of the Si surface by micron-sized Sn particles in addition to Sn vapor deposit.

SEM at 36 cm from Target, Laser Only

After Sn ablation by *laser alone* at **far-field** (36cm from the electrode)
No debris mitigation tool present & 10min (60k shots) @ 1.2×10^{-5} Torr

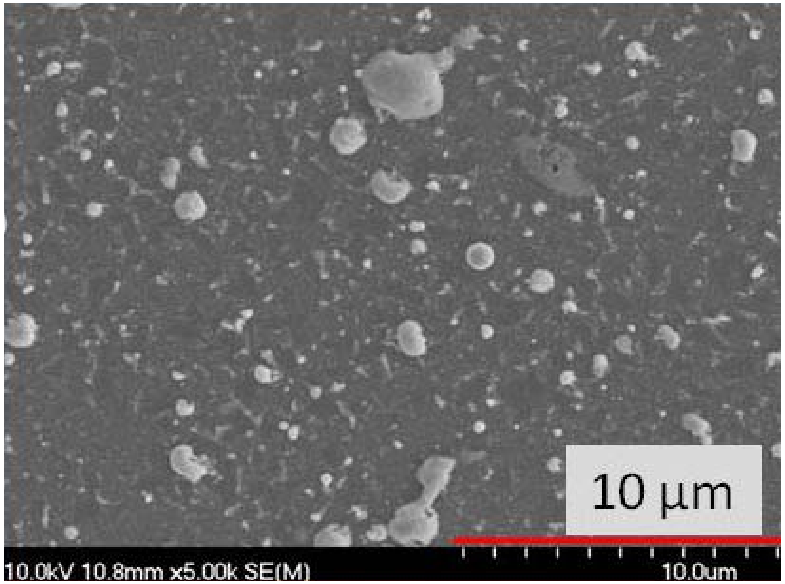


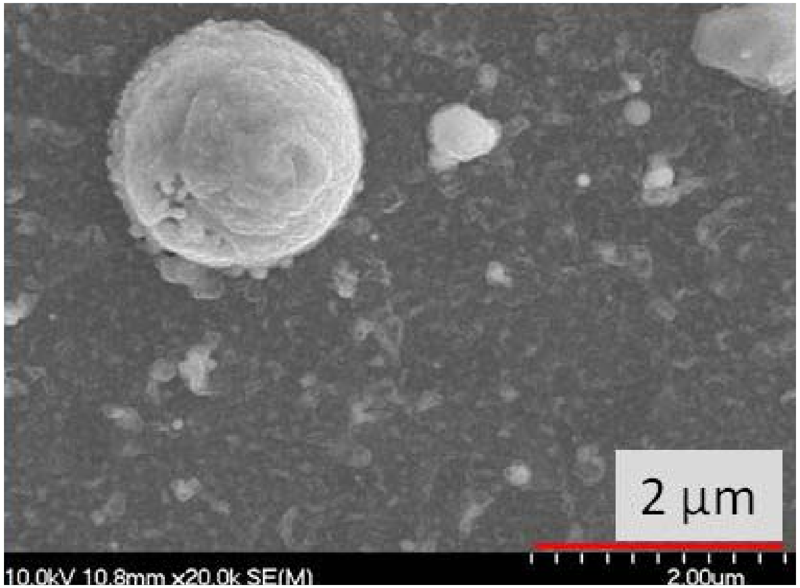


- Even at far-field, Sn micro-size particles deposit in molecular flow.
- Potential problem in the rear parts of the collector mirrors and IF region.
- Different contrast between unmasked and masked areas is due to carbon contamination induced by laser irradiation of the electrode.

SEM at 36 cm from Target, EUV Operation

After Sn ablation by laser & pinch at **far-field** (36cm from the electrode)
No debris mitigation tool present & 10min (60k shots) @ 1.2×10^{-5} Torr

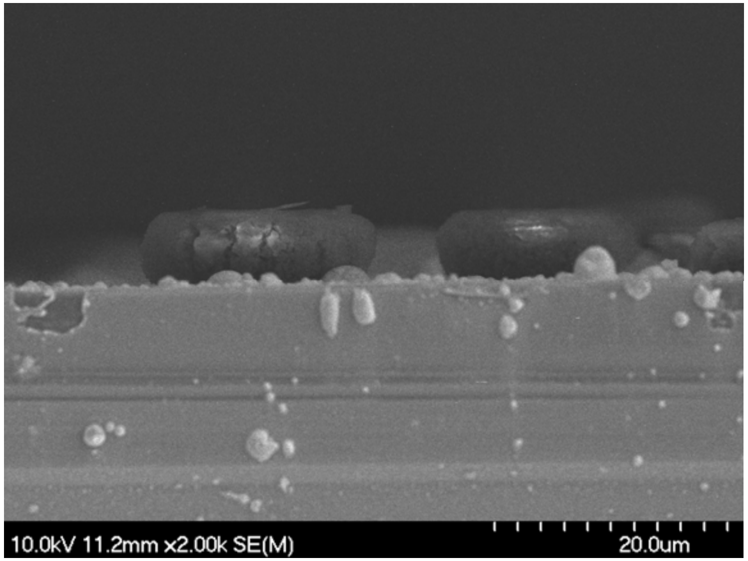




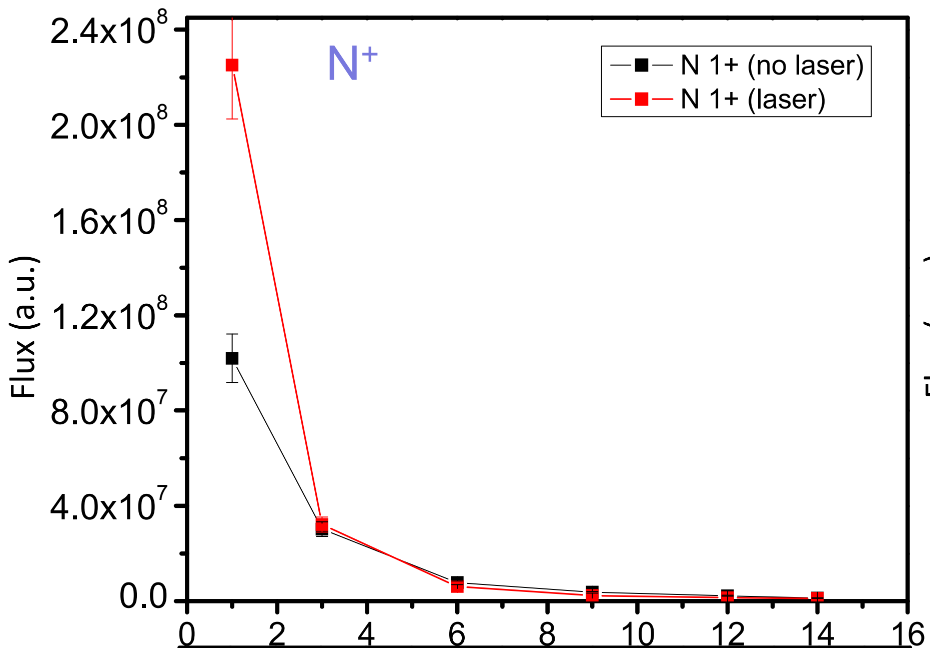
- Because of hot plasma, molten Sn particles are deposited on the Si surface.

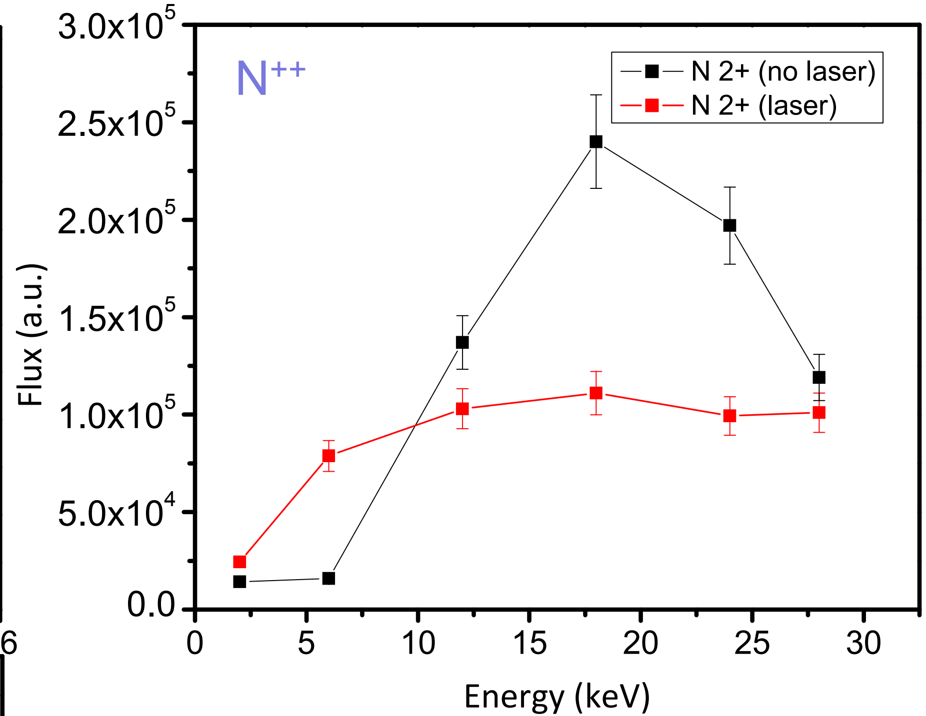
- The rough surface indicates the existence of energetic ions, as witnessed by the plateaued debris.

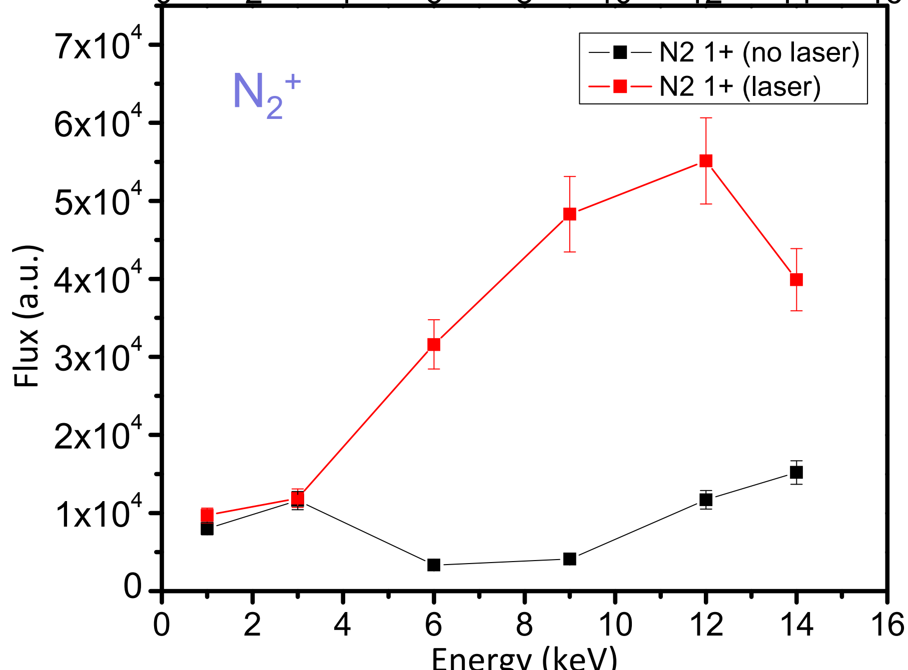
- With laser ablation alone, of course, there are no energetic ions detected by the ESA.



ESA N ion spectra from LADPP, no mitigation



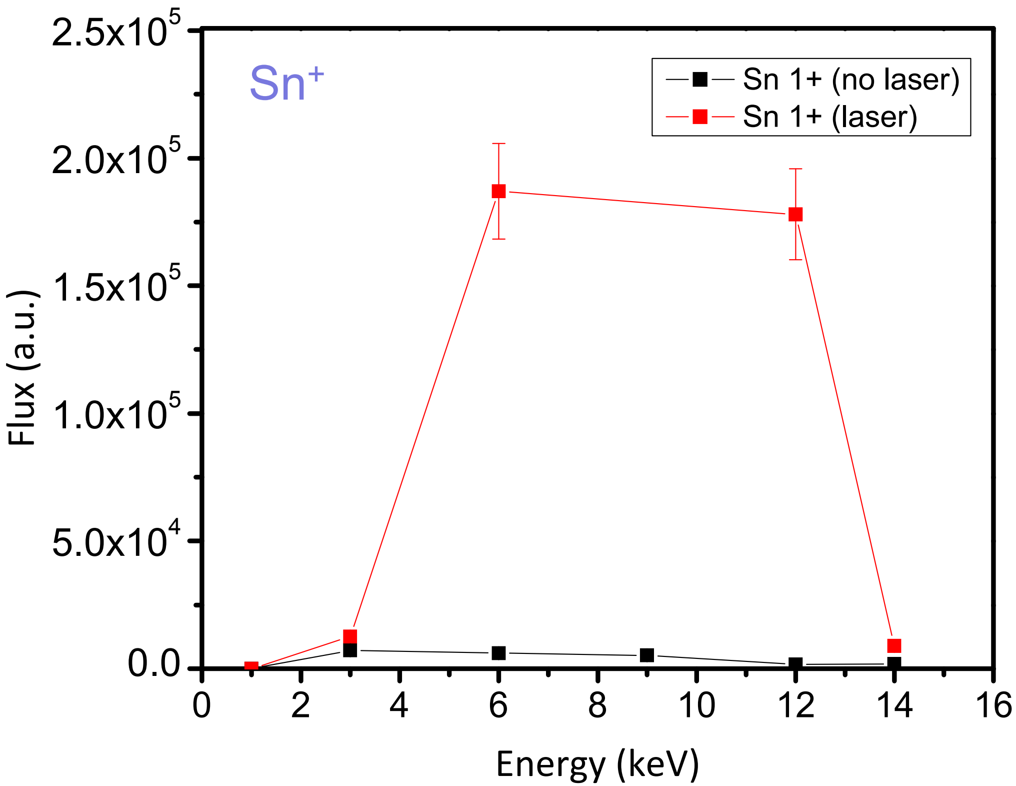


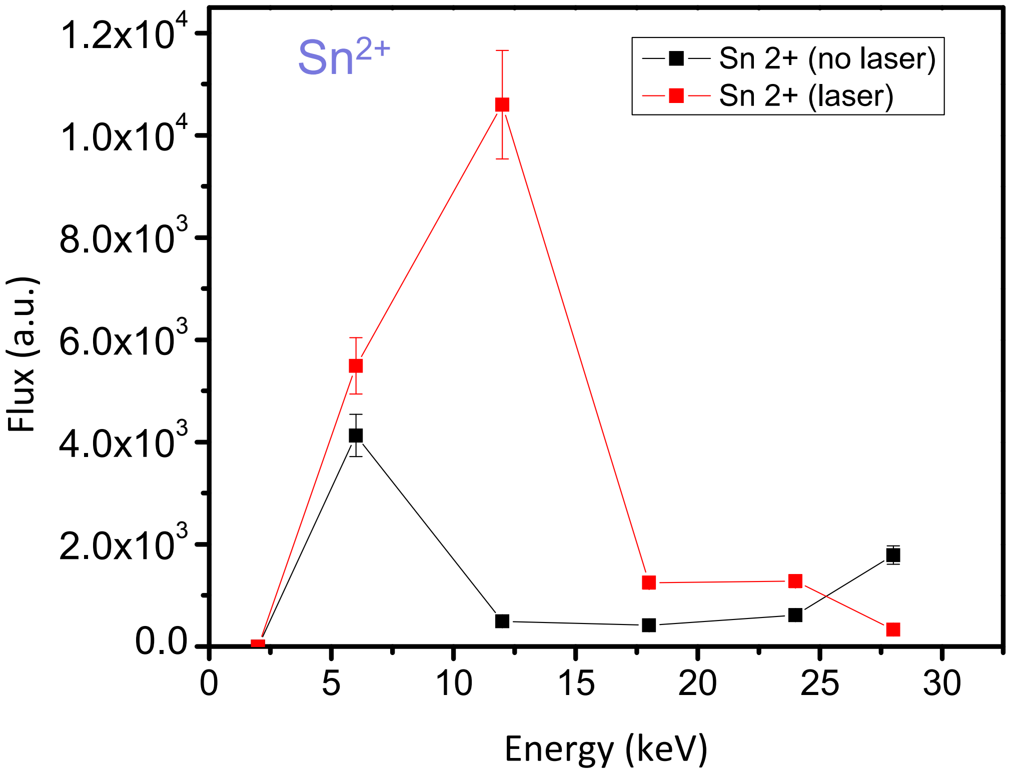


- Nitrogen (pinch gas) ion spectra when using the pinch alone (black) and the combination of pinch and laser (red).

- Under pinch and laser together, more singly charged ions (N^+ , N_2^+) and less doubly charged ions (N^{++}) are detected.

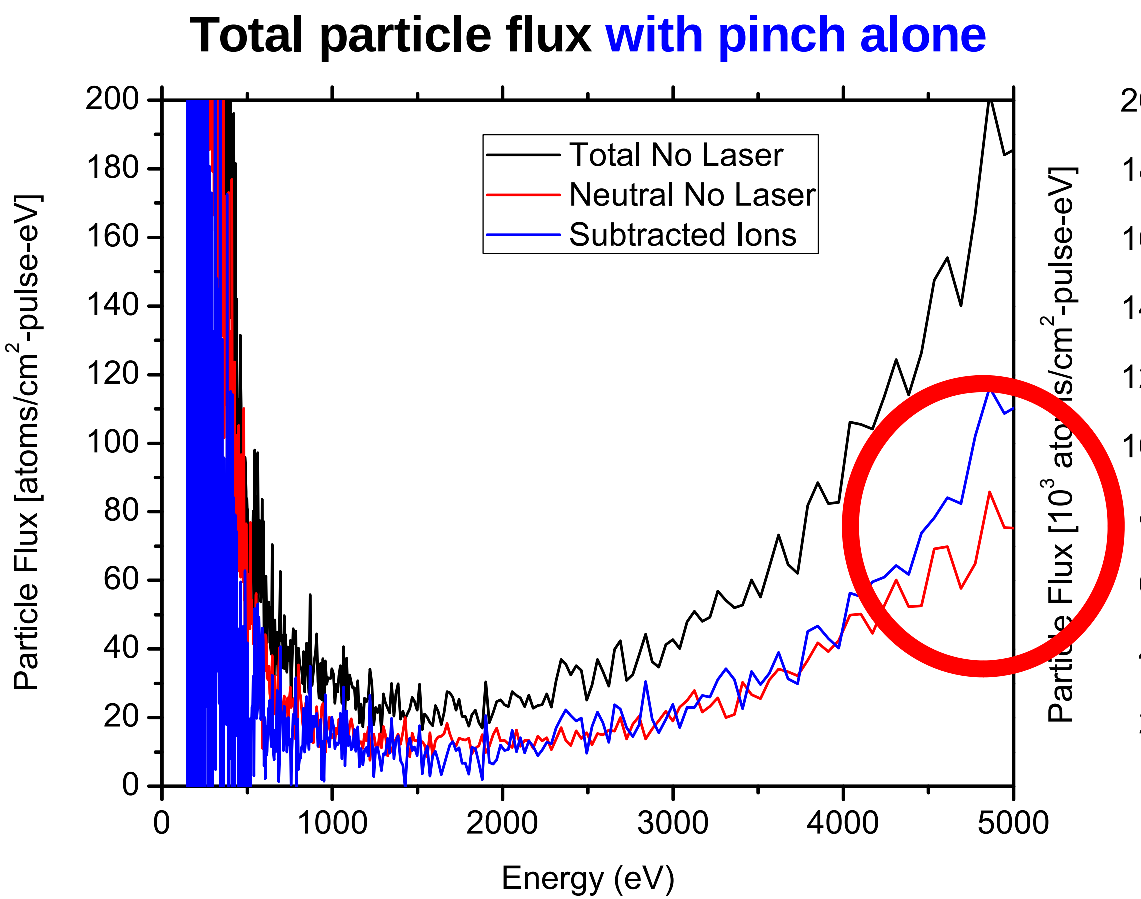
ESA Sn ion spectra from LADPP, no mitigation

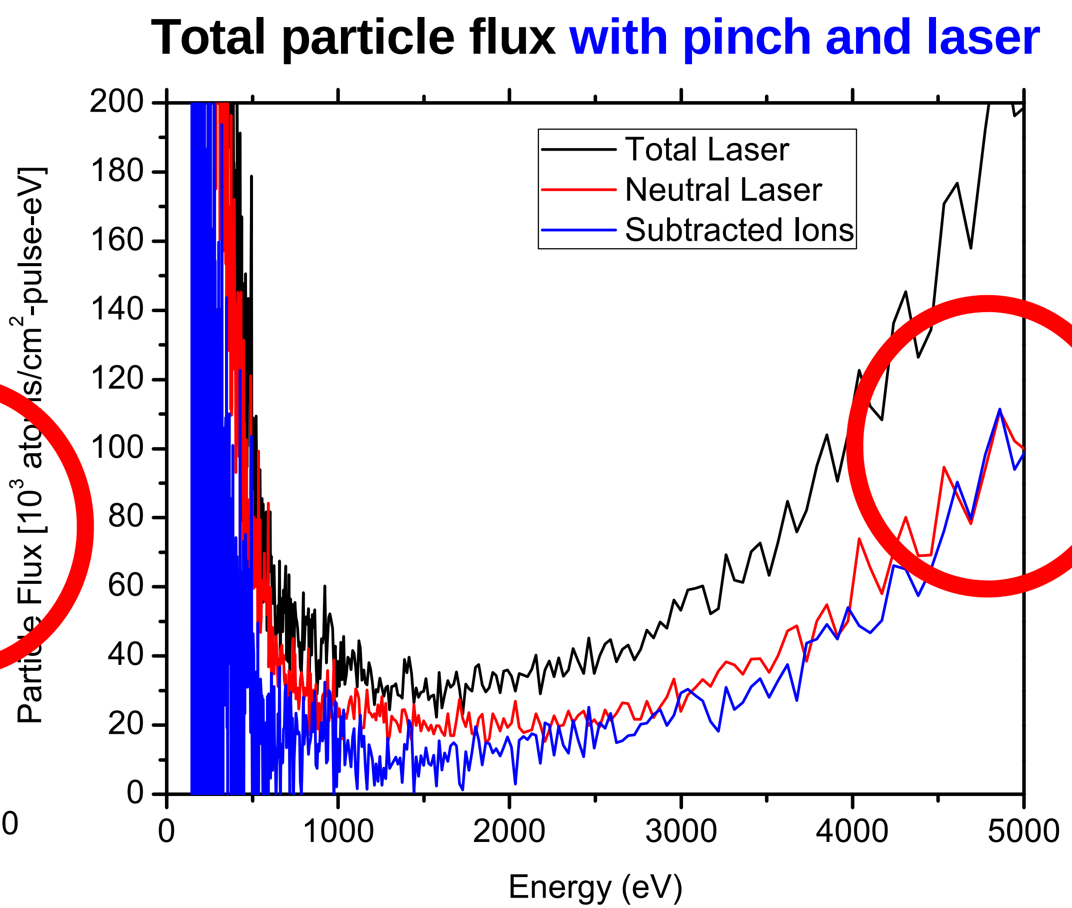




- Without laser, fewer energetic Sn ions are detected.
- The addition of laser ablation leads to a larger flux of Sn 1^+ and 2^+ ions and more EUV light
- The ablated Sn is involved in the pinch process.

Neutral Fluxes

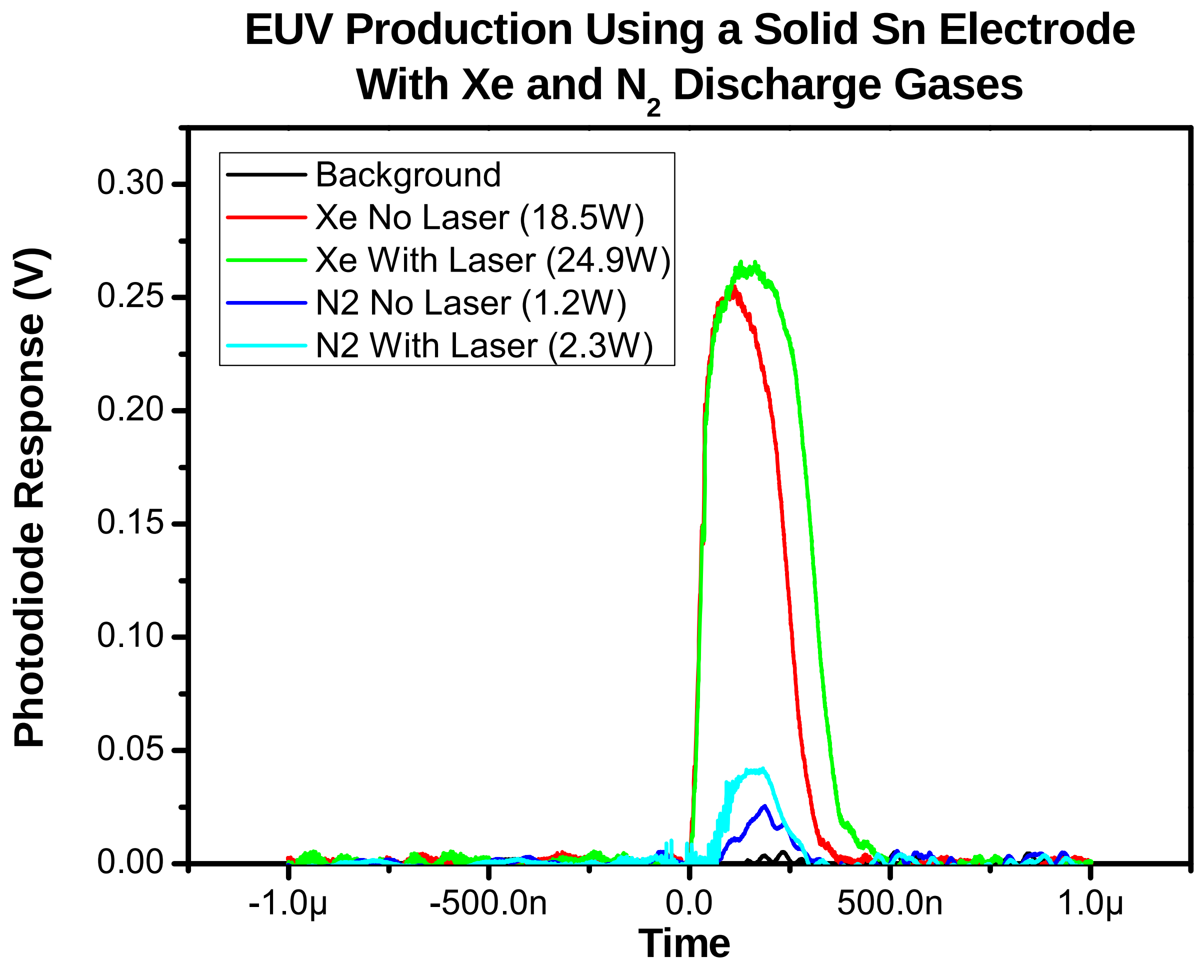




- When the laser is used along with pinch, the energetic neutral flux is slightly larger than with the pinch alone. Red line is the neutral flux.

- More neutrals are created in LADPP, than compared with DPP with Sn containing gas.

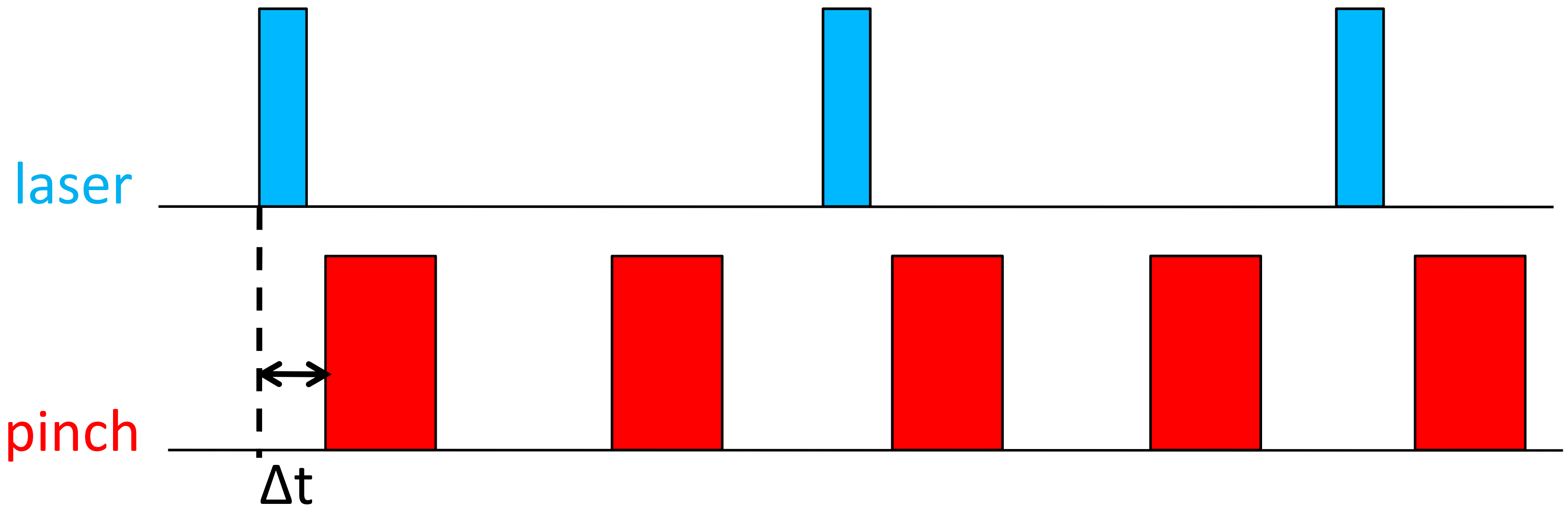
EUV output – total area under the curve



- A 35% increase in EUV output is observed when ablating Sn electrode with laser in conjunction with Xe pinch compared to Xe pinch alone.

- EUV output is nearly doubled while using Sn as the EUV fueld for the LADPP source.

Future work: Optimize Δt to improve CE

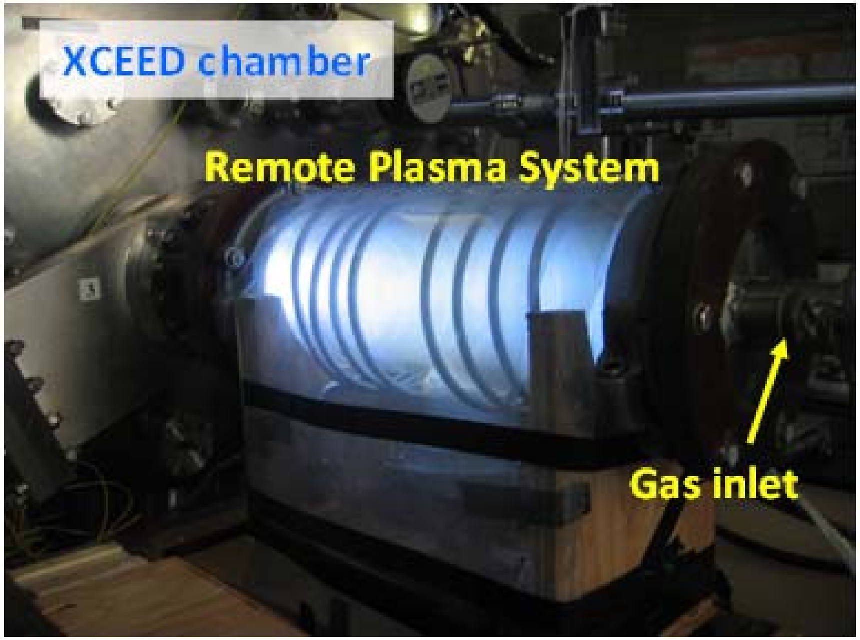


- To improve the conversion efficiency of our LADPP, we are going to optimize Δt between laser and pinch.
- Δt, order of 100s ns will be effective to improve CE.
- Similar amount of time was measured with time resolved pictures for laser ablation plasma front to reach at the electrode (Teramoto et al, 2009 SPIE).

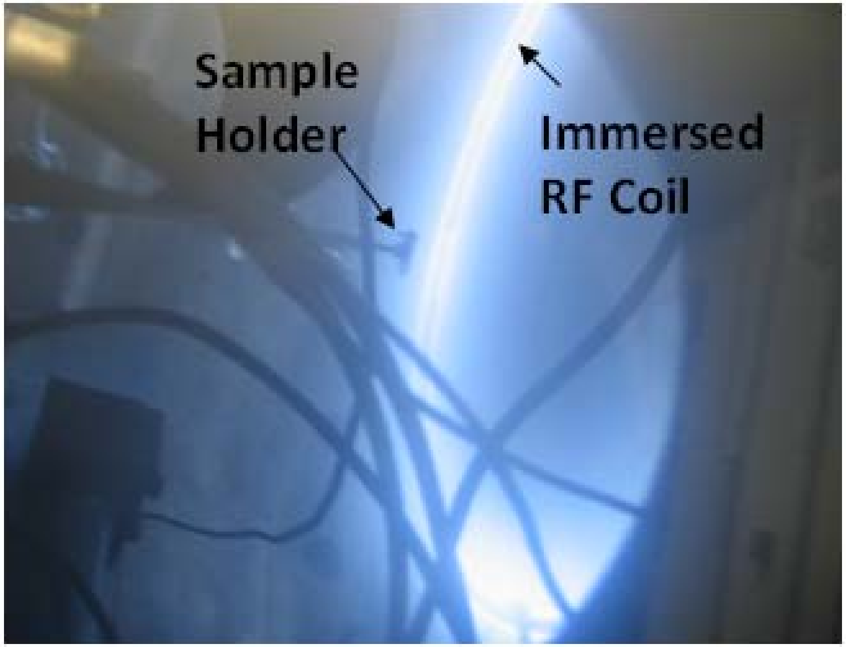
Can we clean Sn splats?

- Debris mitigation dramatically reduces the amount of Sn that reaches the mirrors.
- Nevertheless, a method is needed to clean Sn splats from LADPP. Debris mitigation is not perfect, and could fail momentarily during a run.
- We have devised a method to clean Sn splats using two different plasma based cleaning techniques.

Remote plasma

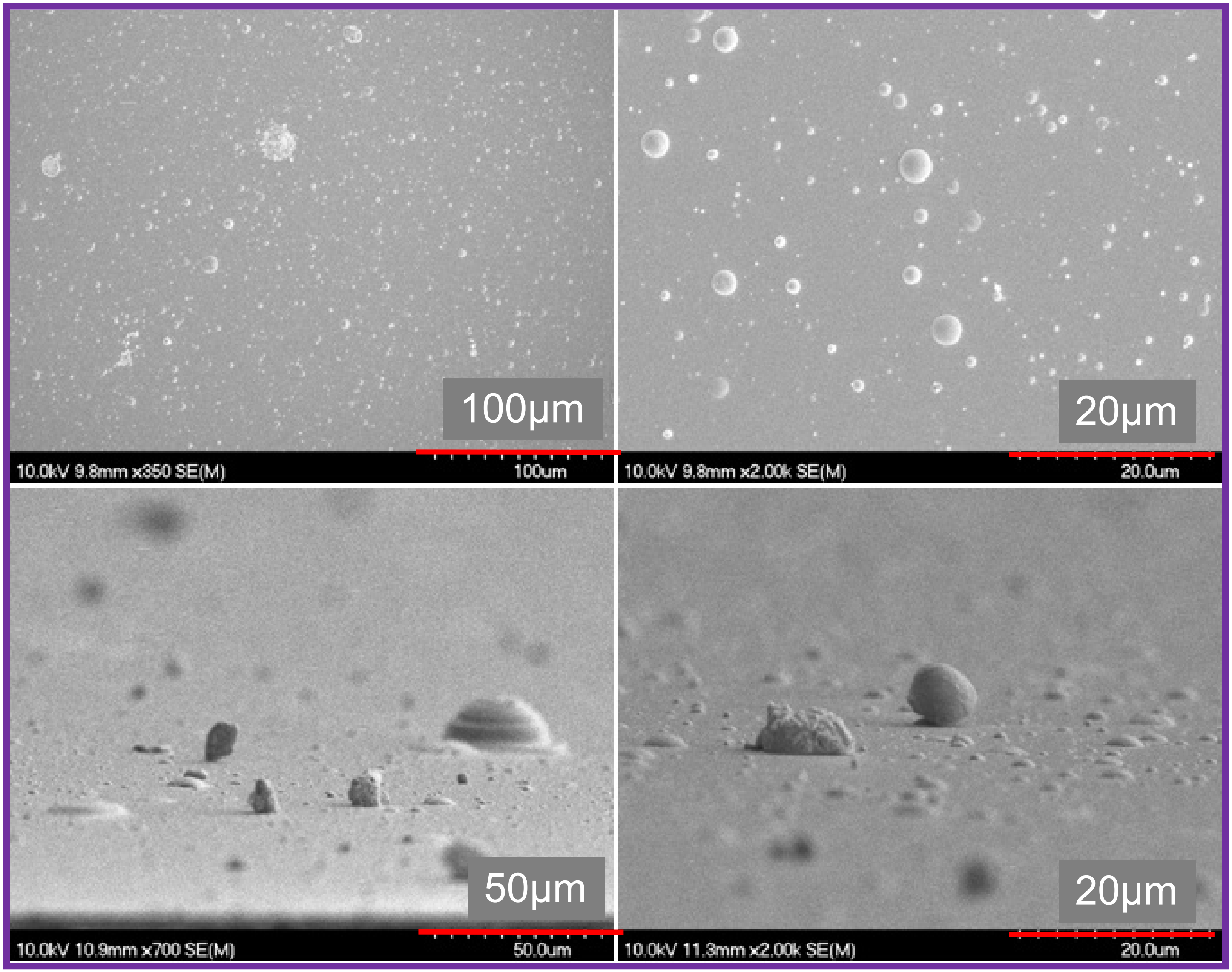


Inductively coupled plasma



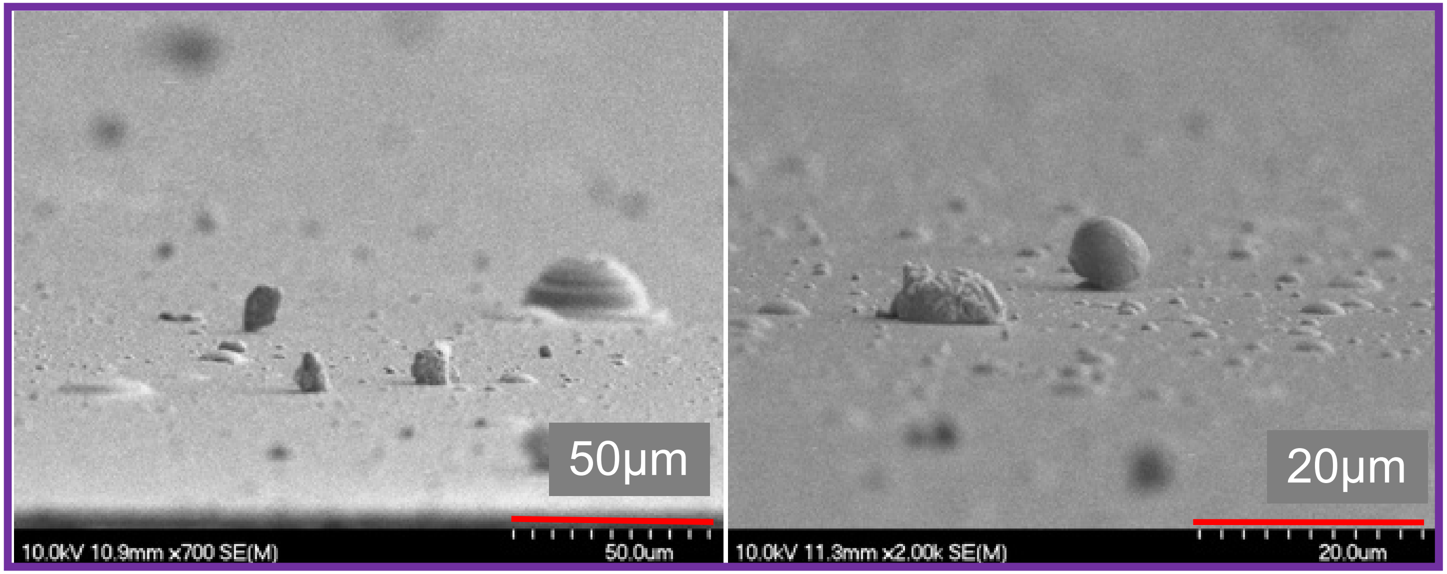
Cleaning

Before cleaning



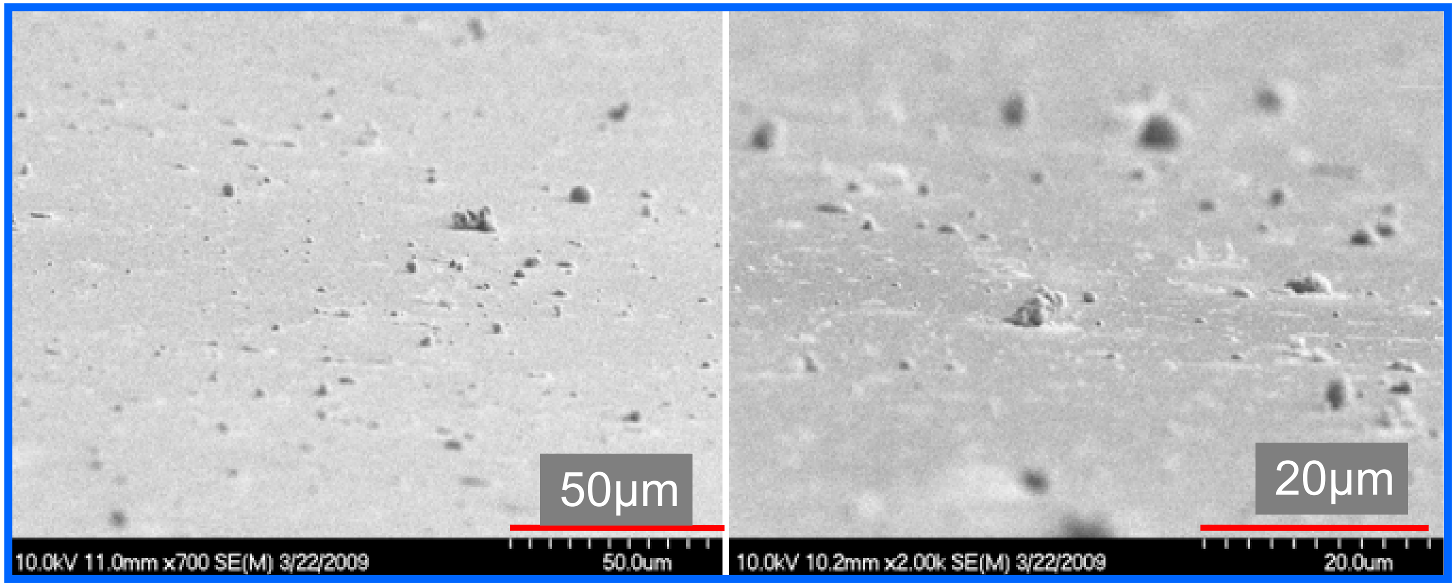
- Contamination results through the combination of Xe pinch and the laser for 1 min.
- Taken from the top (top two); from the tilted side (bottom two).

Cleaning



Before cleaning

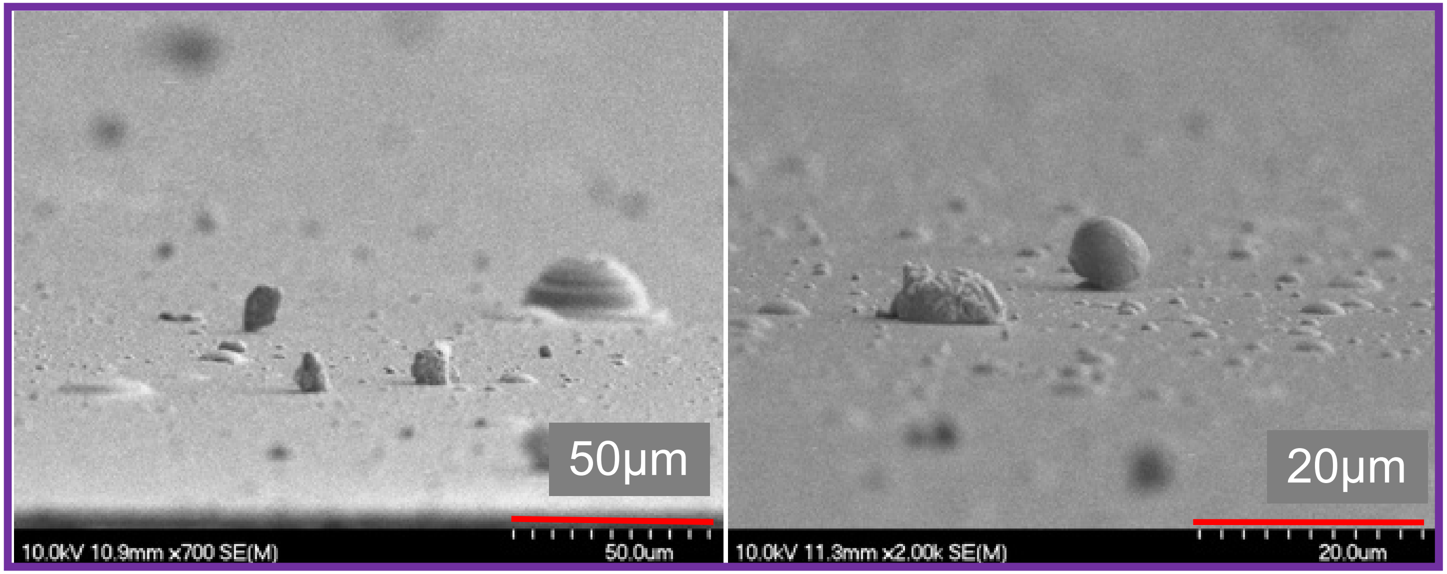
After cleaning by remote plasma (condition A)



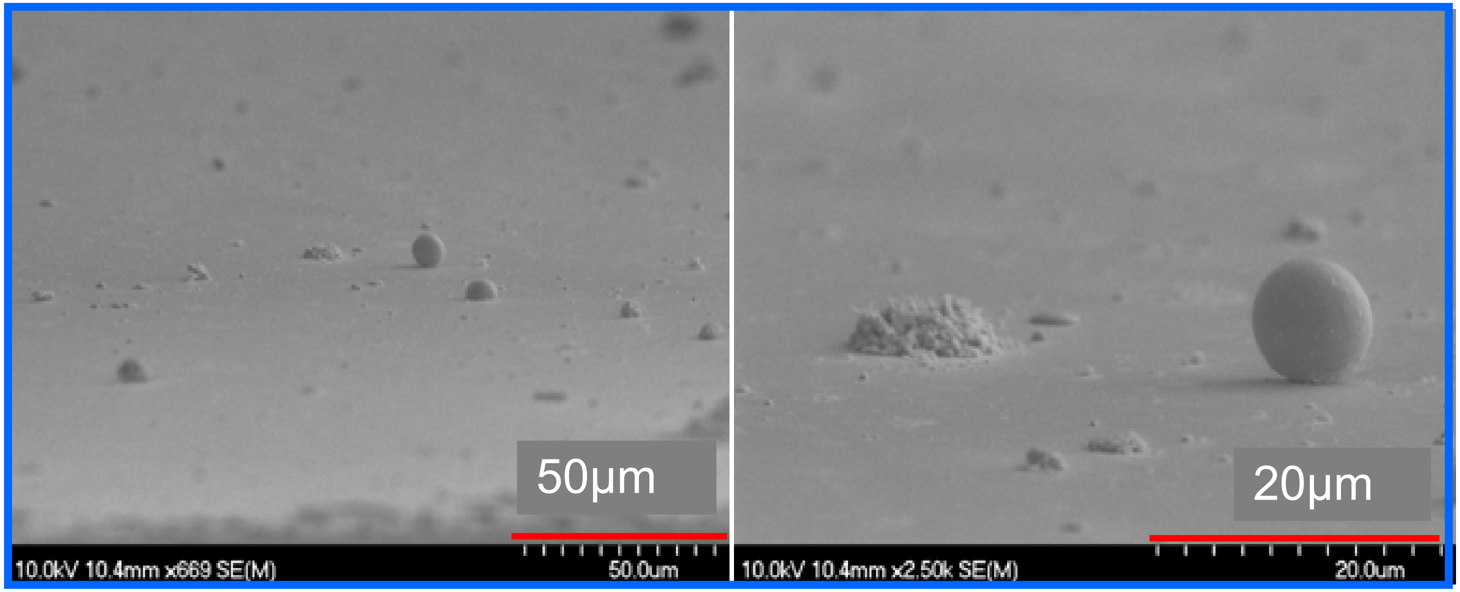
Hardly removed

Cleaning with Remote Plasma

Before cleaning



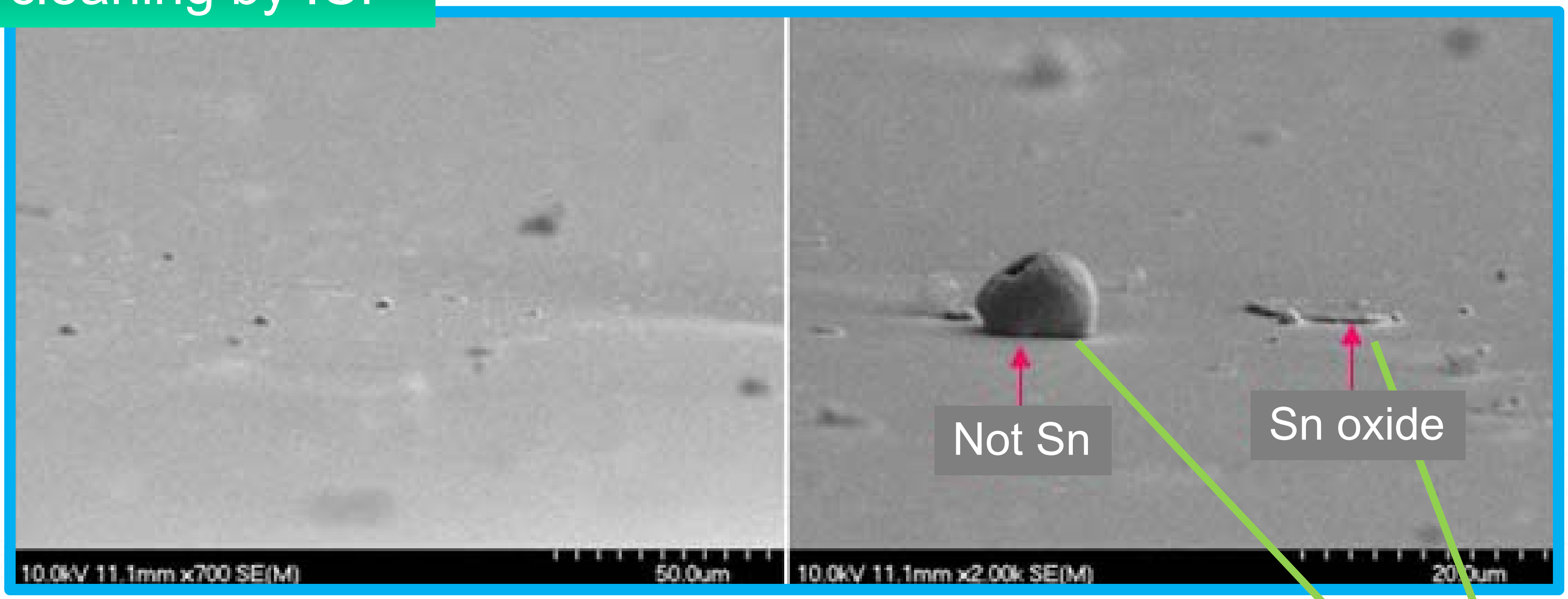
After cleaning by remote plasma (condition B)



Better but not enough

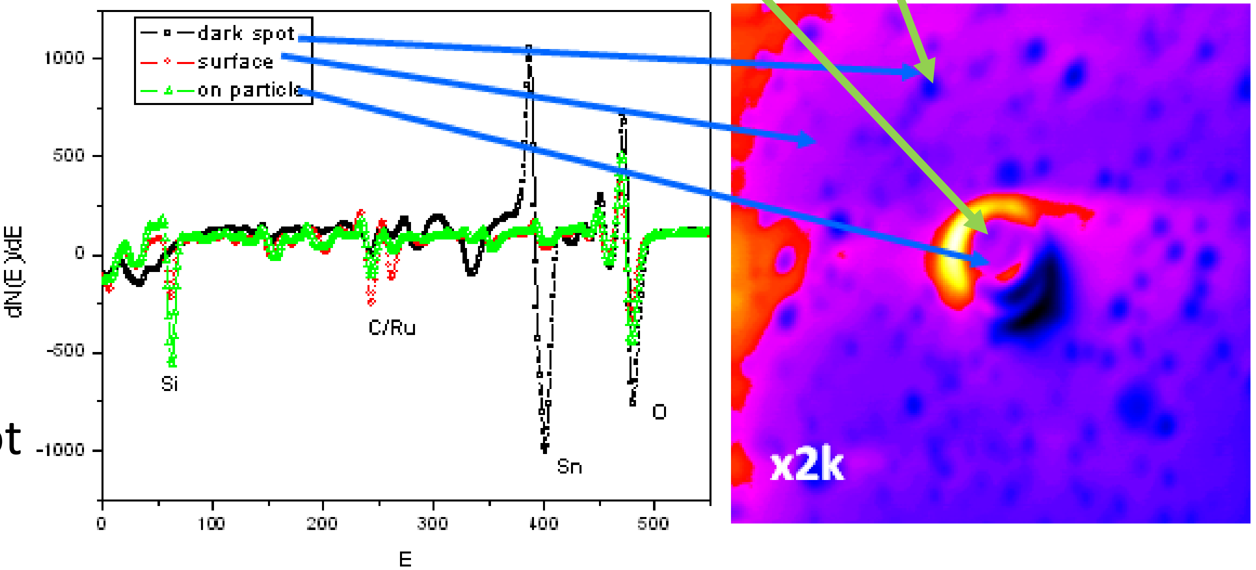
Cleaning with Internal ICP Coil

After cleaning by ICP

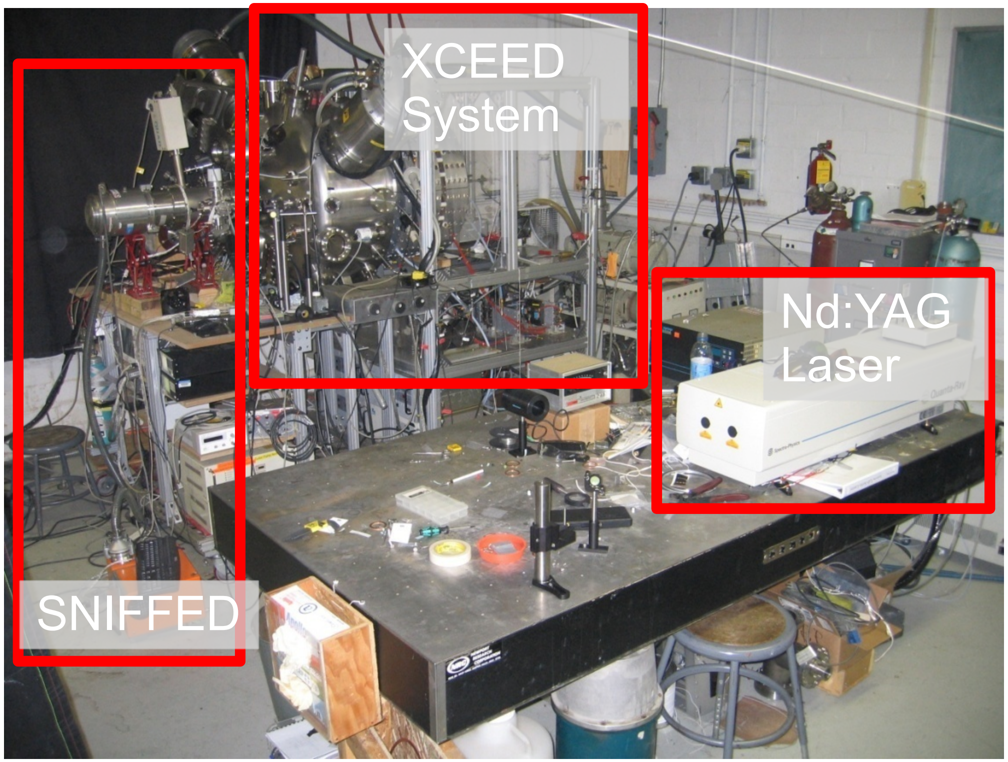


- A considerable removal of Sn particles is achieved by an ICP.

- From AES, it turns out that the residues on the surface are tin oxide or other materials due to poor cleanliness. SnO_2 would not grow if system were cleaner.



Intermediate Focus Measurements

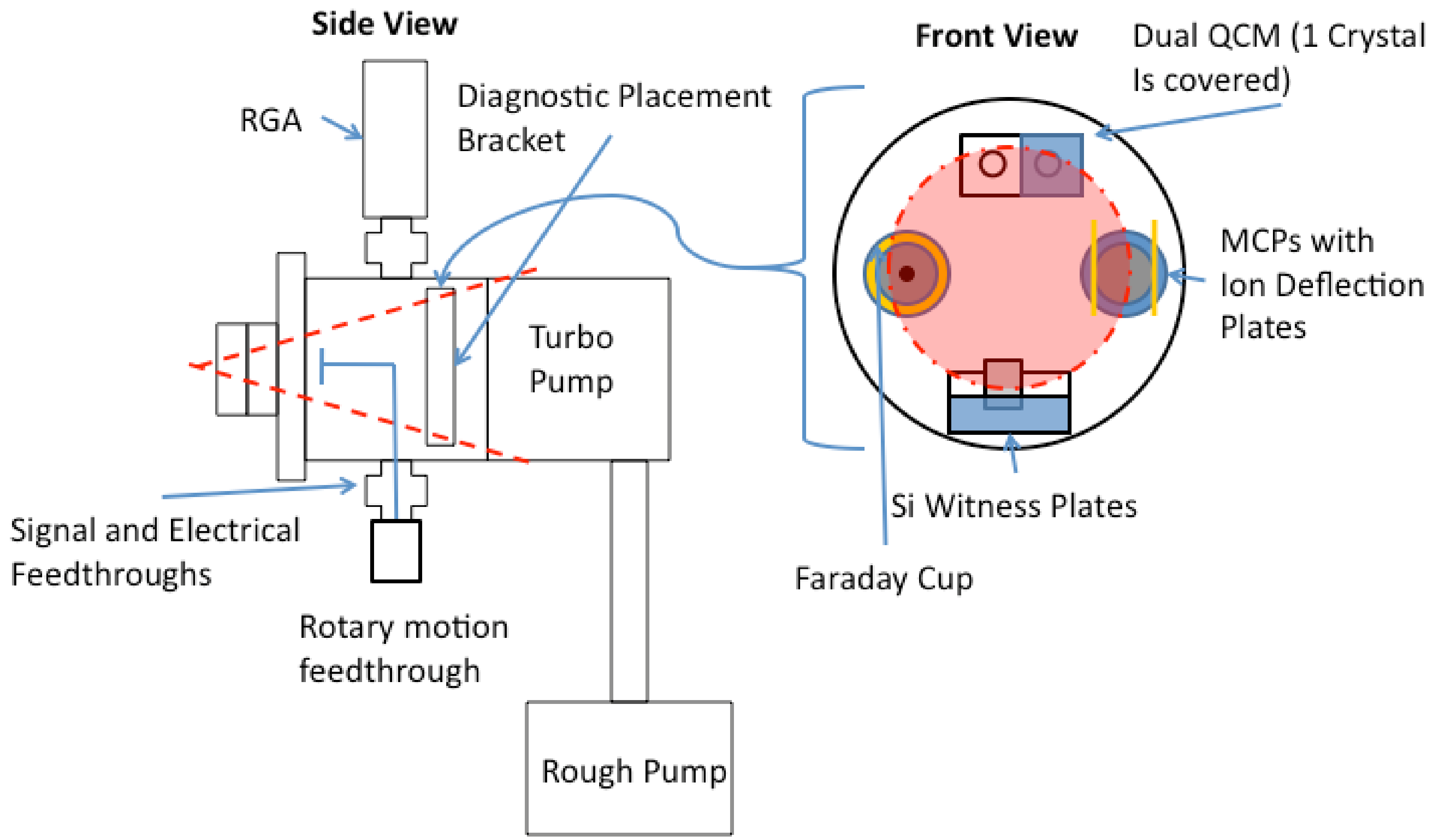


- In order to measure debris at the intermediate focus, three devices are used:

- The Nd:YAG laser ablates Sn within the XCEED XTS 13-35 source, creating a Sn based EUV light source.

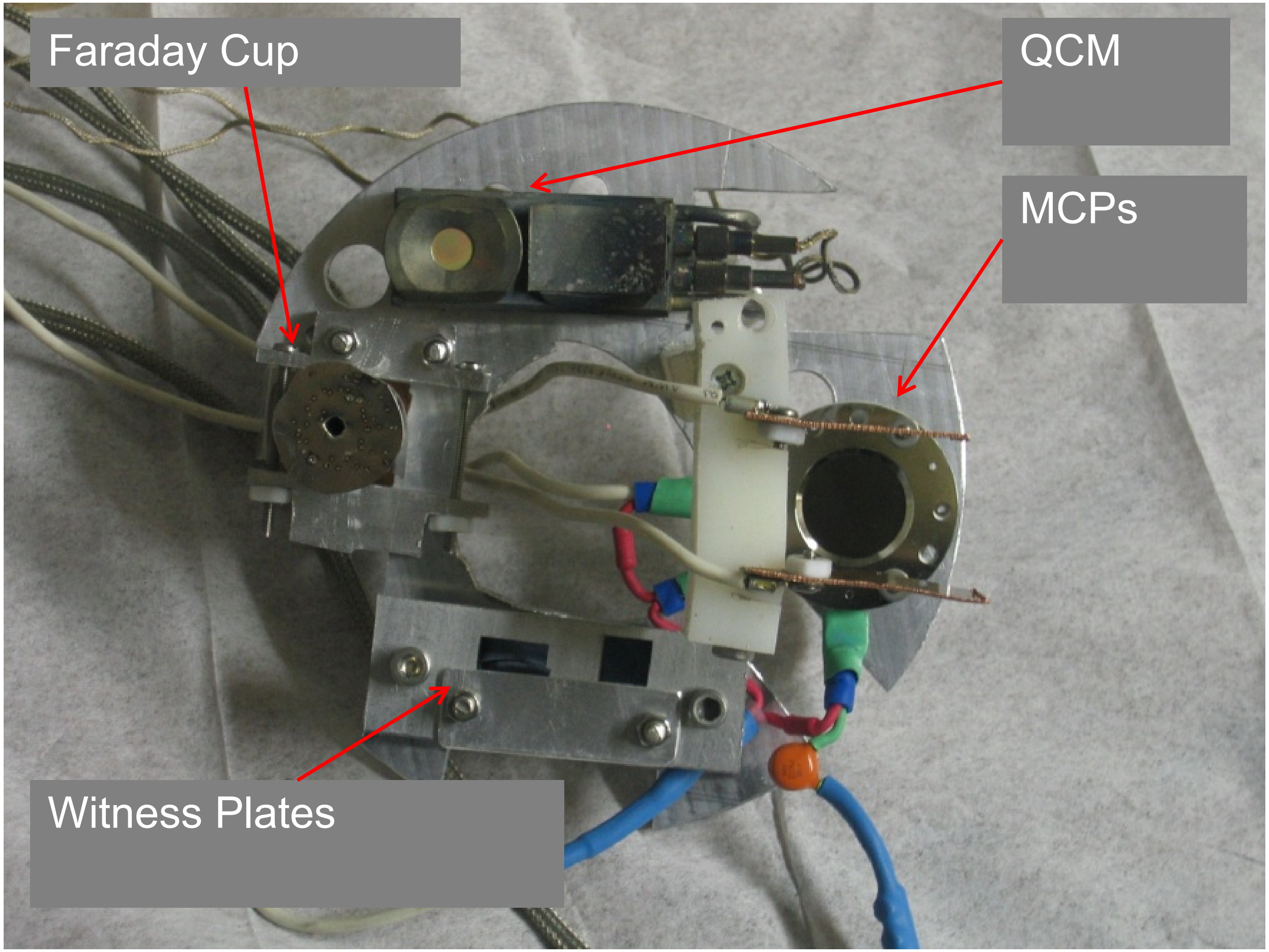
- The **S**n **I**nterediate **F**ocus **Fl**ux **E**mission **D**etector (SNIFFED) measures the debris ejected at the intermediate focus of the XCEED system.

Conceptual SNIFFED Setup



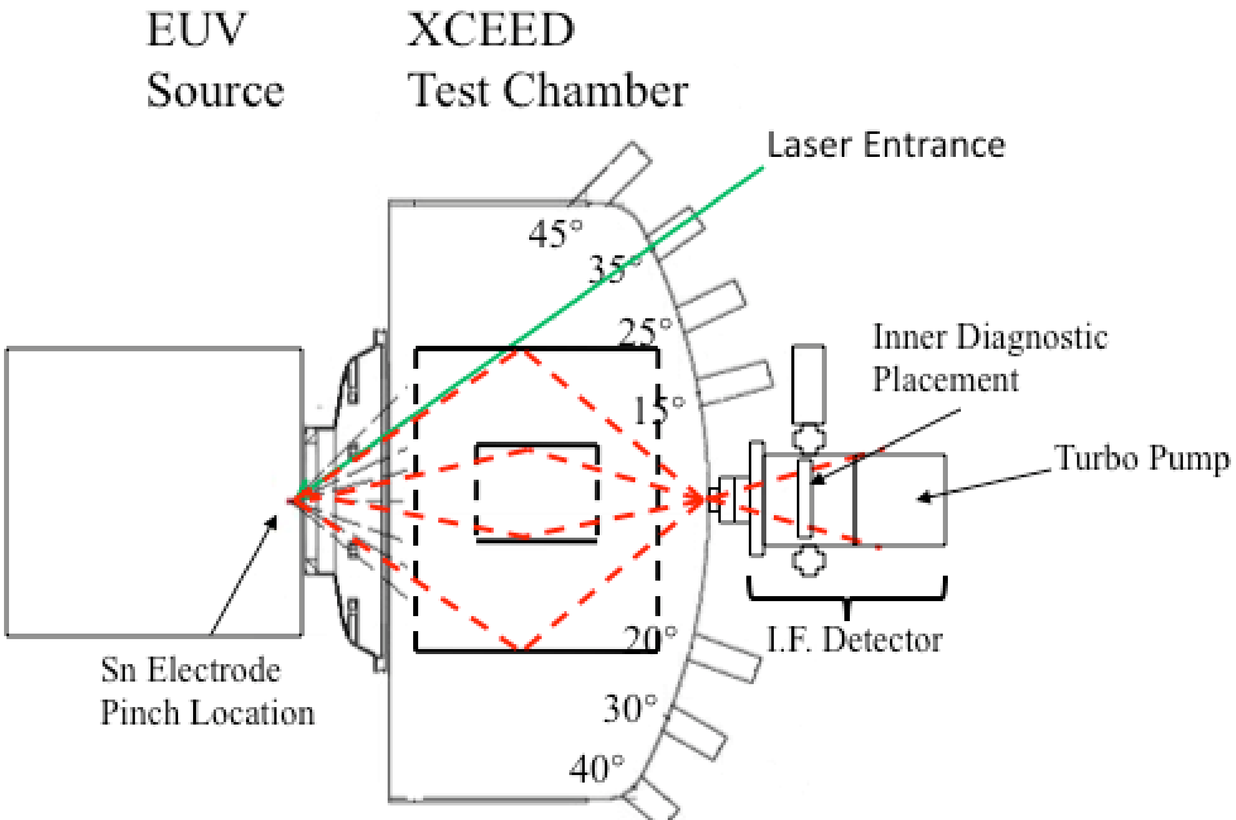
• The SNIFFED detector consists of a dual quartz crystal monitors (QCM), microchannel plates (MCPs) with ion diversion capabilities, Si witness plates, a Faraday cup, as well as a residual gas analyzer (RGA). A rotary motion feedthrough allows direct LOS and EUV to be blocked from the diagnostic for comparison purposes

SNIFFED Detector Components



- SNIFFED is capable of measuring charged debris flux, neutral debris flux, particulate build up, as well as residual gas presence by utilizing the Faraday cup, MCPs, QCMs, Si witness plates, and the RGA respectively.

SNIFFED Placement in Source

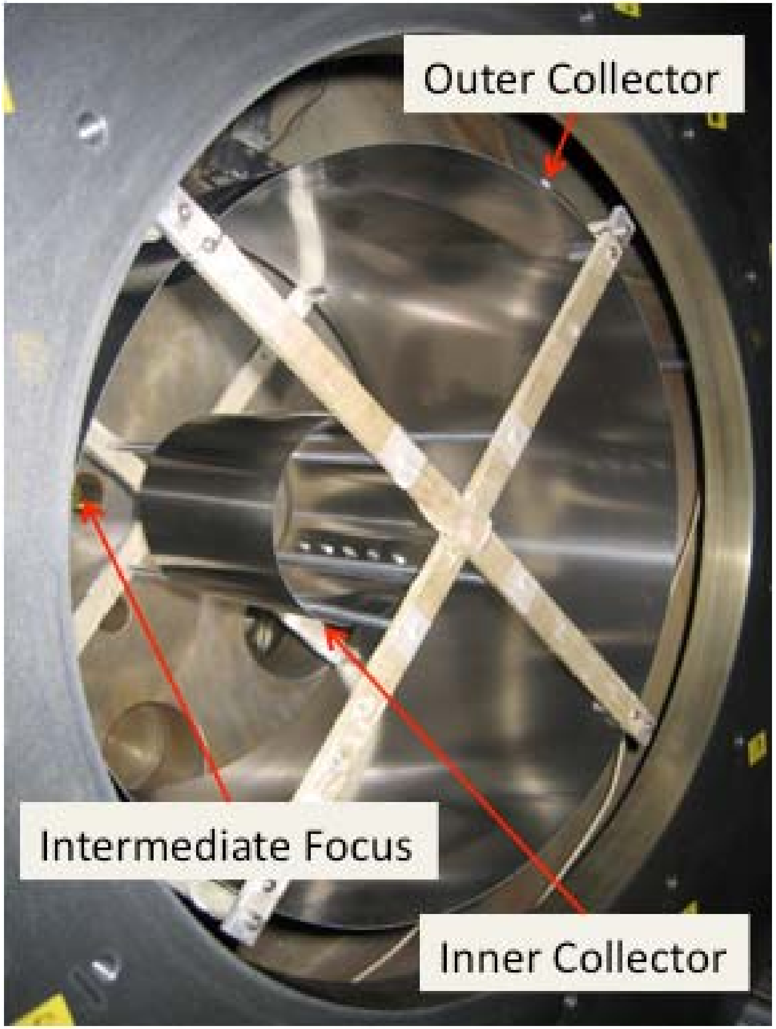


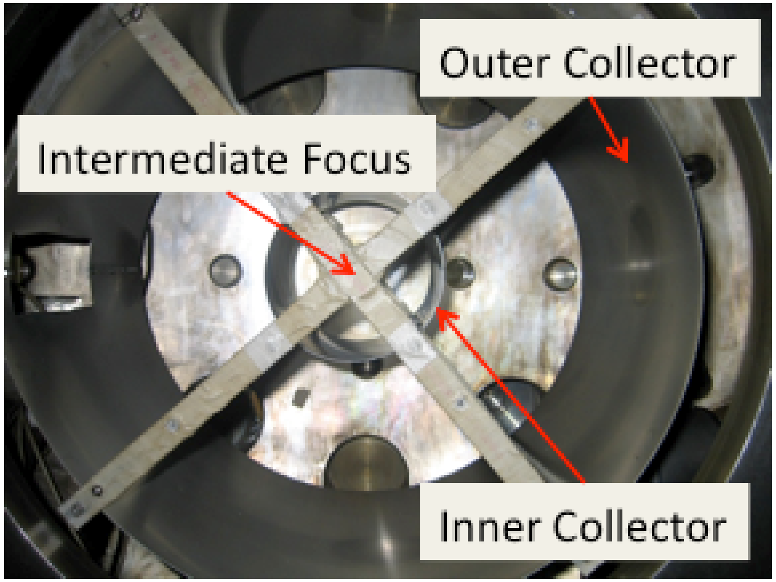
- A two shell mock-up collector optic is placed inside of the XCEED system to act like a real collector optic.

- Two shells (5" and 17" diameter) allow for a simulated reflectance of light from 10° and 30° respectively. The direct line of sight is also blocked.

- The SNIFFED components are each placed on the cone of emission for the 10° reflectance

Mock-up Collector Optic

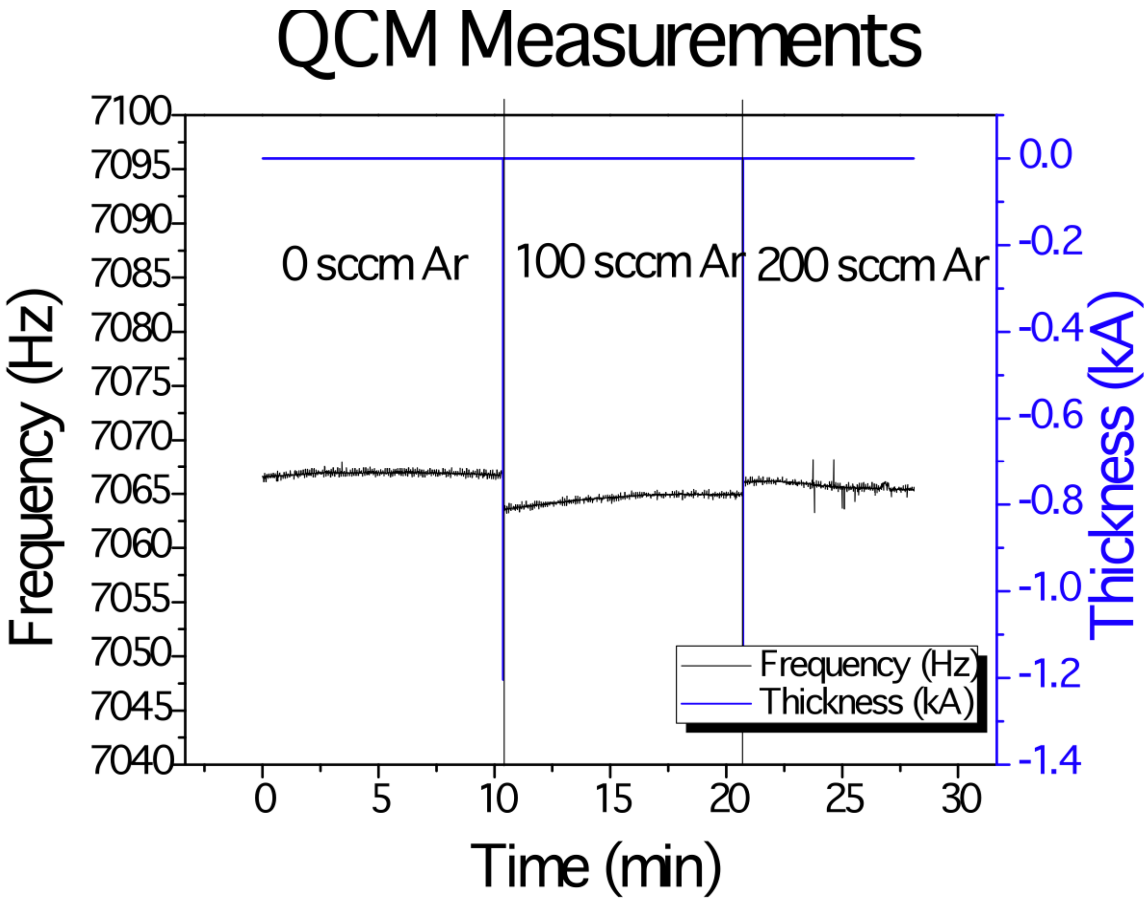




- Two shells are suspended perpendicular to the EUV source in order to mimic the reflection of EUV photons to the IF.

- The shells are made out of stainless steel, and specularly reflect light at 10^o and 30^o.

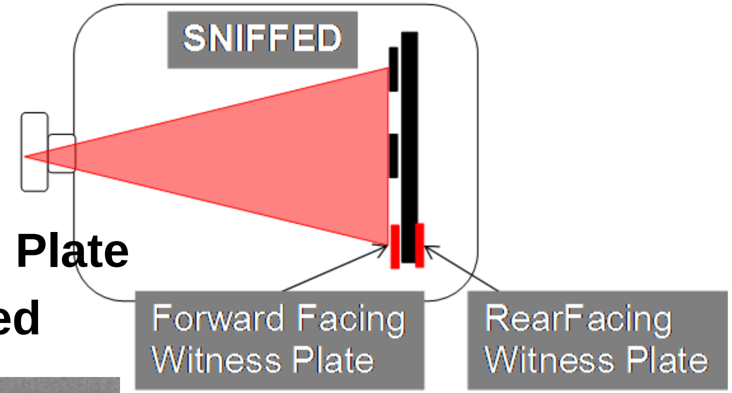
IF Measurement Results: QCM



- QCM measurements reveal no observable increase or decrease in surface thickness during the exposure of SNIFFED to the IF.

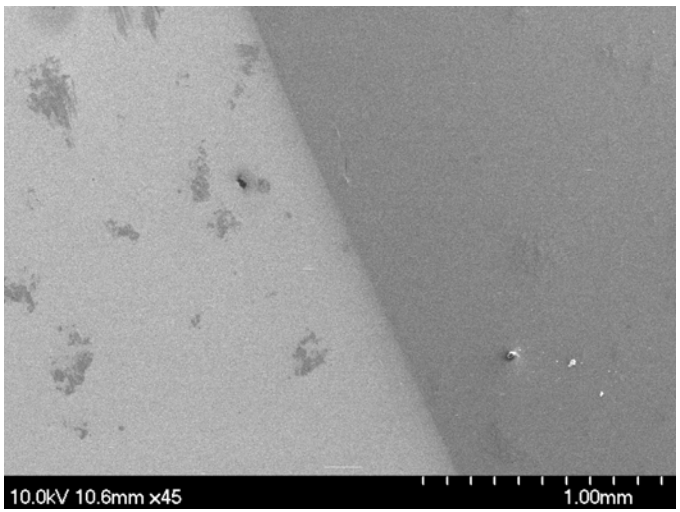
- Discrepancy between the time periods is a result of the data being patched together, and the system being altered between runs.

IF Measurement Results: Si Witness Plates



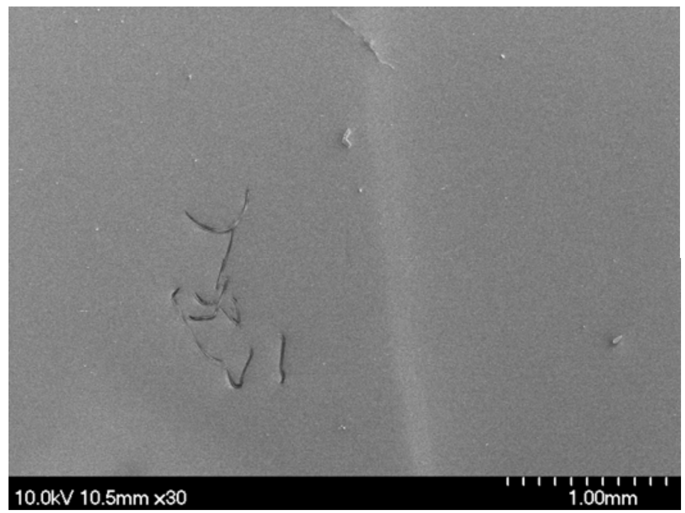
Rear Facing Witness Plate

Uncovered **Covered**



Forward Facing Witness Plate

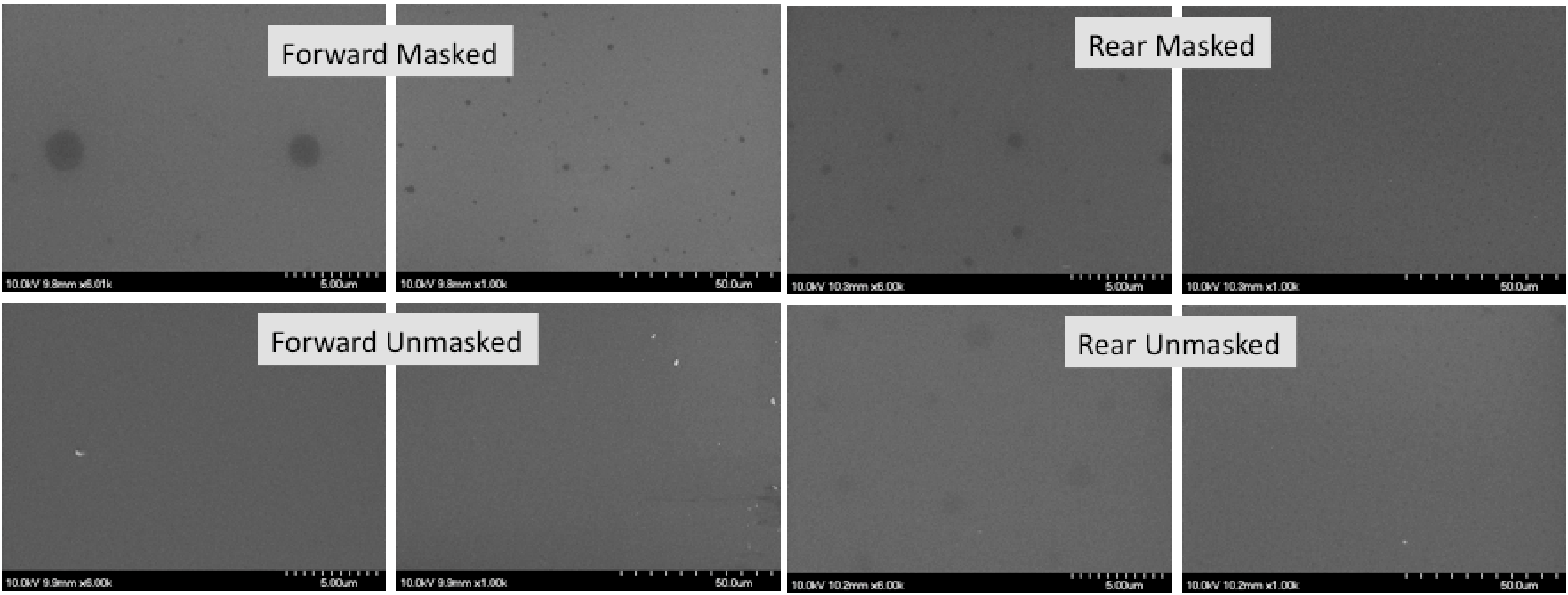
Covered **Uncovered**



- 0 sccm Ar buffer gas
- 85 sccm N pinch gas
- 35 minutes operation duration
- 20 Hz pinch / 100 Hz laser

- Despite lack of evidence for deposition or erosion, there are thermal effects evident on the Si surfaces.

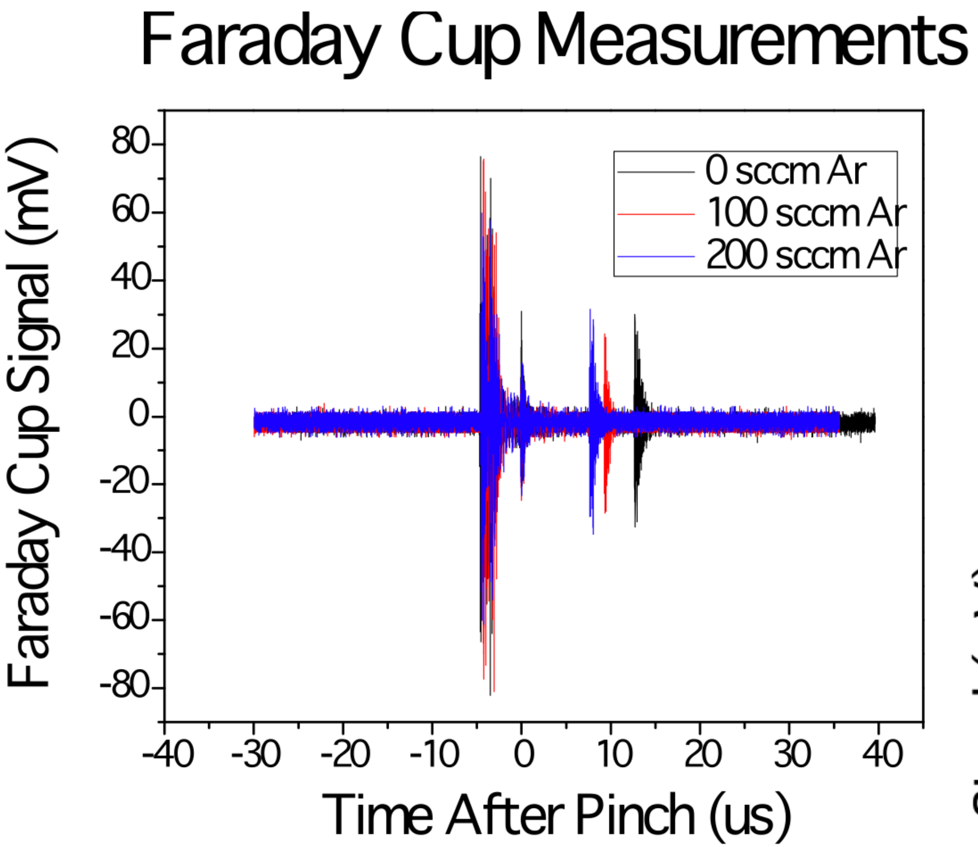
IF Measurement Results: Si Witness Plates



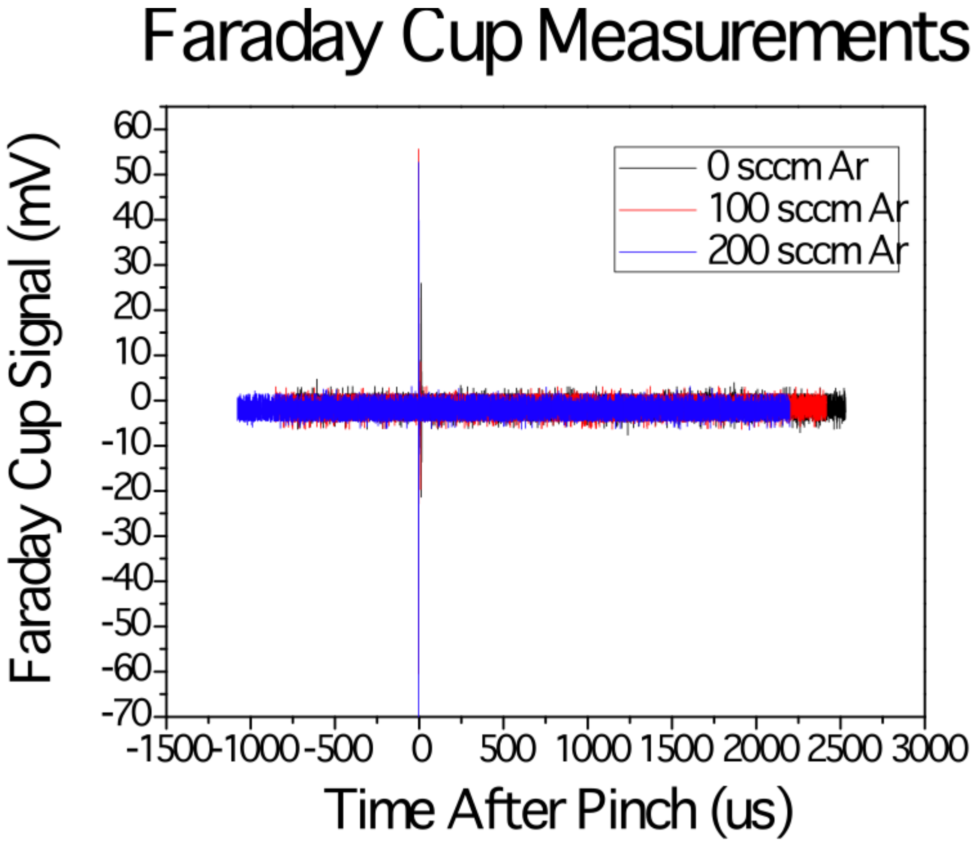
- 200 sccm Ar buffer gas
- 85 sccm N pinch gas
- 35 minutes operation duration
- 20 Hz pinch / 100 Hz laser

- In comparison to the 0 sccm Ar cases, there is very little difference between the masked and unmasked portions of the Si witness plates.

IF Measurement Results: Faraday Cup

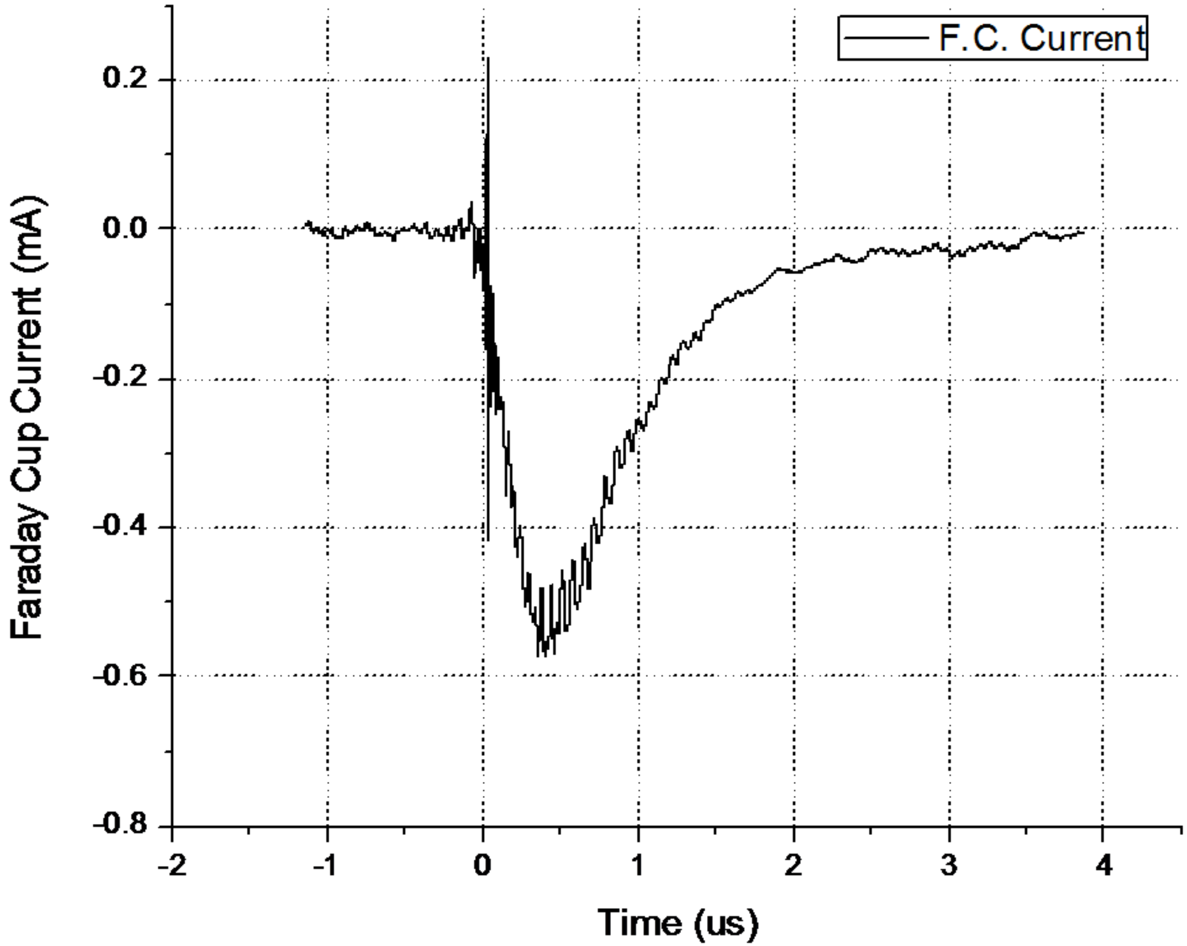


- Faraday cup measurements reveal a lack of charged debris at the intermediate focus. Spikes going both positive and negative are electric switching noise.



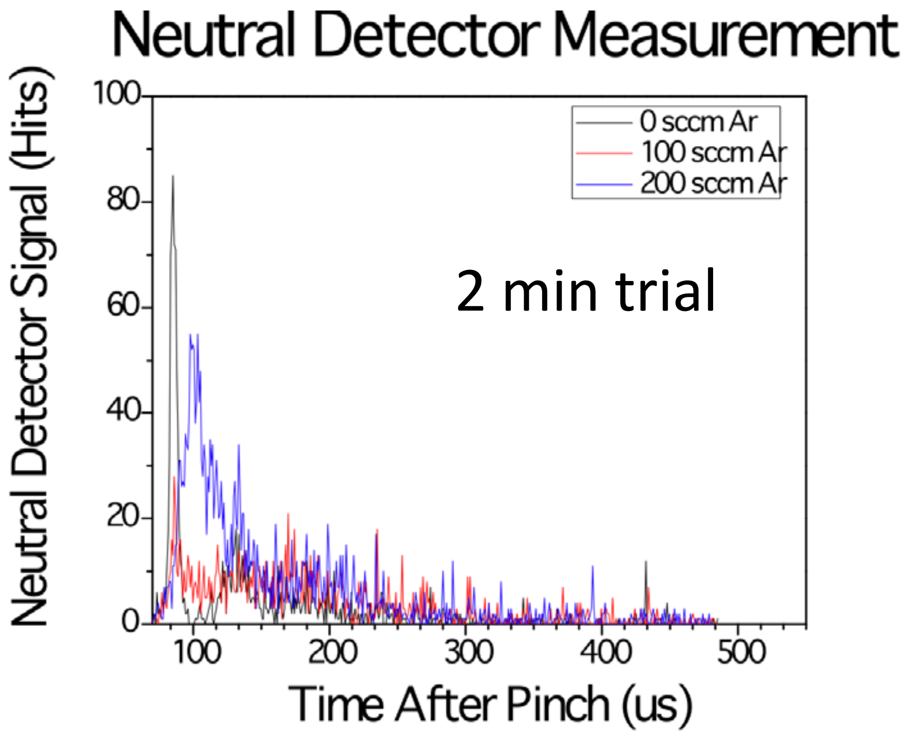
- The two pictures show both a short time span and long time span after the pinch to verify the lack of late arrival.

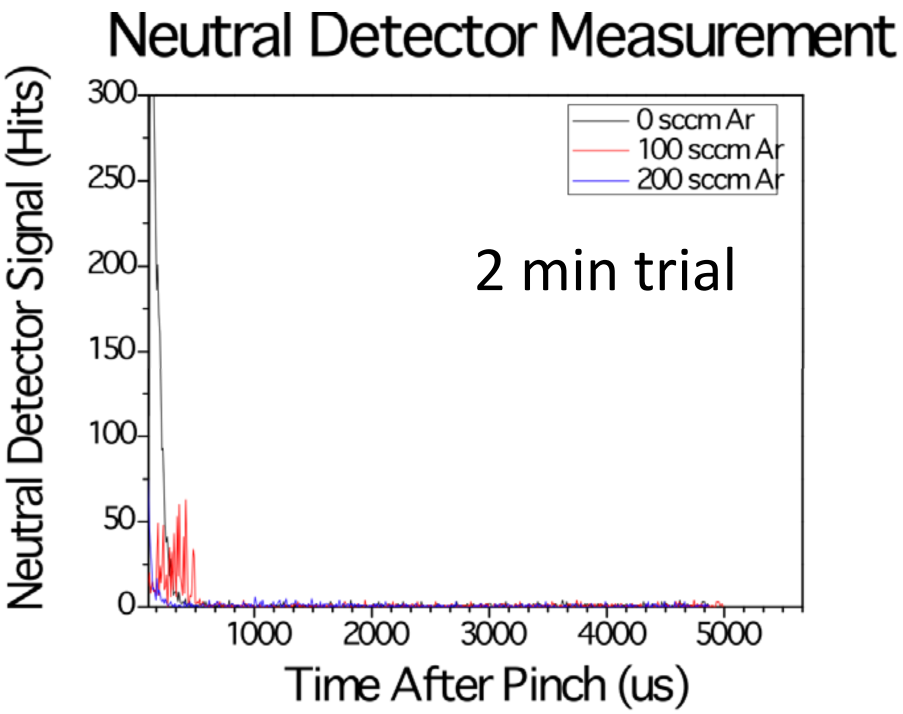
Outside of IF Measurement Results: Faraday Cup



• Previously presented results revealed that outside of the collector optics, in LOS of the pinch itself, a measureable electron flux was observed. The charge non line of sight charge accumulation accounts for a flux of ~ $4x10^{13}$ electrons/m^2

IF Measurement Results: Neutral Detector



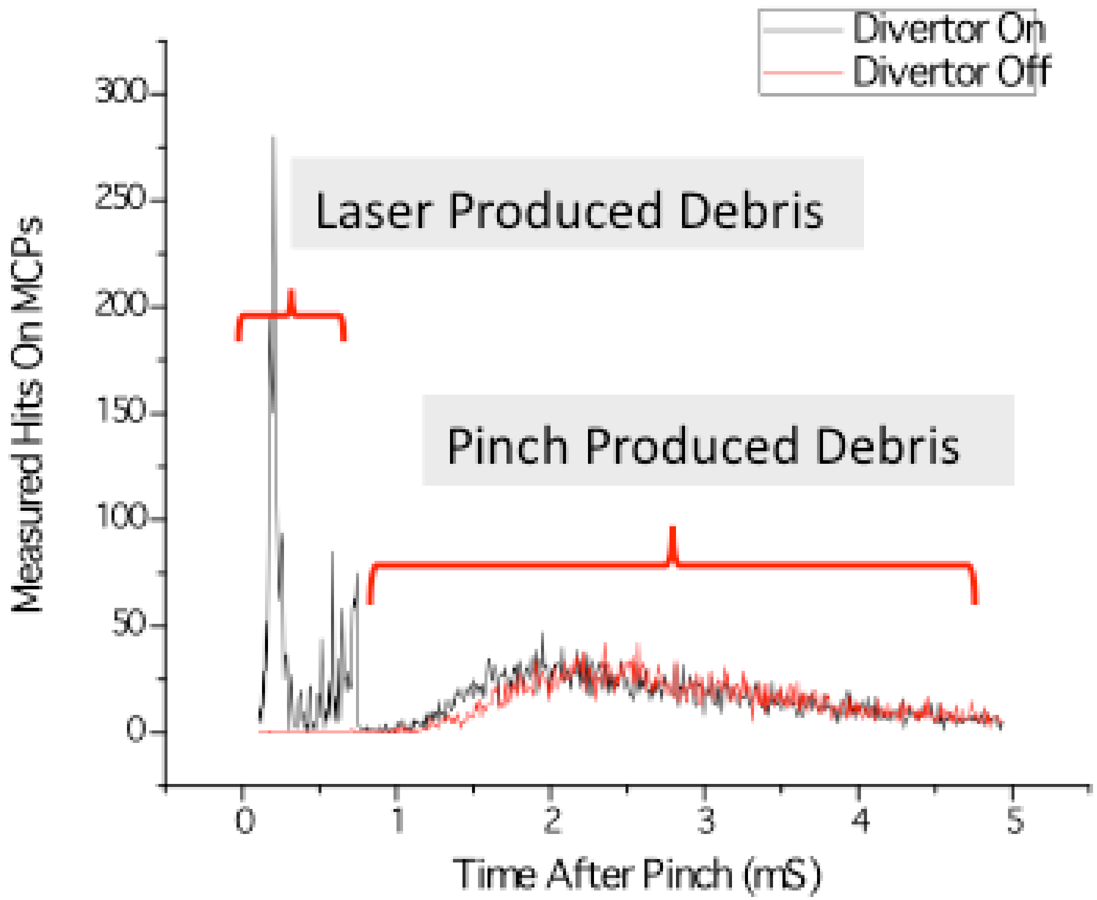


- Neutral detector measurement reveals nearly a 100 us delay between the creation of EUV and the introduction of debris into the IF.

- An observable flux is observed from 100 to 500 us after which there is no noticeable flux observed

- All observed debris is created by the pinch alone. No laser debris was observed during these measurements. More neutrals are seen when debris mitigtion is **on**.

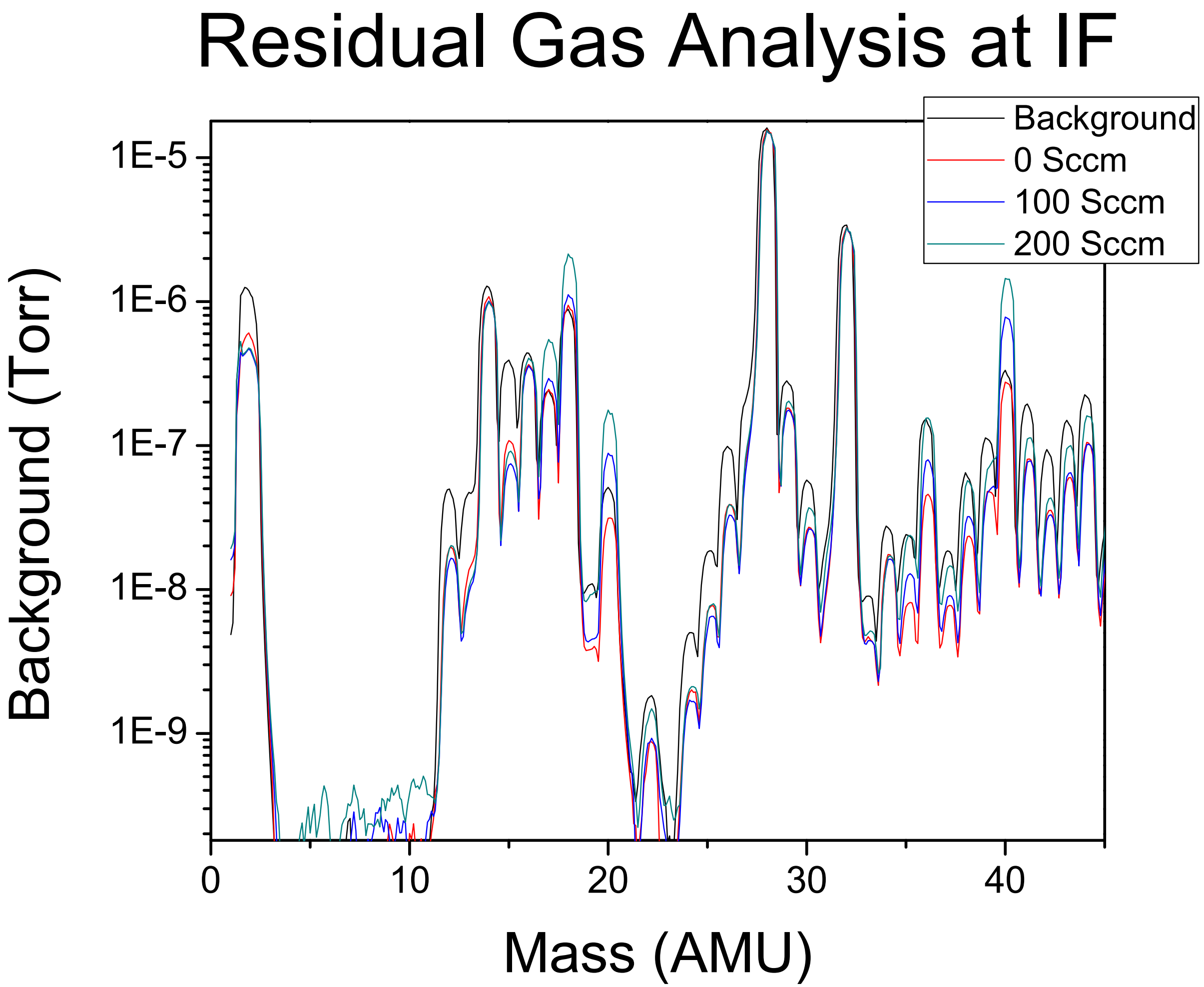
IF Measurement Results: Neutral Detector



- 85 sccm N / 0 sccm Ar
- 20 Hz pinch / 100 Hz laser

- The results shown reveal an interesting result of the use of a laser.
- As mentioned previously, the laser and pinch do not perfectly align at all moments, so it is possible to capture data with and without the debris created by the laser.
- The pinch debris is noticed as expected between the 100 and 500 us periods of time.
- A secondary set of debris follows the laser pulse. This pulse produces much more debris for a shorter period of time than the pinch. Laser debris is mostly stopped by mitigation.

IF Measurement Results: RGA



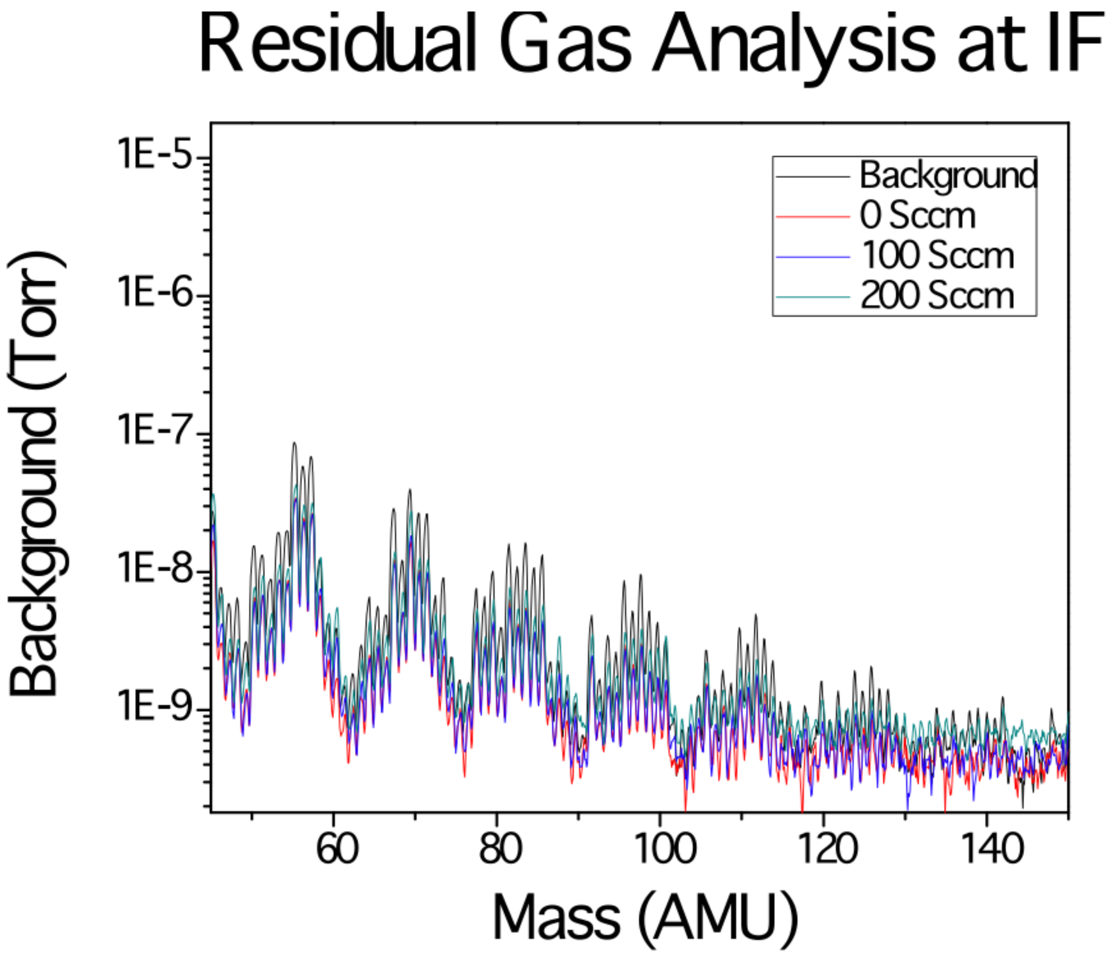
- 85 sccm N
- 20 Hz pinch / 100 Hz laser

- The addition of more buffer gas has the result of increasing the amounts of Ar and Water vapor present at the IF

- These results show that while increasing buffer gas may reduce total energetic debris as shown in the MCP results, it also introduces species located within the transfer lines.

- Of interest however, is the lack of increase or decrease in the amount of residual nitrogen located at the IF. All signals are 14 and 28 are the same and the most significant peak.

IF Measurement Results: RGA



• The addition of buffer gas had little to no observable effect on the presence of hydrocarbons due to pump oil

• There is very little observable Sn vapor pressure, as is to be expected given the condensability of Sn

Summary

- We have simulated an LADPP environment, with the use of laser ablation, a 35% increase in EUV power has been observed.
- Sn splats or micro-sized particles are generated in LADPP.
- Sn ablation lowers the electron temperature and therefore the energy of the ions
- We can clean Sn splats using an internal ICP coil and do so at a very rapid rate.
- Delayed energetic neutral debris is found at the intermediate focus even with debris mitigation in place..
- Mechanisms responsible for this debris and how it can be eliminated are being investigated.

Acknowledgements

- Sematech for support
- Kazuaki Hotta, EUVA for support and assistance
- Matt Tomkowiak, Pi Zonooz, Undergrad assistants

Thank you for your attention