EUV Light Source Development at EUVA

EUVA
(Extreme Ultraviolet Lithography System Development Association)

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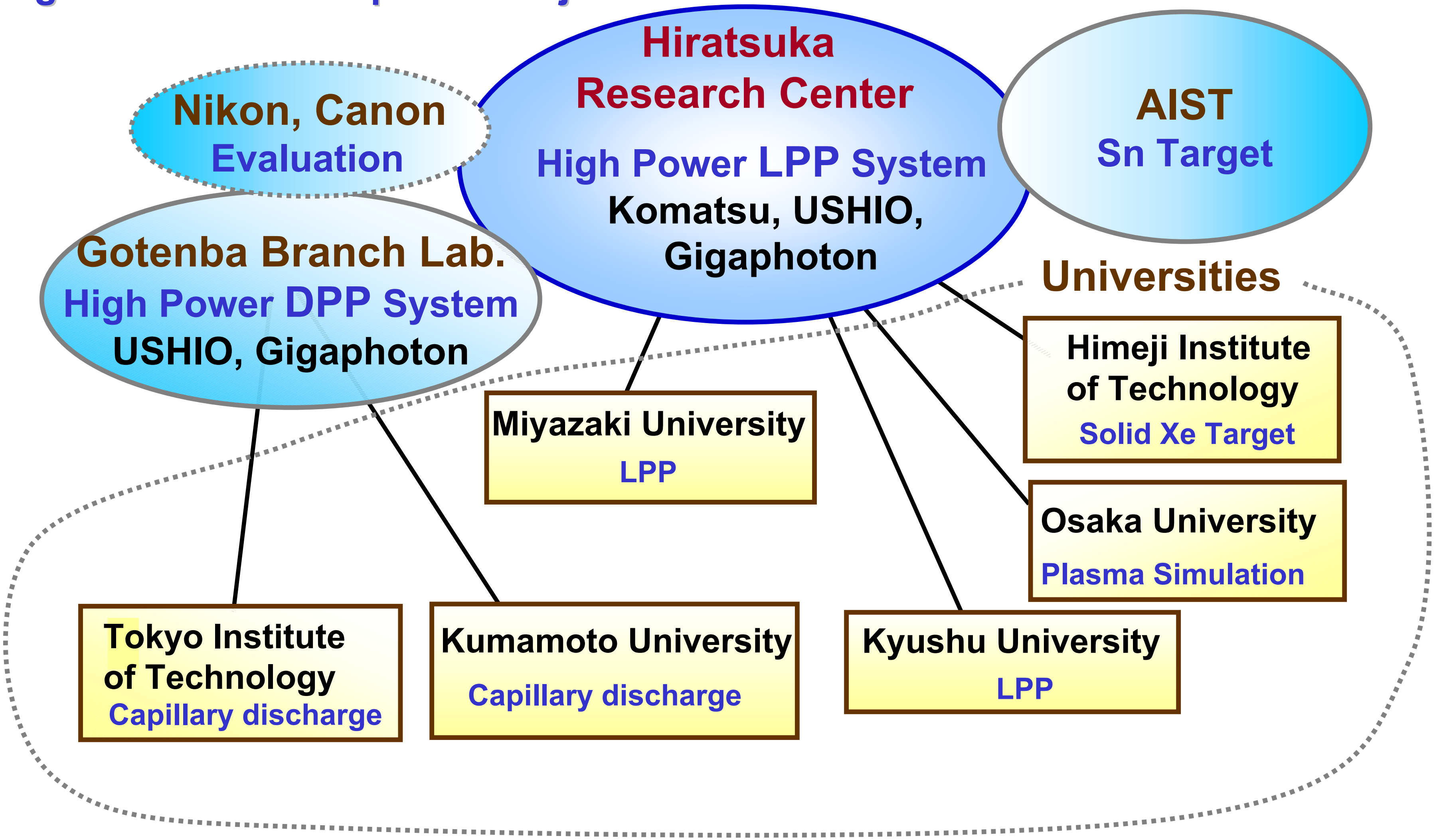
**EUV Source Workshop
February 23, 2003
Santa Clara, California**

Outline

- EUVA Members and Organization
- Main Research Topics
- Targets and Time Schedules
- Light Source Development: LPP & DPP
  - Hiratsuka R&D Center
  - Gotenba Branch Lab.
- Summary

EUVA Organization

Light Source Development Project



AIST: National Inst. of Adv. Industrial Sci. & Technology

EUVA Main Topics

AIST GIGAPHOTON USHIO KOMATSU

Topic 1

High Power and High Quality EUV Light Source Development

Topic 2

Diagnostics of EUV Light Sources and Mirror Damage

Universities

Tokyo Institute of Technology

Osaka University

Himeji Institute of Technology

Miyazaki University

Kumamoto University

Kyushu University

Canon Nikon

Targets and Time Schedules

Fiscal Year	2002	2003	2004	2005	2006
EUV Power @Intermediate focus		→ 4W		→ 10W	
Development of LPP •Hiratsuka Research Center (Komatsu, Gigaphoton) •AIST •Himeji Institute of Technology •Osaka University •Miyazaki University •Kyushu University	**~ 2.5kW Nd:YAG** Xenon target •Development of other targets •Simulation of plasma physics		**~ 5kW Nd:YAG** New targets		
Development of DPP •Gotenba Branch Lab. (USHIO, Gigaphoton) •Tokyo Institute of Technology •Kumamoto University	Experimental system •High rep-rate power supply •Capillary discharge		Improved High repetition rate		

LPP Development

<u>Mar. 2003</u>

Completion of 1st experimental setup.

Evaluation of liquid jet target.

<u>Middle 2004</u>

Collector optics installed into chamber.

Improved high power laser system.

<u>Mar. 2006</u>

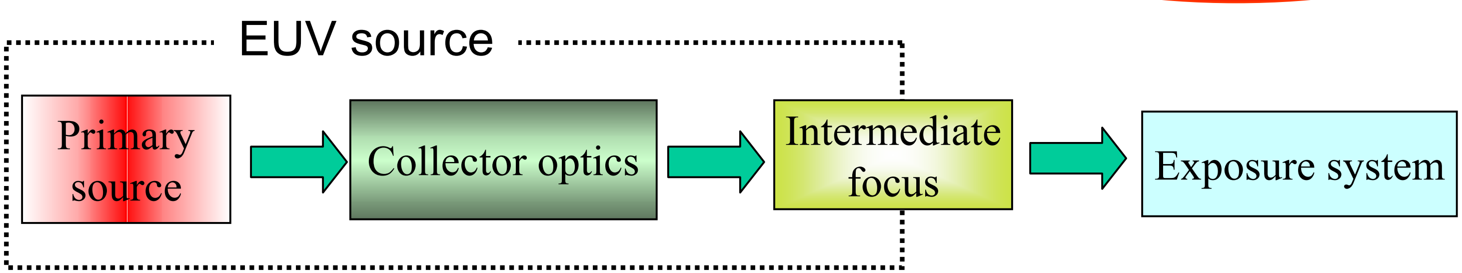
Higher EUV power and longer system lifetime.

(Debris & thermal management).

1W
(primary source)

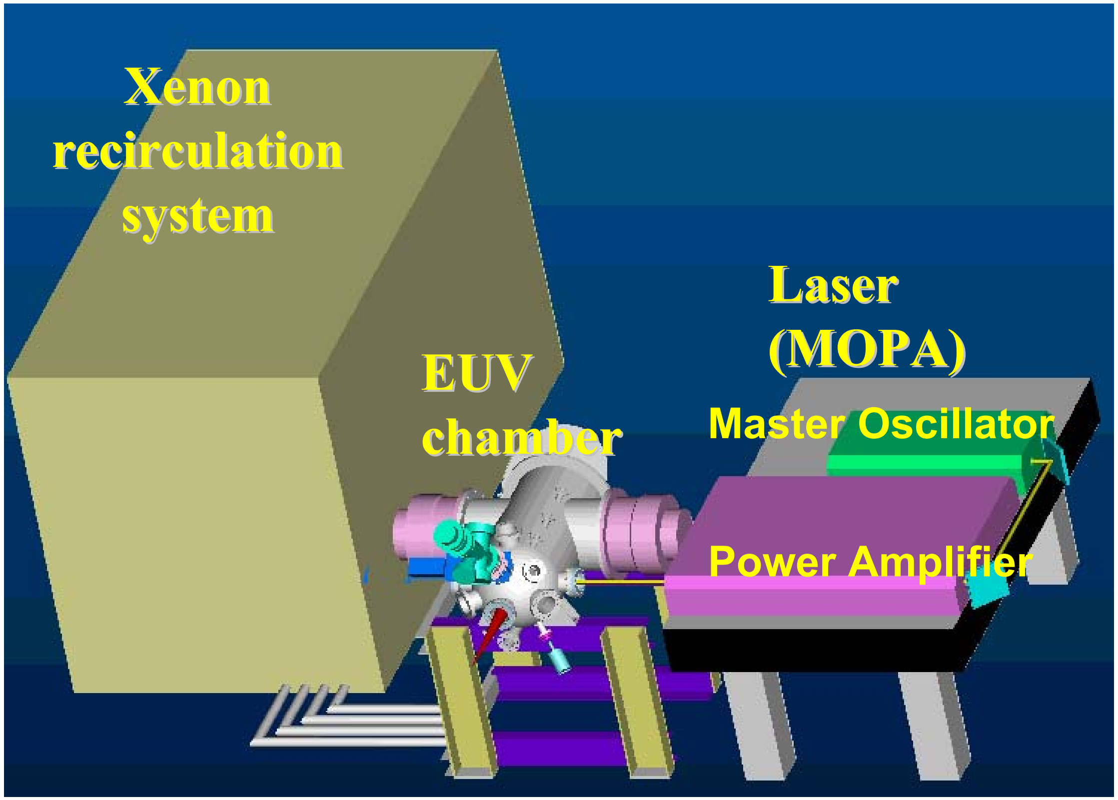
Milestone 1
4W @intermediate focus

Milestone 2
10W @intermediate focus

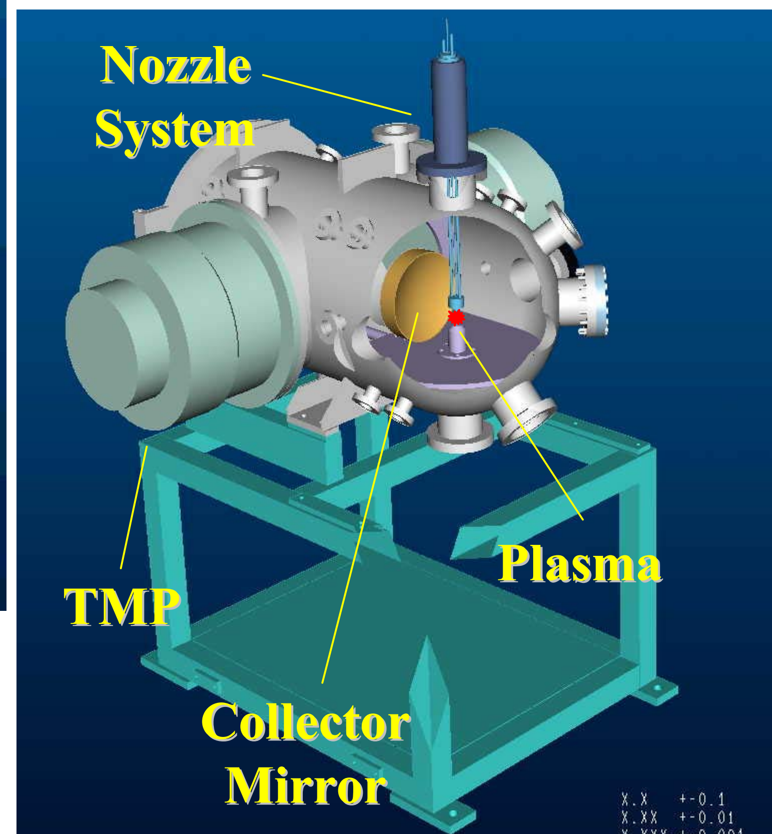


LPP System Schematic

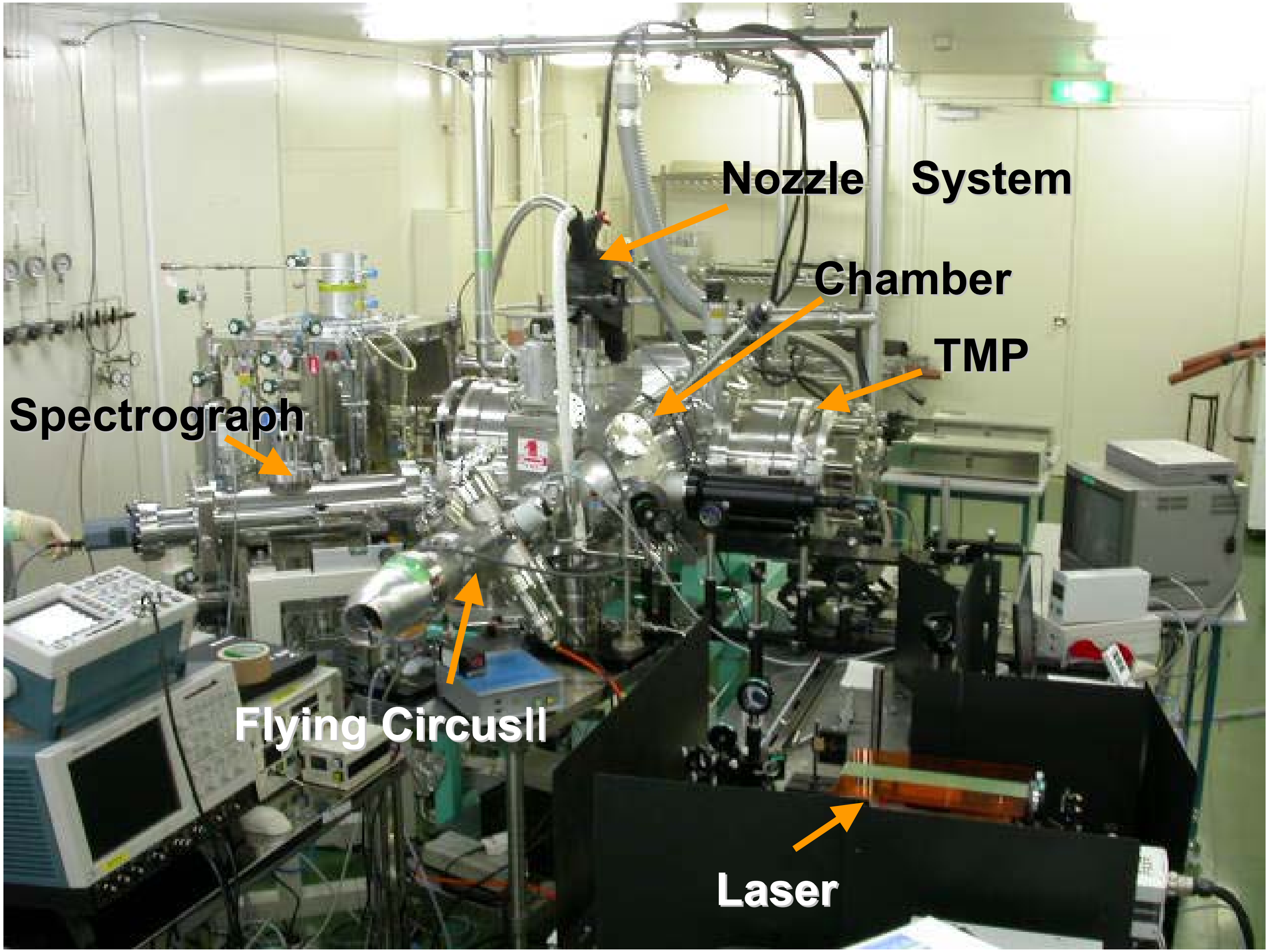
Complete EUV System



Vacuum Chamber



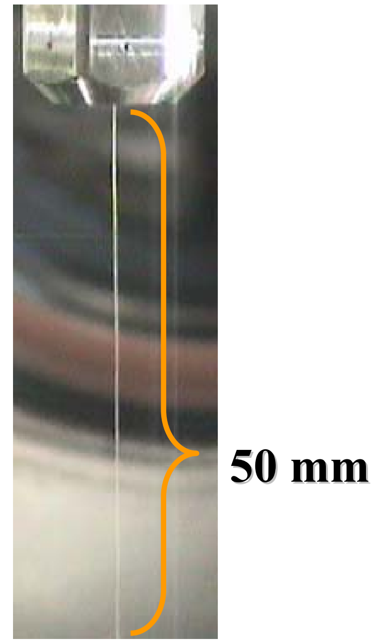
LPP System



Nozzle System
Chamber
TMP
Spectrograph
Flying CircusII
Laser

Xenon Jet Experimental Test-Stand

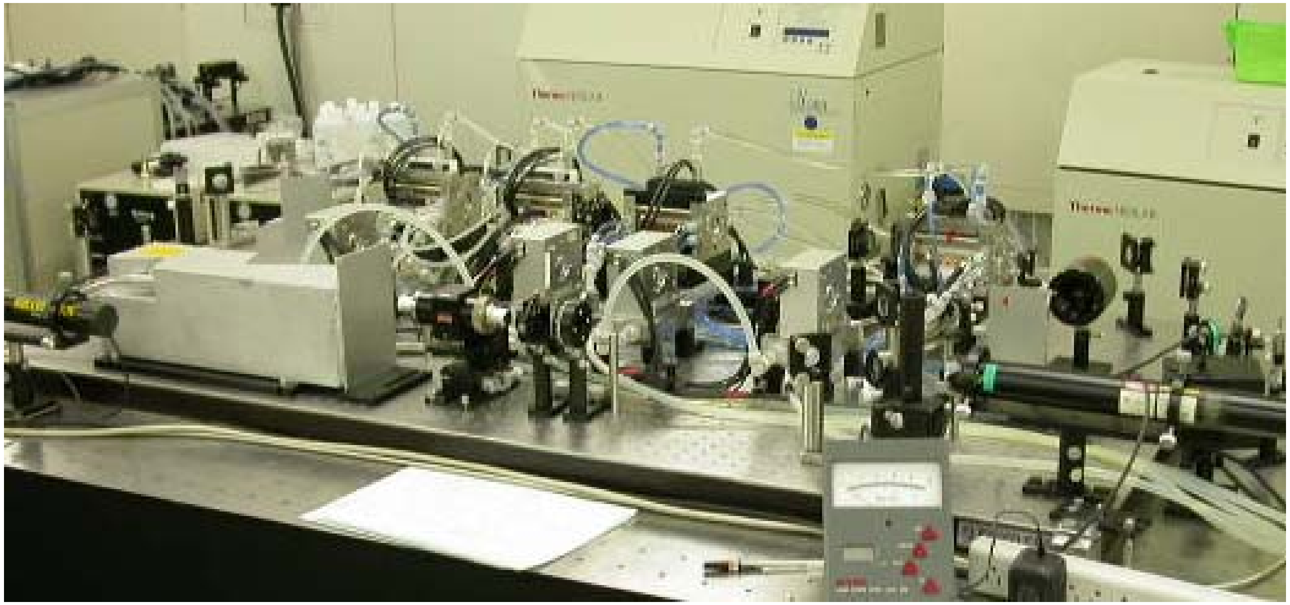
Liquid Xenon Jet System



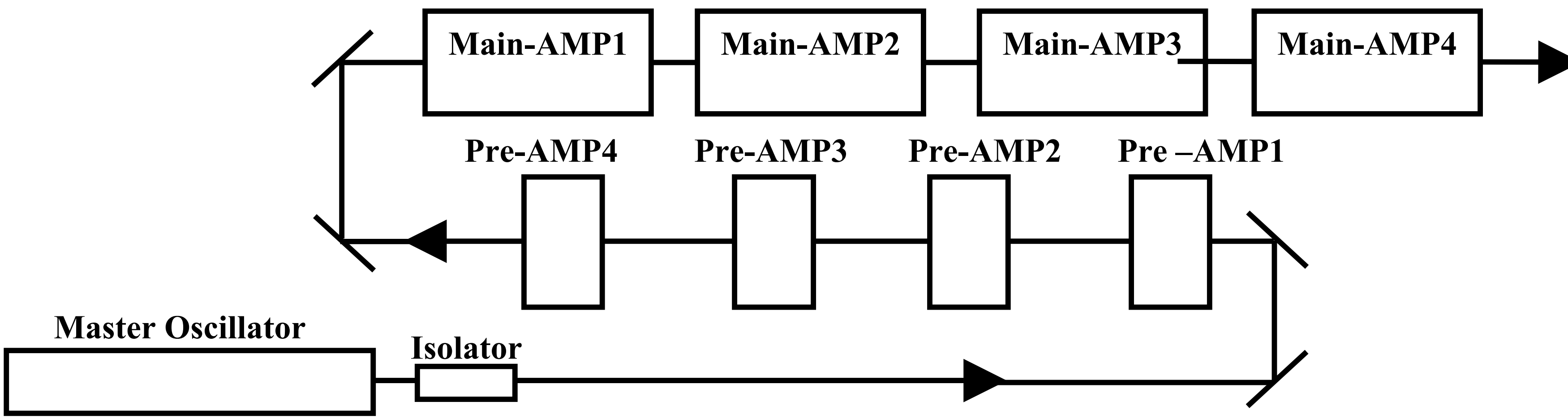
Xe Jet

Xe Temperature:	**160K - 190K**
Xe Pressure:	**<5MPa**

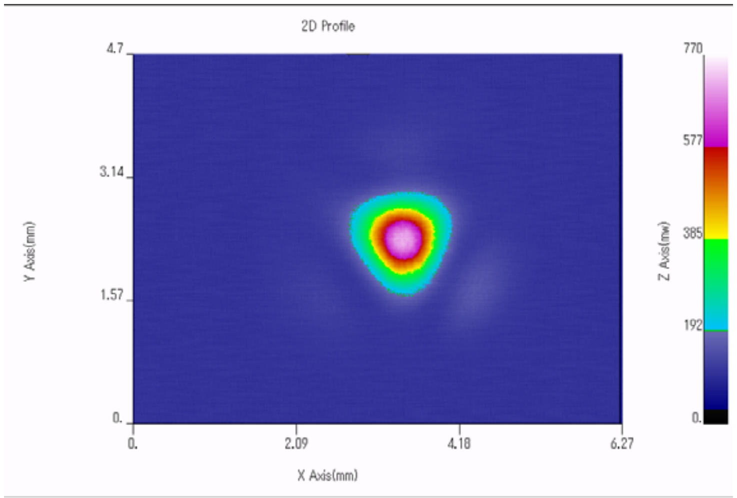
Driver Laser System - Schematic -



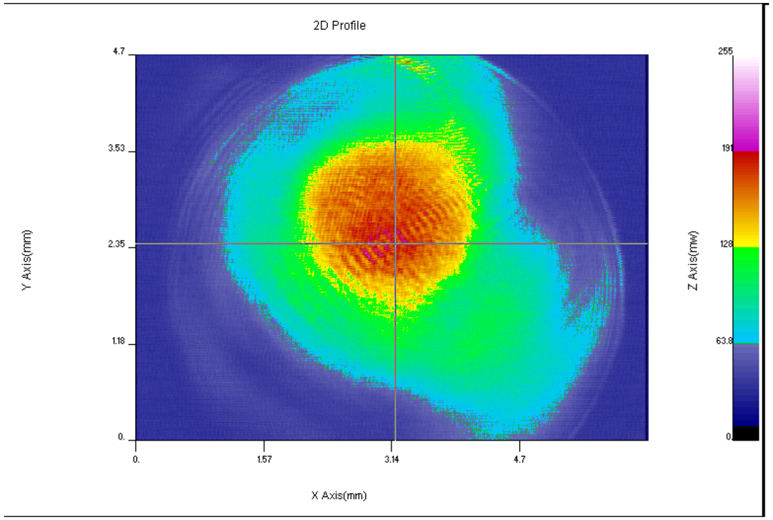
-Average Power: 500 Watt
-Rep. Rate: 10 kHz
-Pulse duration: 30 ns



Driver Laser System - *Beam Profile* -



Before Main Amplifier
60W

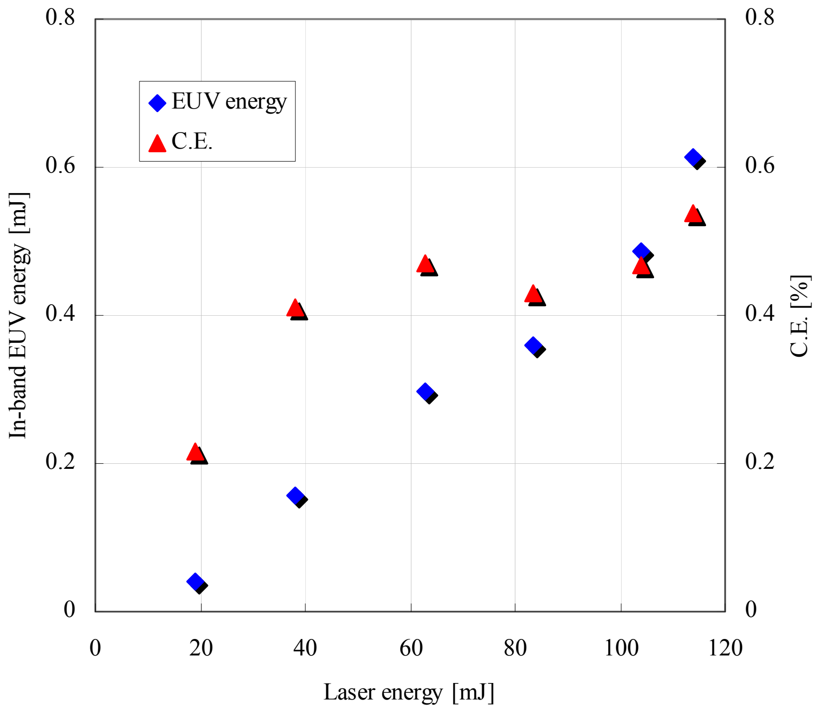


After 3-Main Amplifier
350W

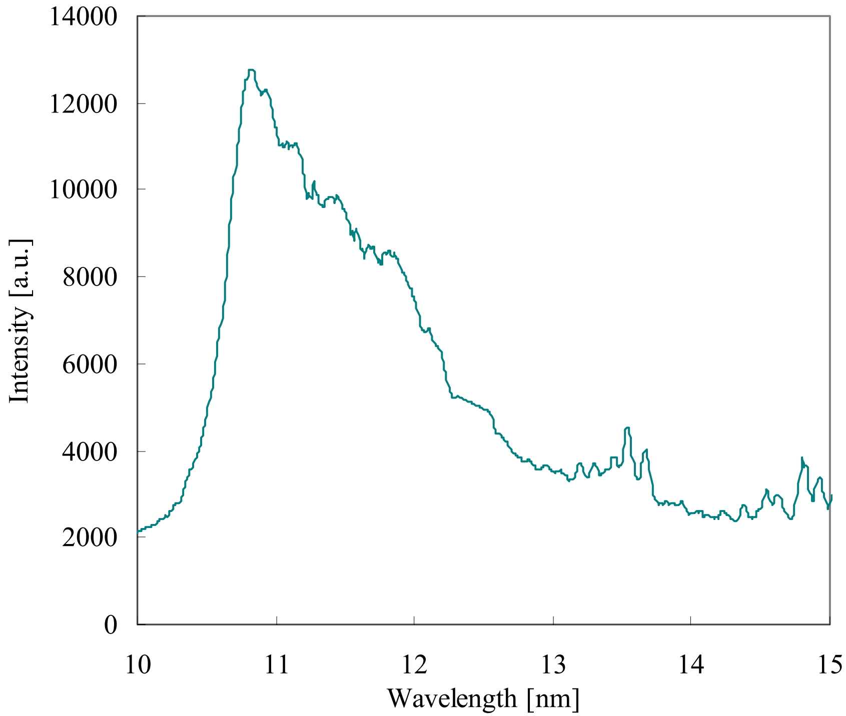
-We achieved 500 Watt @ 10kHz.
-Further driver laser system improvements:
Deformable mirror (beam quality)
Shorter pulse duration oscillator (several ns)

Characteristics of EUV Radiation

EUV Energy



EUV Spectra



-In-band EUV energy: 0.61 mJ

-Conversion efficiency (C.E.): 0.53% (2%BW, 2π sr)

DPP Development

Mar. 2003

Construction of an experimental system.

Primary source evaluation.

5W
(primary source)

Middle 2004

Build collector optics into chamber.

Improved high repetition pulse power generator.

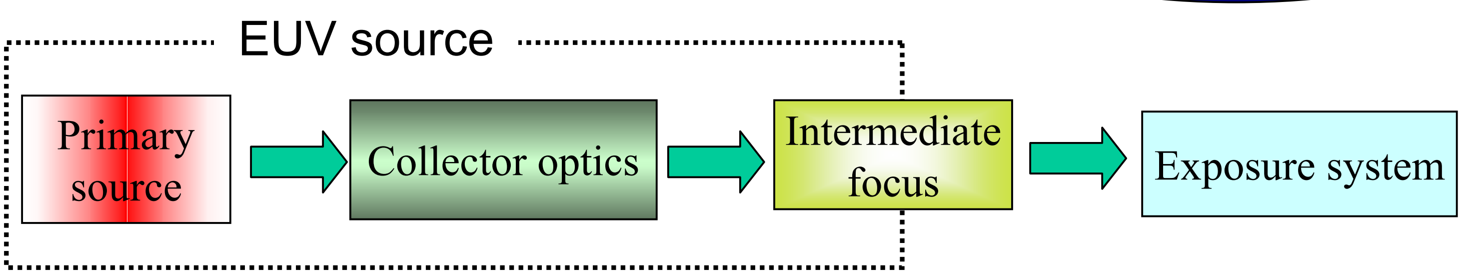
Milestone 1
4W @intermediate focus

Mar. 2006

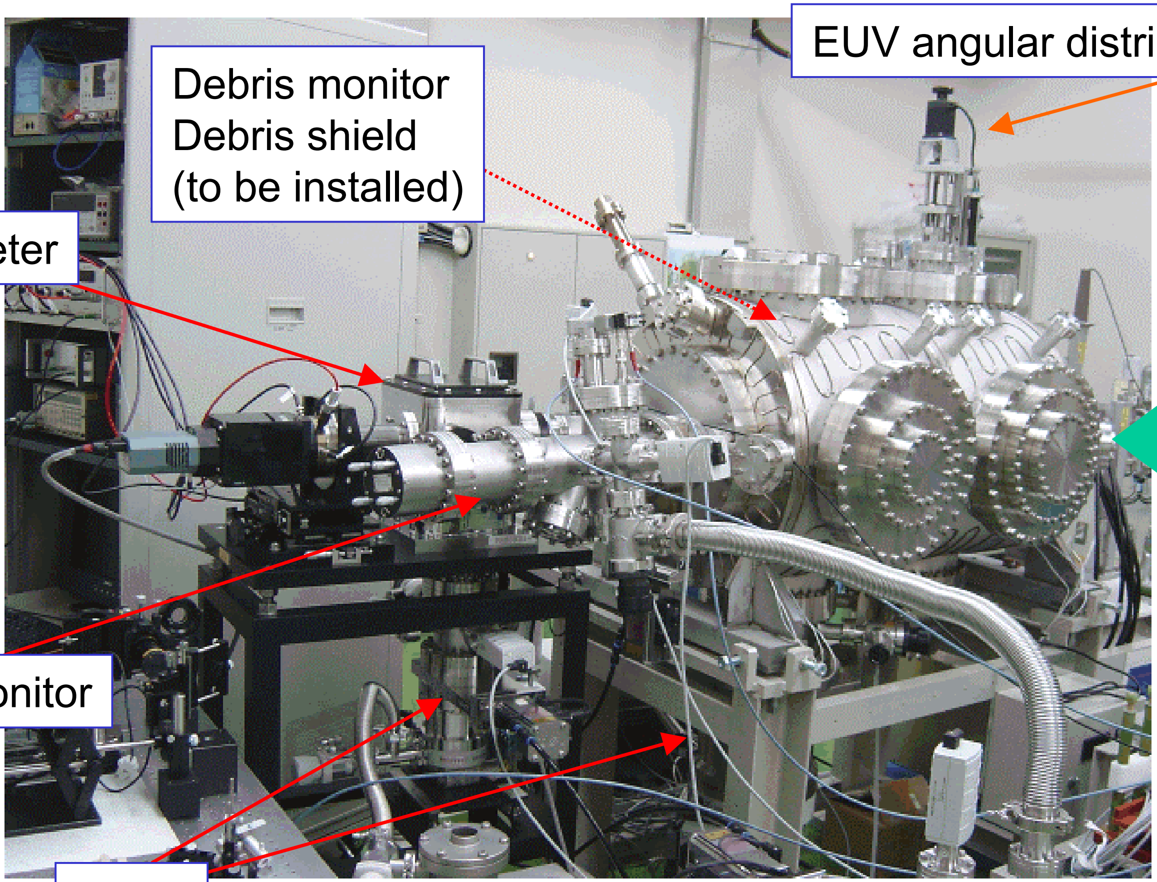
Higher power and longer lifetime.

Debris mitigation,thermal management.

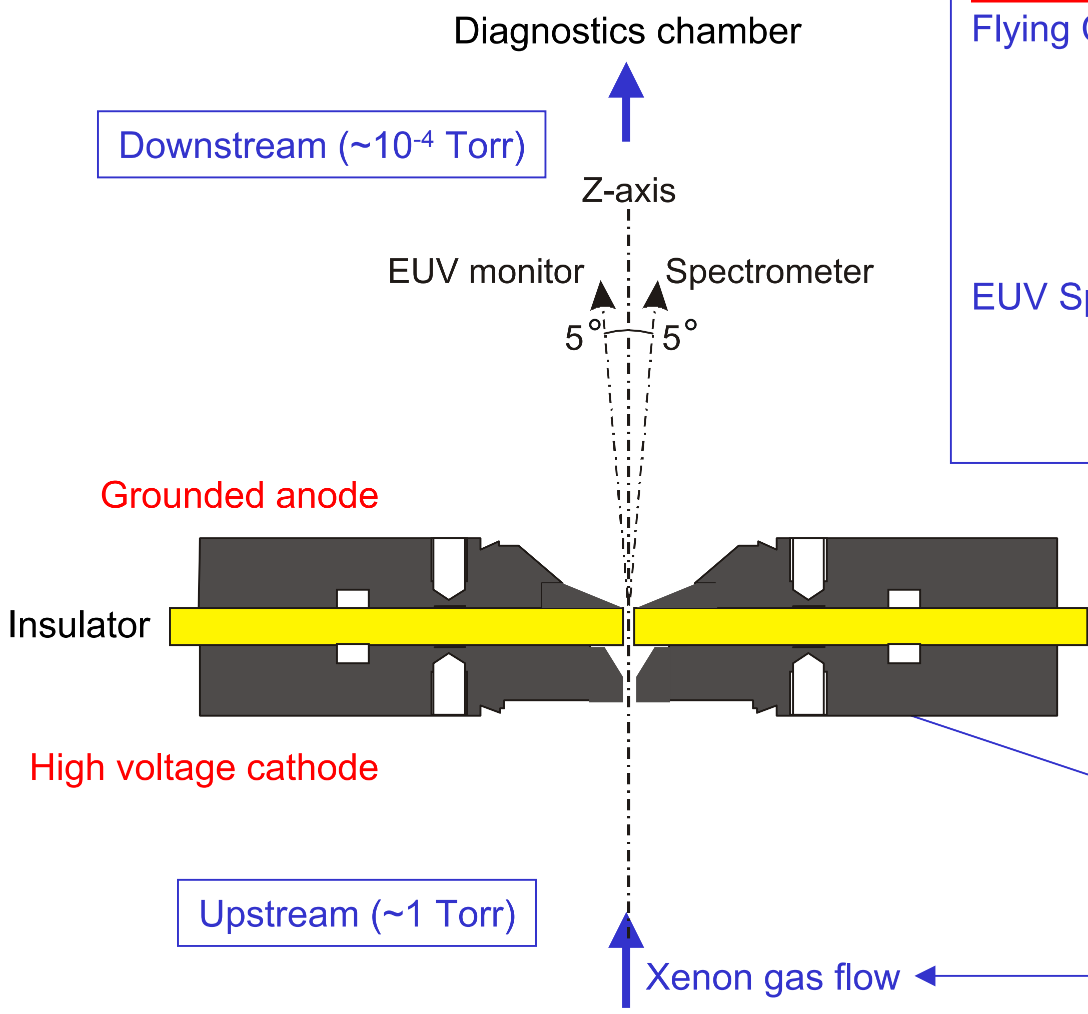
Milestone 2
10W @intermediate focus



Picture of EUV Diagnostics System



Capillary Z-pinch Discharge Head



EUV detectors

Flying Circus II (Scientec Engineering)
- ϕ200 mm, r=500 mm,
- Mo/Si, multi-layer concave mirror
- + Zr filter (Luxel Corp., 150-nm thick)
- + AXUV-100G (IRD Inc.) photodiode
  - 9-V biased, 50-Ohm terminated

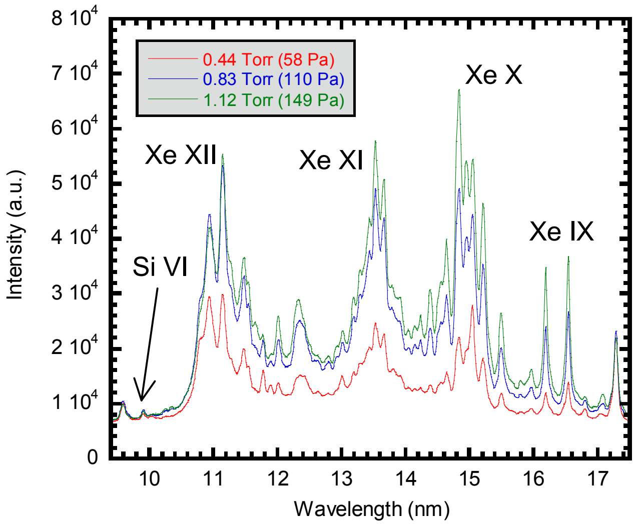
EUV Spectrometer
- 9-17 nm
- 1200 g/mm
- 2-stage MCP + CCD

Capillary
- Material : silicon carbide (SiC)
- Diameter : 2.3 mm
- Length : 6.0 mm

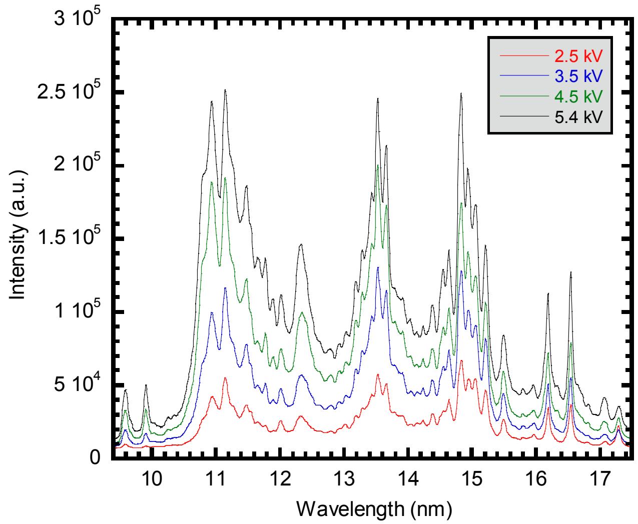
Filled gas
- Xenon
- Controlled by mass-flow controller

Comparison of EUV spectra for the voltage scan and the gas-pressure scan

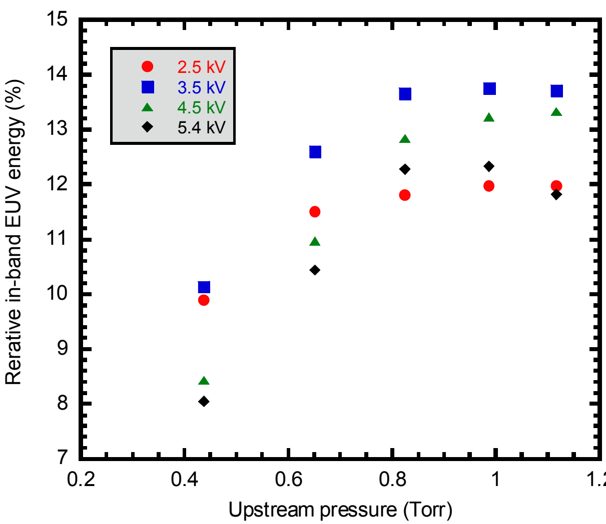
EUV spectra for 2.5 kV of charging voltage



EUV spectra for 1.12 Torr (149 Pa) of upstream gas pressure



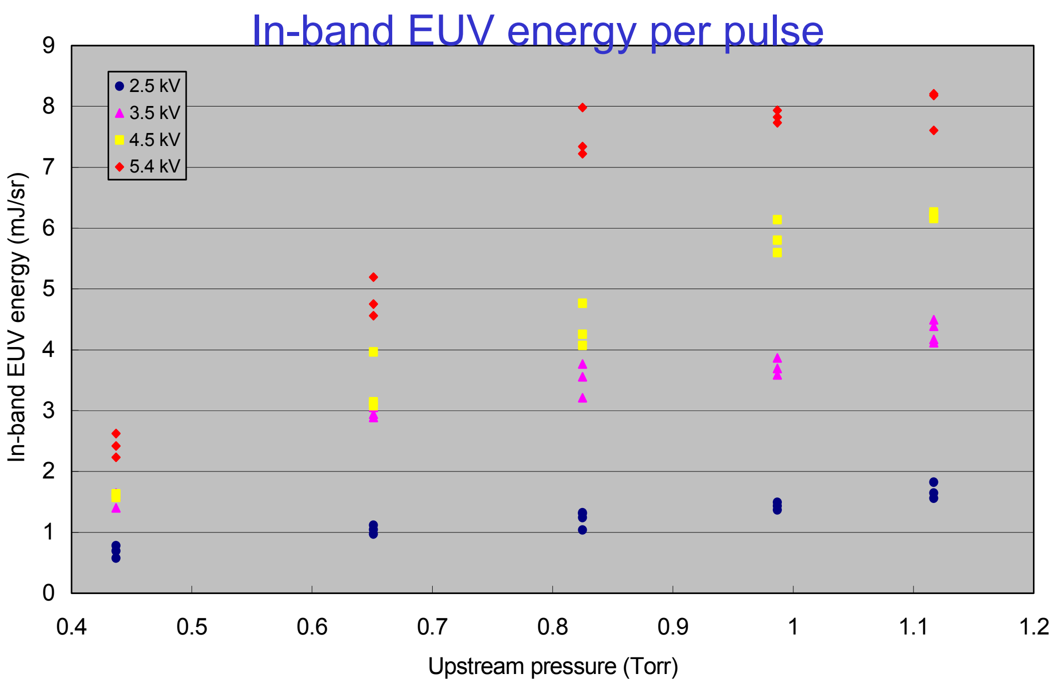
Relative spectral in-band EUV energy

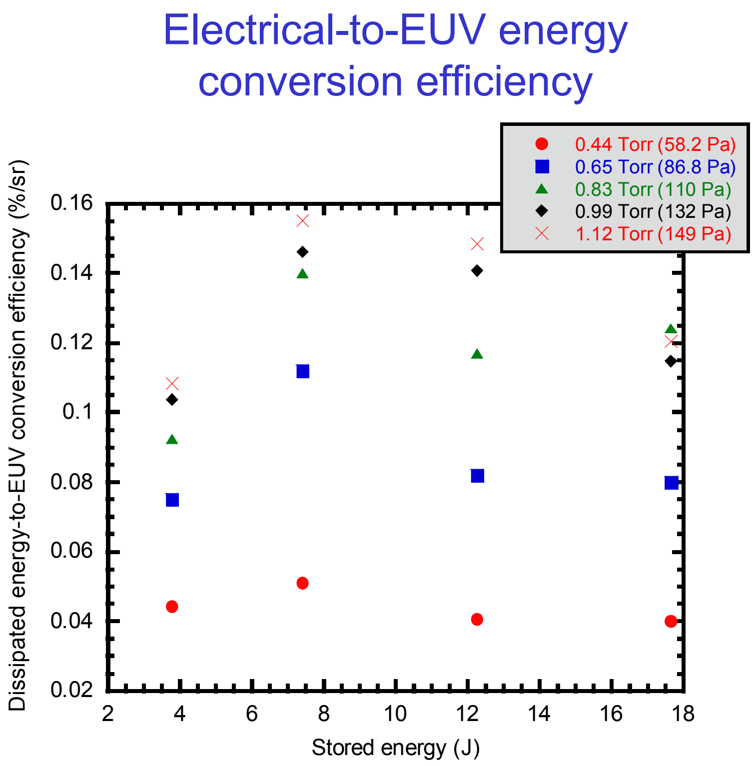


$$\text{Rerative in-band spectral energy} = \frac{\int_{13.23\text{nm}}^{13.77\text{ nm}} I(\lambda)d\lambda}{\int_{9.37\text{nm}}^{17.46\text{ nm}} I(\lambda)d\lambda} \times 100\ [\%]$$

- Higher gas pressure caused increase both in spectral intensity and relative in-band spectral intensity.
- Higher current caused increase in spectral intensity. However, relative in-band spectral intensity decreased for 4.5 and 5.4 kV of charging voltage.
- Higher current resulted in higher spectral intensity of Si VI lines. It means the higher debris generation for the given experimental parameters.

Dependencies of EUV energy on gas pressure and conversion efficiency on stored energy for unit solid angle





- EUV energy increased in proportion as gas pressure increased, and was in proportion to stored energy of the generator.
- 7.4 J of stored energy showed the highest conversion efficiency for the given current pulse and capillary load configuration at any gas pressure.

Development Activities

Top 3 issues of technology development

Issue 1 EUV conversion efficiency :

Optimization of the plasma

(Pump pulsewidth, Size, density, Lower reabsorption)

Issue 2 Thermal management:

Efficient cooling(Mirror & Chamber)

Issue 3 Background Gas absorption:

Efficient pumping, prevent diffusion

Topics for Precompetitive research/development

Topic 1 Higher Repetition Rate

Topic 2 Uniform Emission

Topic 3 Stability Improvement

Update EUV Source Development Roadmap

EUV Source Performance Roadmap

Metrics	Mar-03	Sep-04	Mar-06
Demonstrated collectable EUV power in a 2% spectral bandwidth in the region between13-14nm (W)	LPP 1 W DPP 5 W at primary source	>4	>10
Available collection solid angle (sr)			$>\pi$
Etendue (mm2str)	-	<1	<1
Demonstrated maximum repetition rate (kHz)	1	>5	>5
Demonstrated steady state repetition rate (kHz)	1	>5	>5
Dissipated total power in source region (at steady state) (kW)	1	2.5	5
Source-facing condenser lifetime (# of pulses to 10% reflectance loss)	-	-	$>5\text{x}10^8$
Pulse to pulse intensity stability (3σ)		<10%	<10%
Pulse to pulse angular stability (3σ)		<10%	<5%
Key risk areas	Efficiency/Thermal		

Summary

Achieved performance

LPP

- Average power of Driver laser ~500 Watt@10kHz
- Plasma Target Xe jet
- EUV in-band energy per pulse ~0.61 mJ / 2%BW , 2π sr
- EUV conversion efficiency ~0.53 % / 2%BW , 2π sr

DPP

- EUV in-band energy per pulse ~8 mJ/sr
- EUV conversion efficiency with Xe ~0.15 %/sr
- Repetition rate
  - Continuous mode operation 10Hz
  - Burst mode operation 400Hz

Acknowledgements

This work was performed under the management of

Extreme Ultraviolet Lithography System Development Association

EUVA ,

a research and development program of

METI.