High Power Short Pulse and Cost Effective Laser Modules for Laser Produced Plasma (LPP) EUV Source

2nd International EUVL Symposium,

30 September - 2 October 2003

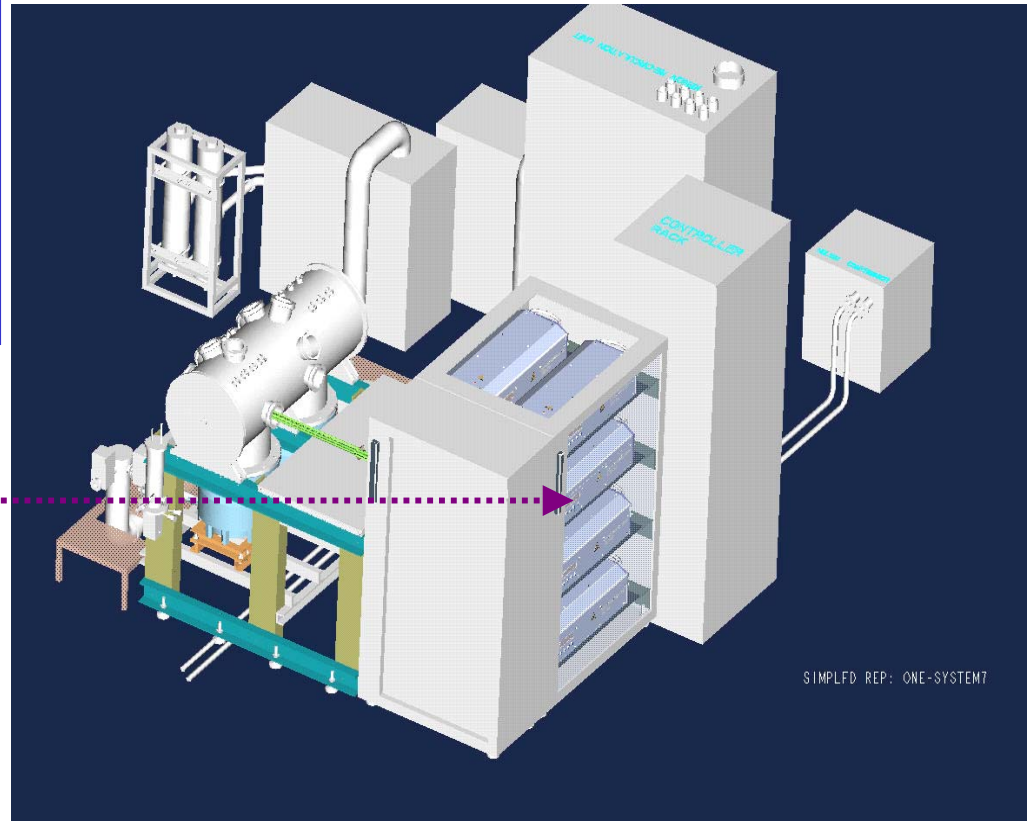
Antwerp, Belgium

Presentation outline

- High power laser development
- EUV source Improvements
  - Xe cluster and filament targets
  - Sn target
- Roadmap and Cost of Ownership
- Summary

Powerlase High Power EUV Source

Powerlase LPP EUV source
- Scalable with more laser beams
- Clean Photons
- Large solid angle
- Cost effective
- Computer controlled

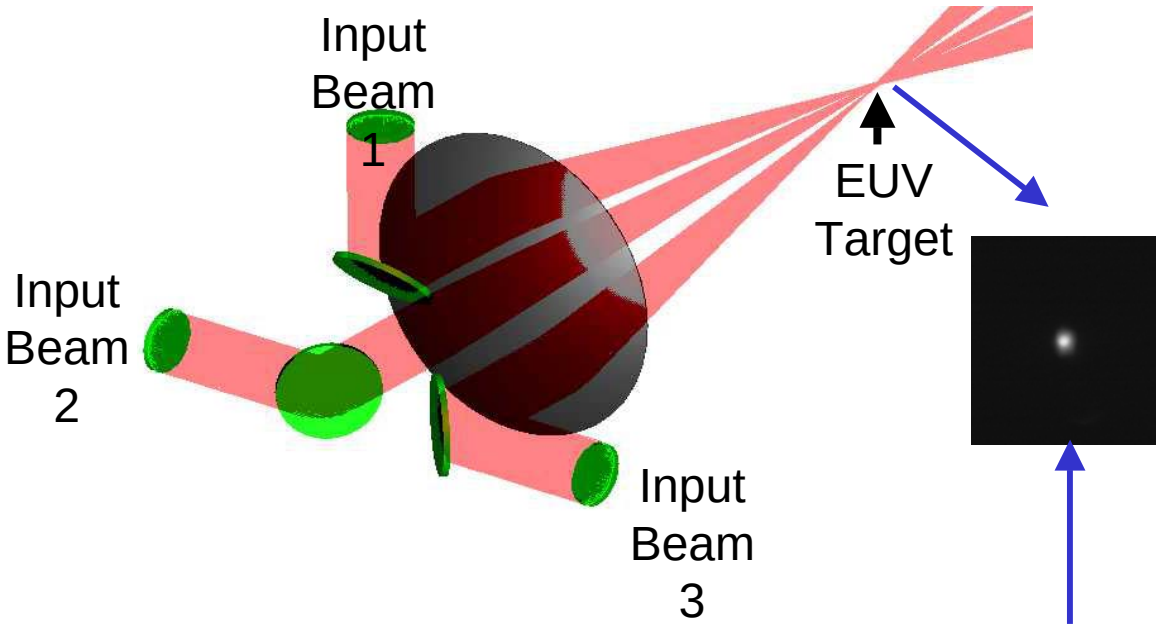


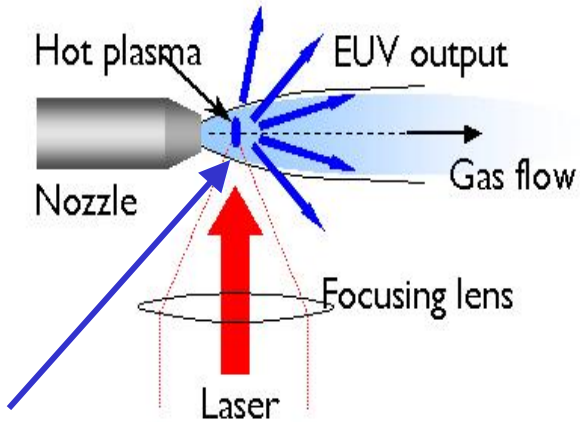
- **High energy conversion efficiency**
- **High power**
- **High repetition rate**
- **High pulse to pulse energy stability**
- **Pulse duration 9ns**

Spatially multiplexed laser beams

Spatial multiplexing

- Beams spatially combined using specially designed optics
- Using a single lens for focussing

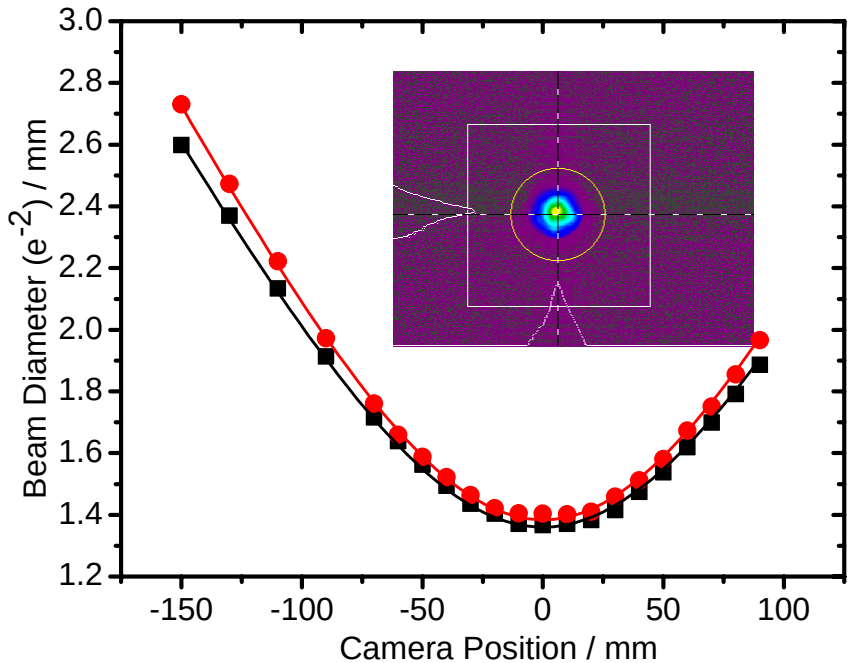




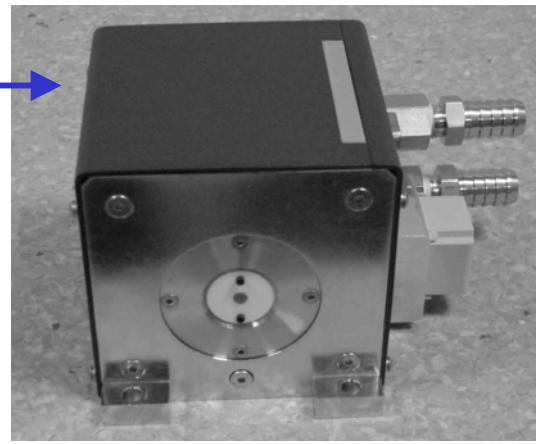
LPP Concept

- Far-field imaging camera permits spatial overlap of multiple beams to be monitored in real time during EUV generation

High power short pulse laser modules



- 18% electrical to optical CE



- Average power~**600W** (4 times higher than 2002)
- M^2 ~12
- Pulse energy of **172**mJ
- Rep rates from 3-10 kHz
- **1 kW laser module will be demonstrated towards the end of 2003**

High power lasers performance

	02	Today	End-03	04
Average power (kW)/module	0.150	0.6	1	1.2
Rep rate (kHz)	3.5	3.5	6	6
Number of multiplexed beams (n)	3	1	3	4
Total Average power for multiplexing (kW)	0.450	0.6	3	4.8

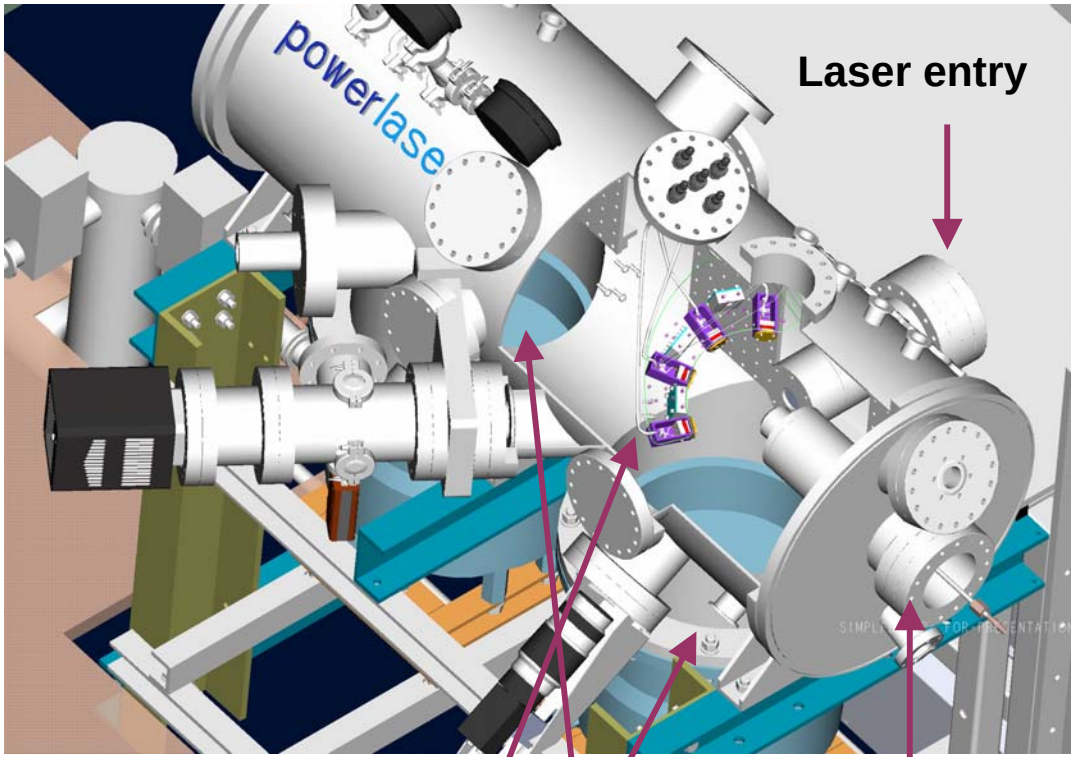
- Straightforward architecture of laser multiplexing
- Suited for any type of EUV target
- Small footprint

Powerlase LPP source can meet the industry requirements

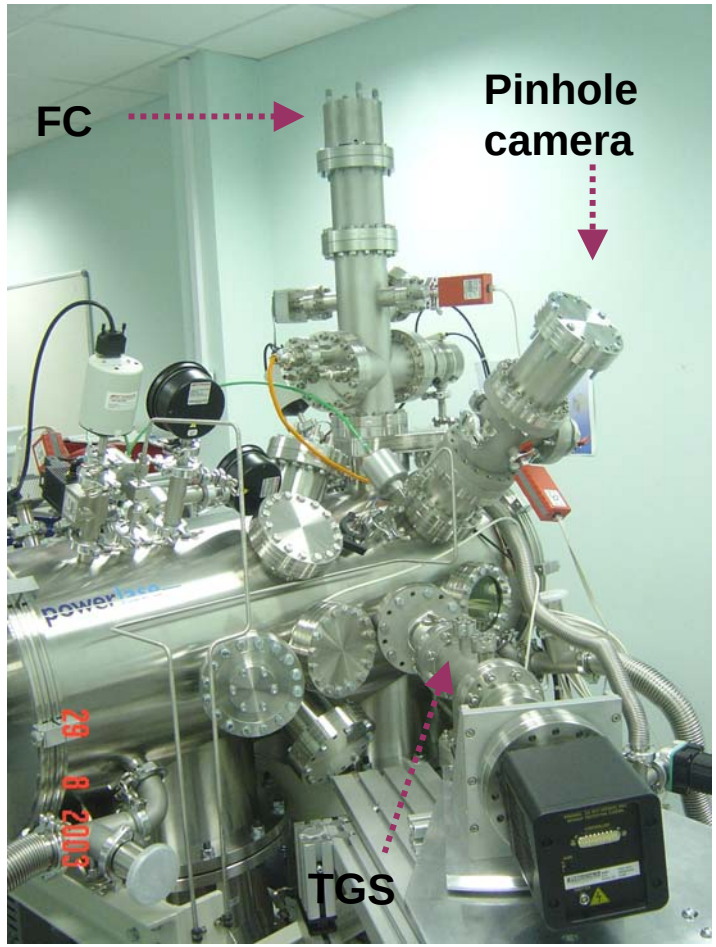
	Oct-02	Today	Imminent	Future		
Solid sate laser driver (kW)	0.450	0.6	3	12	20	16
Net conversion efficiency (%)	0.5	0.9	0.9	1.1	1.1	2.5
EUV power (W/2π)	2.25	5.4	27	132	220	320
Collection angle (sr)	2π	2π	2π	2π	2π	2π
Optical transmission	50%	50%	50%	50%	50%	50%
EUV at IF (W)	1	2.7	13.5	66	110	160

- High power laser improvements
- Xe target improvements
- Need non-Xe targets such as Sn to increase the CE

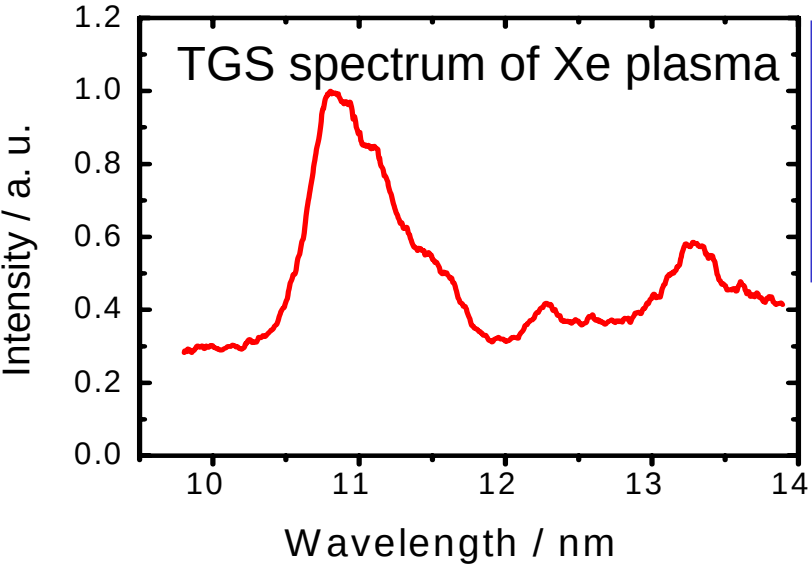
Interaction chamber and diagnostics



- Angular distribution
- Out-band
- Sample holder



Xe-target/ Recycling and contamination control

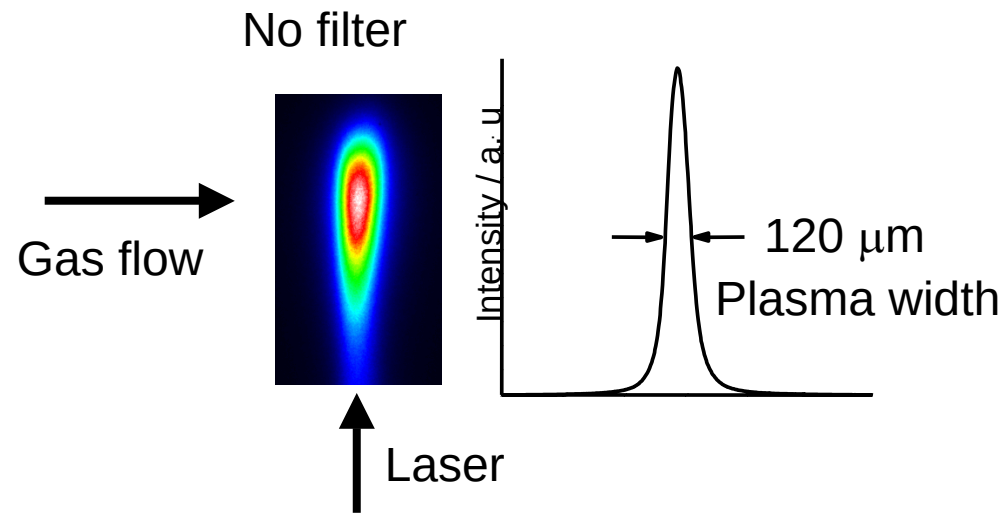


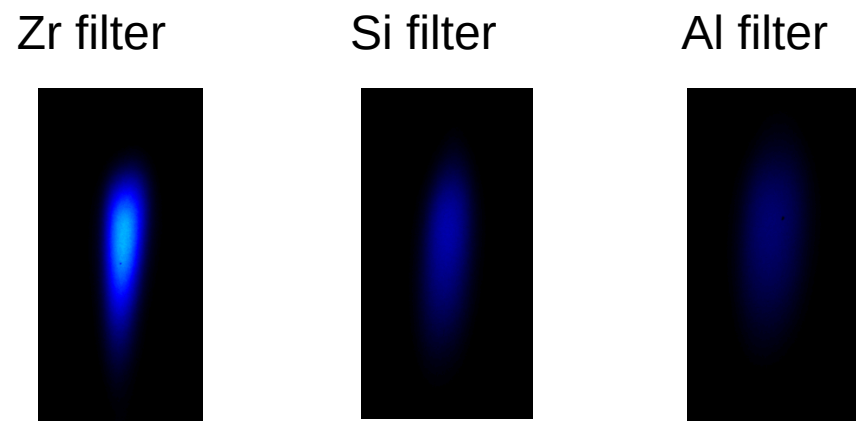
- The Xe gas is compressed, recycled and purified continuously
- Extremely low Xe consumption

RGA is monitoring the presence of hydrocarbons and water vapour which have detrimental effect on the MLM :

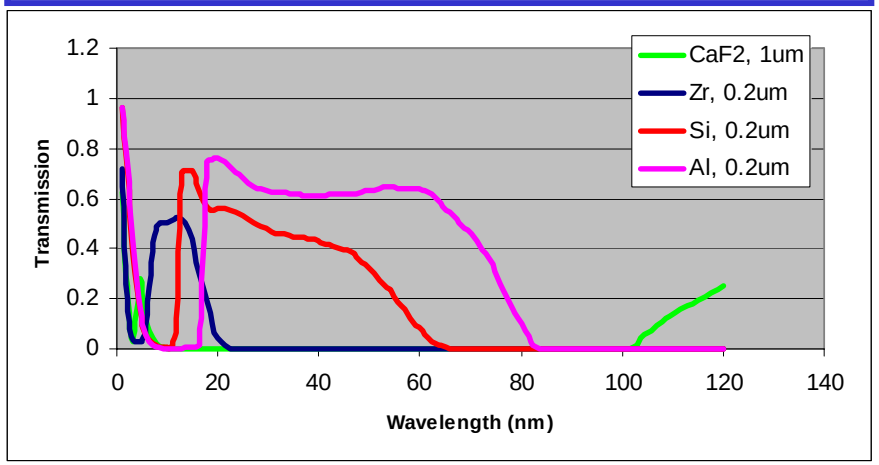
- Water level (peak 18) ~10^{-9} mbar
- Hydrocarbon level was measured using RGA: $\Sigma 45..200 \leq 5\times10^{-10}$ mbar

Source size measurements



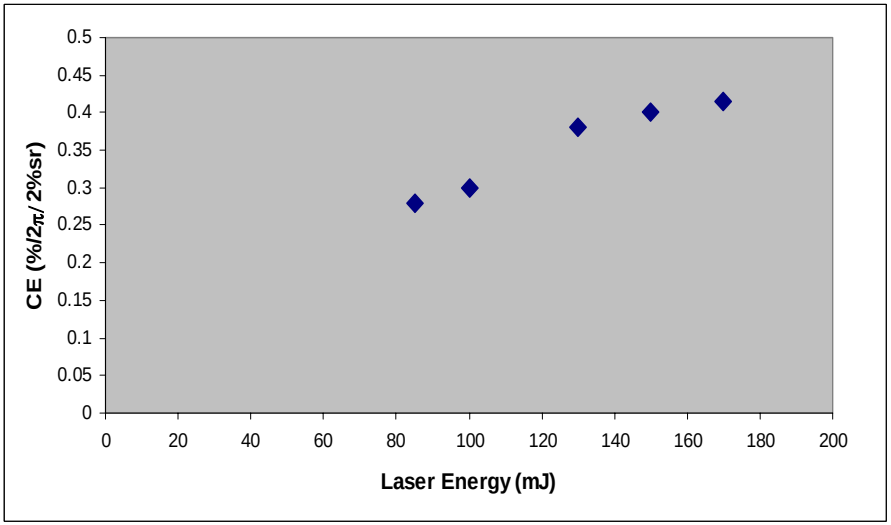


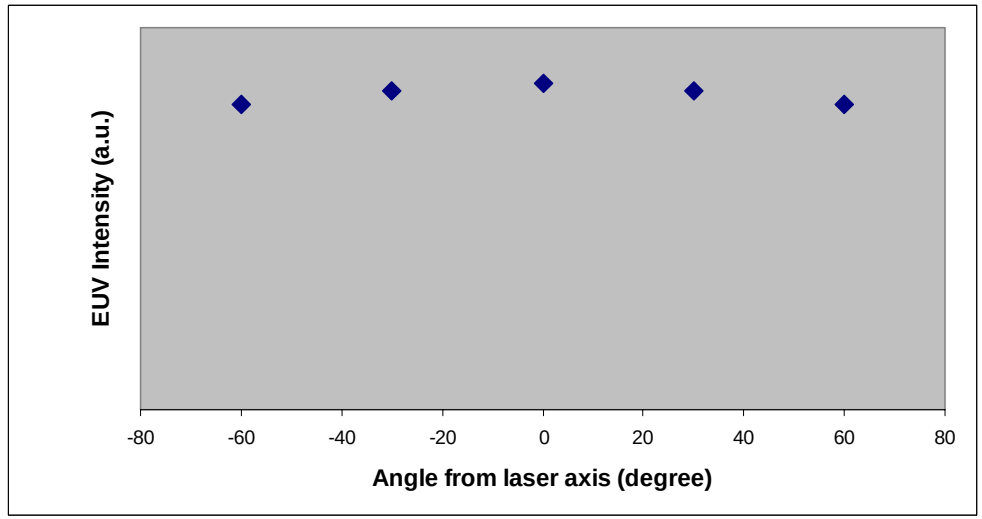
- Pinhole size of 50 μm
- Magnification of 4
- Filters of 200 nm thickness
- Princeton Instruments SX-1024 Soft x-ray back illuminated CCD Camera



- Source size was measured in different wavelength bands
- 5-20 nm band shows strong emission consistent with out-band measurement

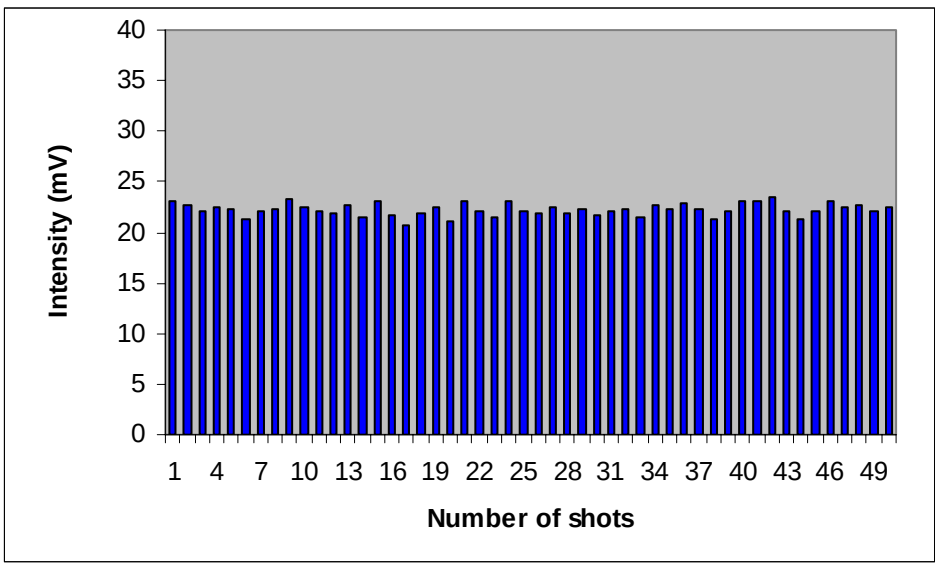
Conversion efficiency and angular distribution





CE versus laser energy

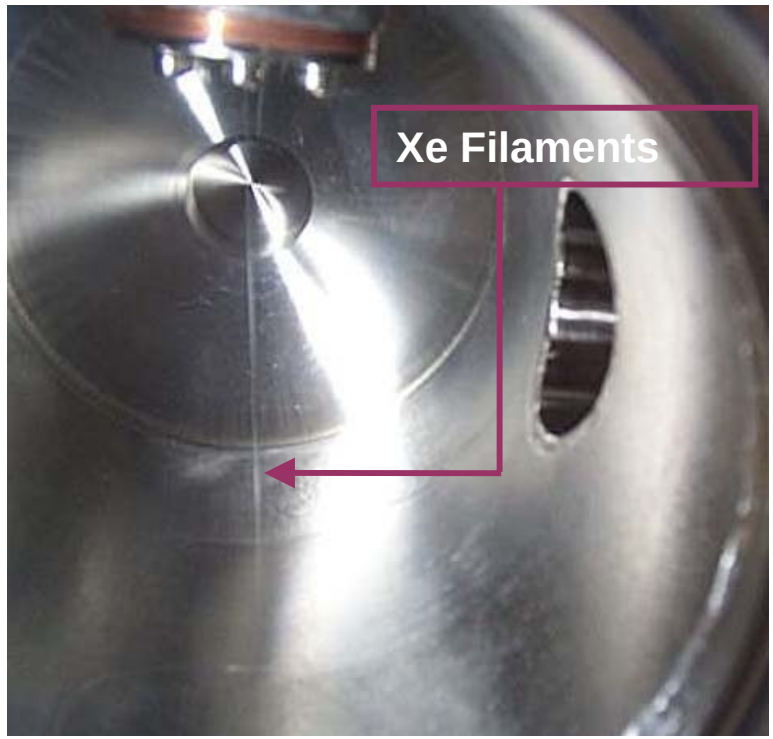
Angular distribution measurements at 172 mJ, it is nearly isotropic



<3% pulse to pulse repeatability

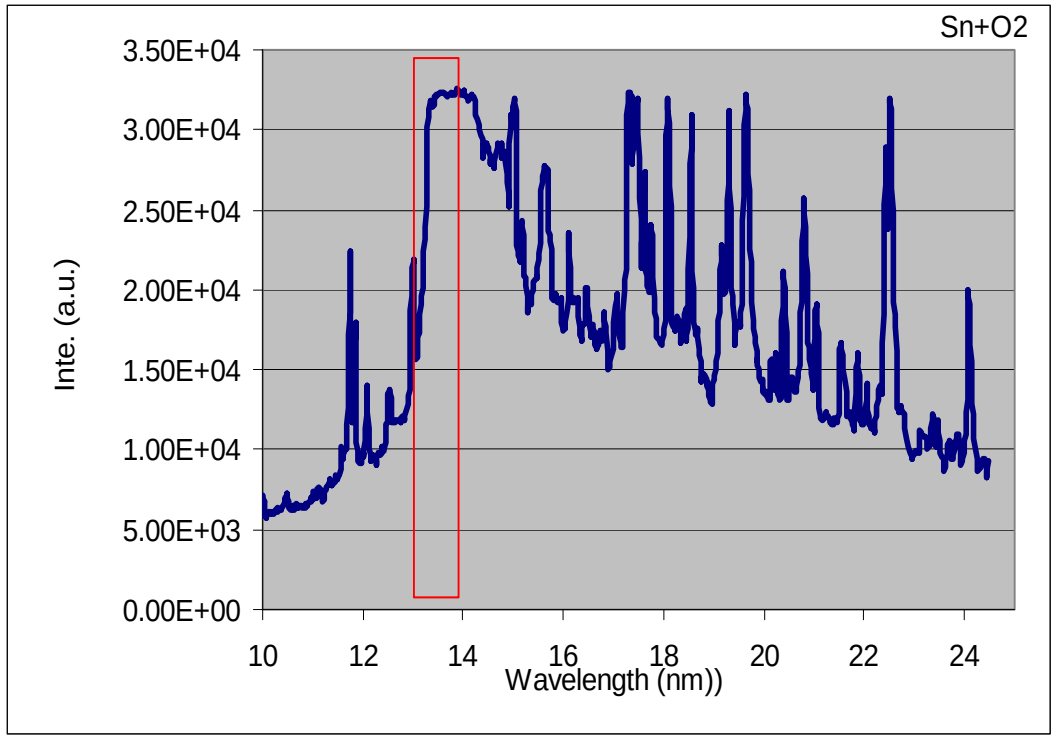
Solid Xe Filaments

- Xe filament to be tested using high power laser
- Our target is to demonstrate CE >1%
- Jet size to be increased to improve CE
- Low Xe background ~10^{-3} mbar



Other forms of target- Sn

- Sn-rich target CE>1.5% achieved at low rep rate
- Modelling shows higher CE can be achieved
- Effect of Sn concentration on CE and debris level
- Refreshable Sn-rich target to be incorporated into our system.

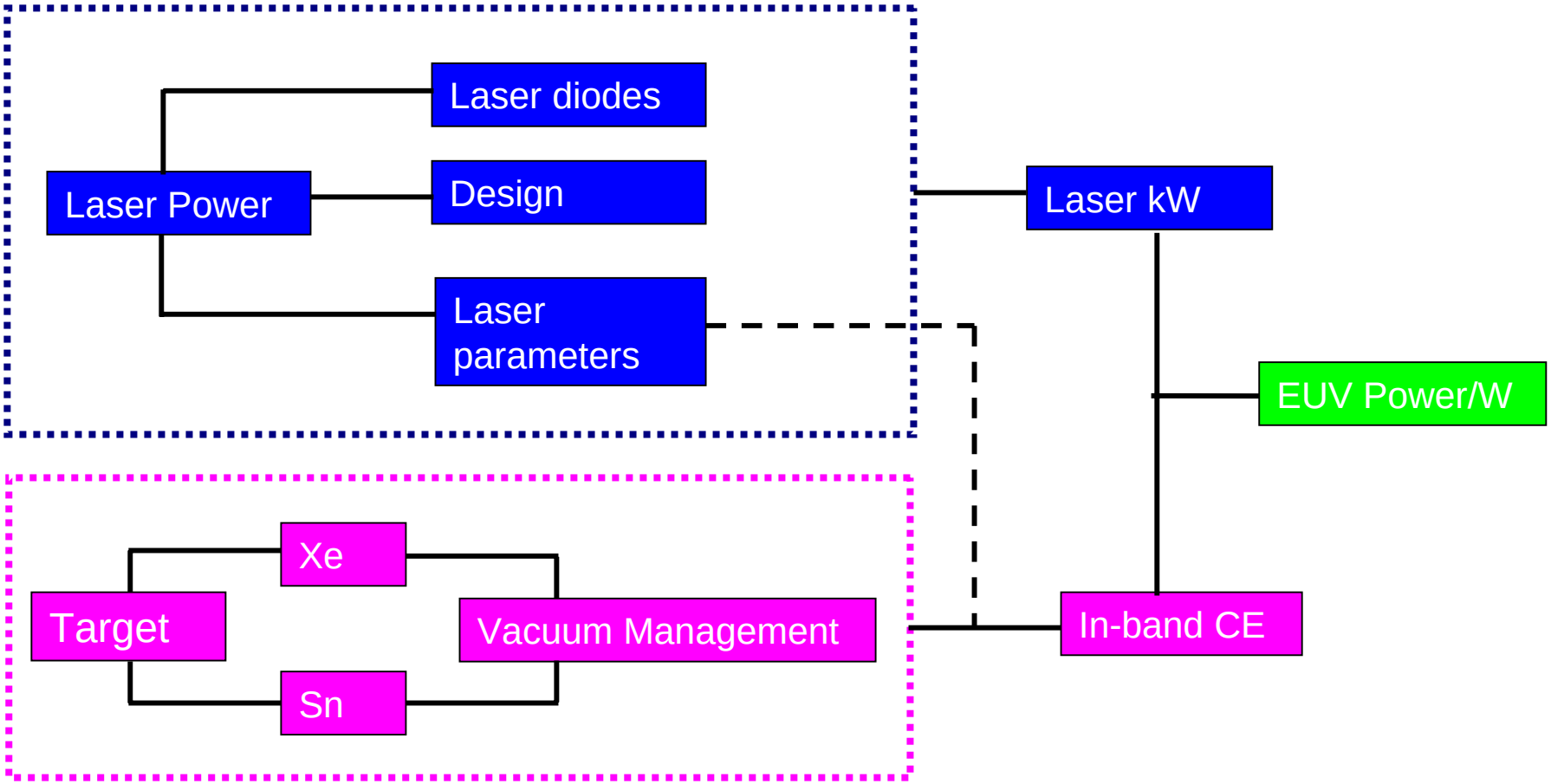


- Spectrum obtained using FFS

EUV Source Development Roadmap

Metrics	2002	2003	2004	2005	2006	2007	2008
Central Wavelengths (nm)	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Demonstrated collectable EUV power in a 2% spectral bandwidth (W/2π)	2.25	24	50	100	220	220	300
Available collections solid angle (sr)	2π	2π	2π	2π	2π	2π	2π
Source emission area (mm^2)	0.007	0.017	0.025	0.05	0.05	0.05	0.05
Etendue (mm^2sr)	0.05	0.11	0.16	0.3	0.3	0.3	0.3
Demonstrated maximum repetition rate (kHz)	3.5	10	10	10	12	12	12
Demonstrated steady state repetition rate (kHz)	3.5	10	10	10	12	12	12
Dissipated total power in source region (at steady state)(kW)	0.450	3	4.8	9	20	12	15
Source-facing condenser life time (# of pulses to 10% reflectance loss)	10^7	10^8	10^{11}	10^{11}	10^{11}	10^{11}	10^{11}
Pulse to pulse spatial stability (μm 3σ)	<15	<10	<10	<10	<10	<10	<10
Pulse to pulse intensity stability (3σ)	9%	<9%	5%	5%	5%	5%	5%
Pulse to pulse angular stability (3σ)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Pulse to pulse pointing stability	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Key risk area	Nozzle	Optics					

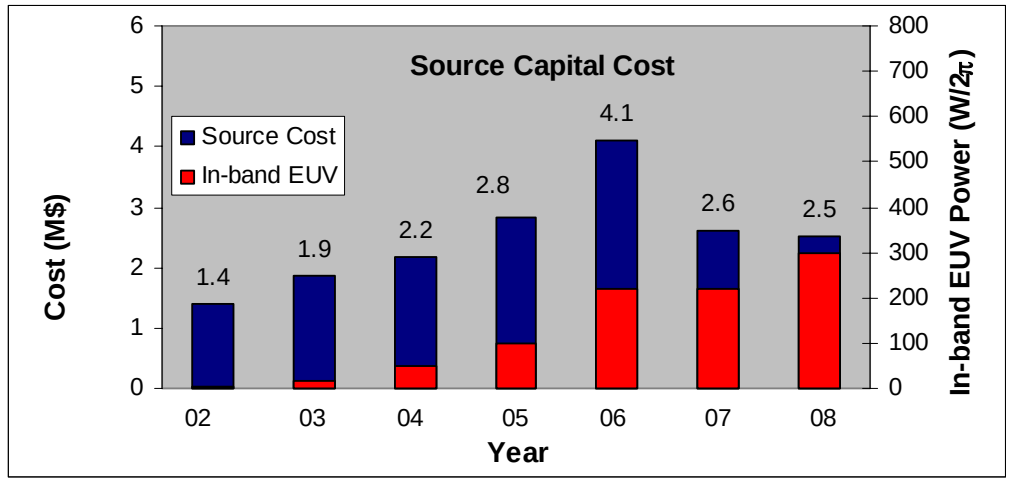
Cost of ownership

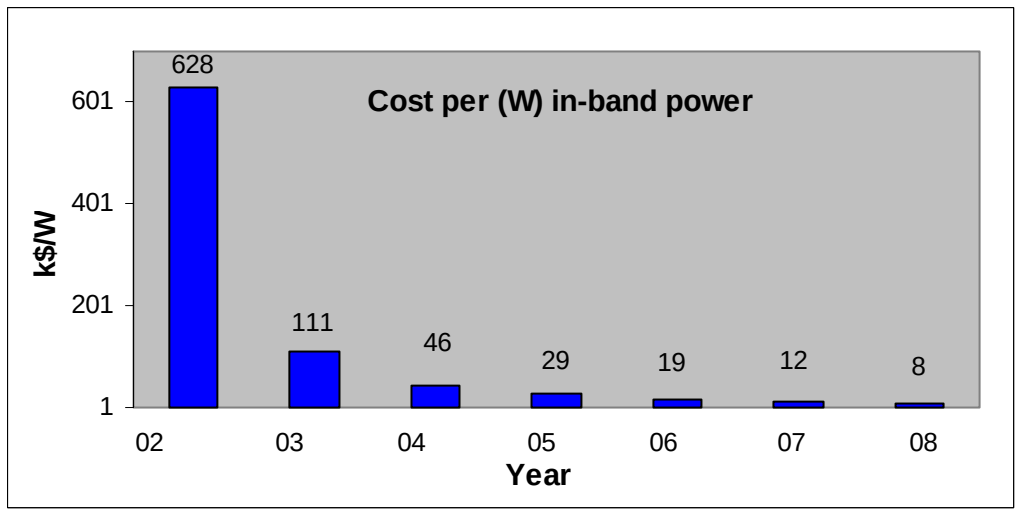


EUV Source cost projections

Cost influences

- Improvements in solid state laser diode cost
- Improvements in solid state laser efficiency
- Numbers of laser modules needed
- In-band EUV conversion efficiency, targets used
- In-band EUV at intermediate focus and collector efficiency of 50% assumed





Powerlase facility

Laser development, Product applications development, Manufacturing

Summary:

- Improve laser driver efficiencies for LPP sources
- High purity re-circulated Xe target
- Clear and cost effective source roadmap to production level EUV source

Acknowledgements

Andrew Comley[1], Ian Henderson[1], Michael Egan[1], Nick Hay[1], Mike Mason[1], Mark Middleton[1], Duncan Parsons-Karavassilis[1], Burly Cumberland[1], Michael Poulter[1], Jo Greenwood[2], Julian Dean[2] , Darren Mennie[2] , Andy Harpham[2]

[1]Powerlase Ltd (Lasers and application)

[2]BOC Edwards (Vacuum and gas management system)