Laser-Produced Plasma EUV Source Program

Cutting Edge Optronics

Northrop Grumman Space Technology

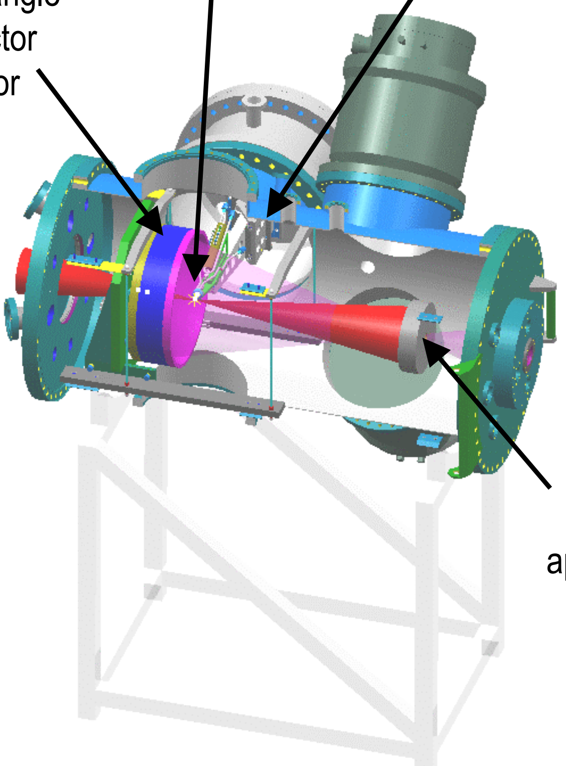
ISMT EUV Source Workshop

23 February 2003

- Technology overview
- Progress summary
- Technology improvements
- EUV source performance
- Optics lifetime and debris mitigation
- Roadmap
- Development

CEO Developing High-Power EUV Source Products

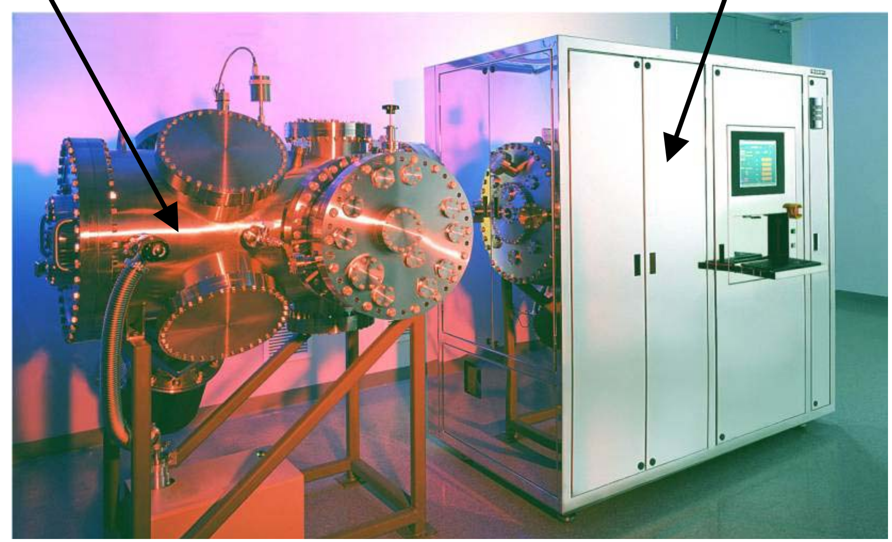
CUTTING EDGE OPTRONICS
NORTHROP GRUMMAN
EUV



EUV source in test chamber

CEO LPP is the highest power, cleanest source

- **Scalable with high-power lasers**
- **Small etendue, even with large-angle collection**
- **Low debris from isolated plasma**
- **Clean spectrum demonstrated**



EUV source at CEO

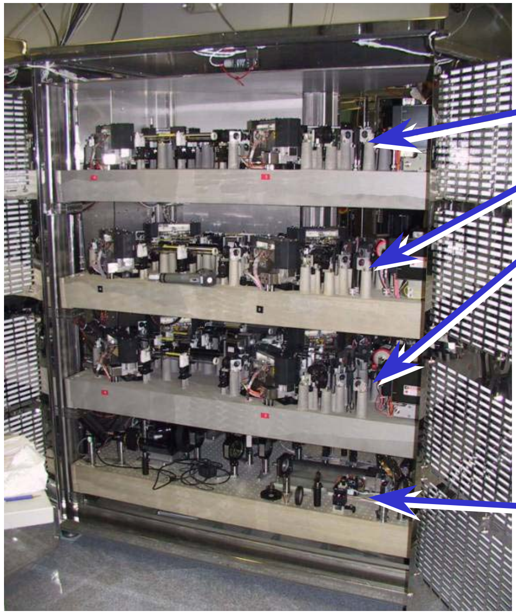
Unprecedented Progress in EUV Production

New data: increased conversion efficiency at multi-kilowatt laser power

	Mar 2002	Oct 2002	**Today**
EUV power (2% BW) **At source, 2π ster** **At output focus interface**	2 W 1 W	12 W 5 W	**22 W** **9.4 W**
Conversion efficiency, including anisotropy	0.3%	0.5%	**0.87%**
Laser pump power	1500 W	2475 W	**2475 W**
Laser repetition rate	2500 Hz	5000 Hz	**5000 Hz**
Dose stability (50-shot ave, open loop)	5%, 1σ	3%, 1σ	**1.6%, 1σ**

High-Power Beta Source Laser Integrated at CEO

- All three modules installed; capable of 4500 W full power
- High pulse rate of 7500 Hz allows better dose control
- Modular design easier to manufacture and maintain, and reduces cost
- Improved over ETS Alpha laser: twice as efficient at less than two-thirds the footprint

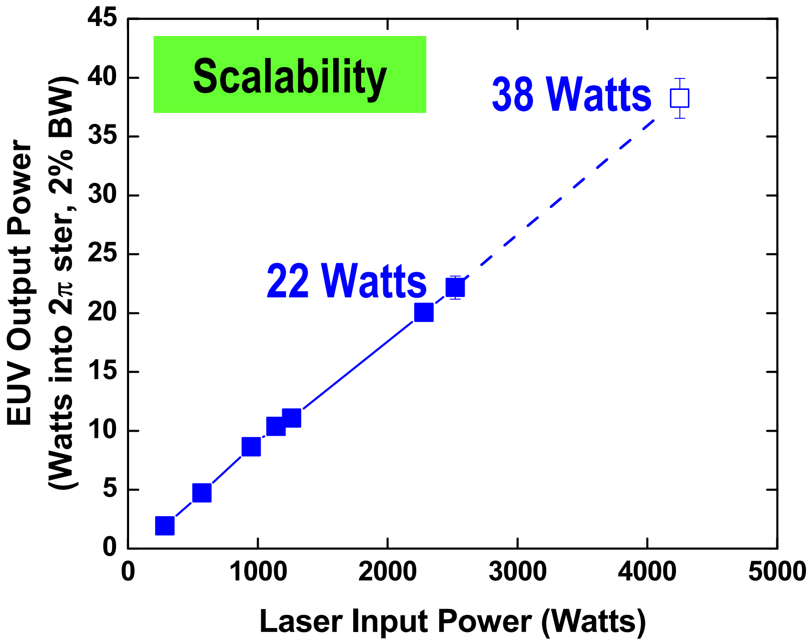


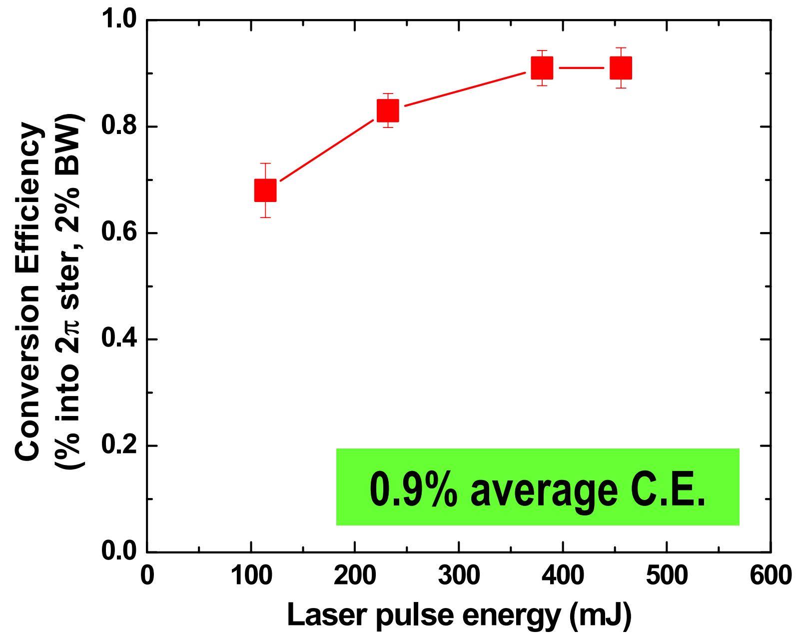
All three 1500 W modules installed

Pointing control & health monitors

Beta laser used in EUV testing

High EUV Power Achieved Using Beta Laser



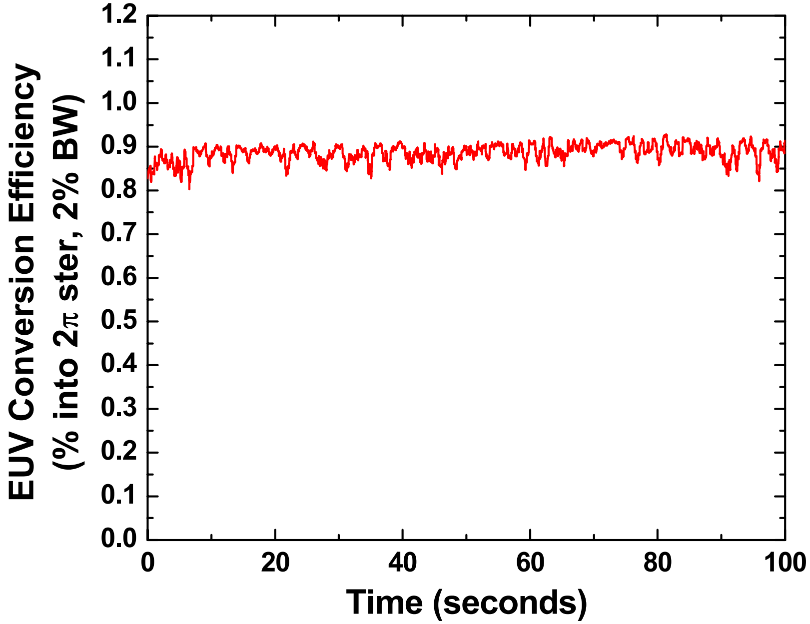


- **Condensed Xe target tested with 2 of 3 laser modules (2500 Watts)**
  - 3-module testing currently underway
  - Expect to generate 38 W of EUV
- **High power, uniform EUV output**
- **No efficiency droop at high power**

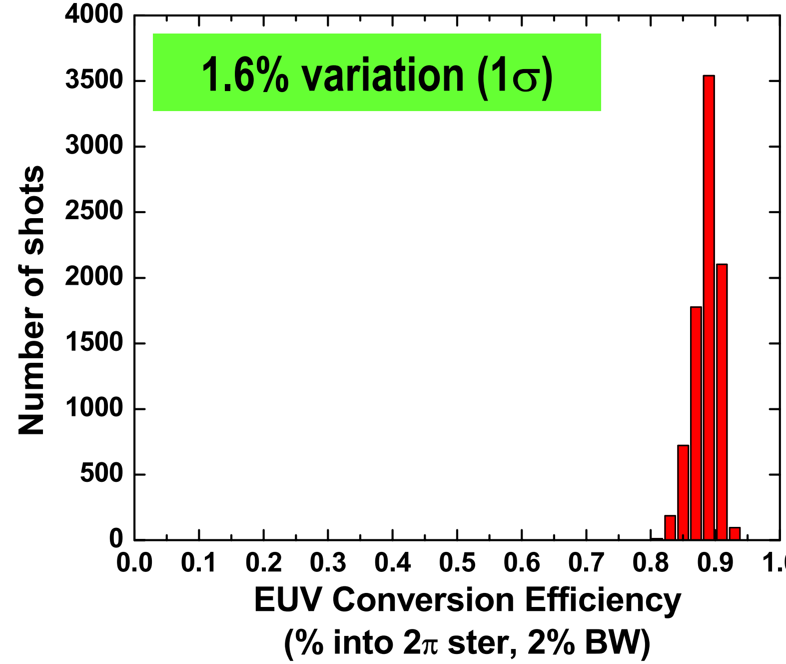
- **High C.E. values result from:**
  - Xenon target optimization
  - Pulse formatting techniques
- **High efficiency includes any anisotropy**
- **Trend shows efficiency increases with pulse energy**

EUV Output Has High Stability

Nearly isotropic, stable EUV dose

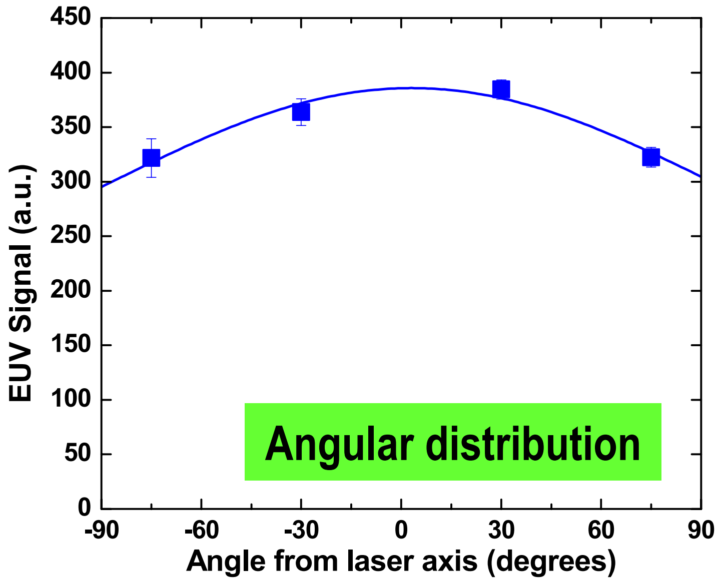


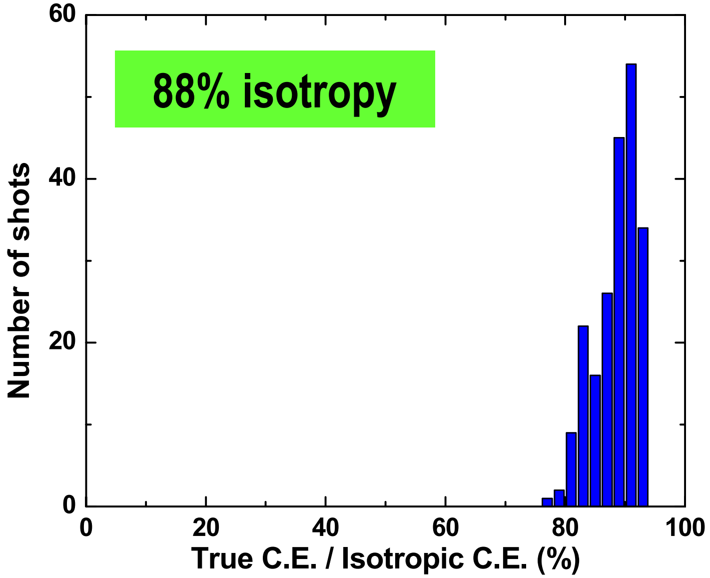
EUV dose variation



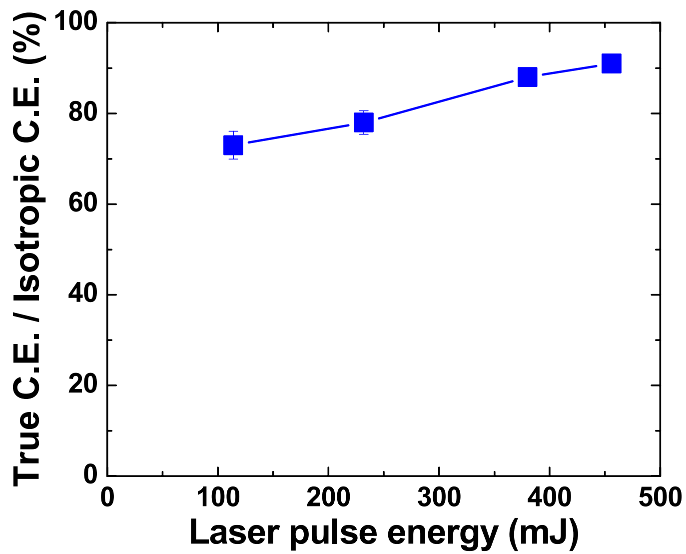
- **Sample shown is hands-free dose stability, 50-shot running average**
- **Automatic laser alignment will improve stability — demonstrated successfully on ETS**

EUV Distribution Supports Large Collection Angles

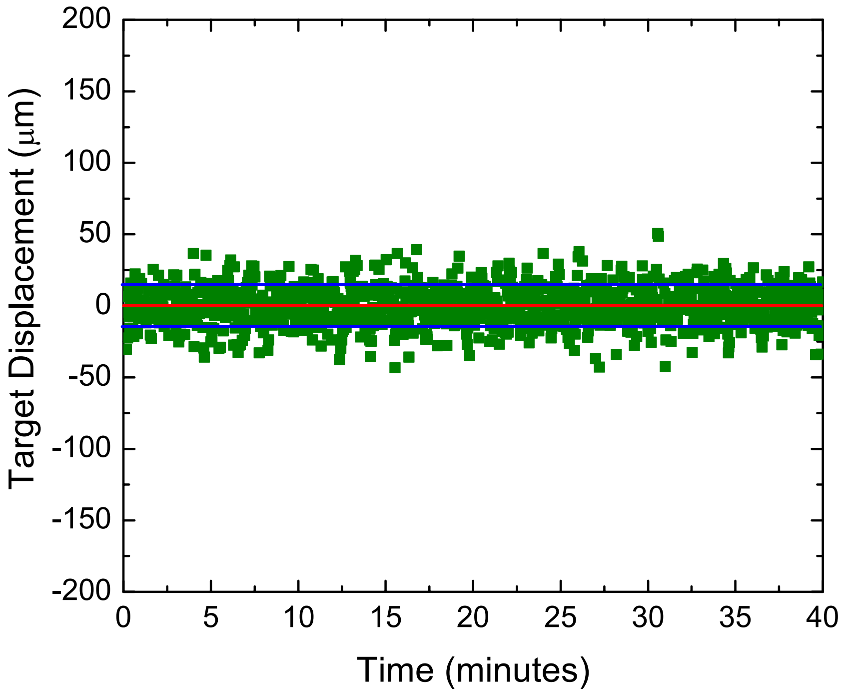




- **EUV angular distribution is nearly isotropic**
  - Isotropy the same in both vertical and horizontal planes
- **Emission uniformity improves with higher laser pulse energy**



Condensed Xenon Target Shows Improved Stability



Target has 10 μm spatial stability (1σ)

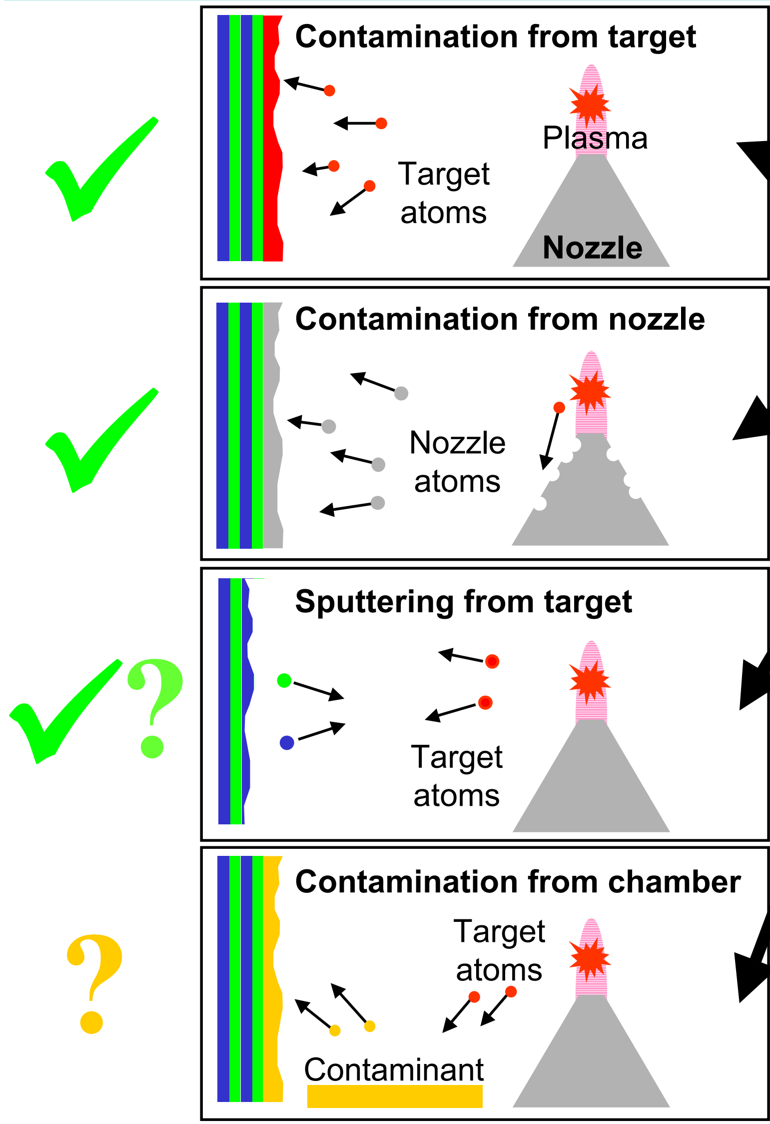
- **Xenon target has good positional stability over long time periods**
- **Target hardware now stands clear of the collector optic**
  - No contamination from nozzle
  - No obscuration of collector
  - Extends life and increases reliability of hardware
- **Closed loop control will further improve stability**

CEO LPP Meeting Beta Requirements

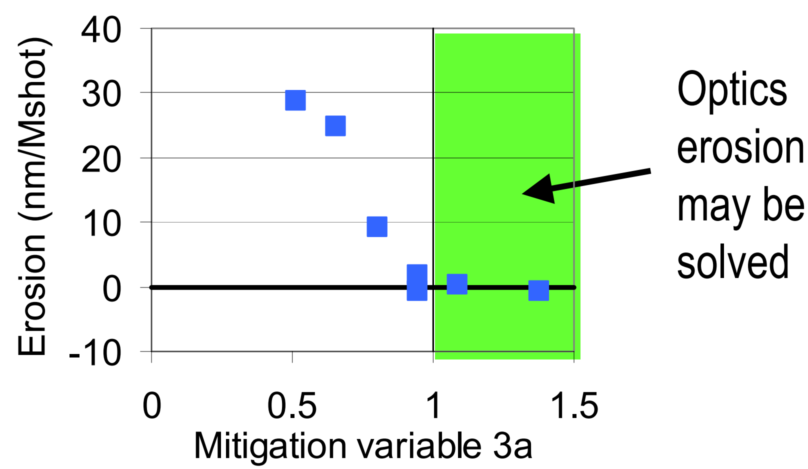
	Oct-02	Today	Imminent	To come		
Laser power at target (W)	2475	2475	4250	12000	16000	16000
Peak efficiency, on-axis	0.6%	1.0%	1.0%	1.2%	1.2%	2.2%
Isotropy (%)	84%	88%	90%	90%	90%	90%
Net efficiency, 2% BW, into 2π	0.5%	0.87%	0.9%	1.1%	1.1%	2.0%
EUV power into 2π	**12**	**22**	**38**	**130**	**173**	**317**
Collection angle (sr)	5.0	5.0	5.0	5.0	5.0	5.0
Optical transmission	55%	55%	55%	55%	55%	49%
EUV at output focus (W)	**5.4**	**9.4**	**17**	**57**	**76**	**123**

- **Laser and xenon target improvements will facilitate higher EUV power**
- **LPP provides a path to meeting future EUV power requirements**
- **Non-xenon targets lead to even higher power**

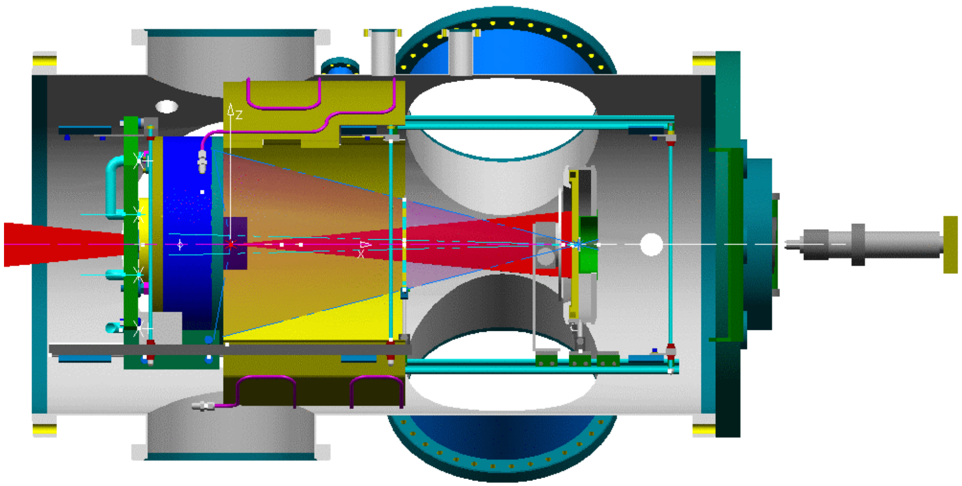
Identifying Optics Life Limiters and Their Mitigation

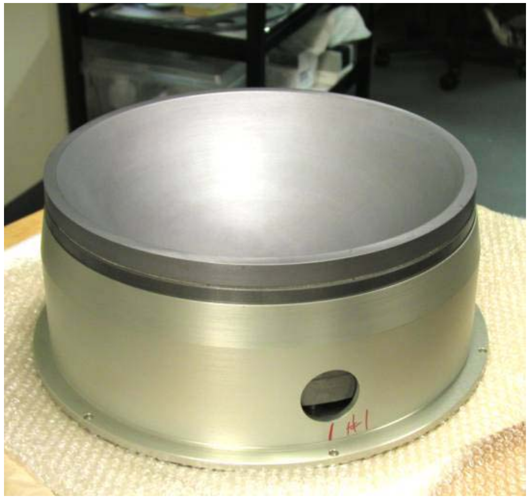


- High power laser and high CE target at hand — now focusing on optics life at high power
- No contamination from gaseous xenon
- No contamination from nozzle hardware — eliminated using large plasma separation
- Tests indicating optics erosion near a solution
- Optics contamination control subject to requirements on chemical environment

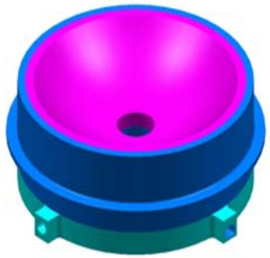


High-Efficiency Collector Mirror To Be Integrated





- **Optic provides learning for source optimization**
  - Measure source effects on optic life — simulates tool environment
  - Integrated EUV at interface — power, spectrum, distribution
  - Qualification of large NA mirror fabrication, coating, and refurbishment
- **Mirror has been fabricated and is now in final polish**
- **Optic to be integrated in EUV test chamber in mid-2003**



Design based on high power cooled optics experience

EUV Source Development Roadmap

Metrics	Oct-01	Mar-02	Oct-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Mar-08
Central wavelength (nm)	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Demonstrated collectable EUV power in 2% spectral bandwidth into 2π (W)	1.2	4	13	22	49	49	89	238	317
Available collection solid angle (sr)	2π	5	5	5	5	5	5	5	5
Source emission area (mm^2)	0.125	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
Etendue ($mm^2 str$)	0.79	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Demonstrated maximum repetition rate (kHz)	5	5	5	5	7.5	7.5	13	13	13
Demonstrated steady state repetition rate (kHz)	5	5	5	5	7.5	7.5	13	13	13
Dissipated total power in source region (at steady state) (kW)	1.3	1.5	1.5	4.5	4.5	4.5	12	12	16
Source-facing condenser lifetime (# of pulses to 10% reflectance loss)	3×10^{8}	3×10^{9}	10^{10}	TBD*	10^{11}	10^{11}	10^{11}	10^{11}	10^{11}
Pulse to pulse spatial stability (μm 3σ)	30	30	30	30**	10	10	10	10	10
Pulse to pulse intensity stability (3σ)	15%	15%	15%	5%**	2%	2%	2%	2%	2%
Pulse to pulse angular stability (3σ)	15%	9%	<9%	<9%**	1%	1%	1%	1%	1%
Pulse to pulse pointing stability (3σ)	TBD								
Key risk areas	nozzle, diodes	nozzle, diodes	diodes, optic	diodes, optic	diodes, optic	diodes, optic	diodes, optic	diodes, optic	diodes, optic
Critical component lifetime (hours)	1000	5000	5000	5000	10000	10000	10000	10000	10000

*Dependent on TBD chamber chemical environment

**Improvements to come with automatic alignment control

Laser and target improvements provide path to highest EUV power requirements

How Far Can Xenon LPP Go?

Pulse rate	= 23 kHz (based on flow rates and interaction lengths)
Pulse energy	= 1 J planned; 600 mJ demonstrated
Xenon CE	= 1.2% demonstrated (2π steradian)
Isotropy	= 90% demonstrated
Collection angle	= 5 steradian optic being built
Throughput	= 55% (no SPF needed)
Total EUV power (Product of above)	**= 109 W at interface**

Xenon could meet industry roadmap — final choice will be based on cost of ownership, not by technology limits

CEO Resolving Issues for LPP Sources

Significant Progress Made

- High power laser in operation — generated 22 W of EUV, 9 W at interface
  - EUV power 10 times greater than 1 year ago
- Conversion efficiency in xenon now at 0.9% — provides path to high power
- Xenon jet hardware is outside collector — does not contribute to debris
- Measurements show spectral purity filter unnecessary

Addressing Key Issues

- Defining photochemical environment to control contamination
  - Need to preserve VNL capability in this!
- Integrated source demonstration with collector mirror in mid 2003
- Improved EUV dose stability with automated laser alignment control
- Moving forward to provide 100 W of EUV with next generation 12 kW laser in 2005