Condenser optic lifetime issues for laser and capillary discharge EUV sources

William P. Ballard, Philip Grunow,
Neal Fornaciari

Source Workshop

February 23, 2003

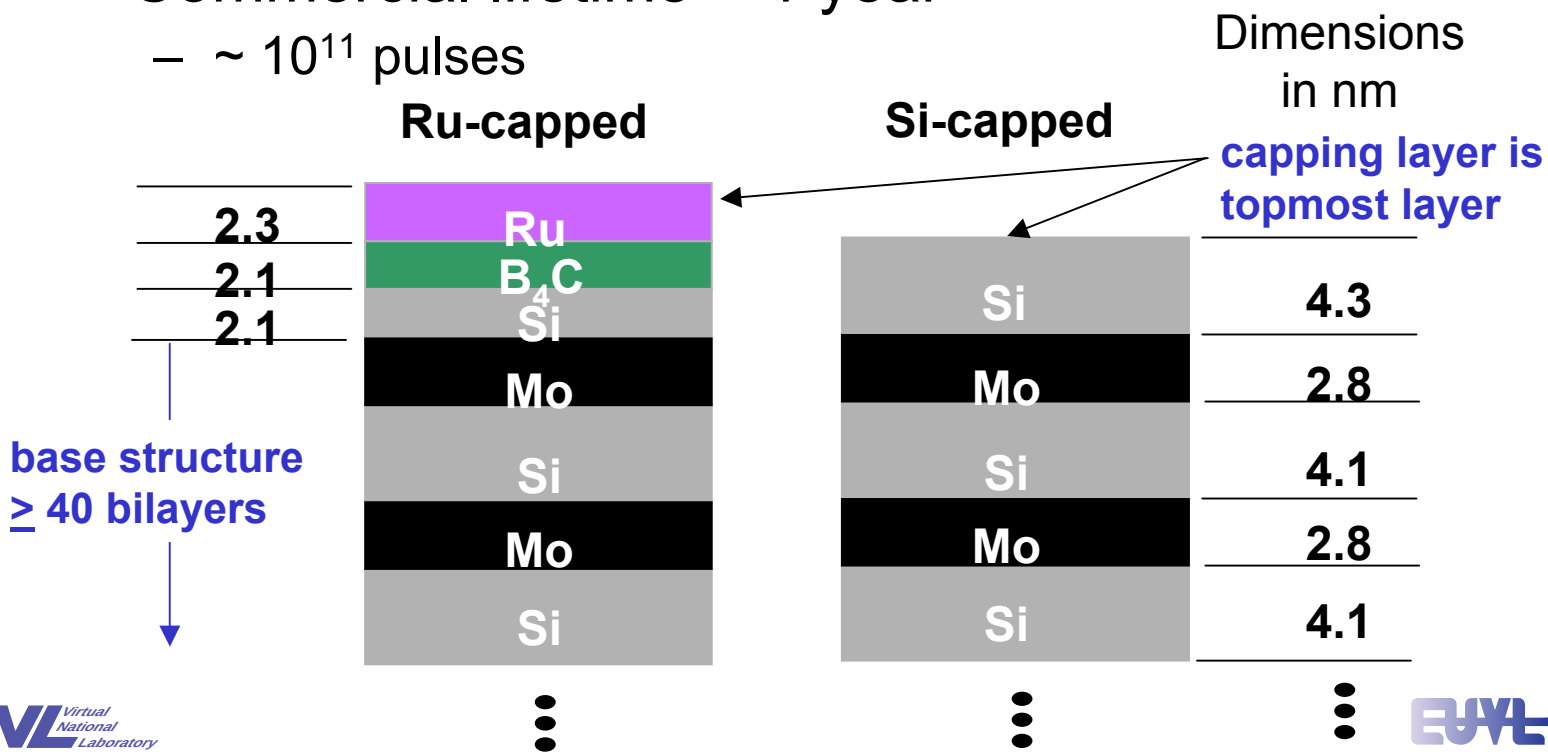
This work was performed at Sandia National Laboratories supported by the Extreme Ultraviolet Limited Liability Company (EUV LLC), by International SeMaTech, and by the U.S. Department of Energy under contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

Laser plasma source: significant environmental changes found at high power

- Switched from 40 W drive to 500 W drive
  - Effects on primary condenser @ ~15 cm from plasma
    - Plasma to collimator separation varied
    - Correlate long lifetime results with short-term witness samples
  - Effects on third mirror in condenser, just before the spectral purity filter
    - Background environment changed from Oxidizing to Carbonizing
    - Stopped using EtOH to protect mirrors due to plasma-induced dissociation carbonizing mirrors

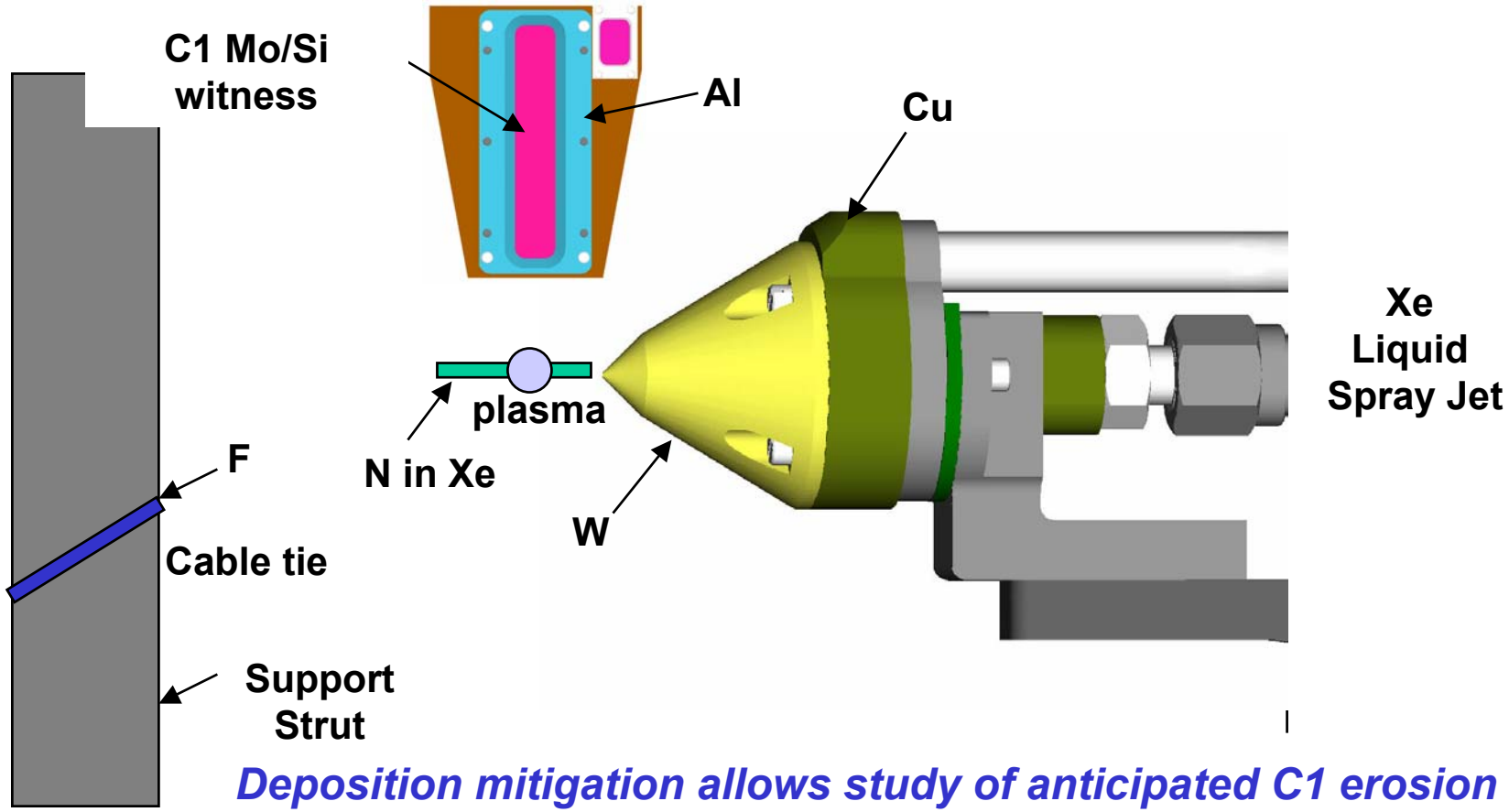
C1 condenser optic requirements

- High reflectivity (~ 67 %) for in-band flux (2% bandwidth about 13.4 nm) over π sr
  - Low contamination and erosion
- Commercial lifetime ~ 1 year
  - ~ 10^{11} pulses



First, sources of condenser deposition identified, mitigated with high power

F, Cu, Al, N sources eliminated by removal, C coating



Deposition mitigation allows study of anticipated C1 erosion

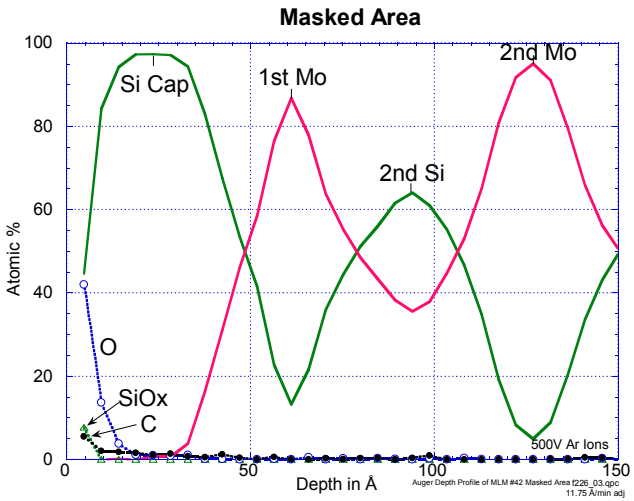
Condenser erosion, oxidation observed

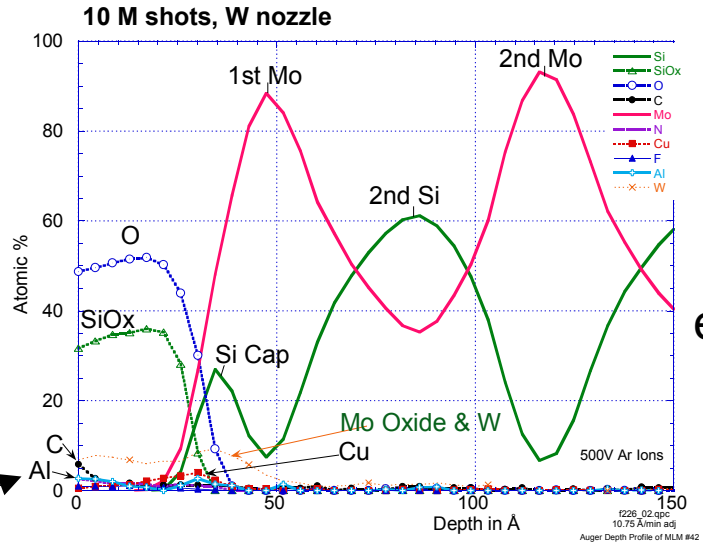
Note: Not a new problem, confirms previous source development work

Laser - Nozzle Gap:

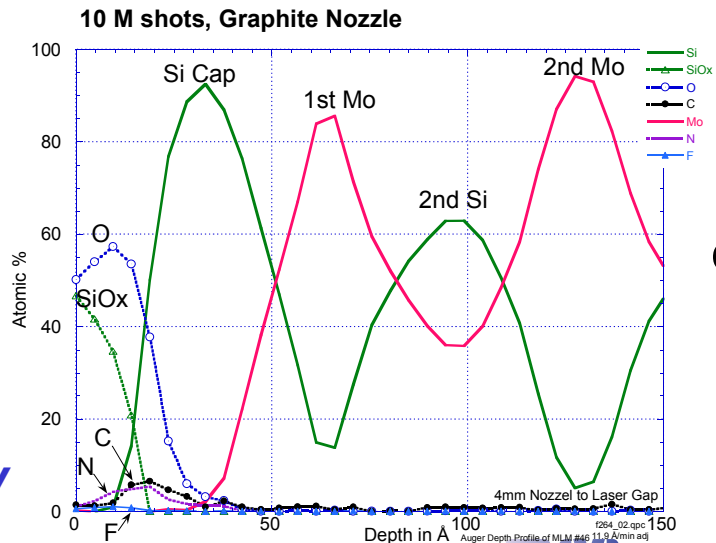
2 - 4 mm

4 mm





More erosion



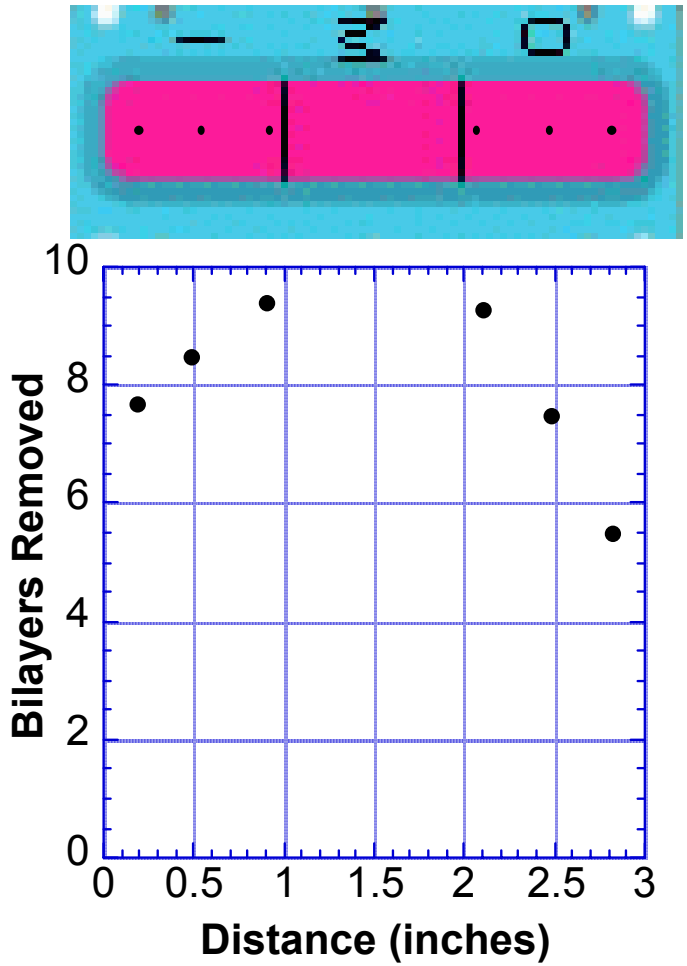
Little erosion

Erosion can be as high as ~40 Å/10M shots
Gap, angle dependence needs further study

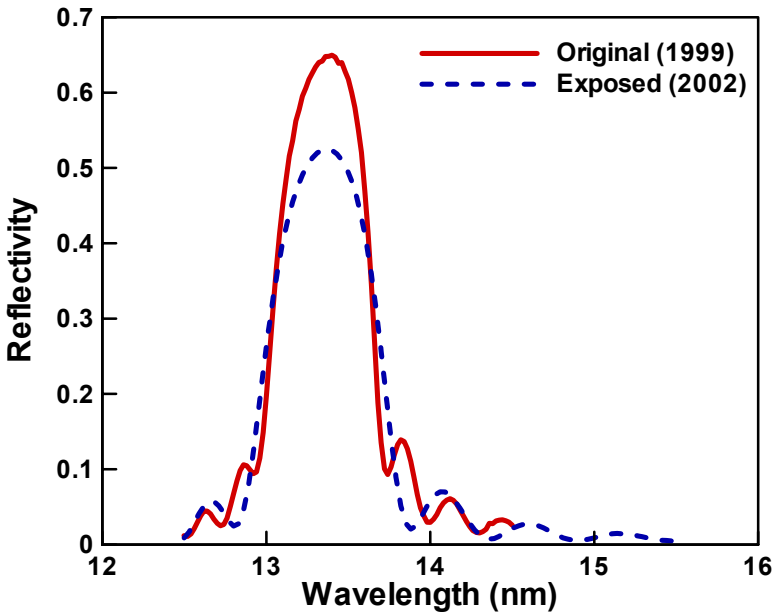
Si Capped MLM Witness Samples Were Exposed to 230M Shots at the Condenser

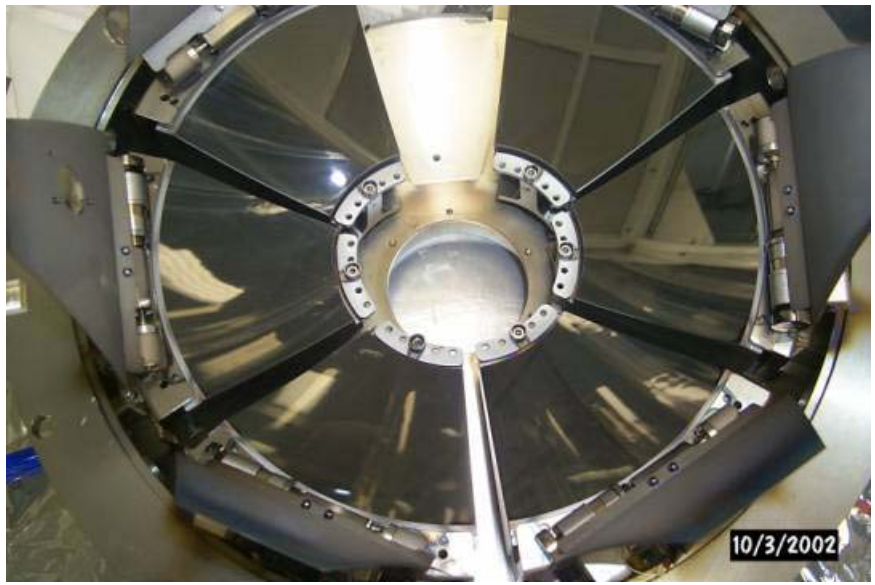
- The inner and outer MLM witness samples had a total of 10 bilayers and were Si Capped
- Fixed parameters include:
  - 4mm nozzle separation,
  - 50μm nozzle orifice,
  - laser Chains 1 & 2 used
- A total of 7 Auger depth profiles were taken on the inner and outer C1 witness sample positions.

Plot of Bilayers Removed after Exposure to 230M Shots



Condenser optic analysis after ~300M pulses



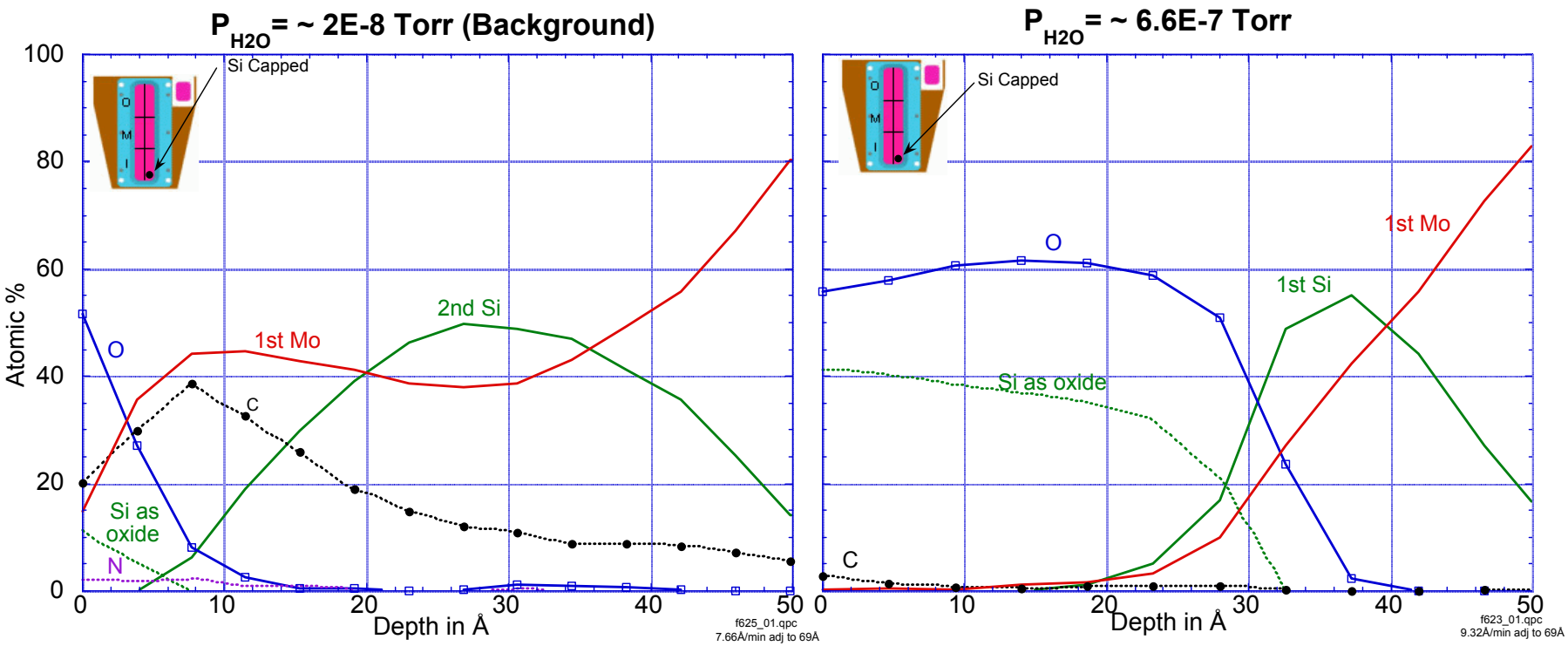


Minor visible damage to multilayer

Reflectivity data consistent with loss of ~15 bilayers

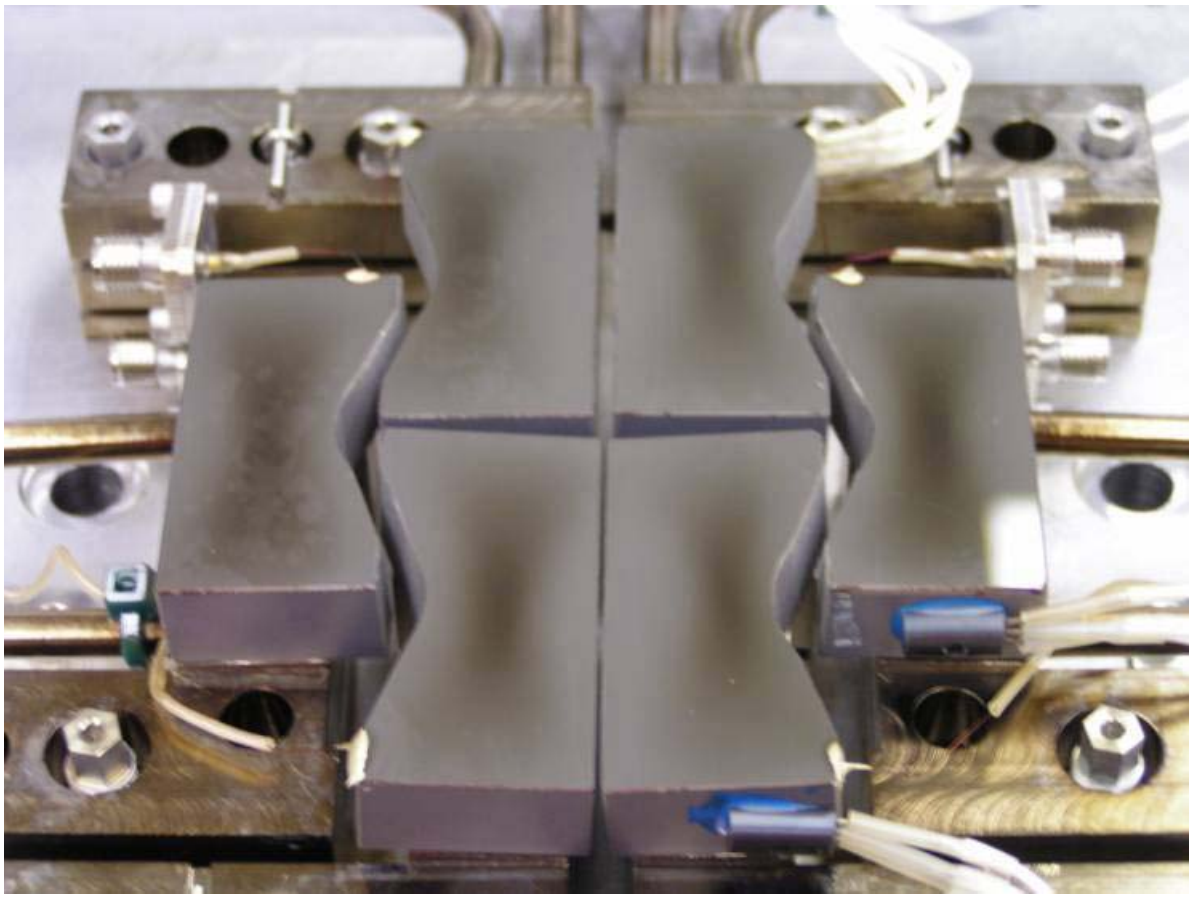
Striations suggest differential erosion across petals

Background H_2O the source of condenser oxidation

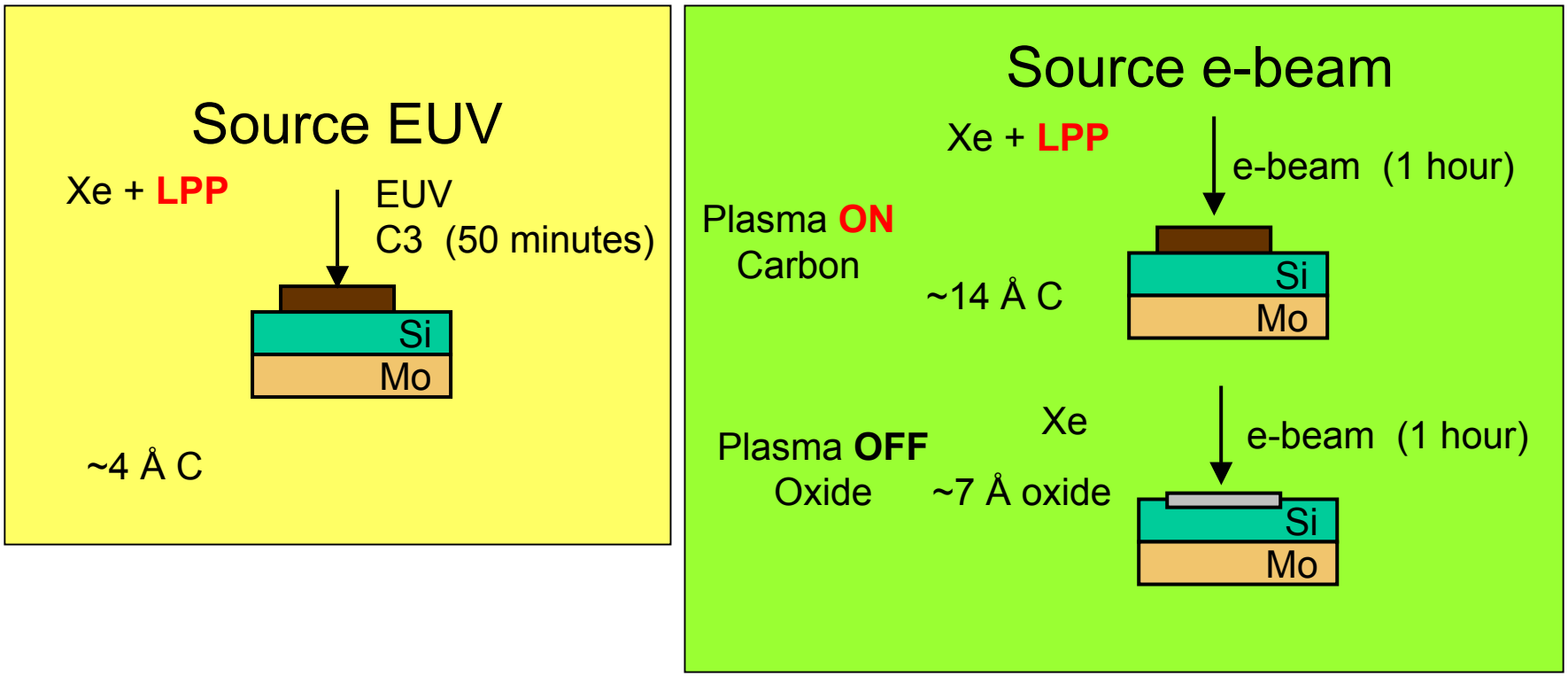


- More C1 oxidation observed at higher P_{H2O}
  - Note decrease in erosion rate at higher P_{H2O}
  - Large change in with only 1 part in 10^4 change in partial pressure

Third condenser mirror: carbon deposition shown to be plasma related

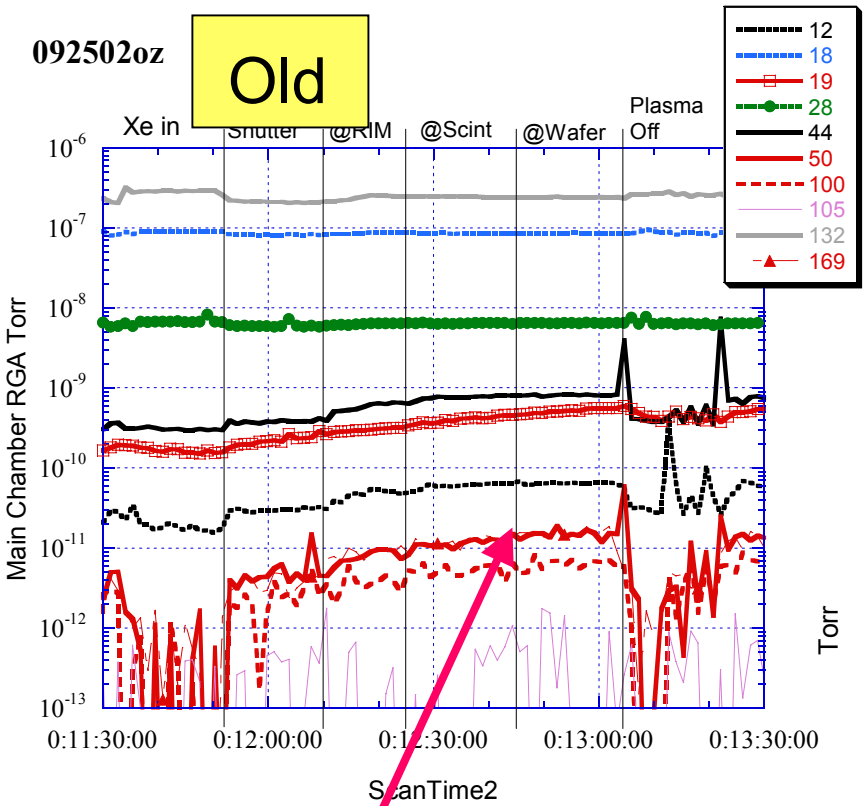


C deposition found at C3; e-beam tests showed deposition plasma related

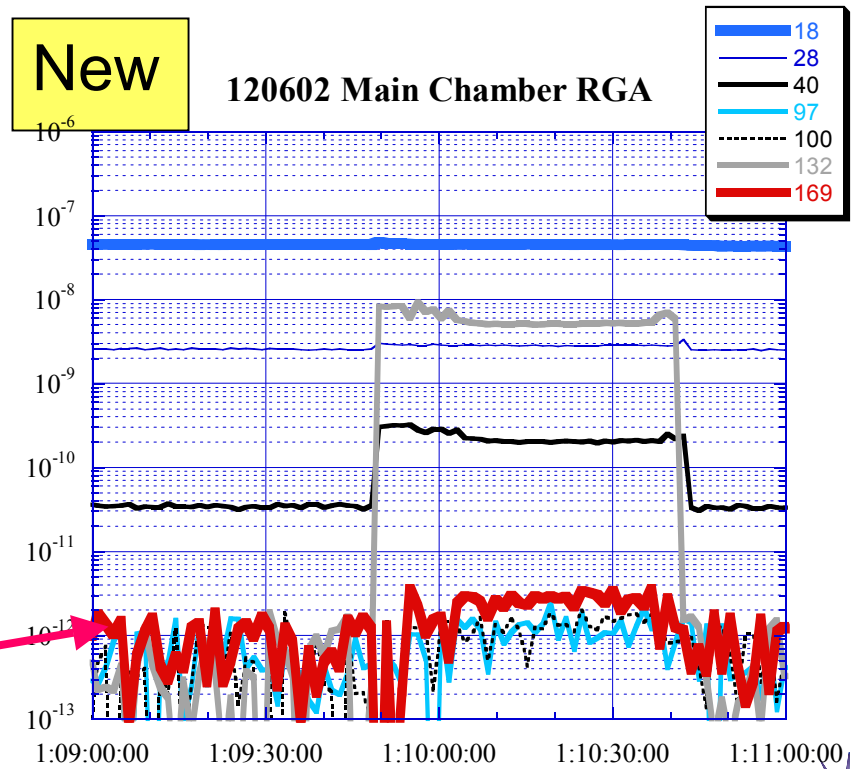


With plasma, environment becomes carbonizing instead of oxidizing

FC levels in main chamber with new seal reduced compared to old SPF seal



- Mass 169 (FC) reduced 7x

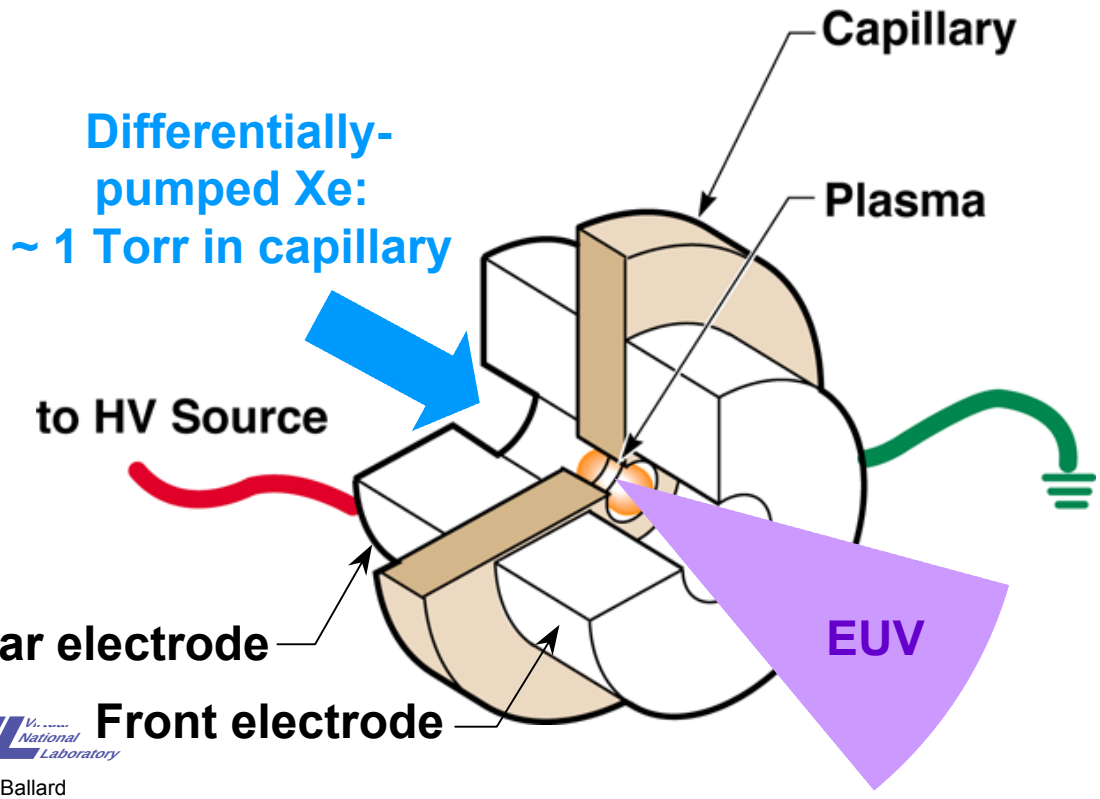


FC

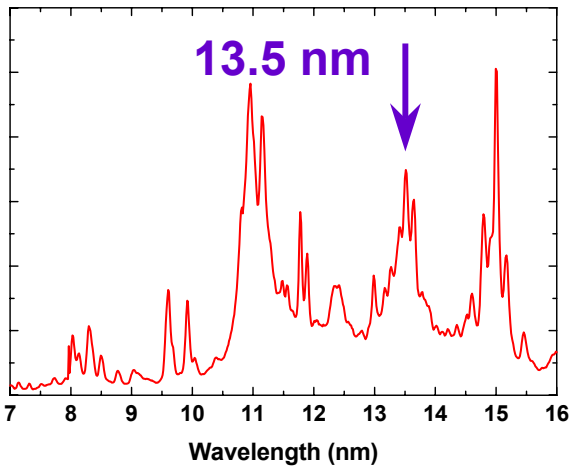
Capillary Discharge Source Overview

Approach

- **Concept originated by Silfvast & Klosner/UCF**
- **Direct electrical ➡ EUV energy conversion**
- **1 kHz, 14 W source in development**
- **Debris mitigation approaches studied**
- **Alternative electrode tested**

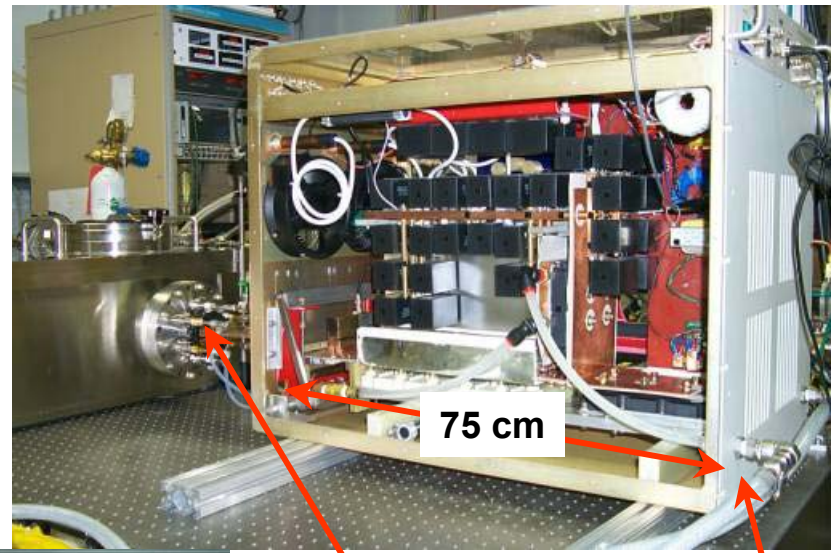


EUV Output Spectrum



14 W output power scale-up

- Repetition rates up to 1 kHz
- 5000 A at 1500 V
- Pulse duration from 0.5 to 4 μs
- Pulsed and Simmer pre-ionization for improved stability and reduced lamp erosion
- Supported by International SEMATECH

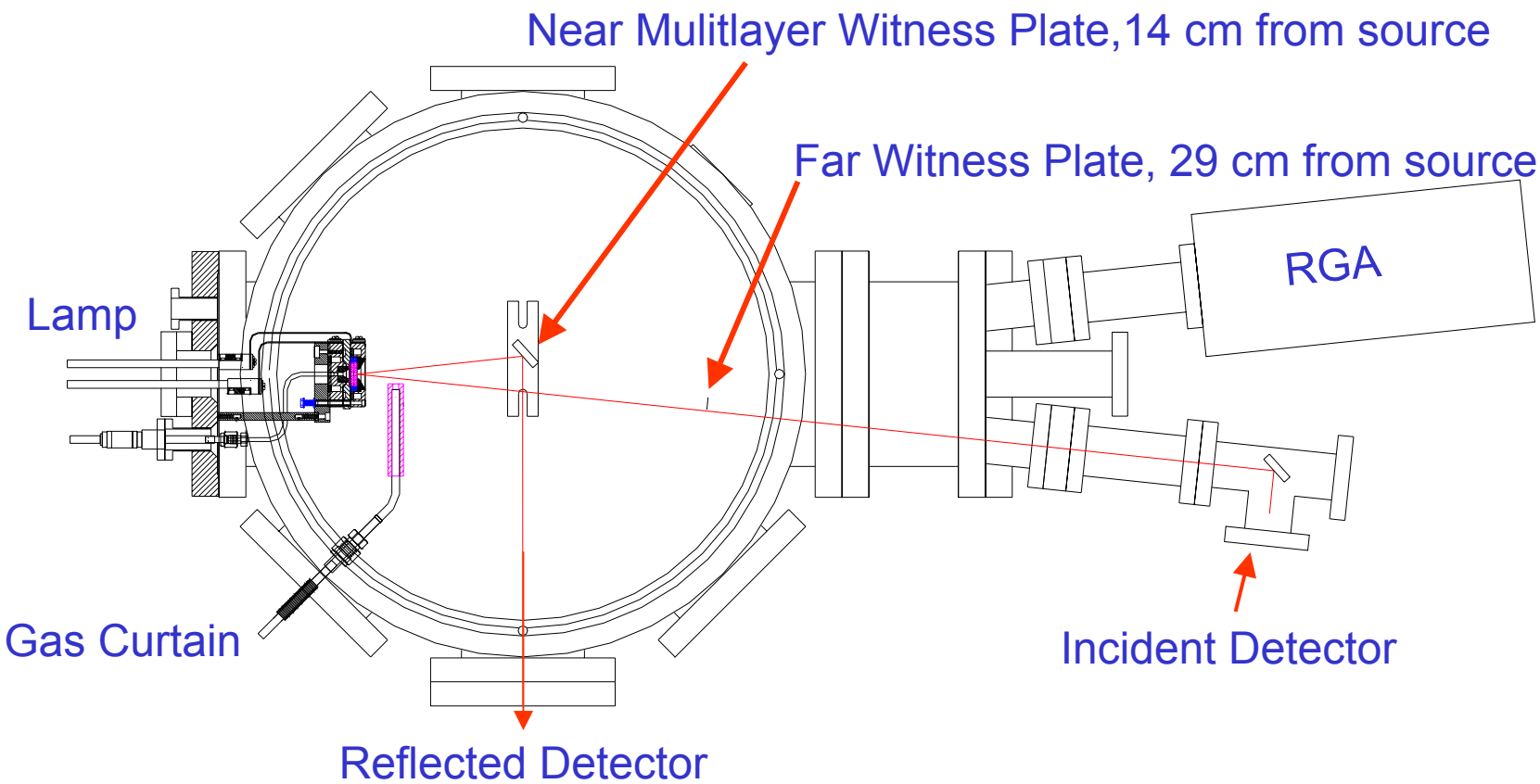


Lamp in simmer mode

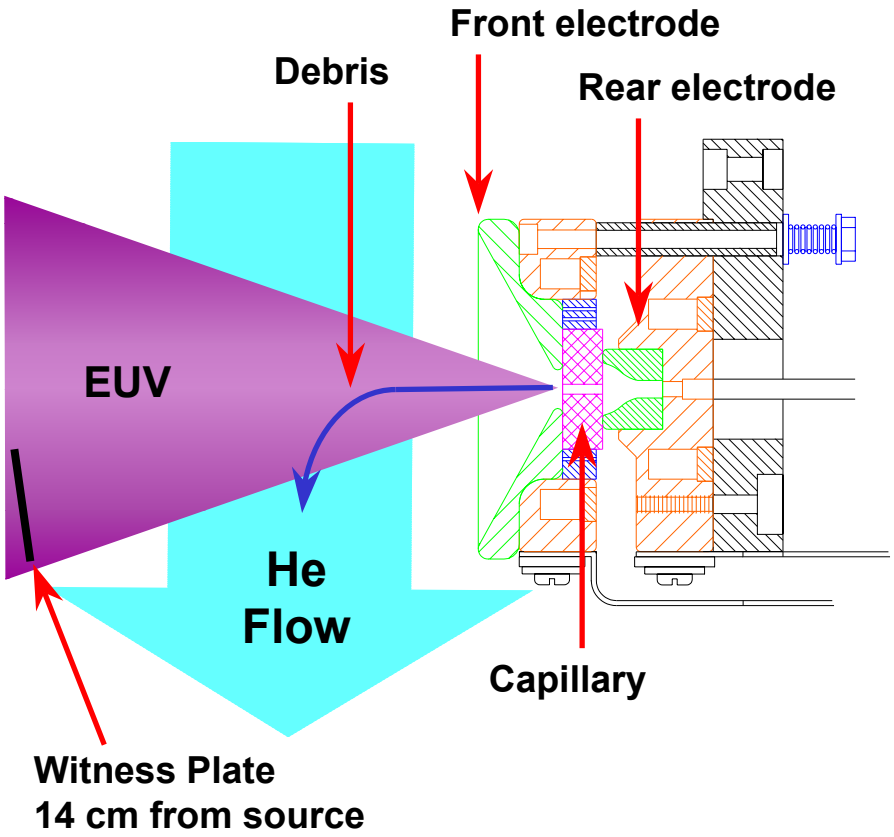
Lamp at 1 kHz

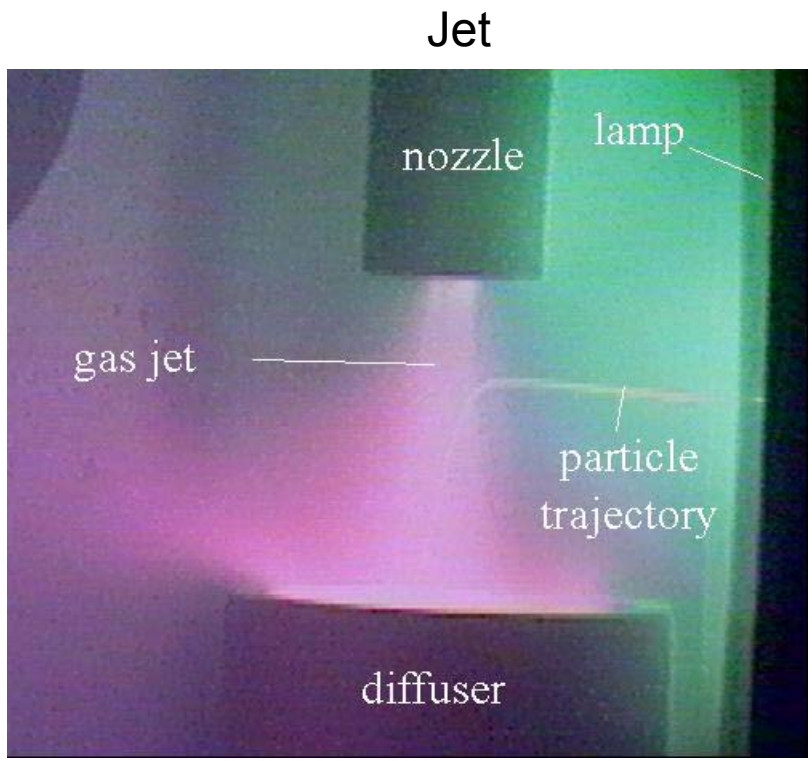
Reflectance lifetime chamber used to measure deposition of particulate and atomic debris

- Debris measurements made with and with out the gas curtain and with a background pressure equal to that with the gas curtain
- **Source operating condition: 1 μs pulse at 500 Hz for 10^6 pulses**



Gas curtain blocks lamp debris

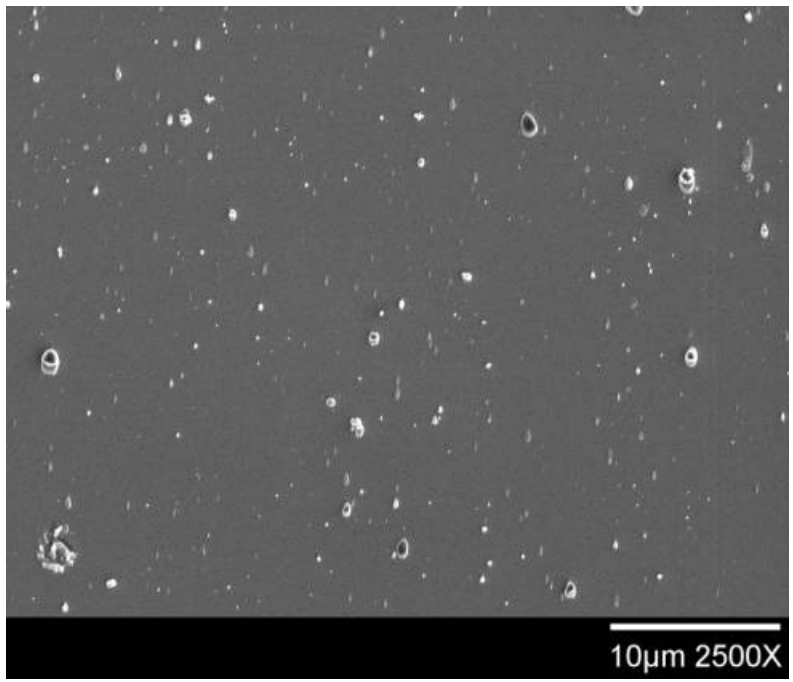




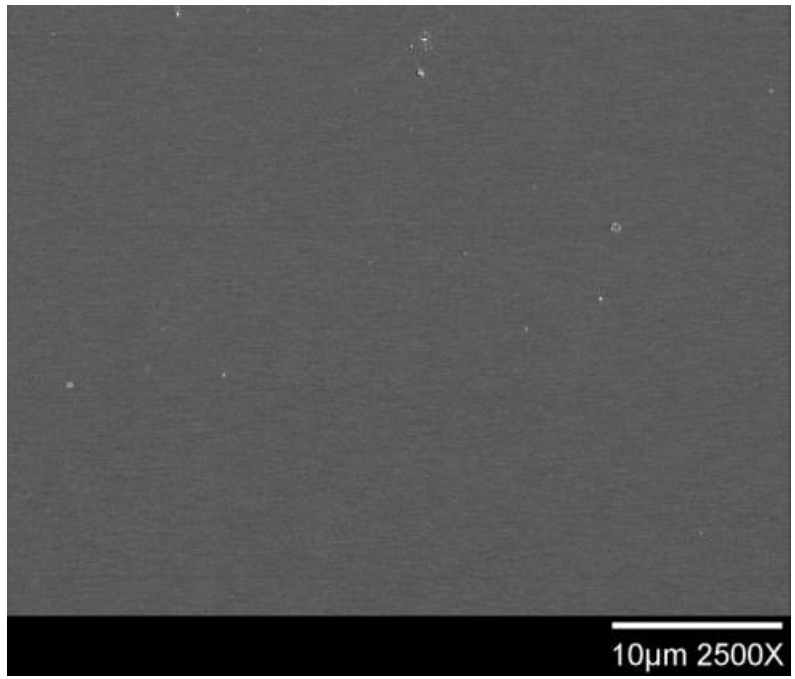
Debris tests run at 500 Hz for 1 million pulses with a 1 μs pulse width

Particulate debris deposition rate reduced by 100x with gas curtain

SEM images of witness plates



Without Curtain



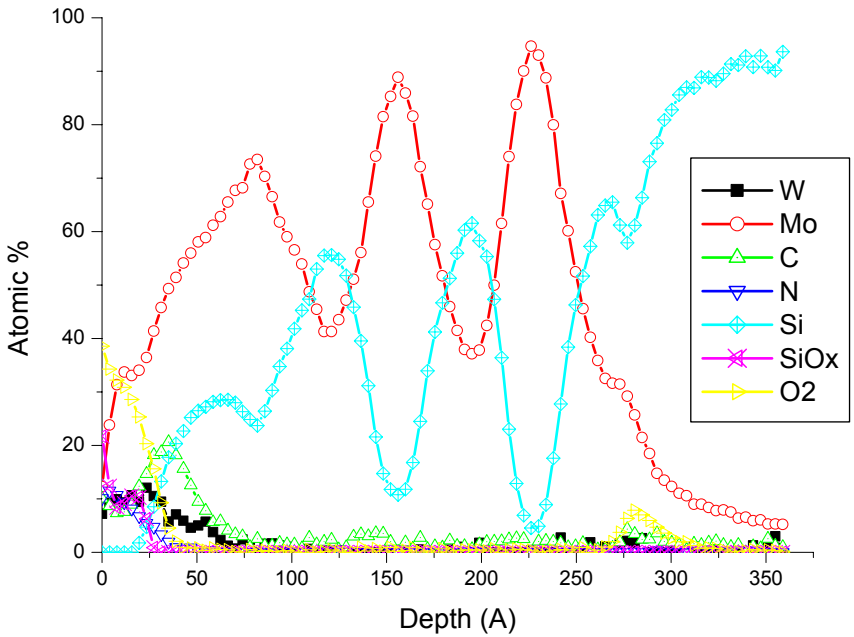
With Curtain

Particle obscuration reduced to .01% after 10^6 pulses

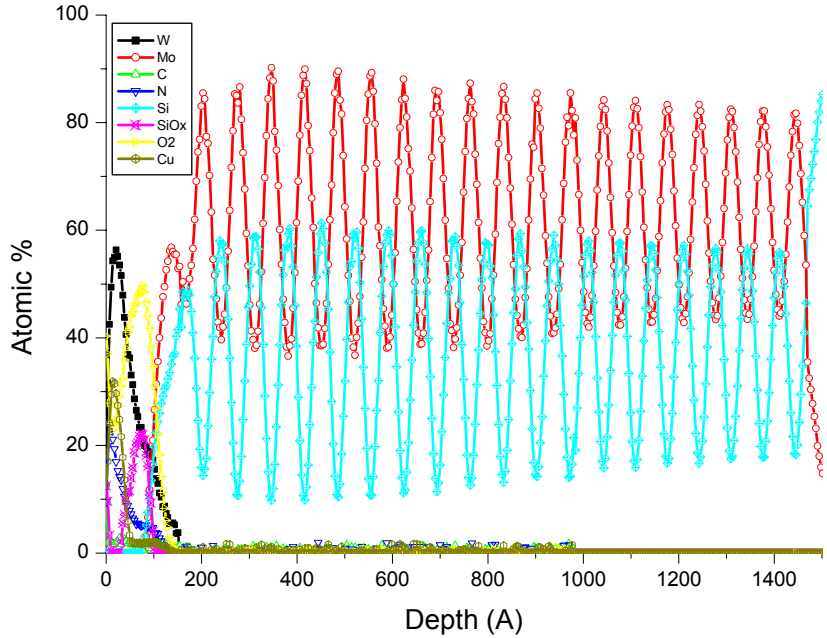
Equates to 10% coverage after 10^9 pulses

Measurements revealed 17x reduction in mirror erosion rate with gas curtain

Auger depth profiles sputtered through to Si substrate on 20 layer-pair Mo/Si multilayer witness plates



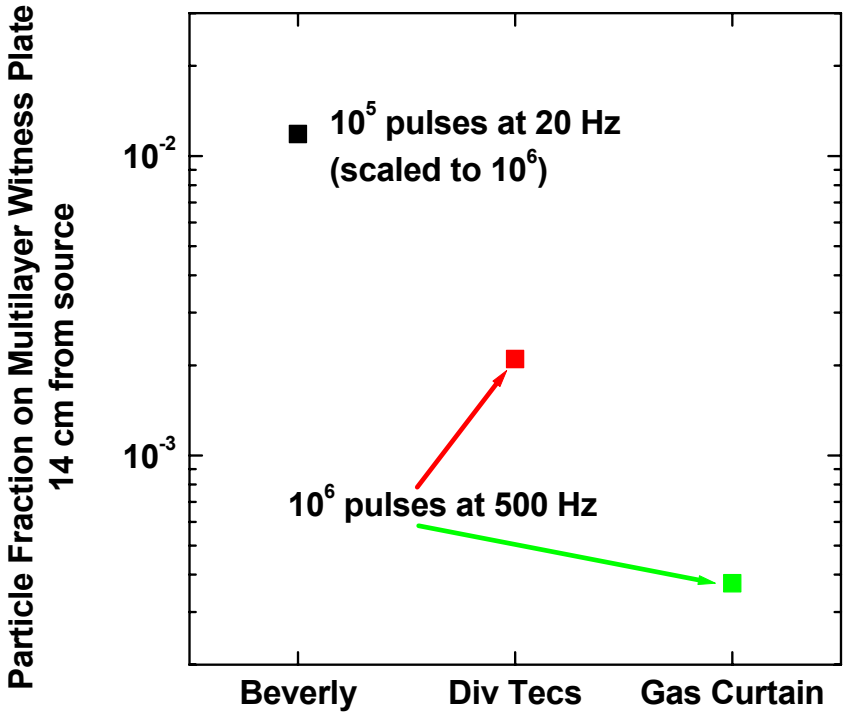
Without Curtain

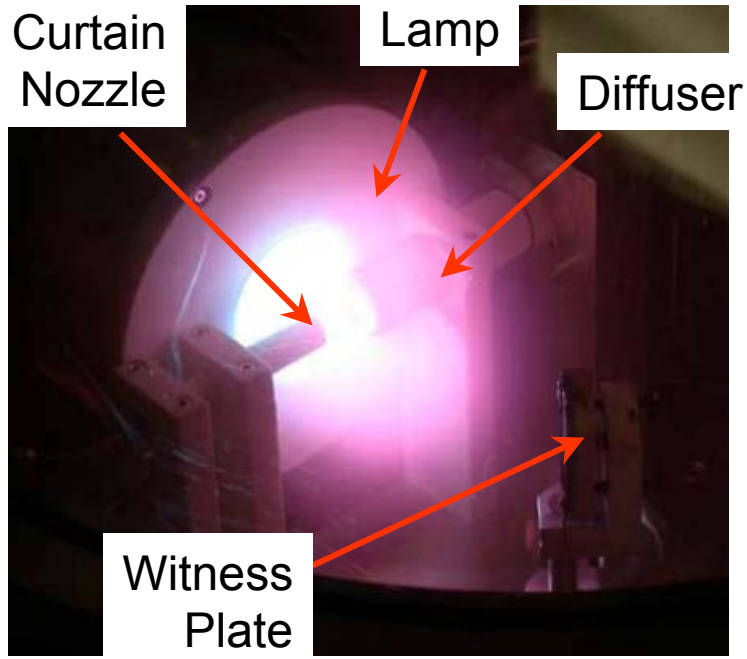


With Curtain

Reflectance lifetime based on erosion
10% loss after ~10^7 pulses

New pulser and gas curtain combined to reduced particulate deposits by 32x …





… and no detectible atomic debris with gas curtain operating

Debris deposition rates without GC and with He background equivalent

Examined physical sputtering as the mechanism for mirror erosion

- Auger depth profiling showed the removal of 17 bilayer pairs from a Mo/Si stack with 1 million pulses of capillary discharge
  - Equivalent to ~10 Million pulses of LPP in EUV

- Studied 100 and 500 Hz repetition rates both with and without the gas curtain

Summary

- Both LPP and discharge EUV sources significantly erode condenser optics at low collected EUV power

- Plasma operation creates secondary environmental effects, such as fluorocarbon outgassing creating a carbonizing environment for secondary condenser optics