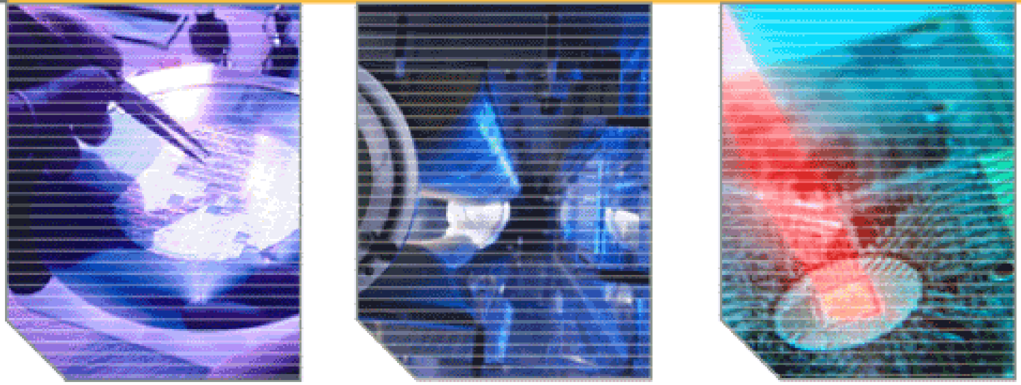
# LPP EUV Source Development for HVM

CYMER®



## 4th International EUVL Symposium, San Diego CA, November 7 2005

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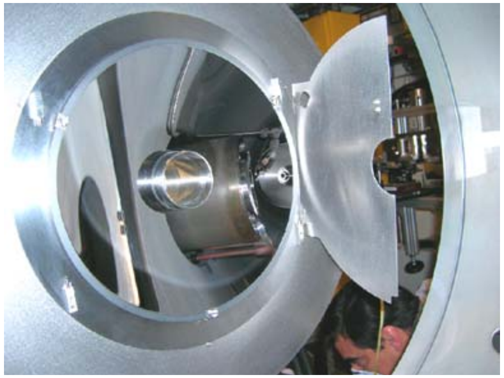
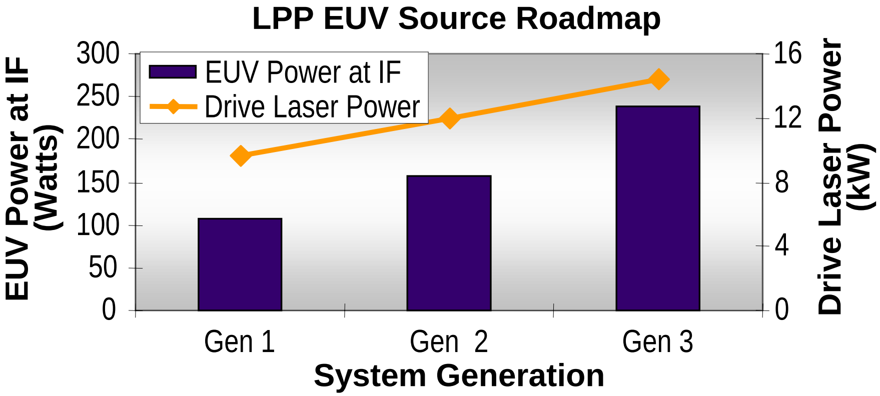
# LPP EUV Source Research and Development

- Laser Produced Plasma (LPP) technology is the most viable HVM EUV source solution

- Extensive focused research to investigate LPP-based HVM EUV Source Technology solutions



- 320mm diameter normal incidence collector with graded multi-layer coating compatible with Li or Sn



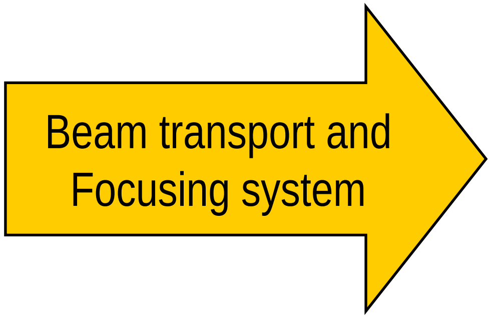
- Committed to development of HVM EUV Source technologies to ensure the timely commercialization of EUV

# System Integration

# Overview of Cymer's second LPP system prototype

## XeF drive laser

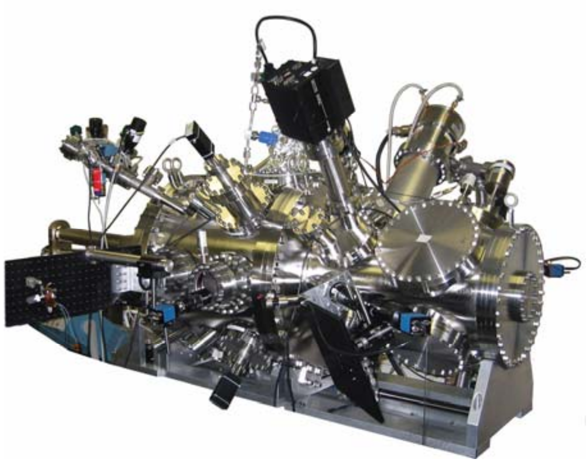
- Wavelength: 351 nm
- Reprate: 4 kHz
- Pulse energy: 200 mJ
- Total power: 800 W



Beam transport and Focusing system

- Active beam steering
- Beam shaping
- Focusing

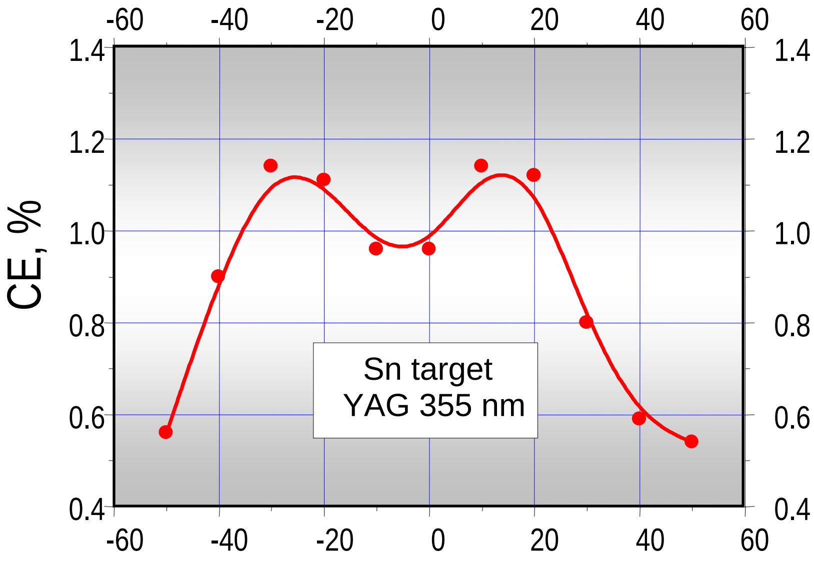
## Source chamber



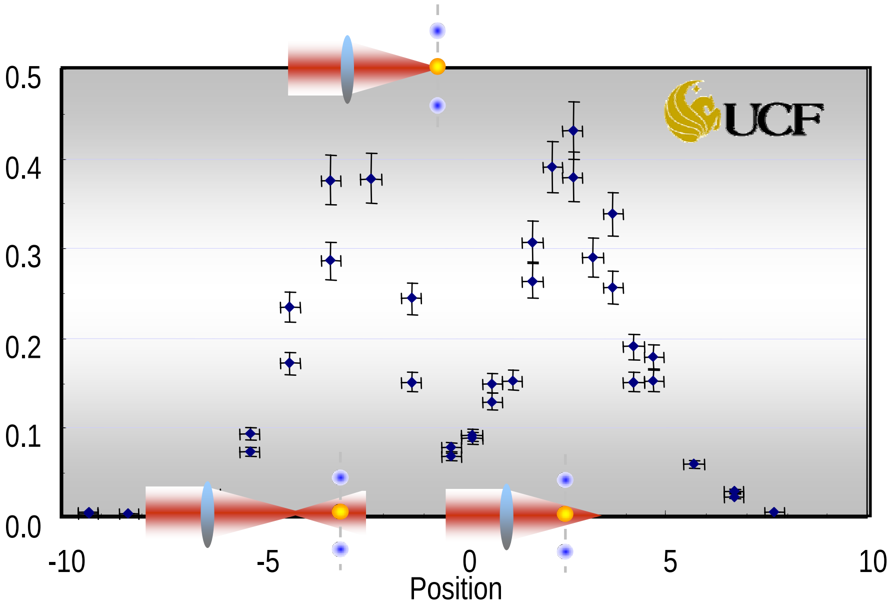
- Tin-droplet generator (sub-100µm)
- Active droplet steering
- Ultra-high-vacuum plasma chamber
- Debris mitigation
- System control software
- Full metrology suite

**CE ~ 0.5%, total power ~ 3W (into 2$\pi$ sr and 2%BW)**

# Tin and 351 nm laser is a low-CE combination



Lens position, a.u.



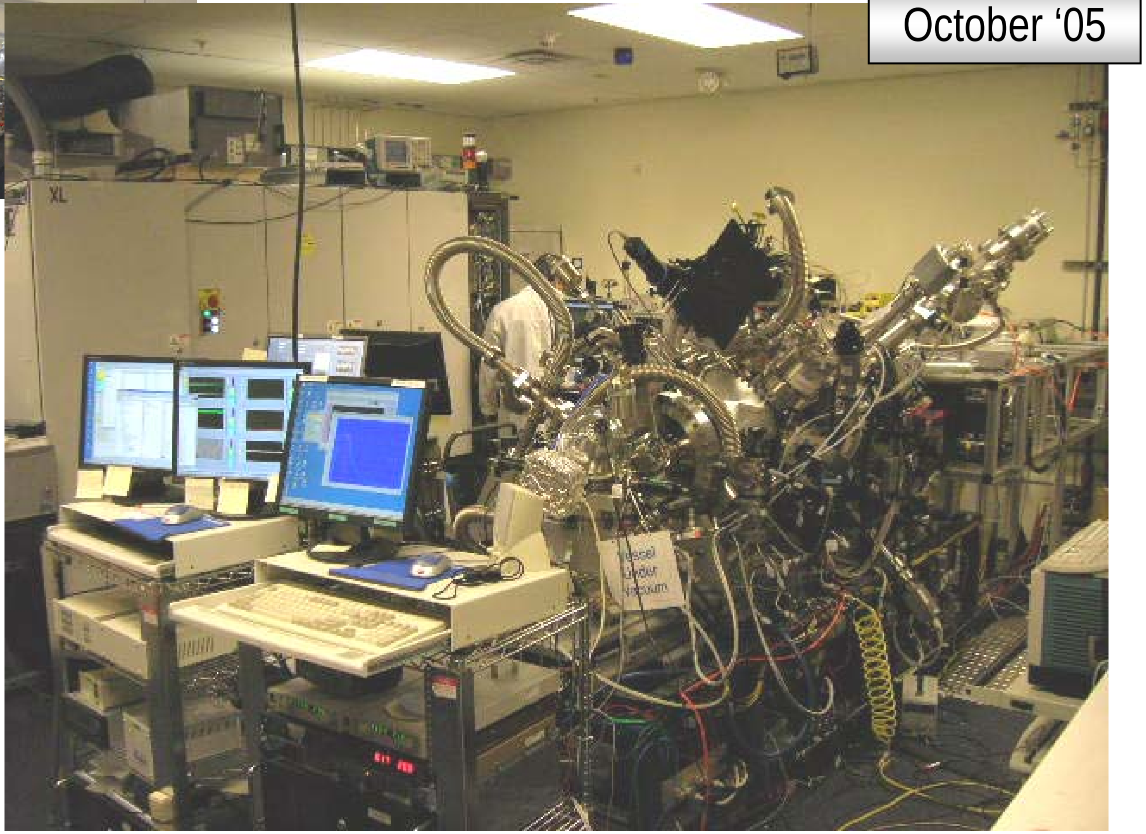
Tin-doped droplets and 355nm YAG*

- Sn droplets @ 355nm independently* shown to have ~0.5%-1.0% CE
- Sn and 351nm is a good R&D platform for system integration learning and component development

* Ref: M.Richardson, UCF

# Second LPP Development System

February ‘05

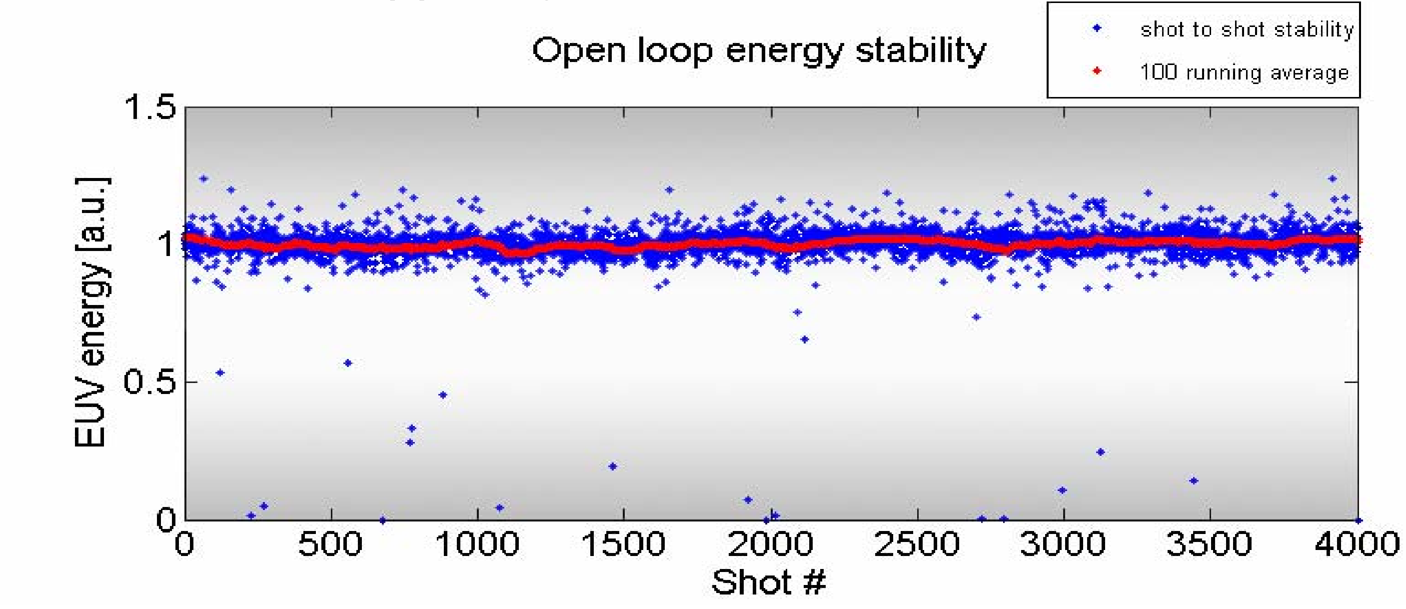


October ‘05

# Shot-to-Shot Energy Stability

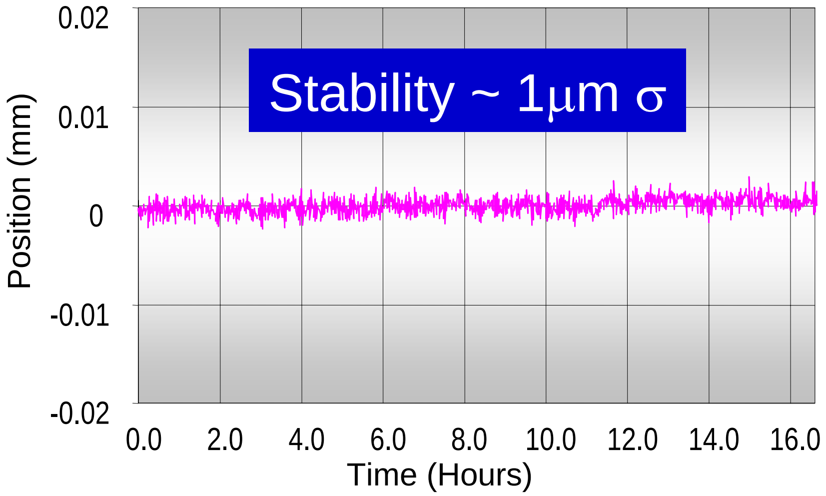
- Improved energy stability due to increased droplet stability and added control features.
- Closed loop energy control is not applied yet.

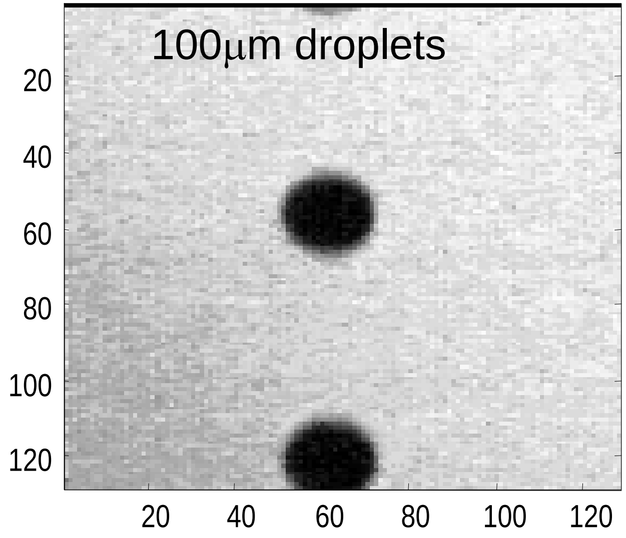
| Open loop energy stability | Nov 2005 | Feb 2005 |
|---|---|---|
| Shot to shot (1σ) | 7.6% | 17% |
| 100 runing average (1σ) | 1.2% | 11% |



# Sn Droplet Positional Stability with Active Control

**Vertical Position Stability at 32 kHz**

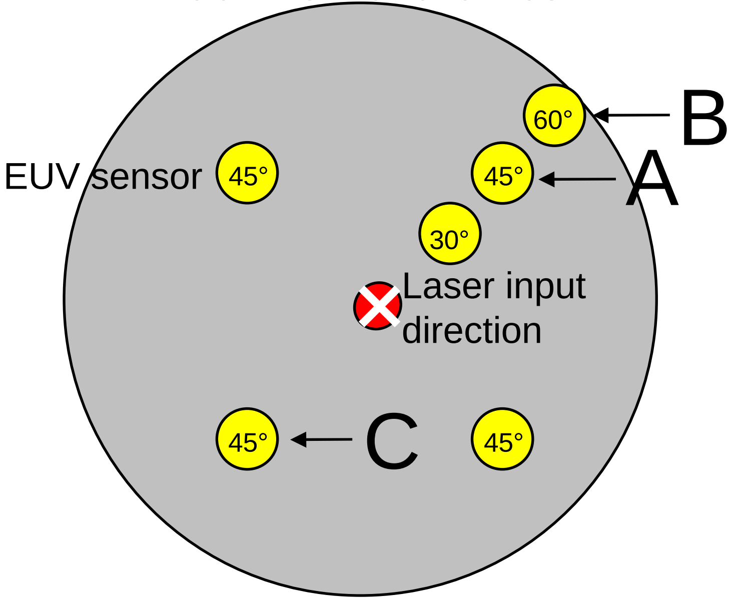




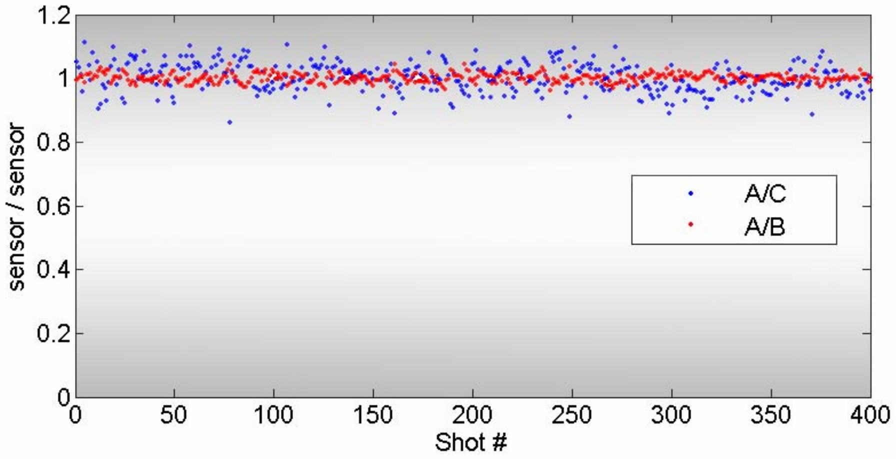
- Excellent vertical position stability achieved using active laser trigger control
- Latest lifetest of 9 hours delivered over 1B droplets using only 30% of available reservoir

# Angular Distribution of EUV Emission

- EUV energy sensors in several directions monitor the shot-to-shot angular distribution of EUV emission.
- The average emission distribution is uniform to within the absolute accuracy of EUV sensors.
- Relative shot to shot variation depend on sensor orientation.
- Correlation is better between adjacent sensors than opposite sensors

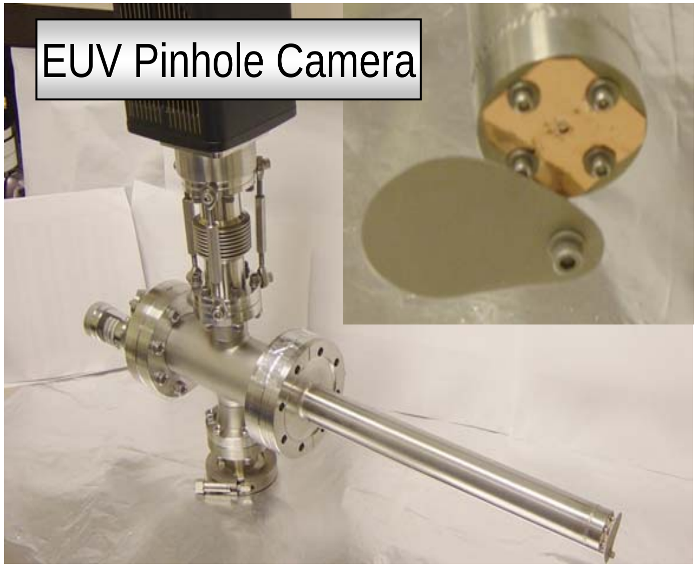


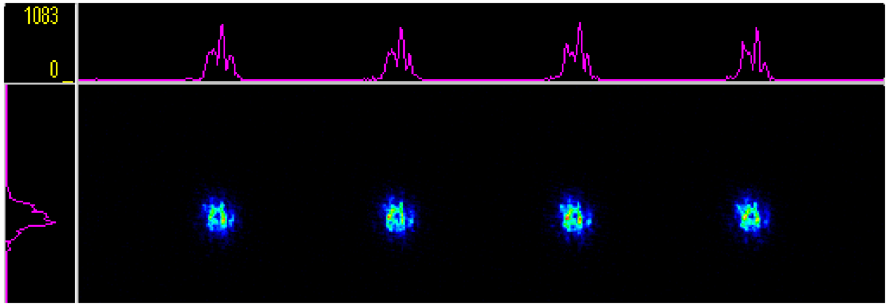
Back view of chamber



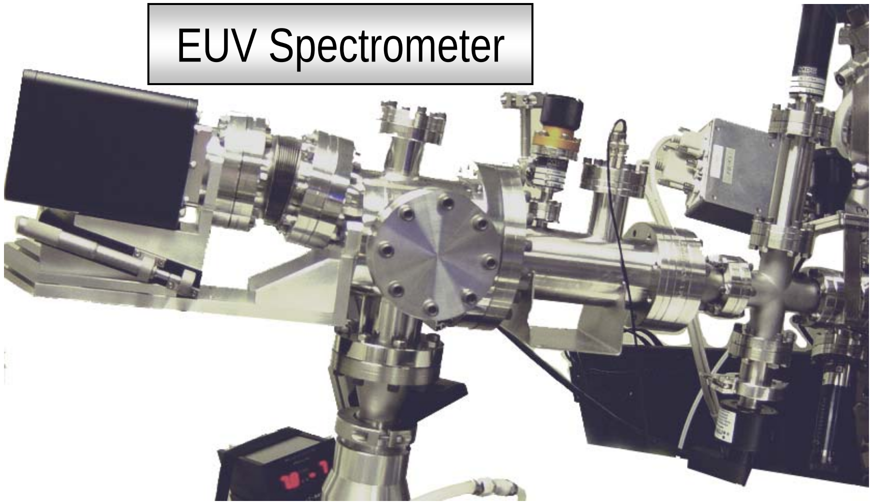
Sensor correlation

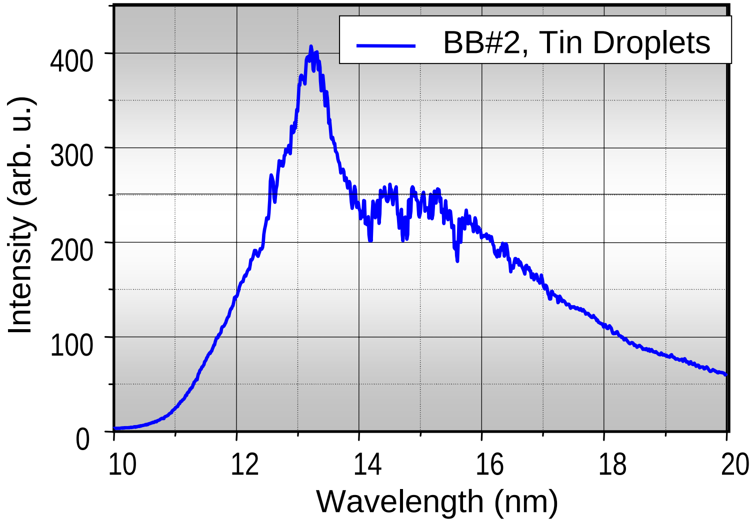
# Sn EUV Images and Spectra


EUV Pinhole Camera



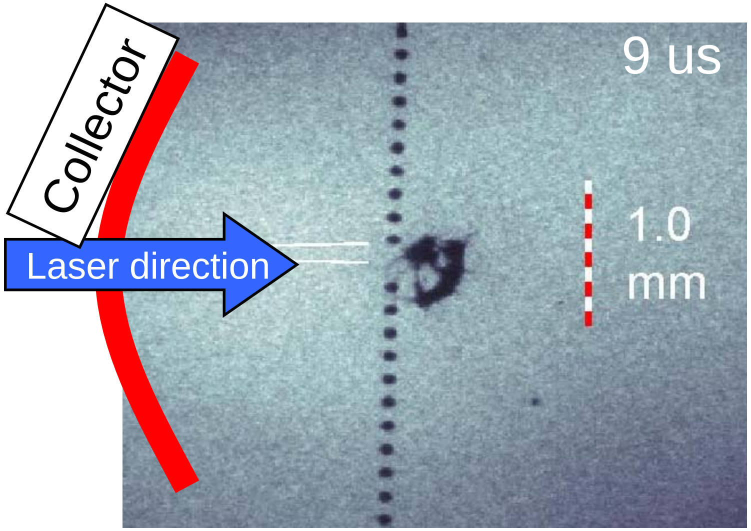
- Sequence of four consecutive EUV in-band source size images.
- Source size ~ 90 um FWHM (For 5sr collector Etendue < 0.1mm$^2$sr)

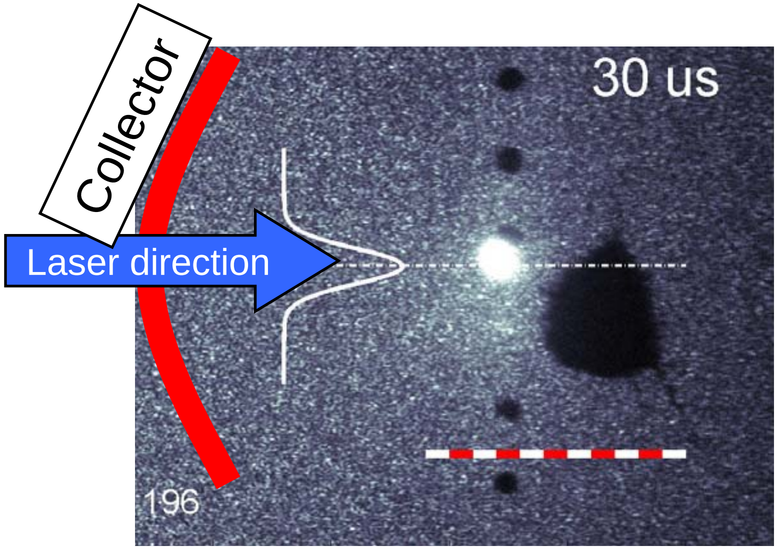

EUV Spectrometer



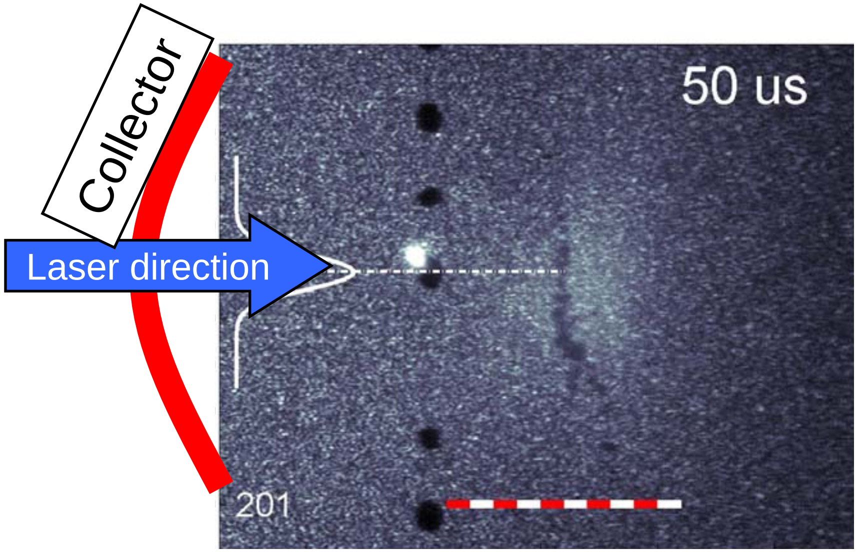
# Mirror Lifetime and Collector Integration

# Shadow imagery of Laser Interaction with Sn Droplets

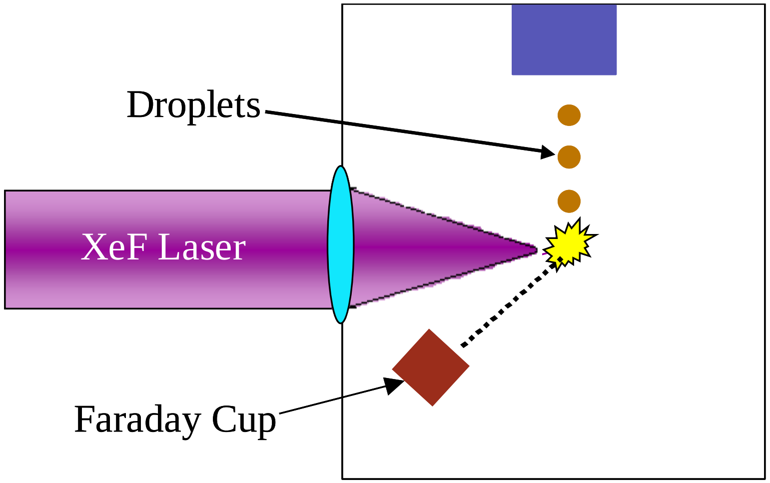


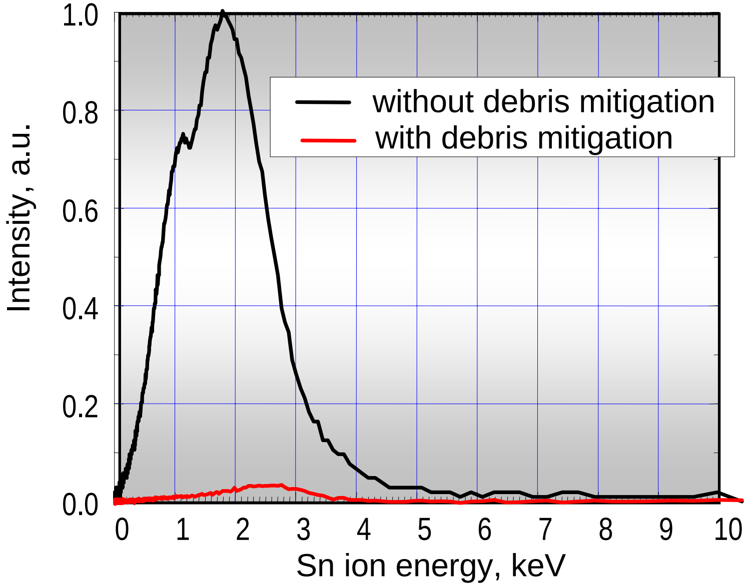


- Bulk of target material ejected away from collector
- Rep rates higher than 50kHz are possible



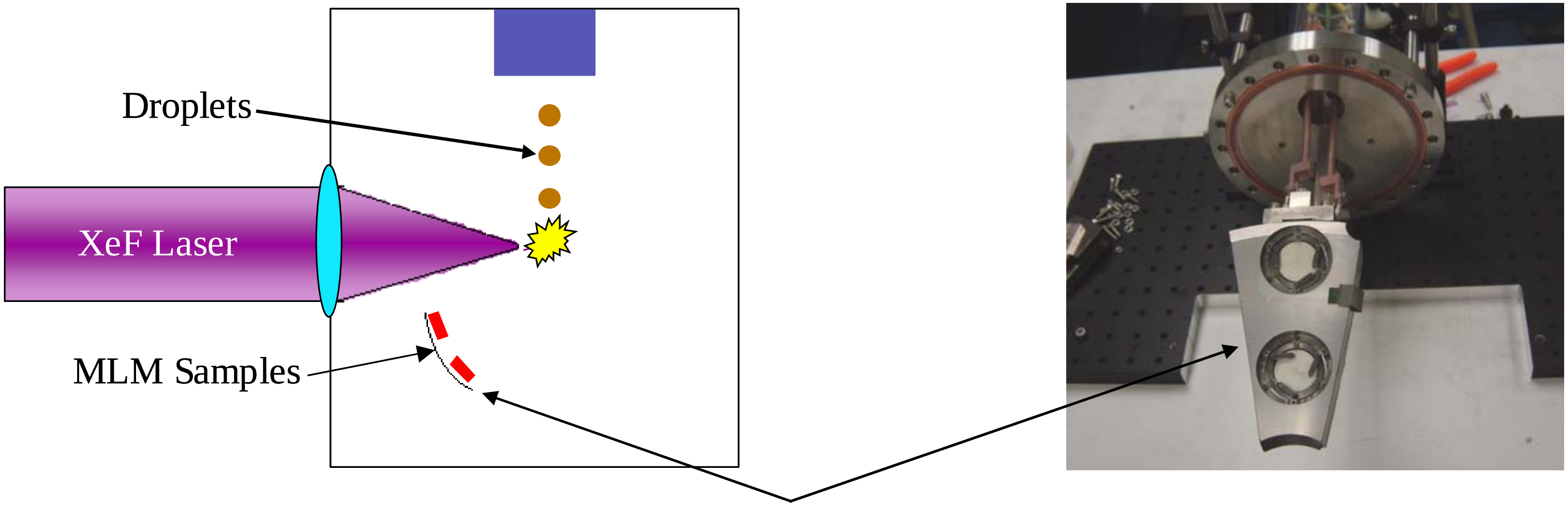
# Debris Mitigation Measurement with Faraday Cup





- ~100:1 reduction of effective Sn ion flux measured at the position of the collector with a single mitigation technique applied

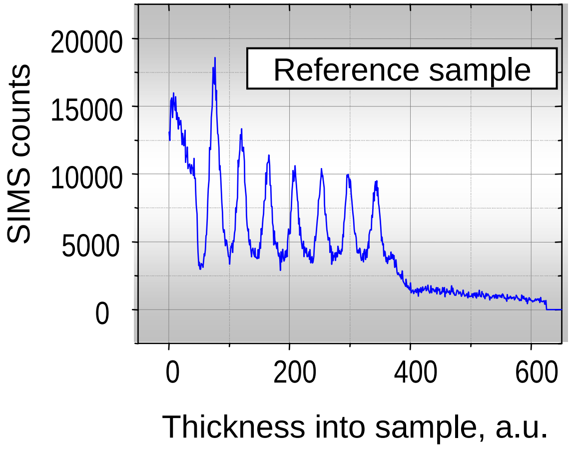
# Sn LPP Collector Life-test Setup

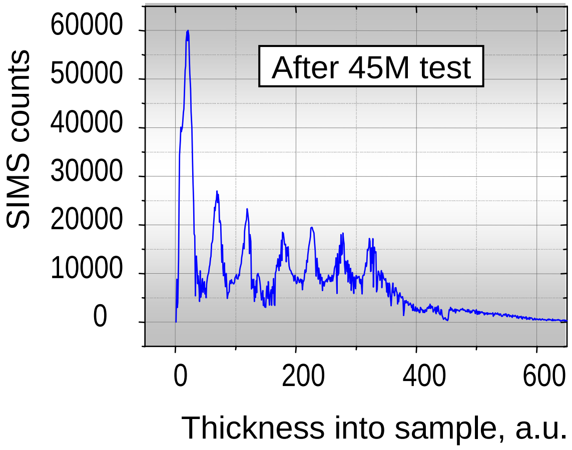


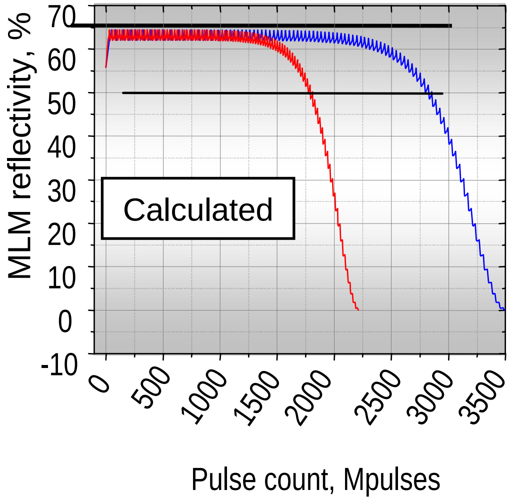
Collector segment in actual collector position

- Witness sample testing was performed prior to installing the collector
- Samples were placed at the same location as the collector surface
- Life-test utilized just one debris mitigation technique
- MLM samples exposed to Sn plasma (45 million pulses)

# Sn LPP Collector Life-test Results

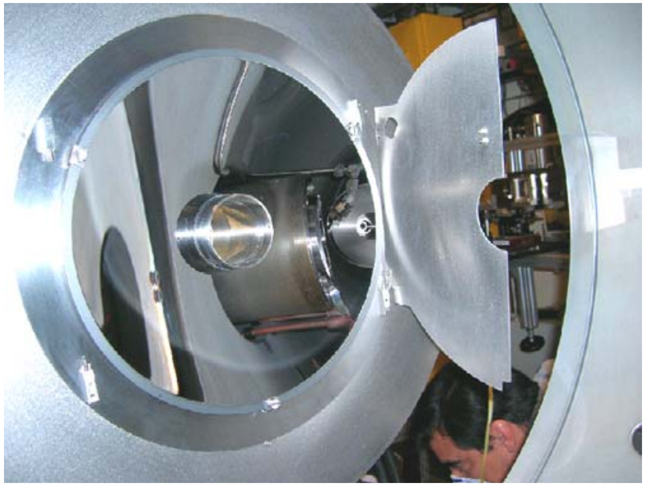


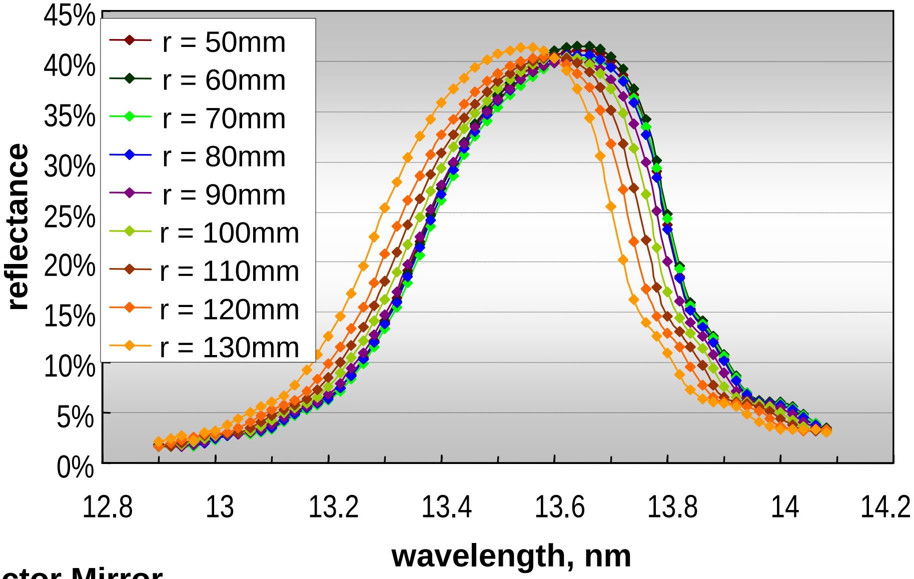




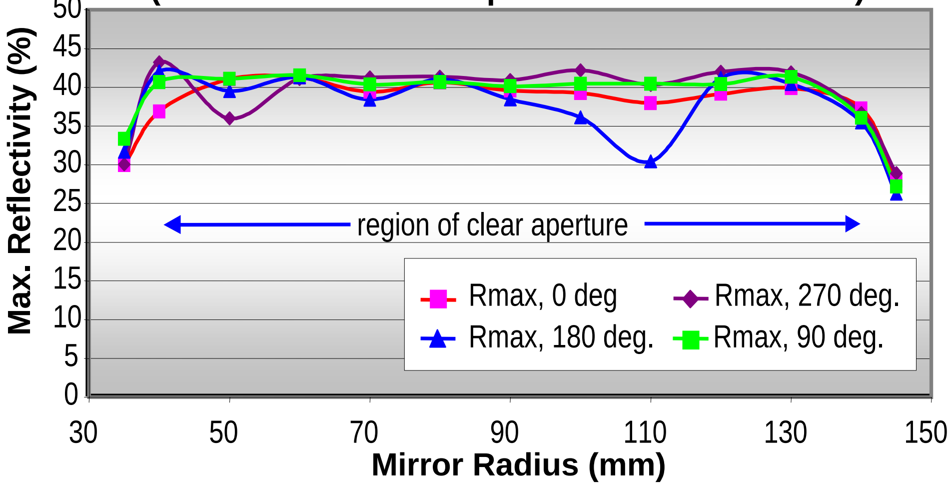
- Reflectivity measurements made by LBNL indicated no degradation
- SIMS analysis shows no Sn deposition on the mirror only one peak missing after >45 million pulses
- Projected lifetime 2 – 3 B pulses based on 10% reflectivity drop
- Combining with an additional debris mitigation technique and/or additional sacrificial layers yields expected lifetime of 45B pulses

# 320mm Diameter 1.6sr Elliptical Normal Incidence Collector with High Temperature Graded Multi-layer Coating





**Reflectometer Reflectivity Results for Collector Mirror (four lines with meas. points across the mirror)**



- First large mirror coated by deposition tool compatible with 5 sr collector
- Increased reflectivity expected through decreased surface roughness

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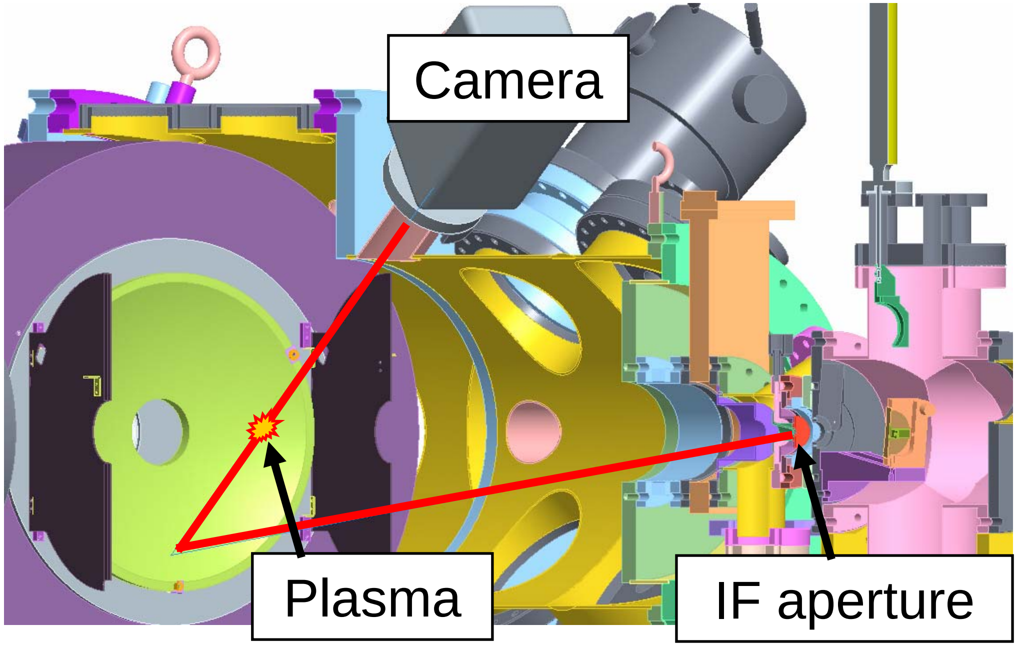
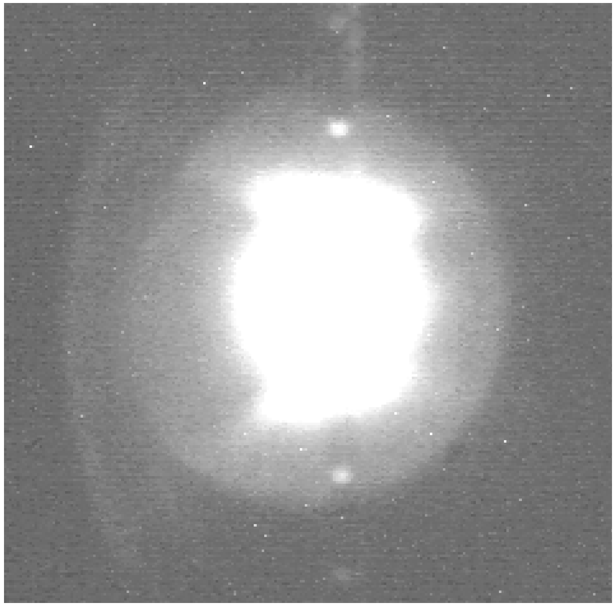
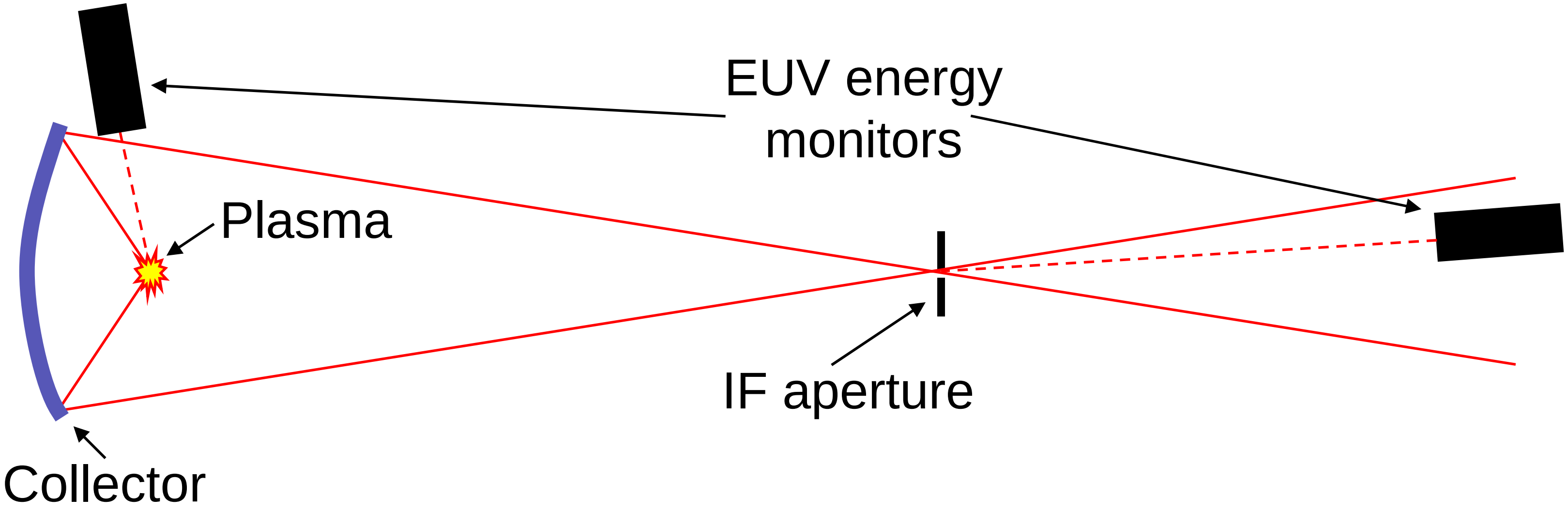
# 1.6sr Collector Successfully Installed and Aligned





Visible image of the plasma
aligned to the IF aperture

# Intermediate Focus Measurement: Correlation



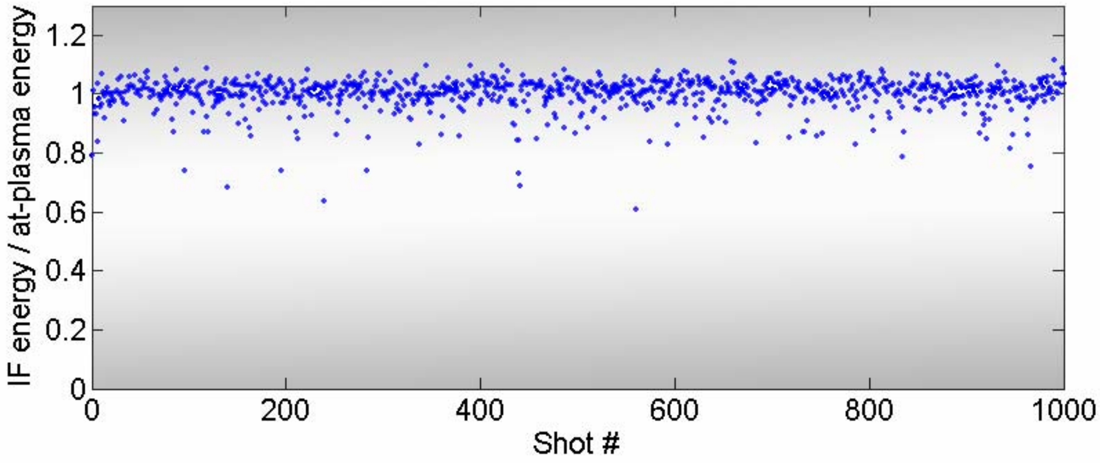
EUV energy monitors

Plasma

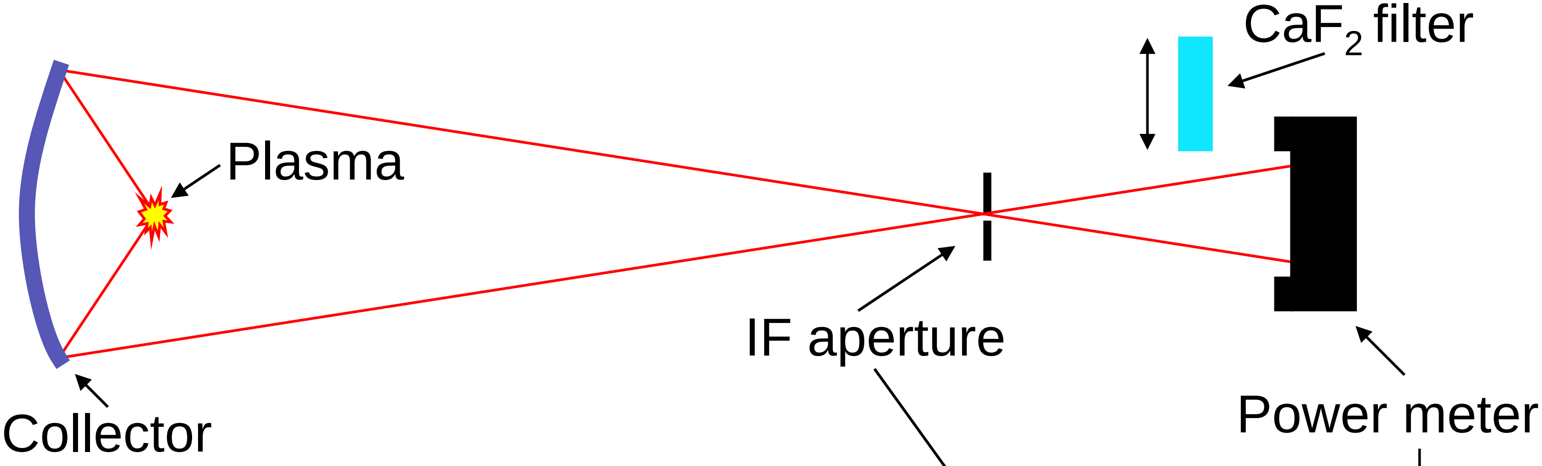
IF aperture

Collector

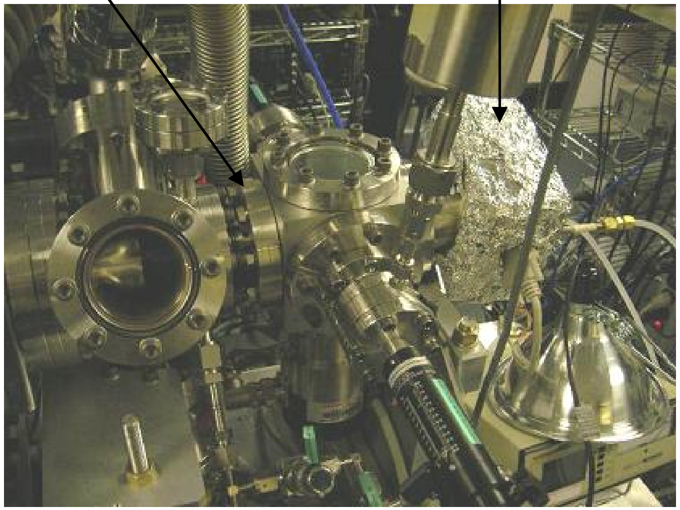
Correlation of pulse-to-pulse EUV energy at the IF and at plasma.



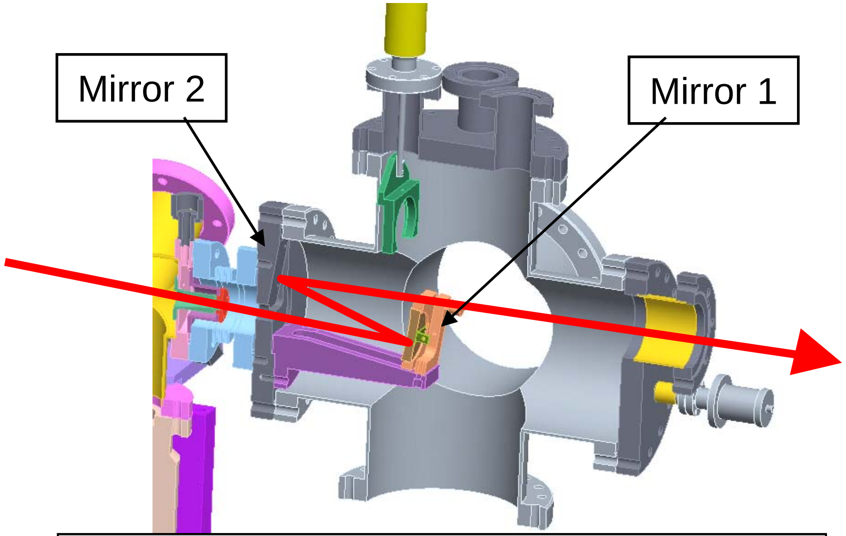
# Intermediate Focus Measurements: Power



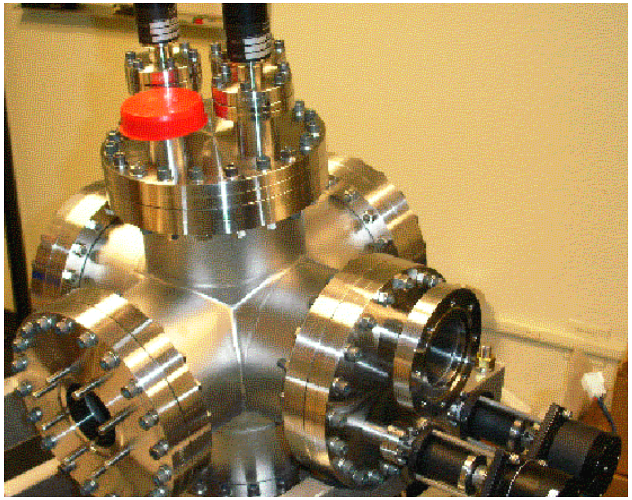
- First IF measurements using a calorimeter
- Measured power as expected from at-plasma measurements
- Measured EUV power at IF was 0.5W
- This corresponds to >1.5 W with a 5sr collector
- Out of band radiation >130 nm (CaF$_2$ filter) was <15% of total power



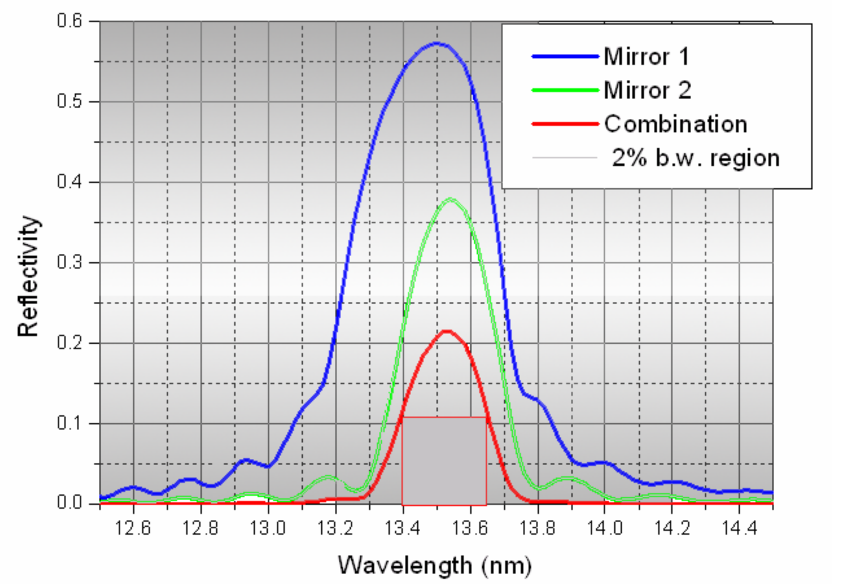
# IF Diagnostic Chamber for Source Characterization



2% BW Imaging or Power  Measurement



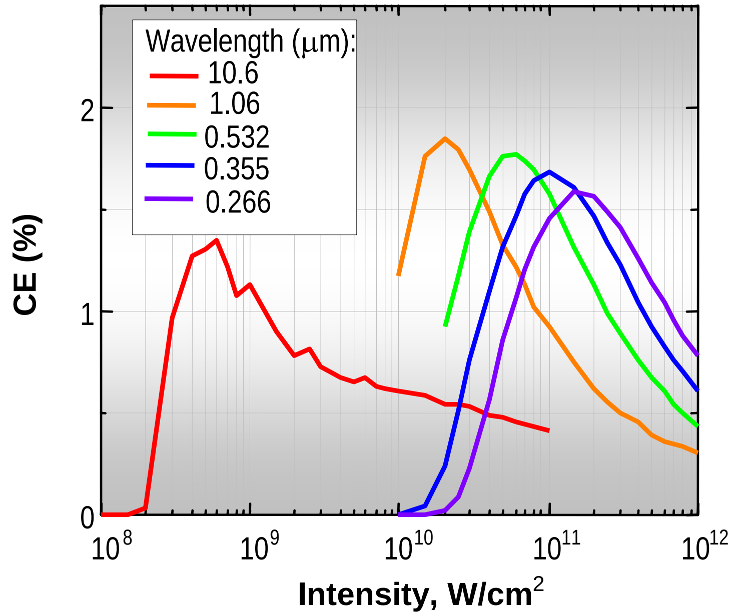
- Combined reflection from two mirrors provides ~2.0% bandwidth transmission
- EUV power-meter or EUV CCD camera can be used for detection



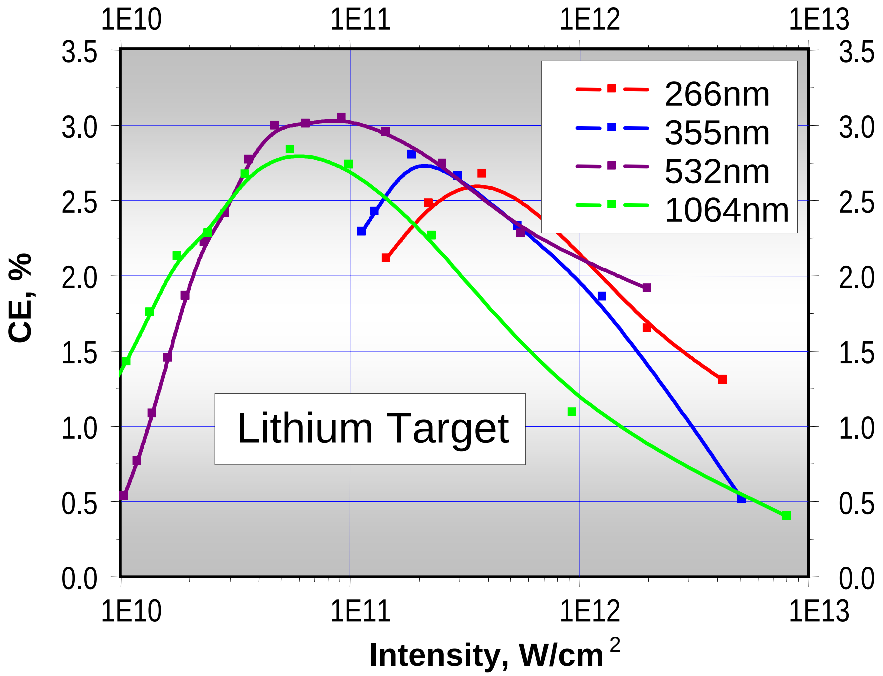
# HVM Options

# Modeled and Measured CE for Li

**Calculated Conversion Efficiency:**



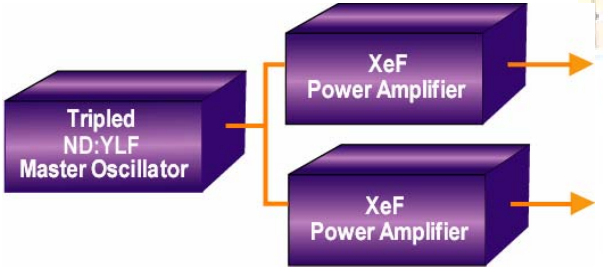
Modeled



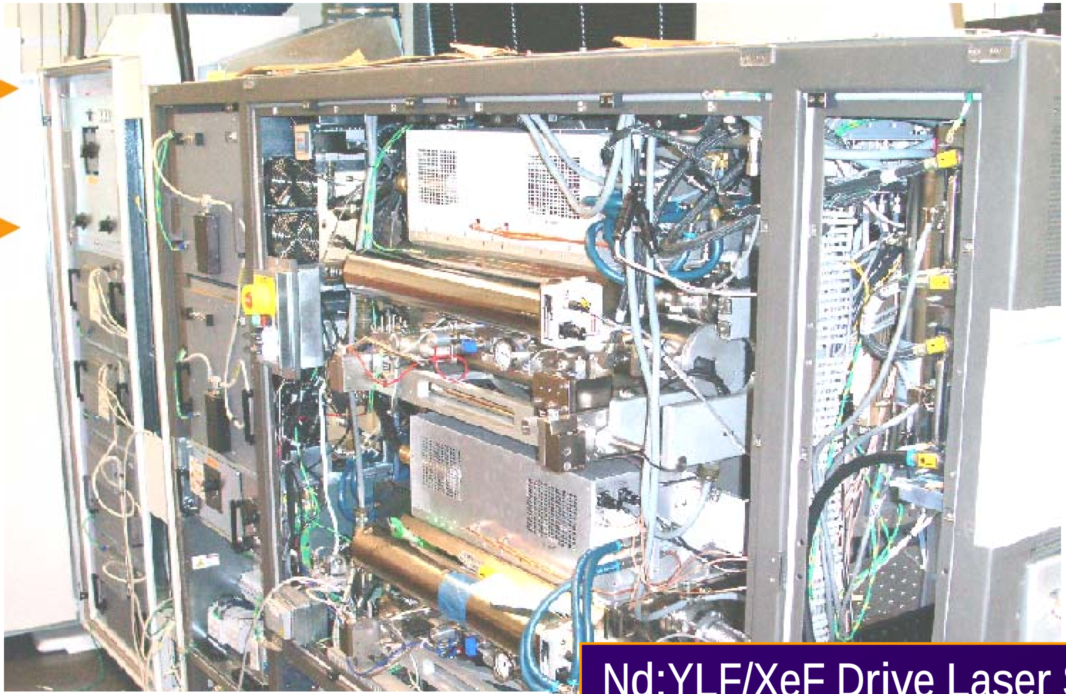
Measured

- Lithium continues to be one of the highest CE elements measured to date
- 266-1064nm drive laser can be used

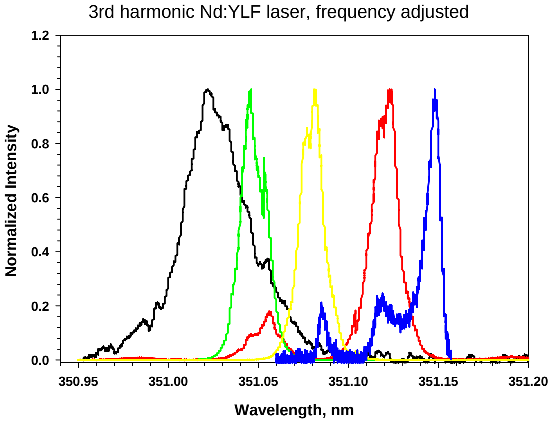
# Excimer Drive Laser Development



- Solid State MO provides required high beam quality
- XeF power amplifiers provide reliable pulse energy



**Tunable 12kHz Nd:YLF MO**

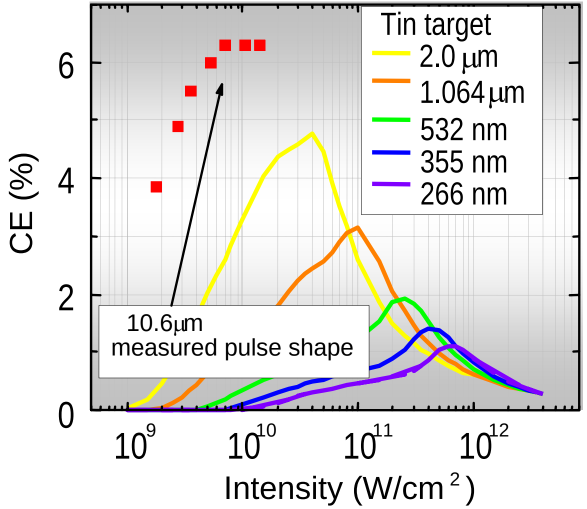


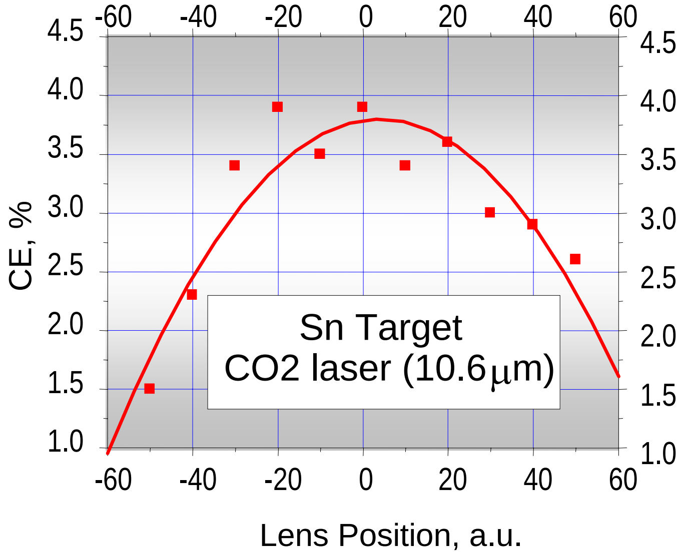
## Nd:YLF/XeF Drive Laser Spec.

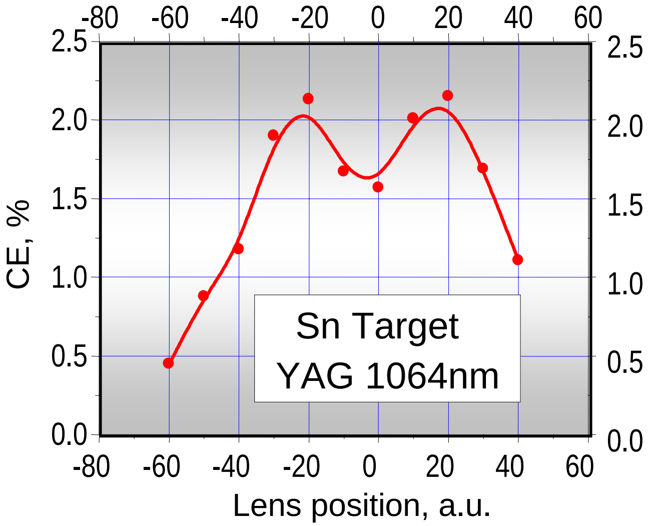
| | |
|---|---|
| Energy/pulse | 200mJ |
| Repetition Rate | 2×6000 Hz |
| Power | 2400 W |
| Beam Divergence | <150 uRad |
| Energy Stability (30pulse) | 1% |
| Efficiency | 3.5% |
| Pulse Length | <16ns |
| Pointing Stability | <25uRad |

# Modeled and Measured CE for Sn

**Calculated Conversion Efficiency: Sn Target**

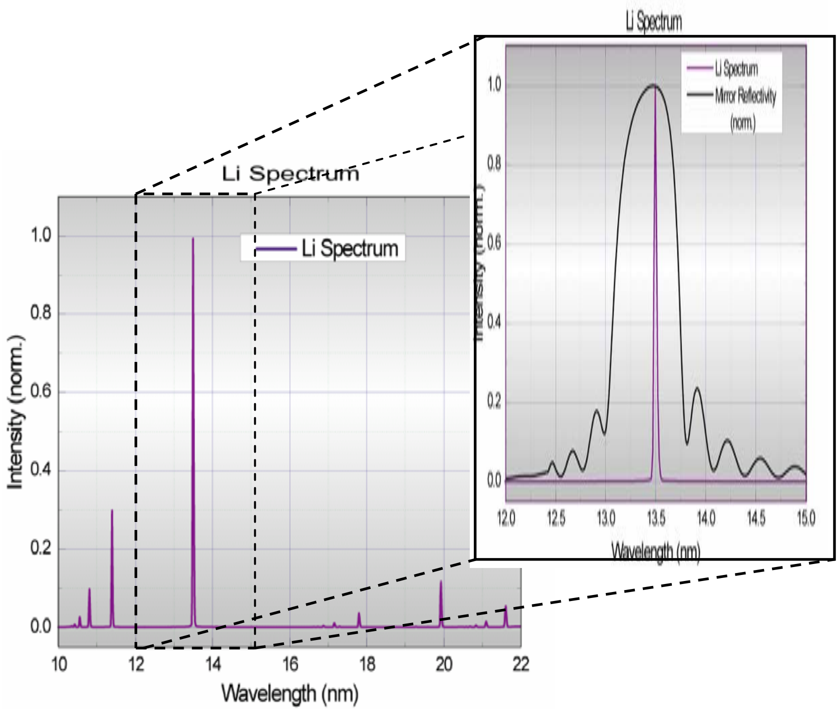


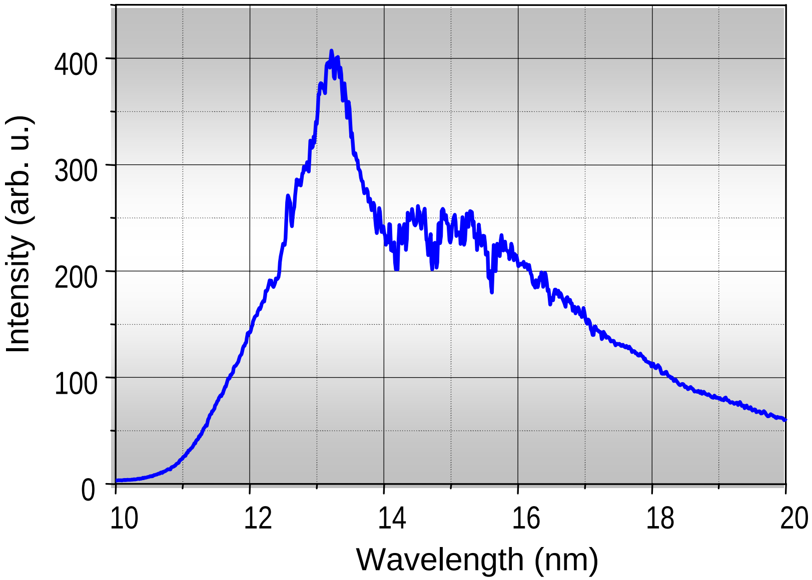




- Modeling suggests and measurement validate that Sn has even higher CE than Lithium at longer wavelengths
- With a collector lifetime solution Sn becomes a viable HVM source element

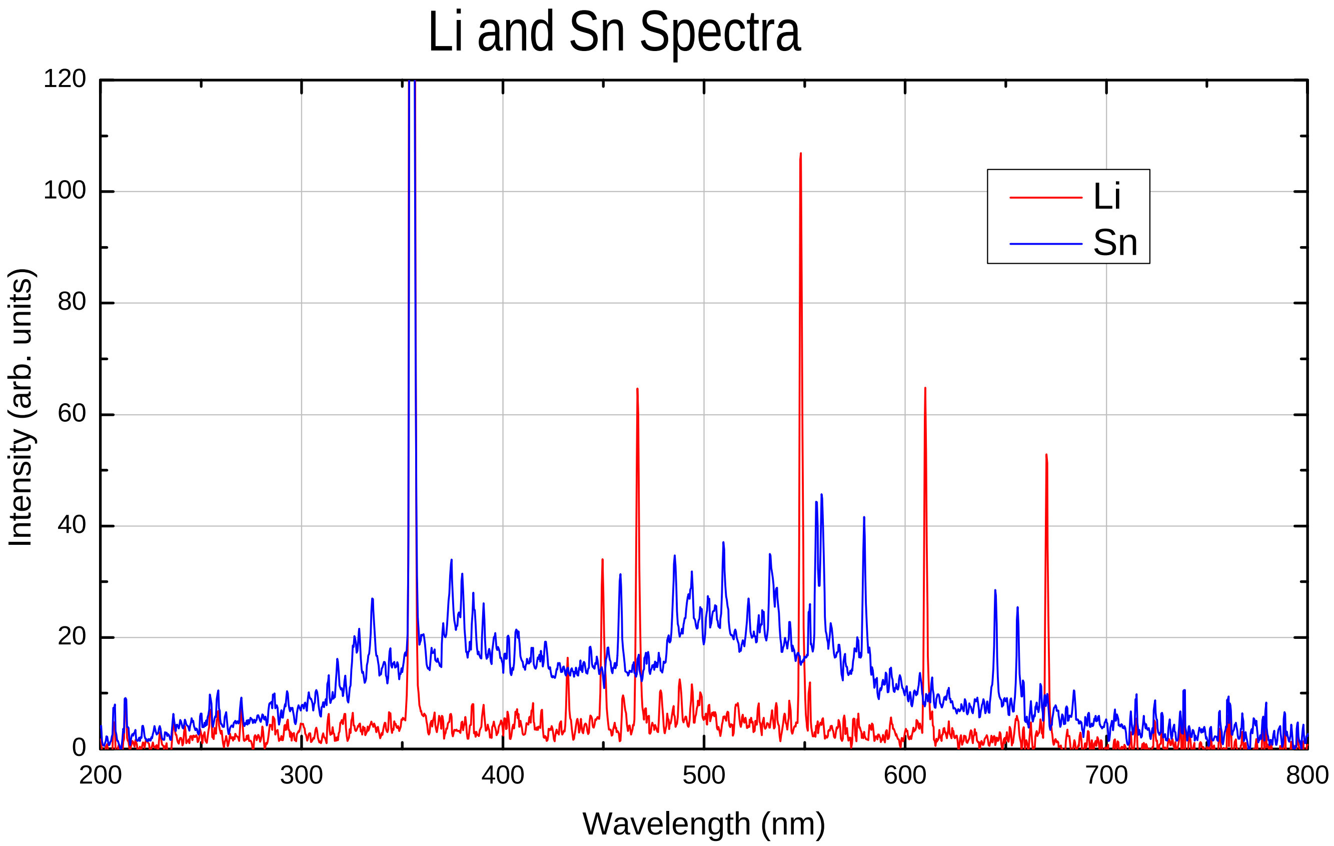
# Li / Sn EUV Spectra





- Li bandwidth << 2%. All power at max of mirror reflectivity
- Sn has significant energy outside 2% BW

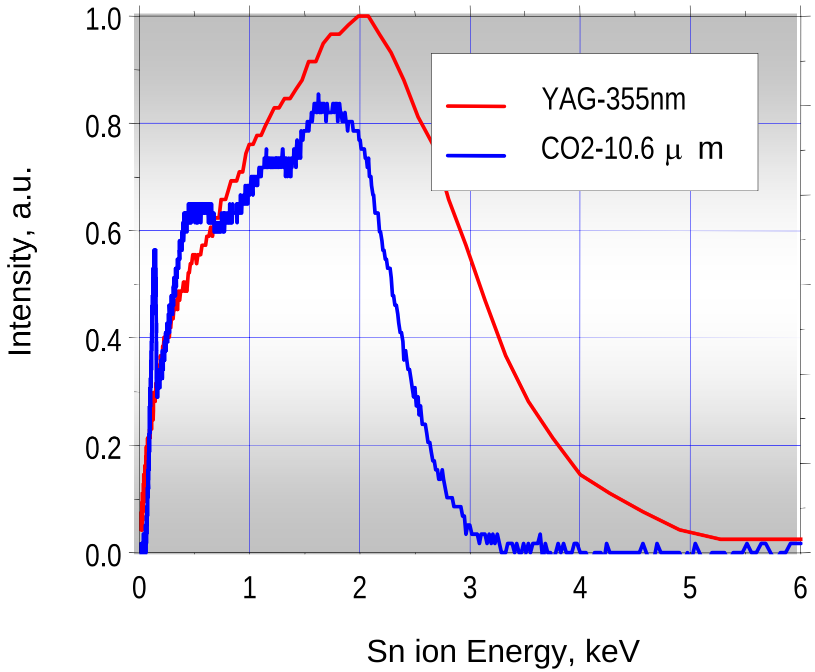
# Li / Sn Out-of-Band Spectra

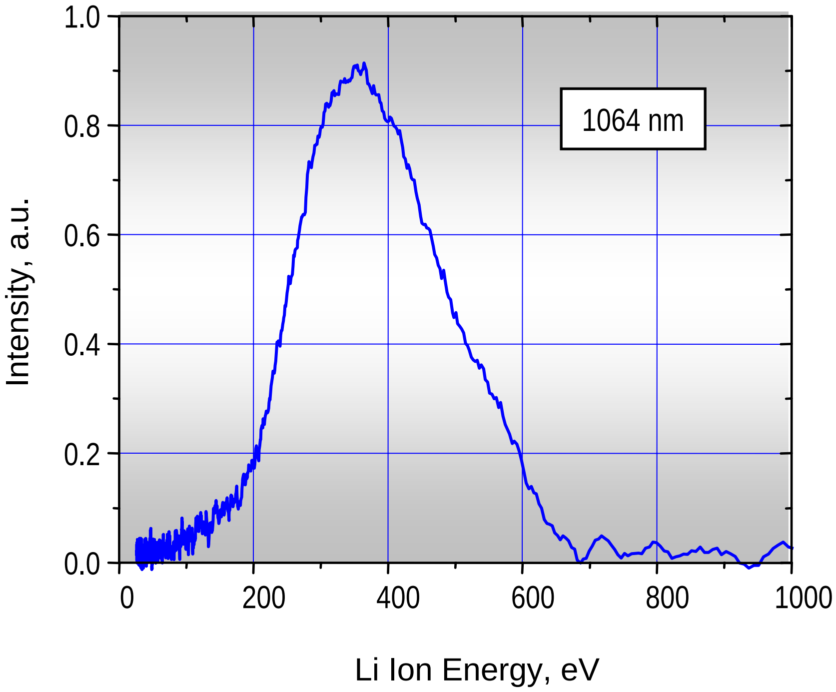


Li and Sn Spectra

- Li Produces Less Ultraviolet – Visible Out-of-Band Radiation than Sn

# Sn / Li Ion Energy Measurements





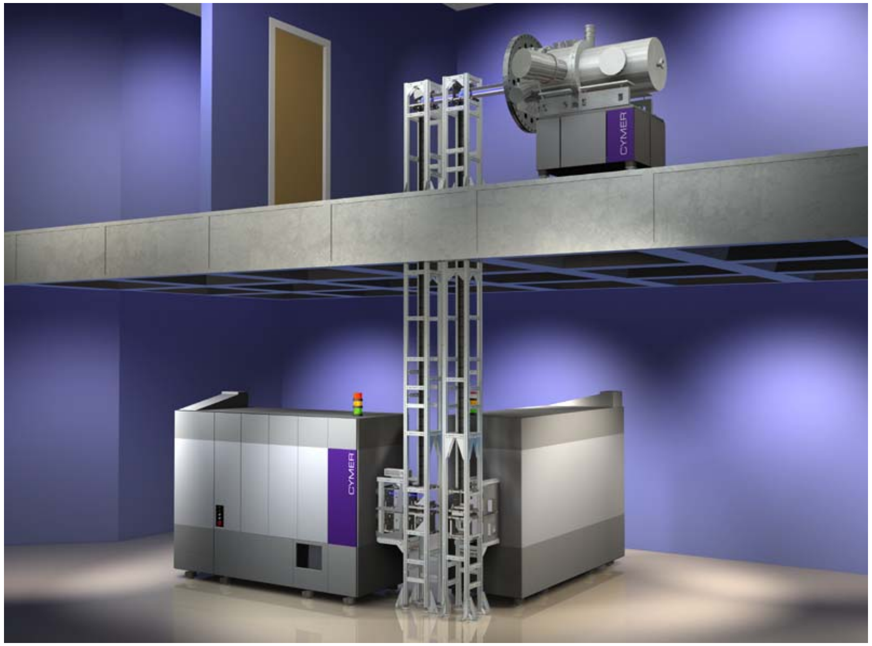
- Li has significantly lower ion energies than Sn

# Roadmap, Challenges, Conclusions

# EUV Source Challenges

Source Material/Delivery
CE
**Droplet stability**
Material purity

Collector
**Lifetime/Cost**
Manufacturability
**Debris Mitigation**
MLM Average Reflectivity
**MLM Thermal Stability**

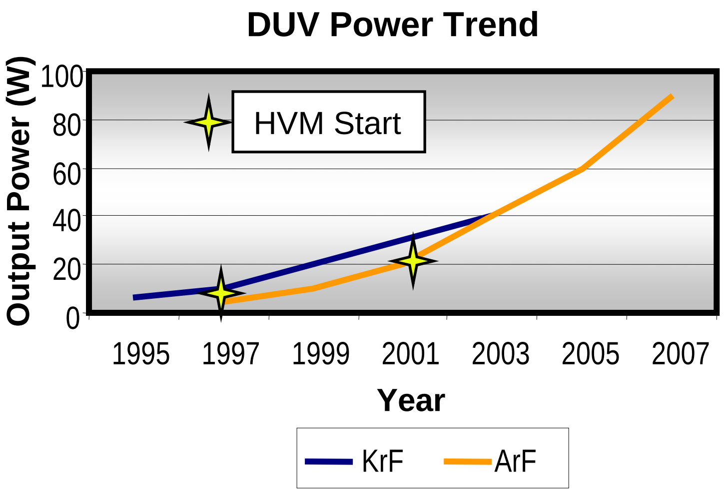


| Laser Type | λ (nm) | Power & effcy | Beam Quality | Optical Matls | Pulse width | Fab Exp. | System Cost | CoO | Resist sens. |
|---|---|---|---|---|---|---|---|---|---|
| XeF | 351 | 😐 | ☺ | 😐 | 😐 | 😐 | 😐 | 😐 | 😐 |
| DPSS | 1064 | ☺ | ☺ | ☺ | 😐 | ☹ | ☹ | ☹ | ☺ |
| $CO_2$ | 10.6 μm | ☺ | 😐 | 😐 | ☹ | ☹ | 😐 | ☺ | ☺ |

# Source Performance Roadmap to HVM and Beyond

| LPP EUV Source Performance Roadmap | | | |
|---|---|---|---|
| | **Gen 1** | **Gen 2** | **Gen 3** |
| Total Rep Rate (kHz) | 48 | 60 | 72 |
| **Laser power (kW)** | **9.6** | **12.0** | **14.4** |
| In-band CE | 3.5% | 4.0% | 4.5% |
| Geometric collection effy (sr) | 5 | 5 | 5.5 |
| Collector average reflectivity | 50% | 50% | 50% |
| Optical transmission | 80% | 82% | 84% |
| **Total power at IF (W)** | **110** | **155** | **230** |

- Cymer is committed to commercializing an HVM EUV light source
- Laser Produced Plasma (LPP) technology is the most viable HVM EUV source solution
  - Due to flexibility and scalability of power
- Cymer is targeting the most feasible and cost effective LPP technology solutions
  - Excimer & Li, Solid State & Sn or Li, or $CO_2$ & Sn



# Acknowledgements

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und Feinmechanik
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- Prism Computational Sciences
  - Joseph J. MacFarlane and Igor Golovkin
- Lawrence Berkeley National Laboratory
  - Eric Gullikson, Franklin Dollar
- University of Central Florida
  - Martin Richardson

Cymer Poster Presentations

- “LPP EUV Source System for HVM Requirements” - Poster Session 2
- “Measurements of EUV at Intermediate Focus” - EUV Source Workshop

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