
Laser-Produced-Plasma Light Source Development for EUV Lithography at EUVA

EUVA

(Extreme Ultrviolet Lithography System Development Association)

**Akira Endo, Tamotsu Abe, Takashi Suganuma, Georg Soumagne,
Yousuke Imai, Hiroshi Komori, Koichi Toyoda,
Yasuhiro Horiike**

**2nd International EUVL Symposium
30 September, 2003
Antwerp, Belgium**

Presentation Outline




EUVA LPP Development

-  Schedule
-  Experimental facilities

Components Development

-  EUV image
-  Angular Distribution
-  Conversion Efficiency
-  Time of Flight

System Development

-  Driver Laser
-  Xenon Jet
-  EUV Power and Stability

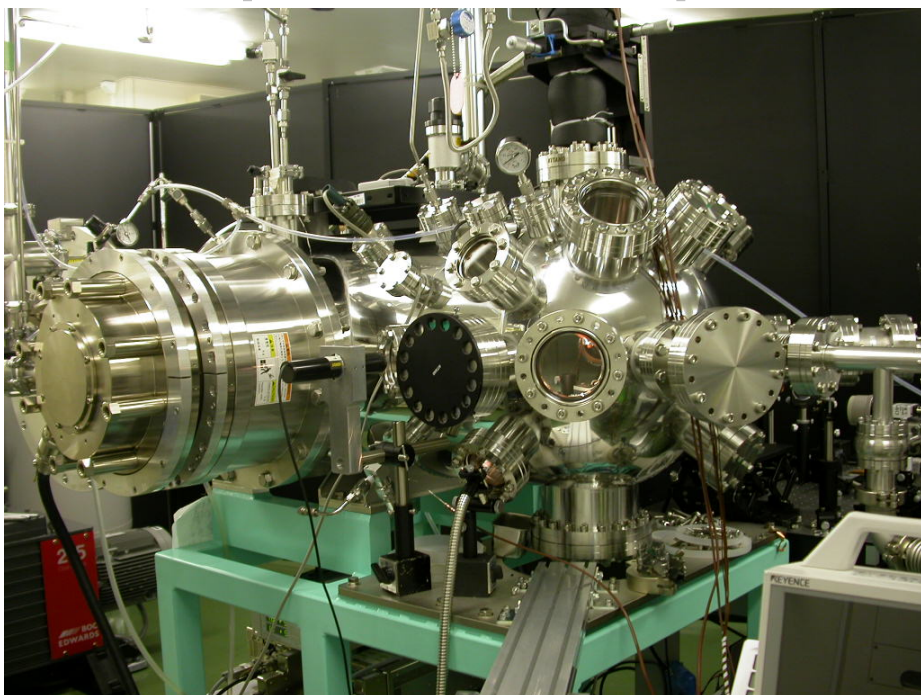
Summary

LPP Development Schedule

Fiscal Year	2003	2004	2005	2006	2007	2008
EUV power @ intermediate focus	--	4	10	12	50	115
Plasma target	Xe	Xe	Xe	Xe	TBD	TBD
Conversion efficiency	0.6%	0.7%	0.8%	0.9%	1.5%	2.0%
Laser power	1.5kW	2.5kW	5kW	5kW	10kW	15kW
EUV power in 2pisr 2%BW	9.0	17	40	45	150	300
Available collection solid angle	--	3.5sr	4.0sr	4.0sr	5.0sr	5.0sr
Repetition rate	10kHz	10kHz	10kHz	10kHz	20kHz	30kHz
	EUVA			Next Program		

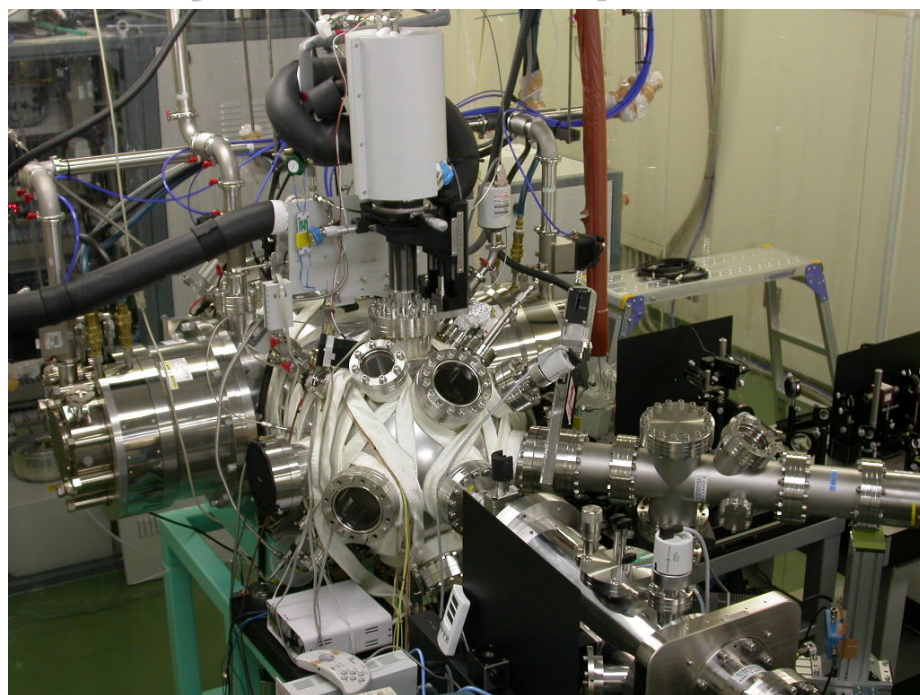
LPP Experimental Facilities

Component development



e.g. CE, Mirror lifetime, Jet stability

System development



e.g. High power laser, Xenon recirculation

Presentation Outline




EUVA LPP Development

-  Schedule
-  Experimental facilities

Components Development

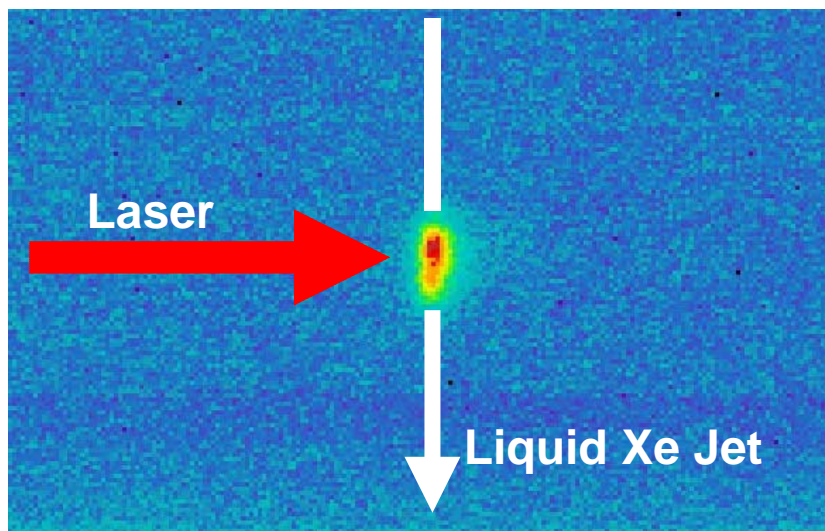
-  EUV image
-  Angular Distribution
-  Conversion Efficiency
-  Time of Flight

System Development

-  Driver Laser
-  Xenon Jet
-  EUV Power and Stability

Summary

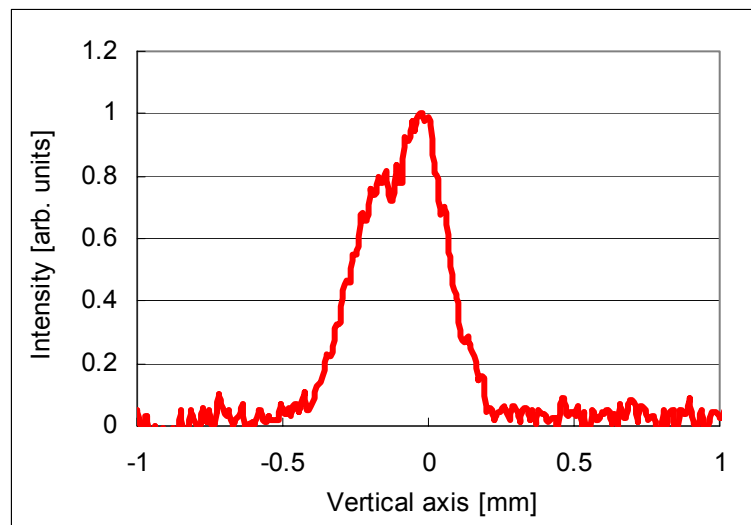
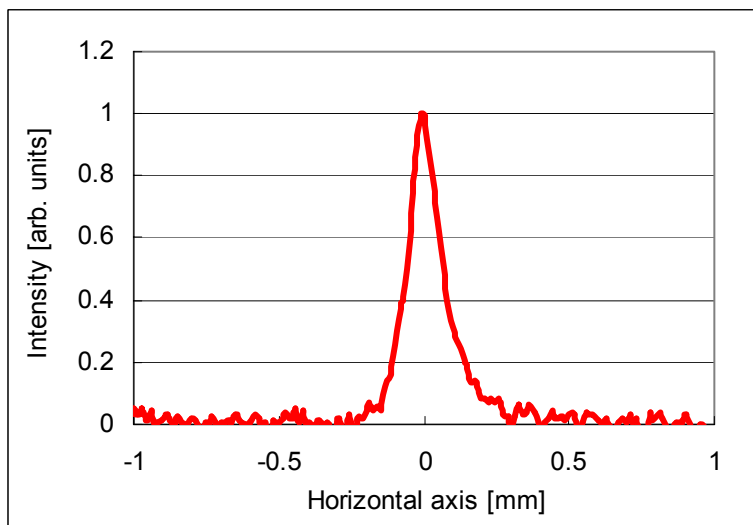
EUV Characteristics (EUV Image)



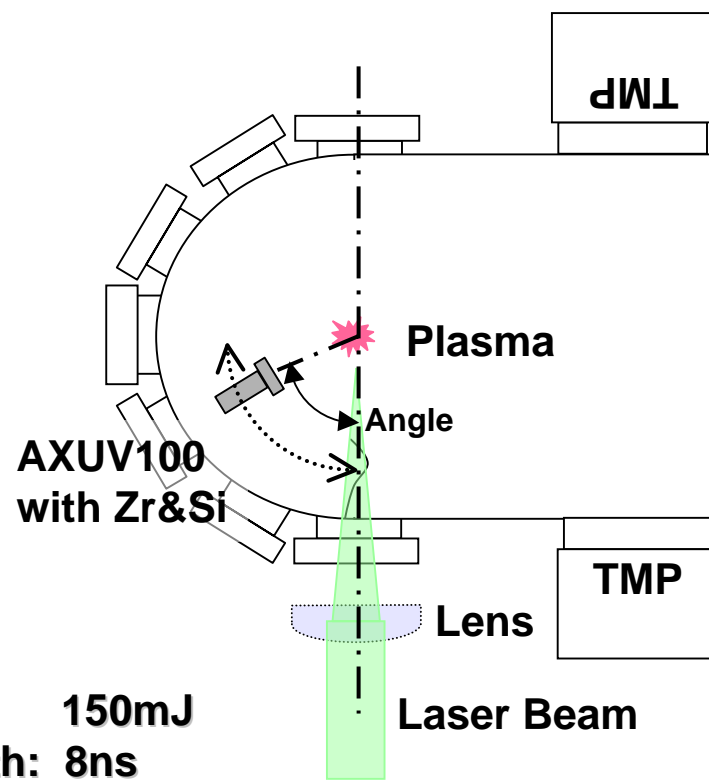
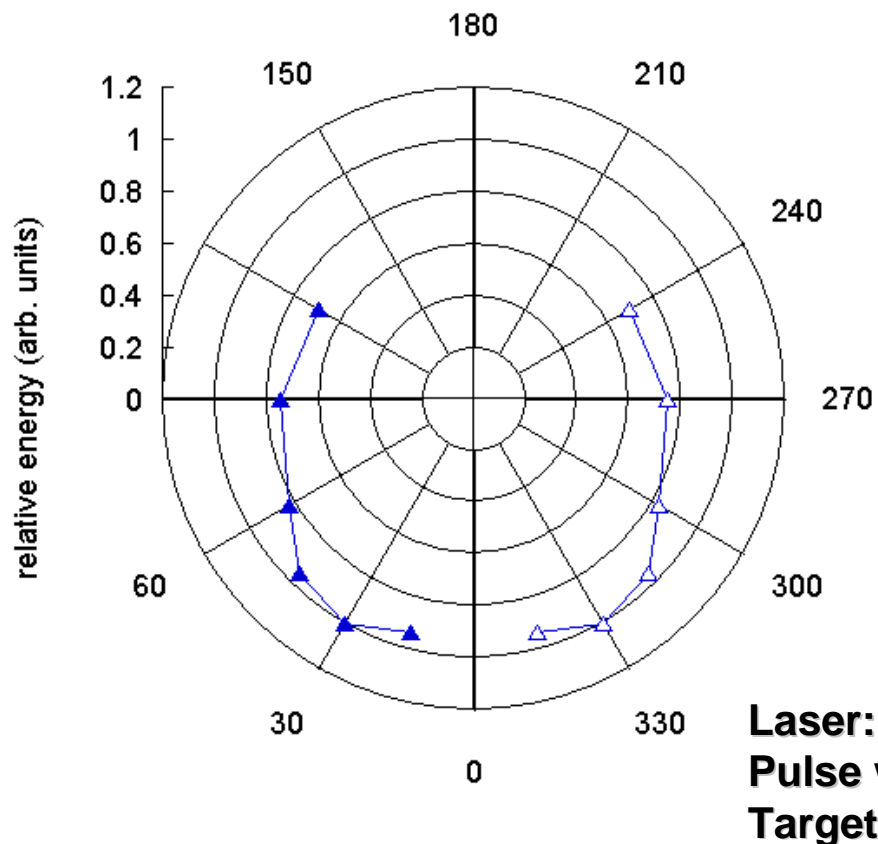
Source size:
<150×300 μm (HxV, FWHM)

Etendue:
<0.13 mm^2sr

Pinhole size: 50 μm
Magnification: 1
Filter: Zr (200nm)



EUV Characteristics (Angular Distribution)

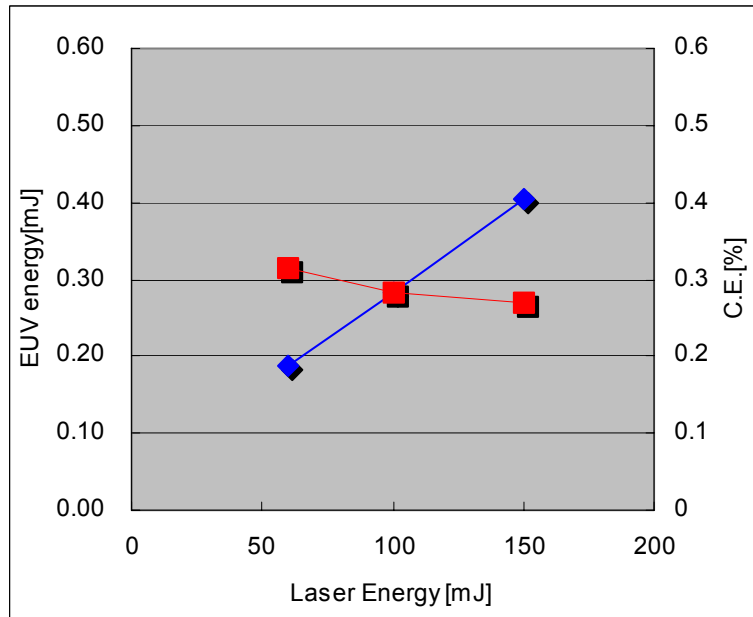


- Nearly isotropic**
- 20% Decrease from 0° to 90°**

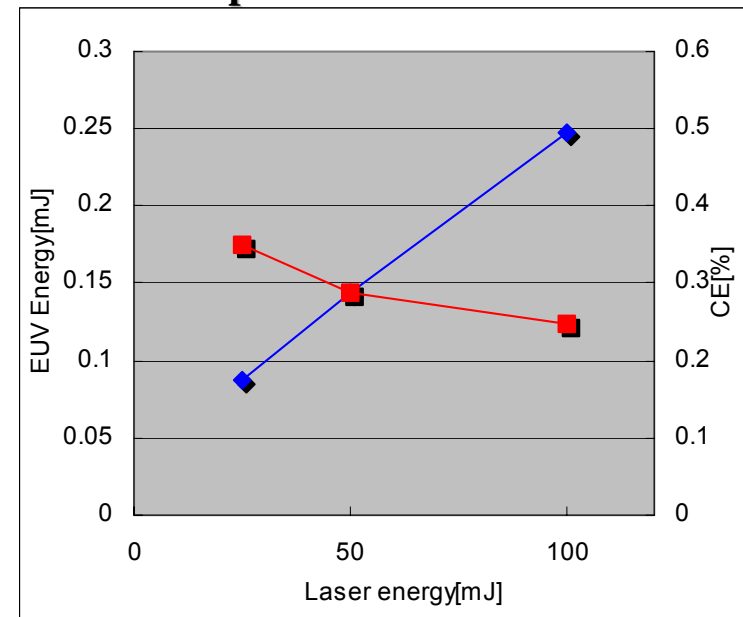
EUV Characteristics (Conversion Efficiency)

C.E. for 8 ns and 150 ps laser pulse durations

Target: $\phi 10\mu\text{m}$ Liquid Xenon jet
Rep. rate: $<10\text{Hz}$



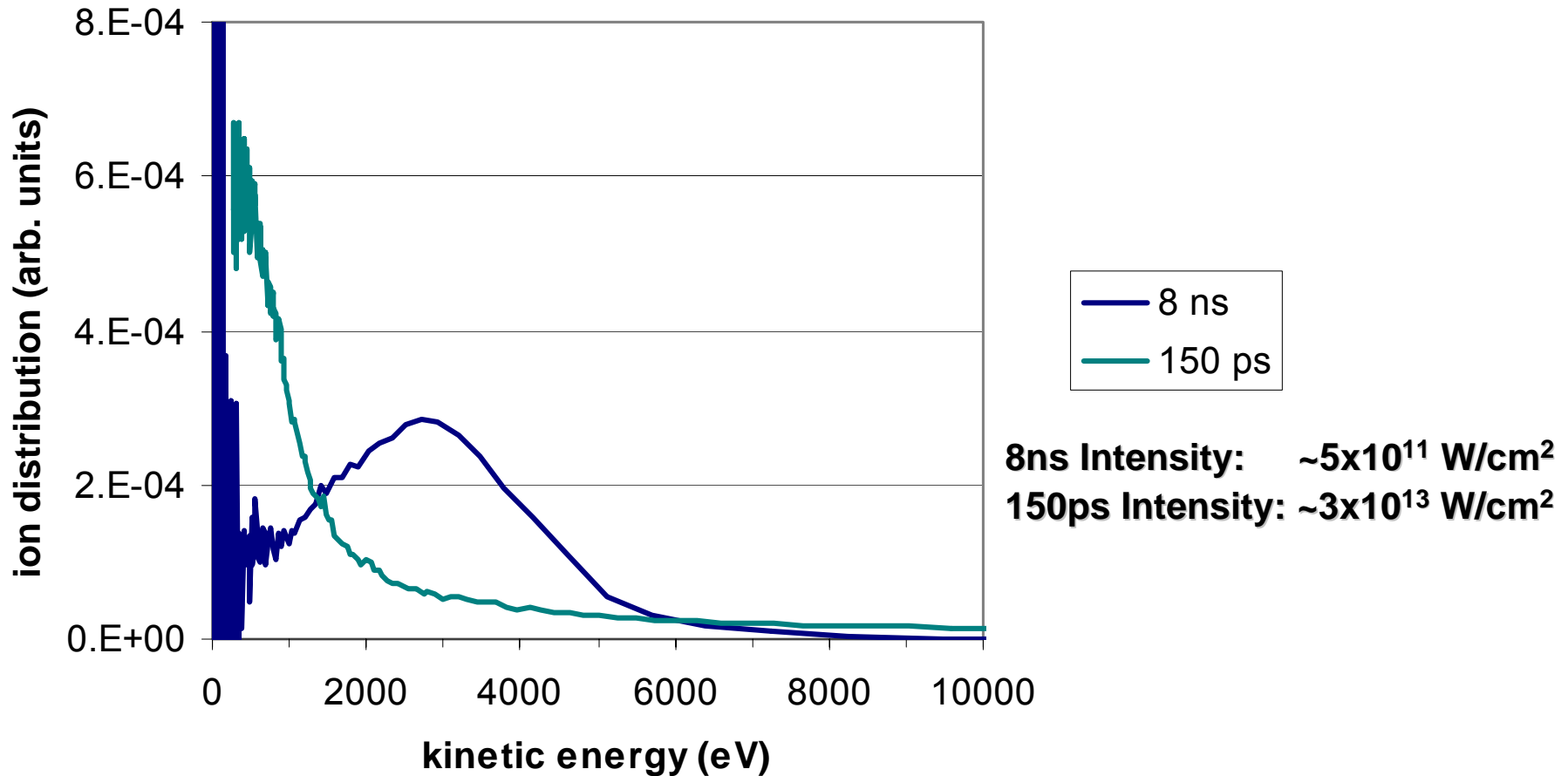
Pulse duration: 8 ns (FWHM)
Intensity: $\sim 5 \times 10^{11} \text{ W/cm}^2$



Pulse duration: 150ps (FWHM)
Intensity: $3 \times 10^{13} \text{ W/cm}^2$

EUV Characteristics (Time of Flight, TOF)

TOF for 8 ns and 150 ps laser pulse durations



detailed information will be presented in "Session 6: Contamination 1"
"Study of ion damage on EUV light source collector mirror", H. Komori, et al.

Presentation Outline




EUVA LPP Development

-  Schedule
-  Experimental facilities

Components Development

-  EUV image
-  Angular Distribution
-  Conversion Efficiency
-  Time of Flight

System Development

-  Driver Laser
-  Xenon Jet
-  EUV Power and Stability

Summary

LPP System Development

	Jun 2003	Aug 2003	Today
In-band EUV power(2πsr)	0.6W	1.0W	2.0W
EUV energy stability (Pulse-to-pulse, 1σ)	6.7%	3.4%	5.4%
Conversion efficiency	0.14%	0.33%	0.33%
Average laser power	300 W	300W	600W
Repetition rate	10kHz	10kHz	10kHz
Laser pulse duration	32ns	6ns	6ns

EUV System Development (Gas Recirculation System)

Gas recirculation system

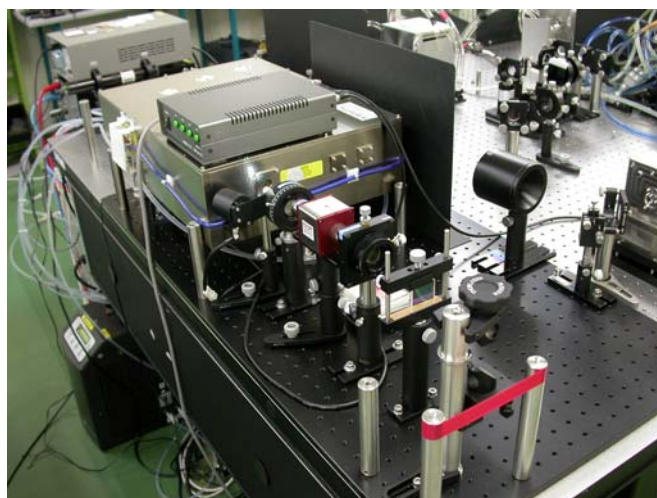
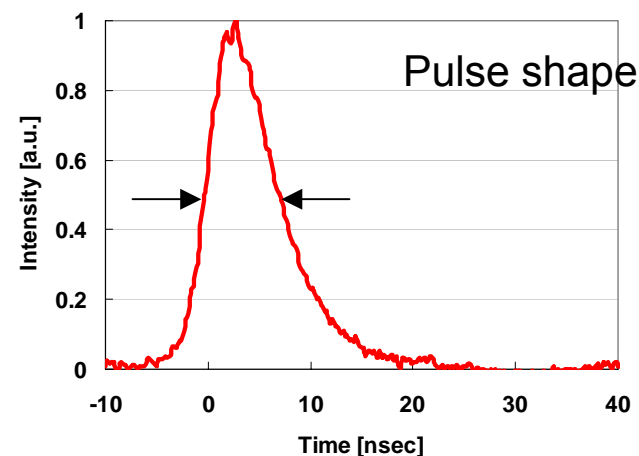
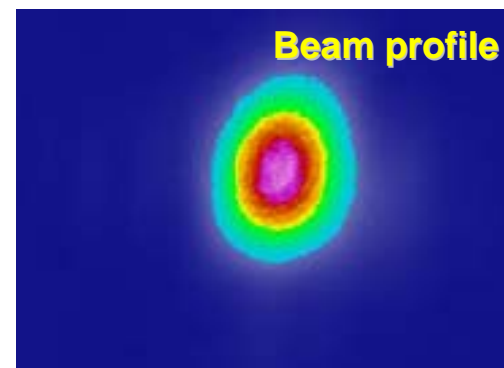
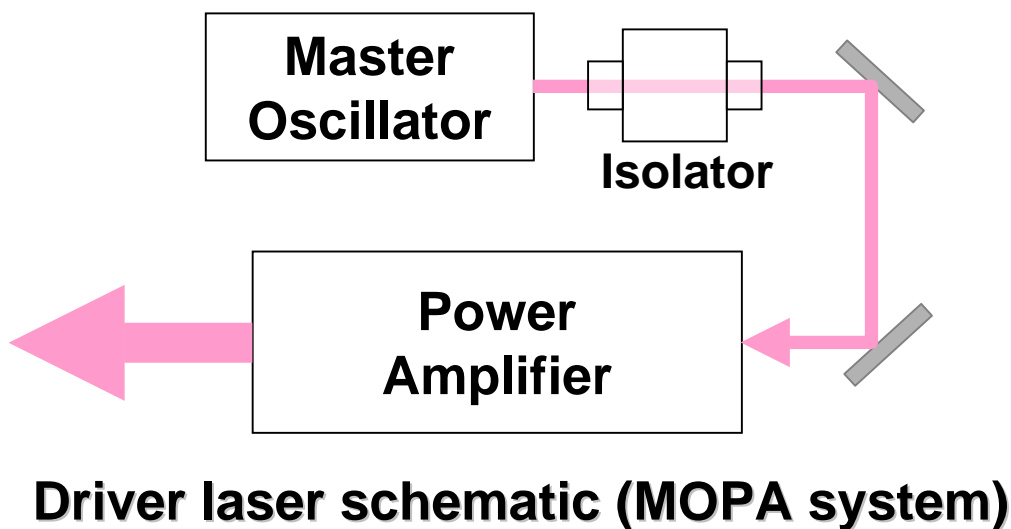


Specifications:

Xe flow rate	<0.4 SLPM
Xe backing pressure	<5 MPa
Xe temperature	180K-200K

Pumping speed	4600 liter/s
Vacuum chamber pressure	~0.1 Pa

EUV System Development (Driver Laser)



Master Oscillator

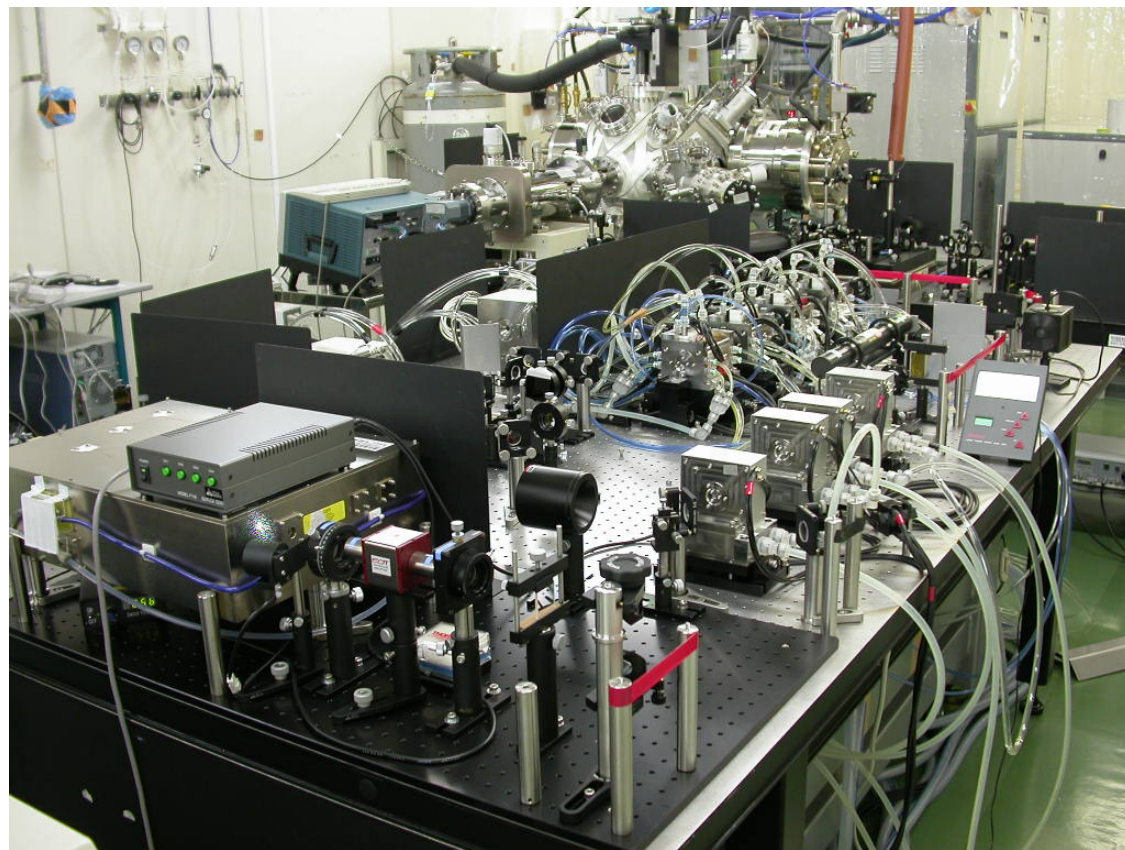
Master Oscillator Specification

Average power : ~ 7 W

Rep. rate : 10 kHz

Pulse duration : ~ 7 ns (FWHM)

EUV System Development (Driver Laser)

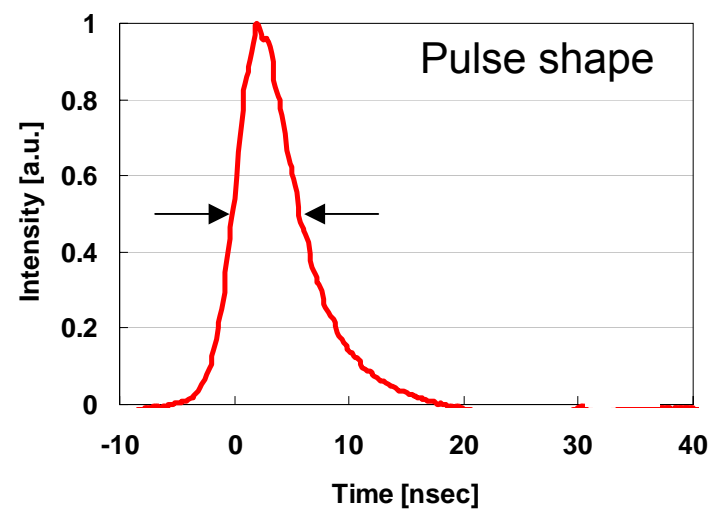
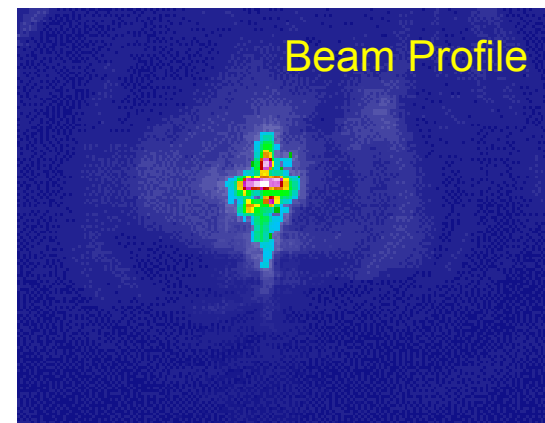


MOPA system specification

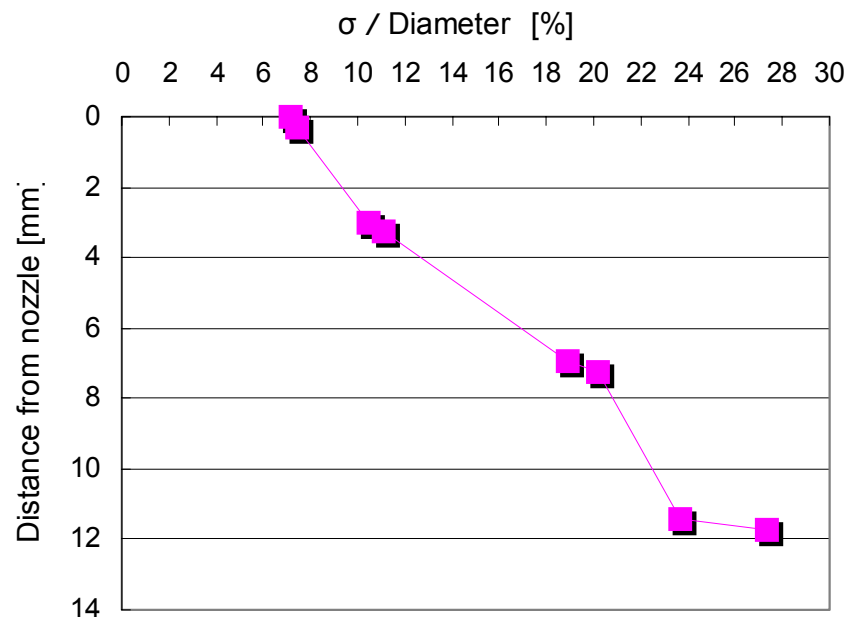
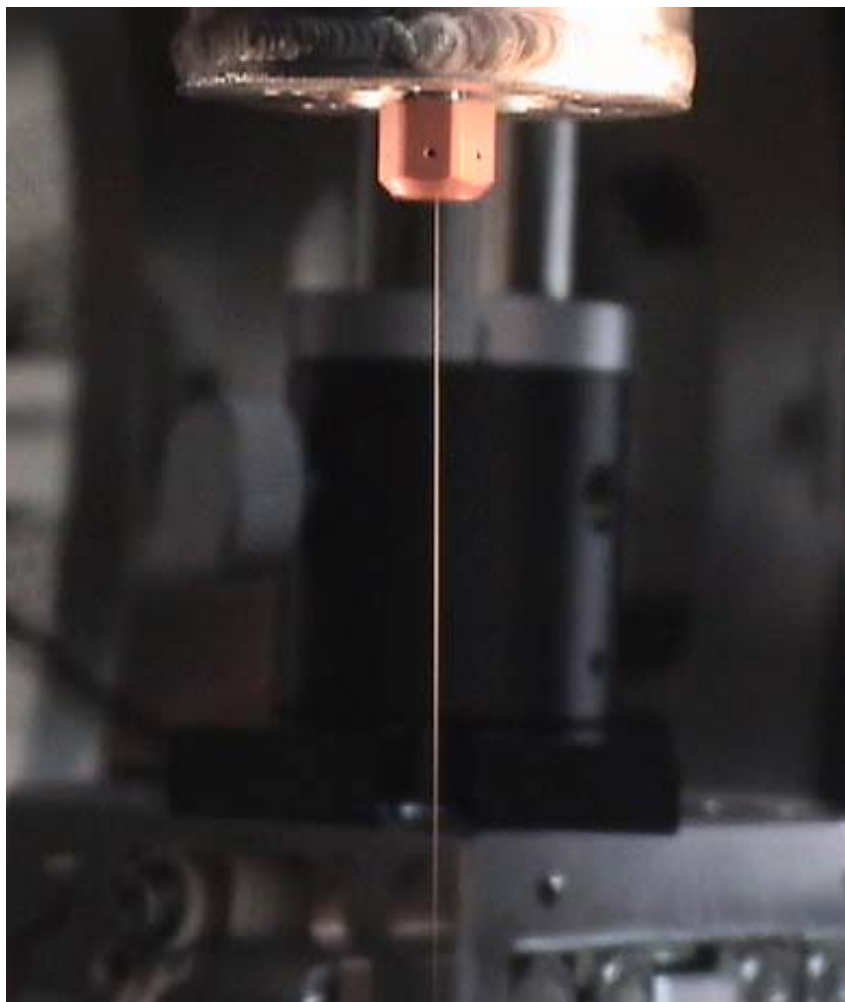
Average power : 600 W

Rep. rate : 10 kHz

Pulse duration : 6 ns (FWHM)



EUV System Development (Liquid Xenon Jet)



Specification

- Target: Liquid Xenon Jet
- Jet diameter: $\sim 50 \mu\text{m}$
- Jet speed: $>35\text{m/s}$
- Spatial stability: $<25\%$ (1)
@10mm from nozzle

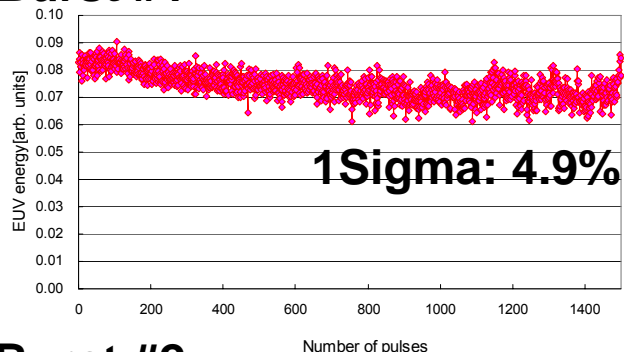
EUV System Development (EUV Power)



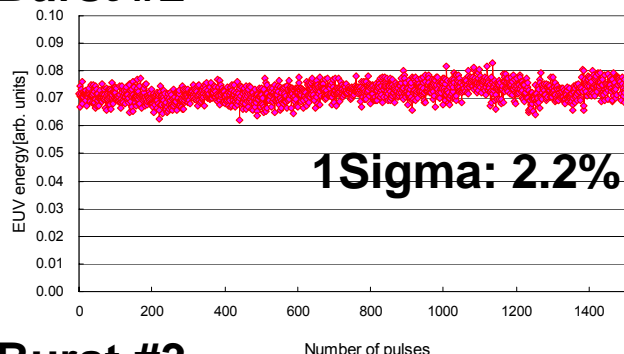
- **EUV Power:** **2.0W** (2%BW/2 π sr)
- **EUV Energy stability:** **5.4%** (1σ)
- **Conversion Efficiency:** **0.33%**
- **Laser Power:** **600W@10kHz, 6ns**
- **Target:** **Liquid Xenon jet**

EUV System Development (Energy Stability)

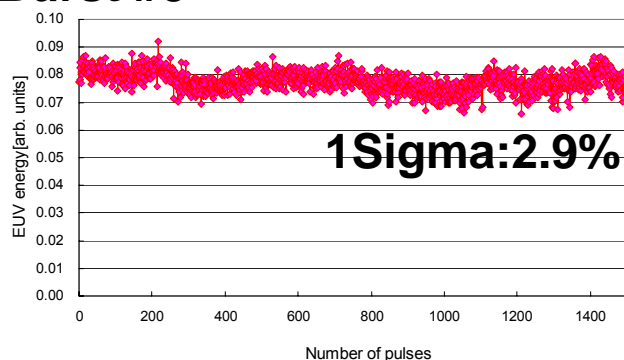
Burst #1



Burst #2

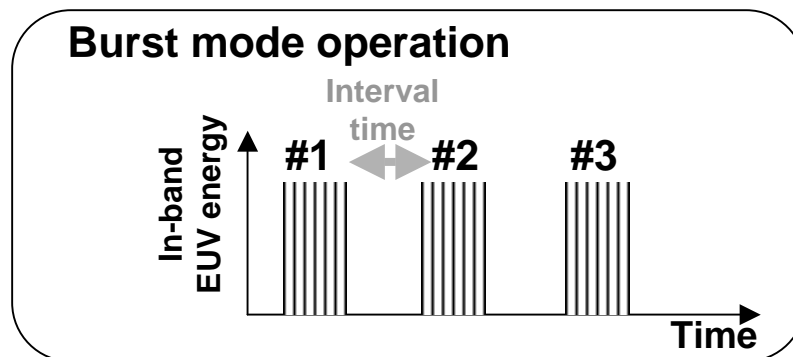


Burst #3



Burst mode operation

- Energy stability: **<4.9%**
(1 σ , 50-pulse ave.)
- Repetition rate: **10kHz**
- Target: **Liquid Xenon jet**
- Number of burst: **3**
- Number of pulses: **1500 pulses/burst**
- Interval time: **2 sec**
- No feedback control of
Laser energy
Laser alignment, etc.



Summary

LPP Light Source Performance

☐ In-band power	2.0W (2%BW 2 π Sr)
☐ Plasma target	Liquid Xenon Jet
☐ Conversion efficiency	0.33% @ 10kHz 0.53% @ < 10Hz
☐ Energy stability	< 4.9% (1 σ , 50-pulse ave.)
☐ Relative change of EUV angular energy distribution	< 20% ($\pm 90^\circ$)
☐ Source size	< 150 × 300 μm (HxV, FWHM)
☐ Etendue	0.13 mm²sr
☐ Laser power	600 W @ 10kHz, 6ns

Main target for 2004:

4W (intermediate focus)

Acknowledgements

This work was performed under the management of

Extreme Ultraviolet Lithography System Development Association



a research and development program of

NEDO / METI.