Japan Update

EUVA

(Extreme Ultraviolet Lithography System Development Association)

Koichi Toyoda

SOURCE TWG
2 March, 2005
San Jose

Outline

- **EUVA**
  - **LPP at Hiratsuka R&D Center**
  - **GDPP at Gotenba Branch Lab.**
- **University**
  - **LPP research at Osaka University (Leading Project)**

Organizations for EUV source development project (Universities, National institutes, and Industries)

ILE OSAKA

MEXT ⟷ Close collaboration ⟷ *METI*

MEXT: Basic research on EUV source plasma

ILE Osaka and Atomic model group
1. EUV plasma experimental facilities
2. EUV database and simulations
3. EUV target development
4. EUV driver : 1J/5kHz/5kW

Himeji Institute of Techno.
1. High-feed Xe cryogenic target
2. mitigation of debris

Kyusyu U.
1. Sn nano-particles
2. EUV plasma with CO_2 Laser

Miyazaki U.
1. EUV absolute spectroscopy
2. Liquid droplets

METI: EUVL system R&D by EUVA

EUVA (source project div.)

- **Hiratsuka Lab.**
  Laser-produced plasma
- **Gotemba Lab.**
  Discharge-produced plasma
- AIST

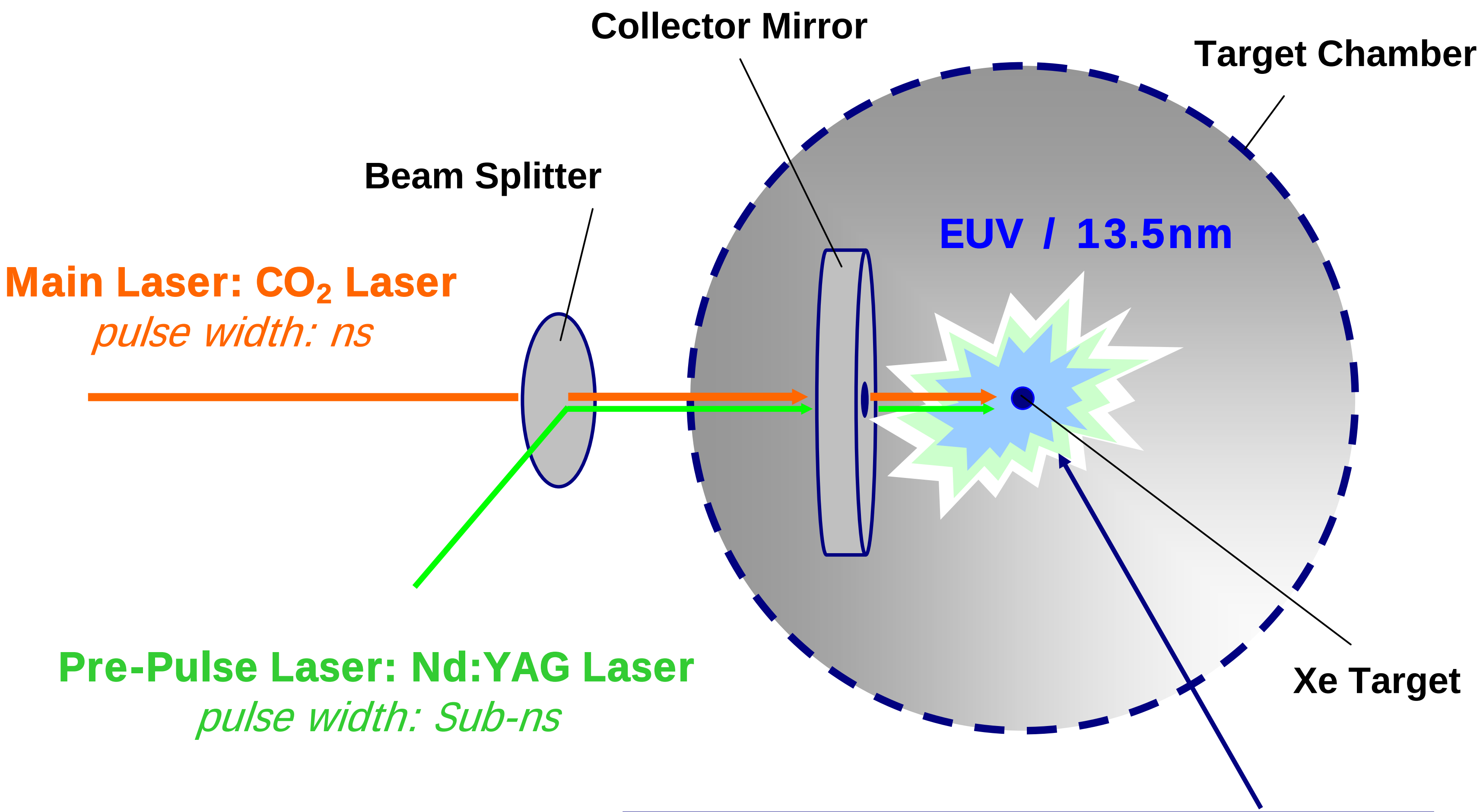
EUV

EUVA

EUV LPP Source Roadmap

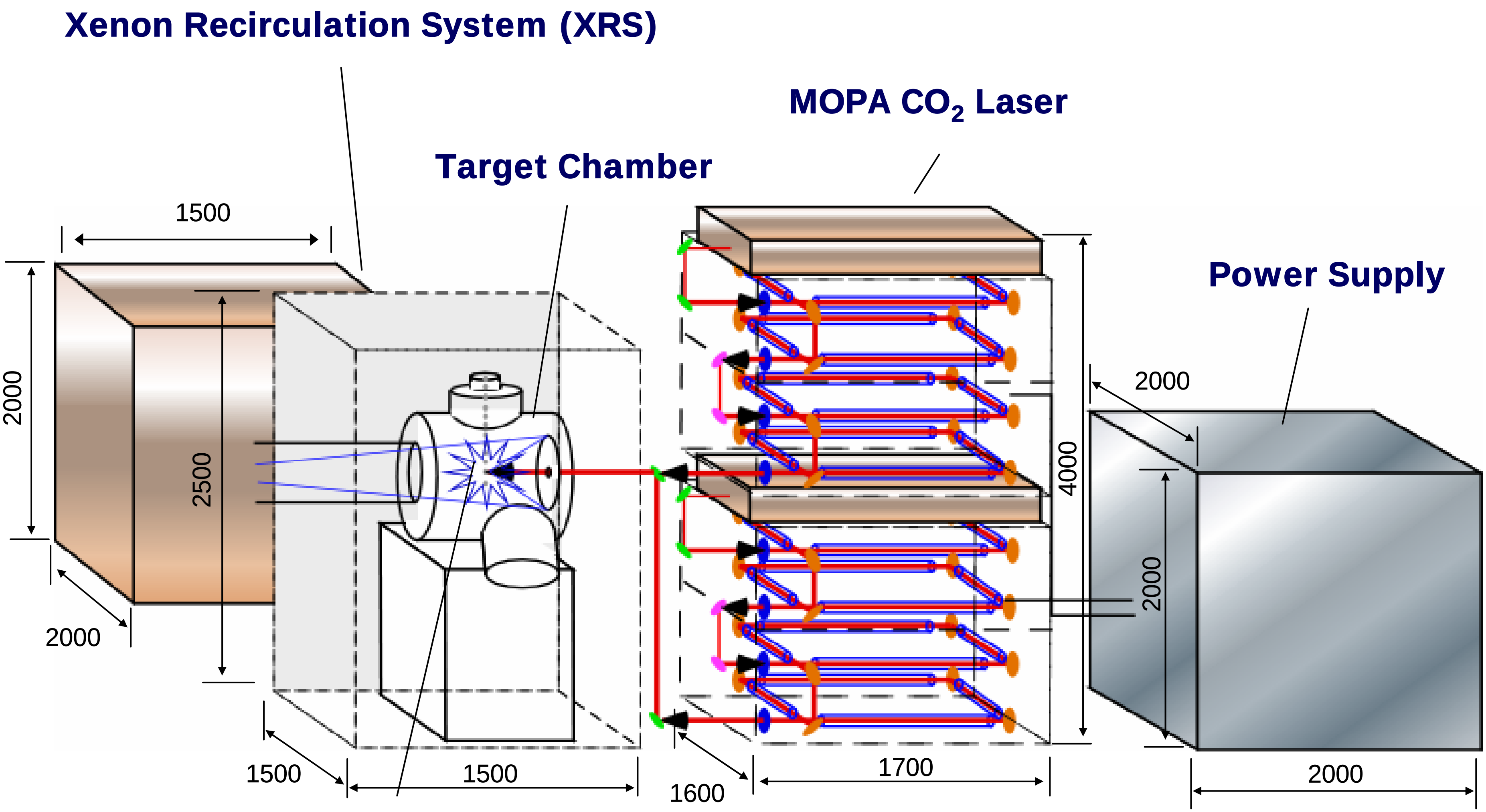
Fiscal Year	2003	2004	2005	~2008
EUV power @ intermediate focus	--	4W	10W	115W
Plasma target	Xe	Xe	Xe	Droplet
Conversion efficiency	0.6%	0.7%	0.8%	TBD
Laser power	1.5kW	2.5kW	5kW	TBD
EUV power in 2pisr 2%BW	4.0W	9.1W	40W	420W
Available collection solid angle	--	--	4sr	5sr
Repetition rate	10kHz	10kHz	10kHz	TBD
Technology for 10W **Nd:YAG Laser, Liquid Xe jet**	→	→	→	
Technology for 115W **CO_2 Laser, droplet target** **Magnetic field mitigation**			→	→

Concept of LPP source by CO_2 laser



Conversion Efficiency (CE) of 0.6 % has been obtained!

LPP source system CO_2 laser



Cost estimation of LPP light source

- **Initial Cost :** **5.6~9.0** Mill.$ @ CO_2, **21.7~31.7** Mill. $ @ YAG
- **Running Cost:** **0.55~0.82** Mill.$/year @ CO_2, **2.54~3.63** Mill.$/year @ YAG

Component \ Total (110 JYen = 1 USD)	CO_2 (C.E.=1.0~0.5%)		YAG (C.E.=1.2~0.8%)	
	Initial Cost (M$)	Running Cost (M$/year)	Initial Cost (M$)	Running Cost (M$/year)
Total	5.6~9.0	0.55~0.82	21.7~31.7	2.54~3.63
Laser System	3.7~7.1	0.32~0.43	20.0~30.0	2.29~3.33
	〈42~84kW, 100kHz〉		〈35~53kW, 10kHz〉	
EUV Chamber	1.2	0.03	1.0	0.02
Xe Re-Circulation System	0.5	0.14	0.5	0.14
Collector Mirror	0.2	0.06~0.22	0.2	0.09~0.14

※ Estimation based on:
- 115W Source Power at I.F.
- 100 units produced in 2016.
- 120 wafer/hr throughput ⇒ 21.3 Billion pulse /year @ 10kHz
  ⇒ 213 Billion pulse /year @ 100kHz

CO_2 Driver laser system for LPP

Xe droplet technology for 115W source

■ Xenon droplet for 115W source

- Irradiation interval : > 600μm
- Driver laser frequency : 100kHz

- Required droplet speed : > 60m/s

■ High speed droplet

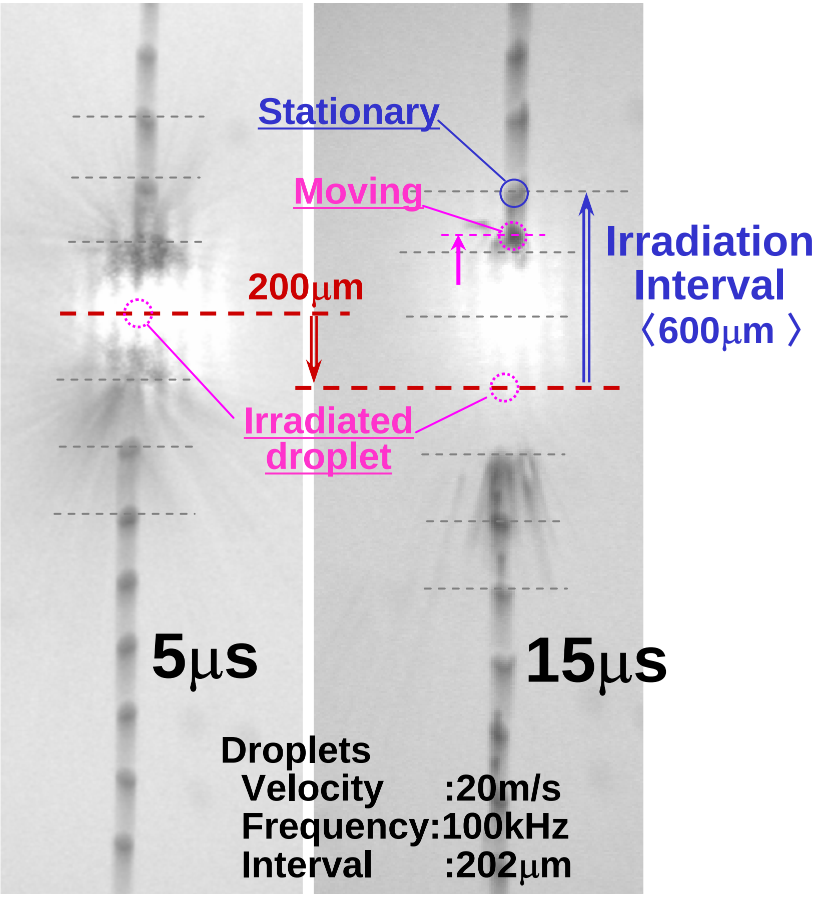
- High pressure Xe supply

$$v = \sqrt{\frac{2\Delta P}{\rho}}$$

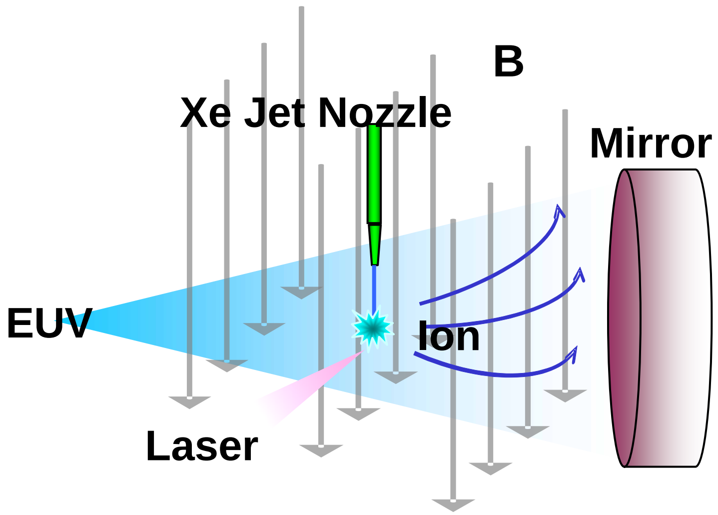
V : velocity
⊿P:Pressure
ρ :Density

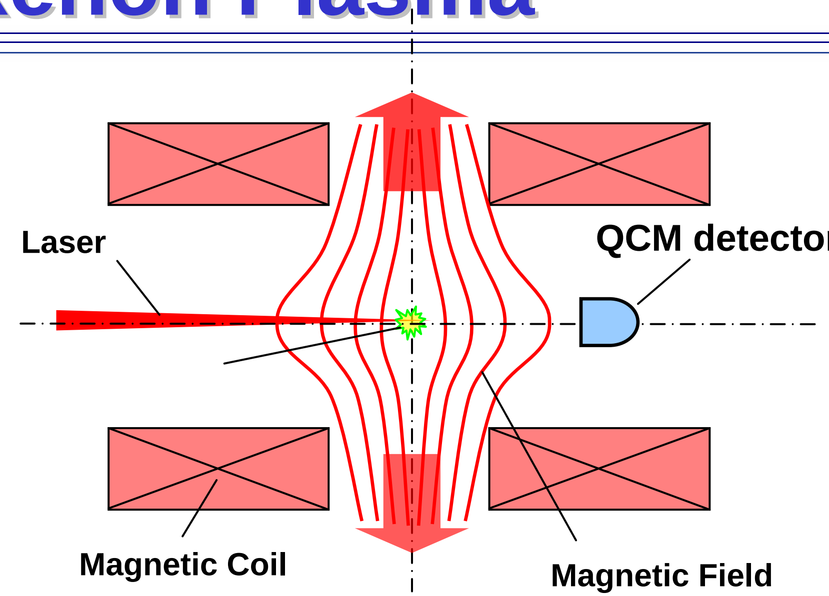
Bernoulli's theorem

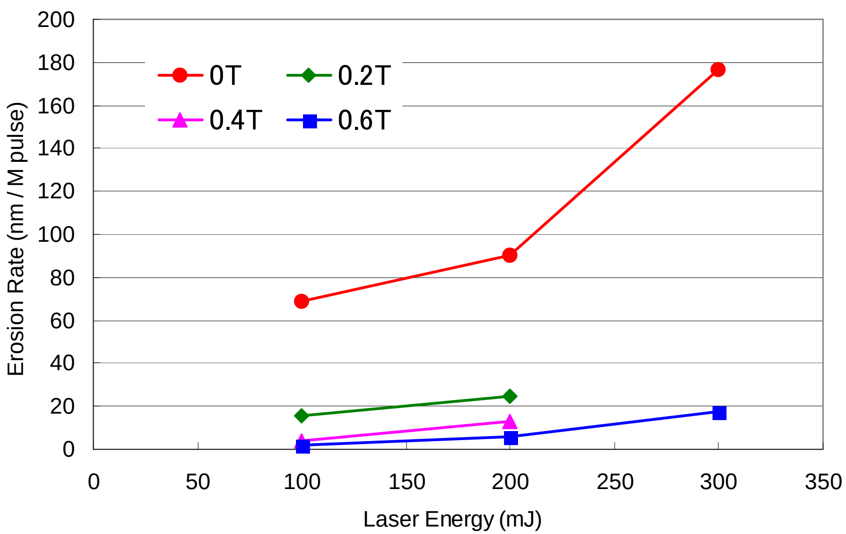
- Required Xe pressure : > 5.4MPa



Fast Ion Mitigation for Xenon Plasma







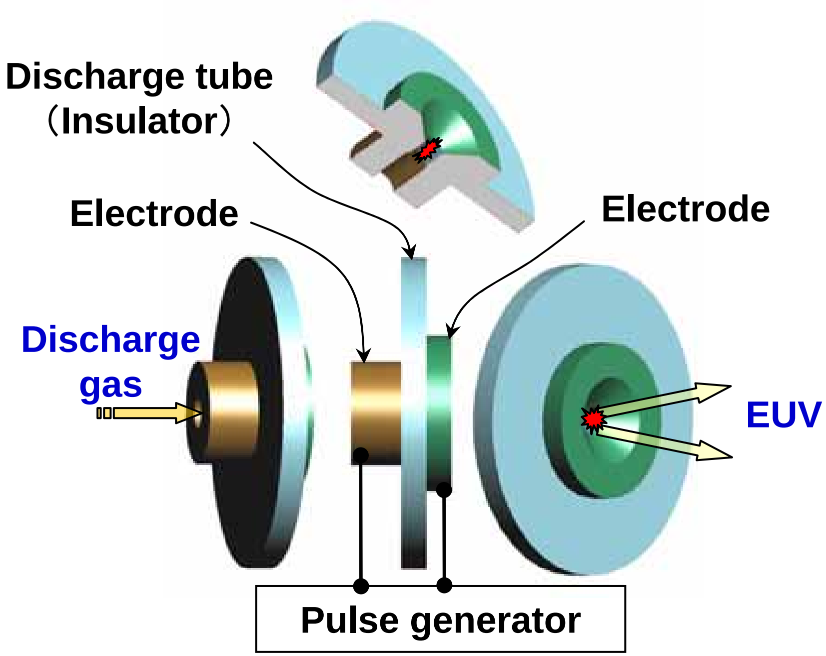
Erosion rate dependence on magnetic field and laser energy

Mirror Life Estimation

Item	Experimental Value Nd:YAG	115 W Source CO2
Laser Energy (mJ)	100	600
Mirror Distance (mm)	95	100
Laser Frequency (Hz)	10	100000
Mirror Life (M pulse)	188	35
Mirror Life with Magnet (M pulse)	5625	1039

Estimated collector mirror lifetime with magnetic mitigation is > 1B pulses.

DPP source development



Our approach

- Moderate diameter of capillary.
- Relatively low current compared to conventional Z-pinch.

- Mitigation of wall damage and effect of plasma instability.
- Small source size.

Key issues for DPP

- Increase of EUV power at intermediate focus.
- Lifetime matter of discharge head.
- Debris mitigation.

DPP performance roadmap

Metrics	Feb. 2004	Jun. 2004	Oct. 2004	Feb. 2005		1Q-2008
EUV emitter	Xe	Xe	Xe	Xe	Sn	TBD
EUV power at IF	2.7W	4.8W	8.4W	19W	47W *	> 50W
EUV emission from primary source	12.6W / 1.45sr	39.7W / 2.1sr	59.3W / 3.1sr	93W / 3.1sr	186W / pi sr **	200W / 3sr
Repetition rate	2kHz	7kHz	7kHz	7kHz	(7kHz)	7-10kHz
Energy dose stability (1 σ)	1.1%	4.9%	1.3%	1.3%	2.4%	< 0.1 %
Angular distribution stability (1 σ)	8.2%	7.9%	4.8%	4.8%	---	< 5%
Mirror lifetime (10% loss)	---	---	---	> $1x10^7$ shot	---	> $0.5x10^6$ sec

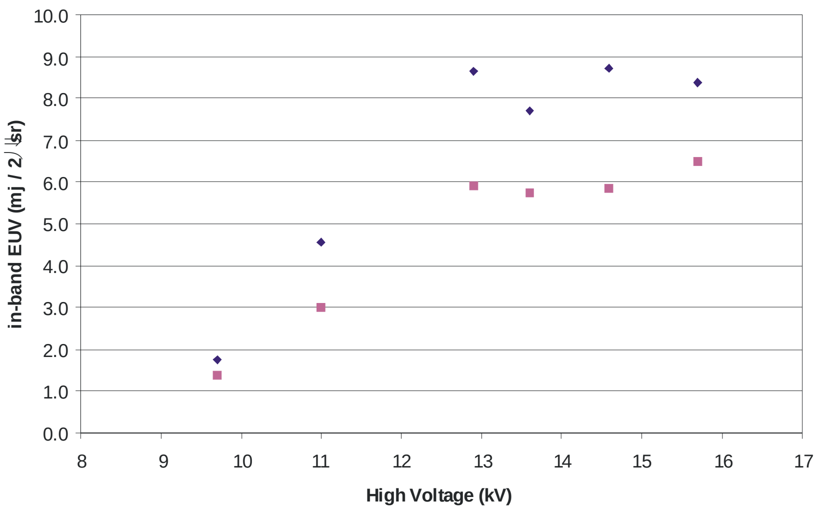
* Pi sr collector optics is assumed

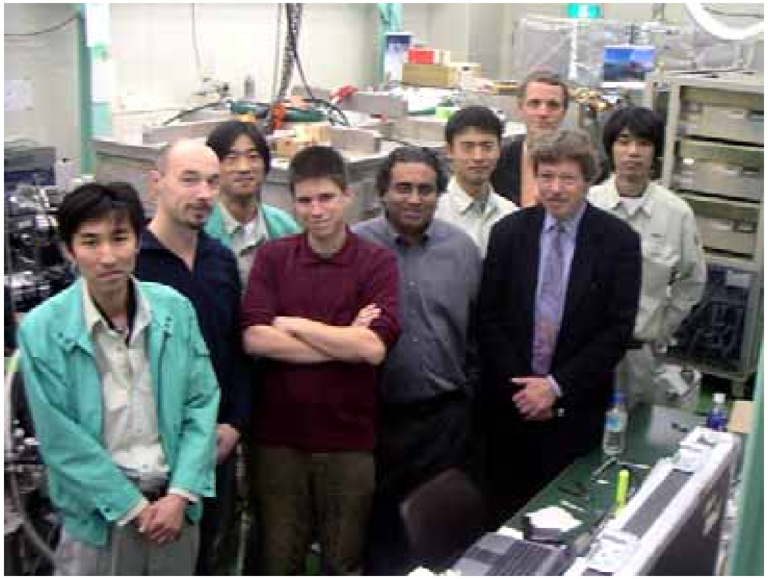
** Estimated value from low rep.-rate measurement results

Flying Circus EUVA source assessment

Flying Circus visit led to upward adjustment of results.

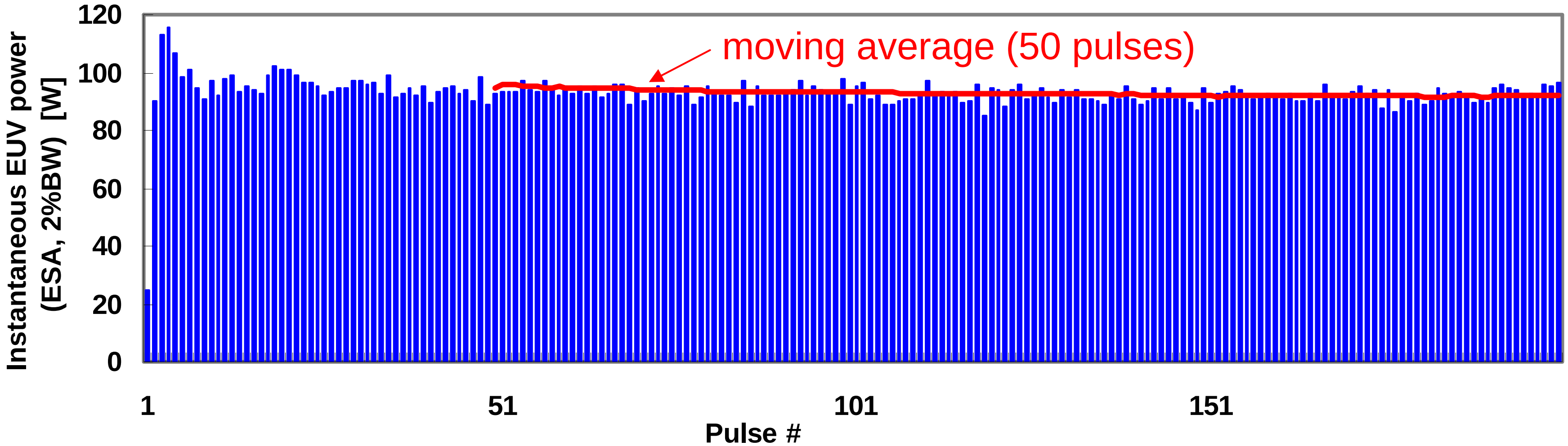
- Energy up to 8.8 mJ/sr (2%BW) @5 Hz
- Source size @200 sccm: ϕ0.17 x L0.8 mm / 80% area ϕ0.24 x L0.82 mm

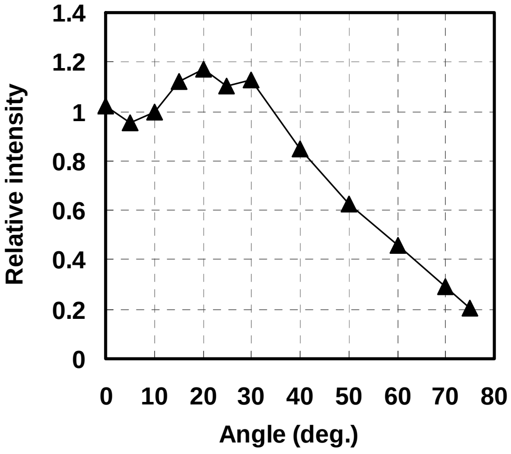




Santi Alonso vd Westen, Caspar Bruineman, Fred Bijkerk, Vivek Bakshi

Performance of primary source





Angular distribution

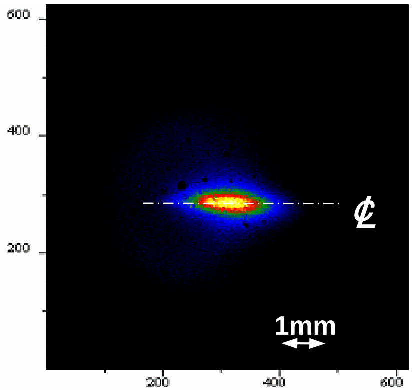
7kHz operation :

Effective solid angle = 3.1 sr

Average EUV power (2%BW) = 93W / 3.1sr (189W / 2 pi)

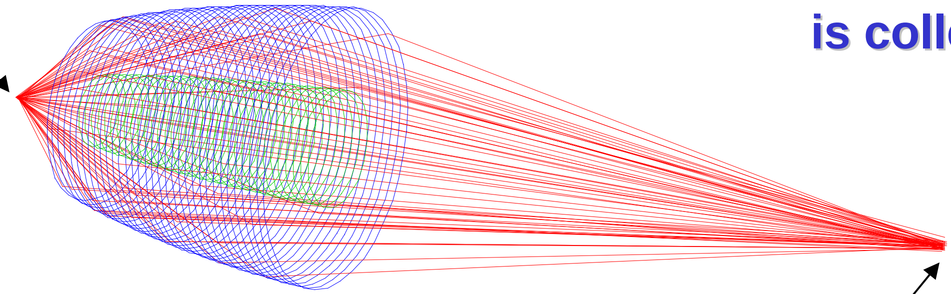
Integrated energy stability (50 pulses, sigma) = 1.3%

Usable power at IF



Source EUV image

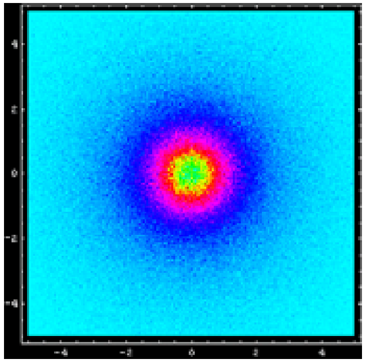
Primary source
(d= 0.5, L= 1.56)



Collector mirrors
(Grazing-incidence)

Focus

28% of source power is collected to I.F.



Focus image

Grazing-incidence collector with cooling line

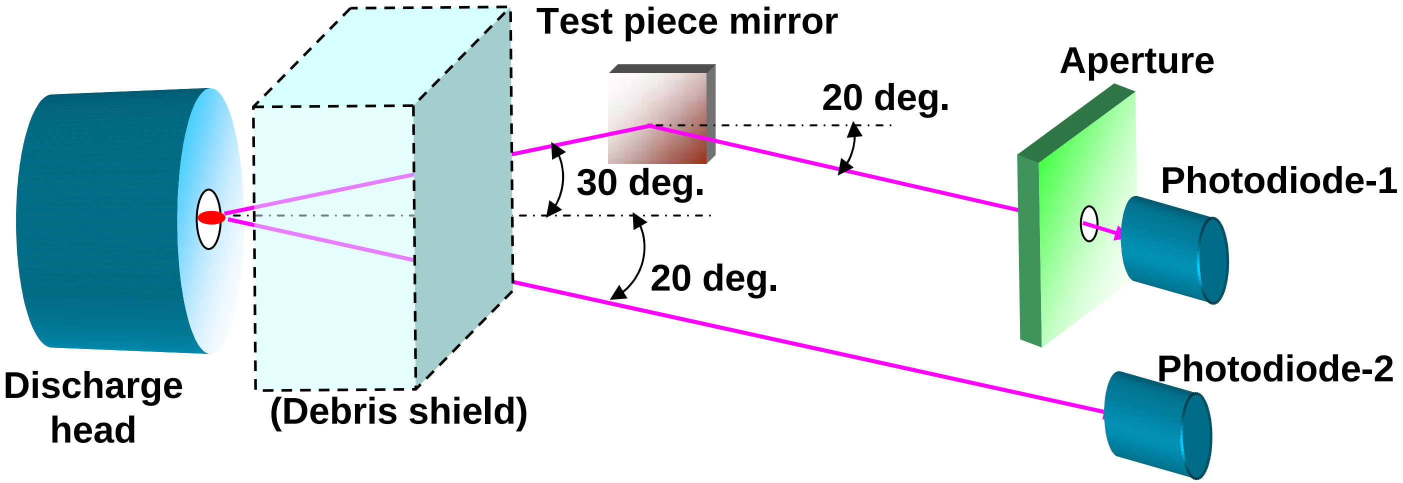
Primary source : 93W

Collection efficiency : 28%

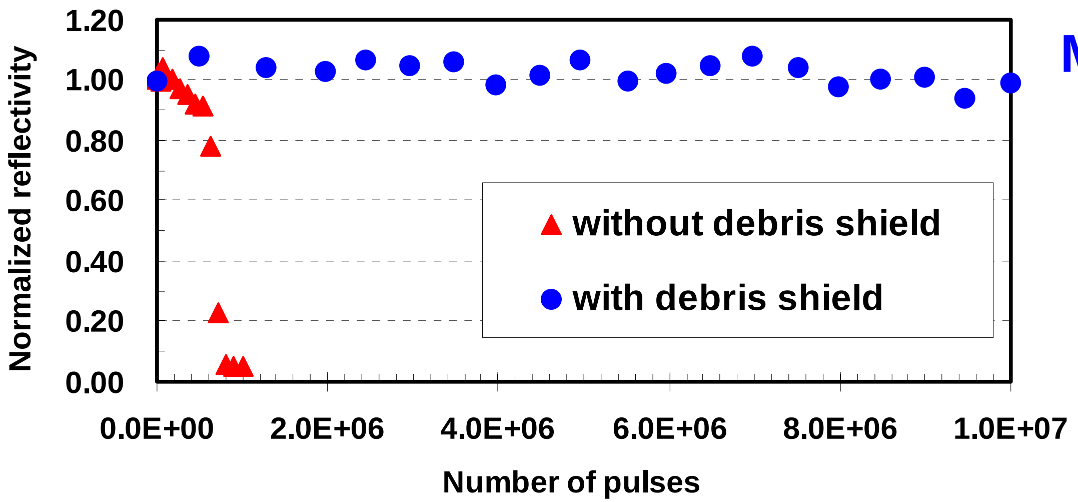
Transmission (gas, shield) : 72%

I.F. power = 19W

Mirror lifetime: reflectivity monitoring



Reflectivity degradation monitor for grazing-incidence mirror

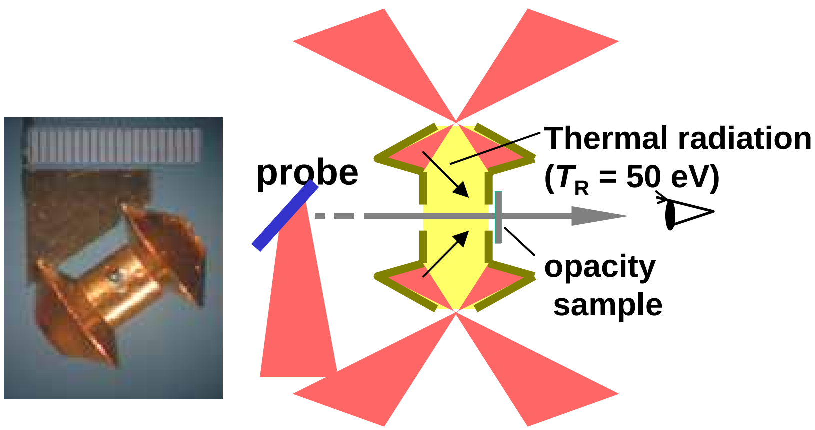


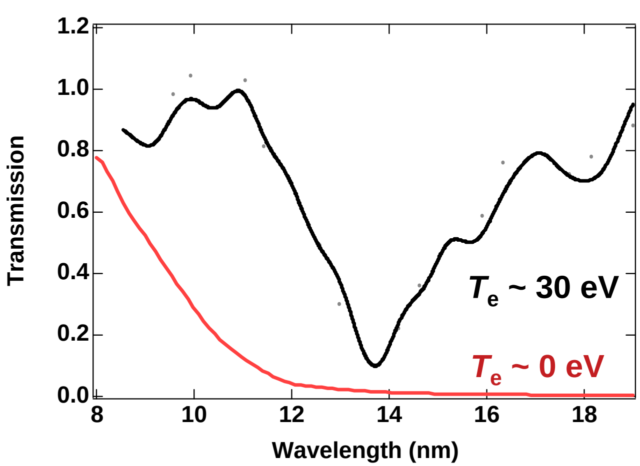
Mirror lifetime:

$>1\times10^{7}$ shots demonstrated.

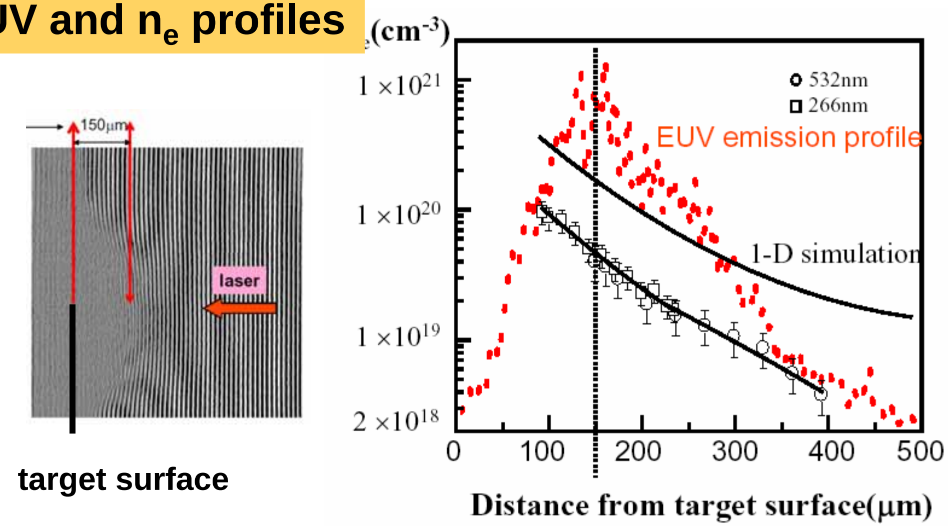
Emission and absorption of LPP Sn plasma are well characterized using J- to kJ-class lasers.

opacity measurement

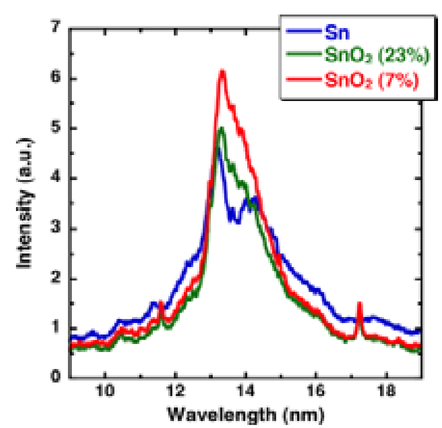


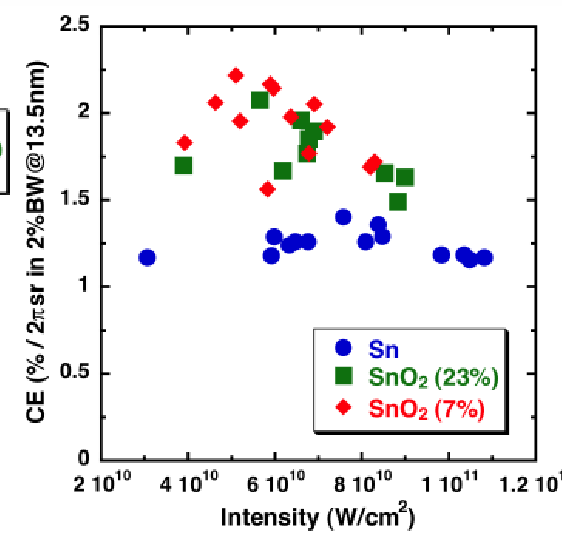


EUV and n_e profiles

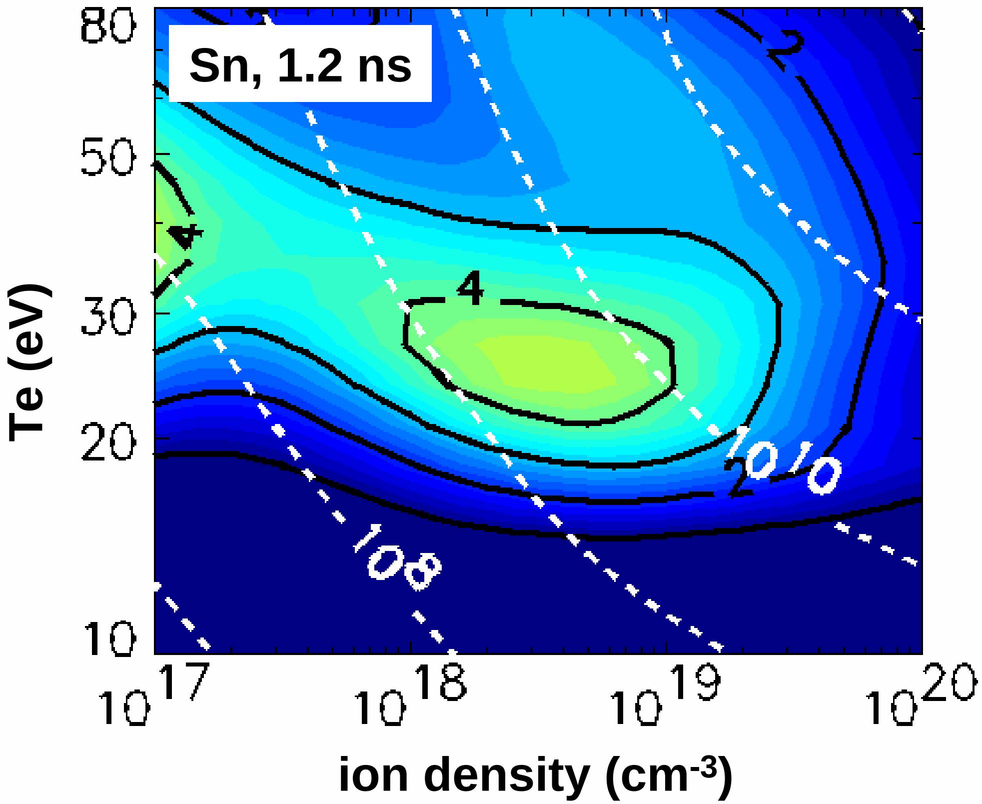


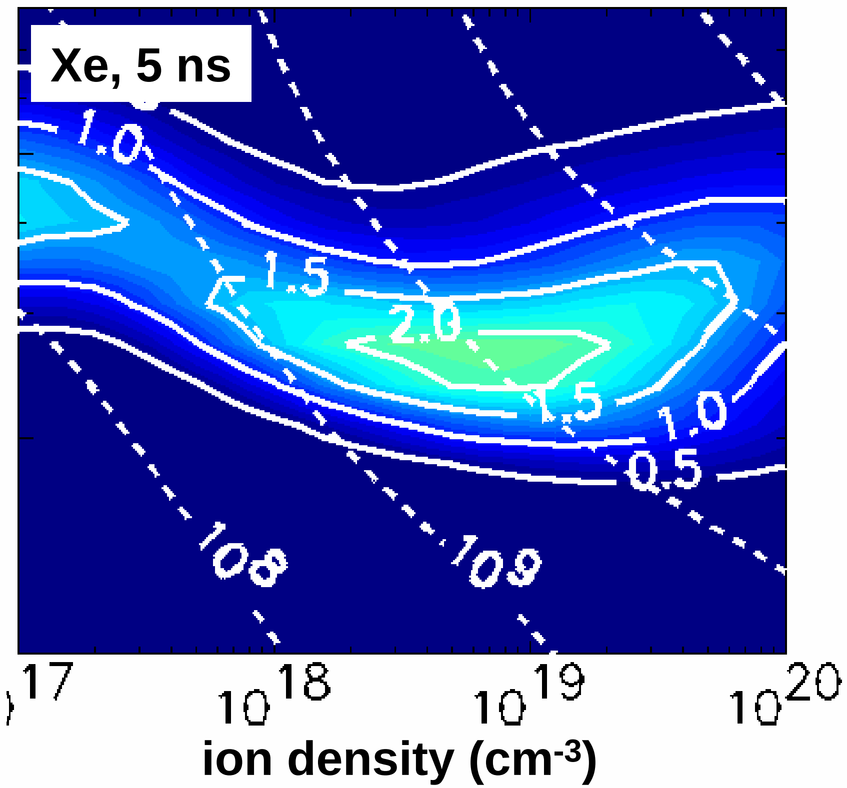
low-density SnO_2

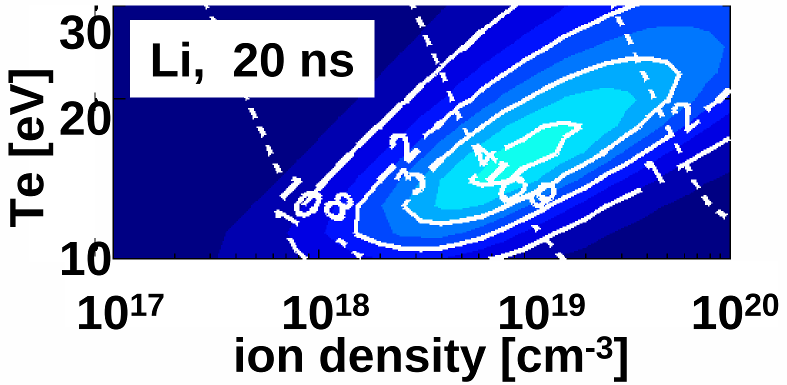




We have theoretically investigated optimum conditions of laser wavelength, intensity and pulse duration to lead to the maximum conversion efficiency for tin, xenon and lithium.

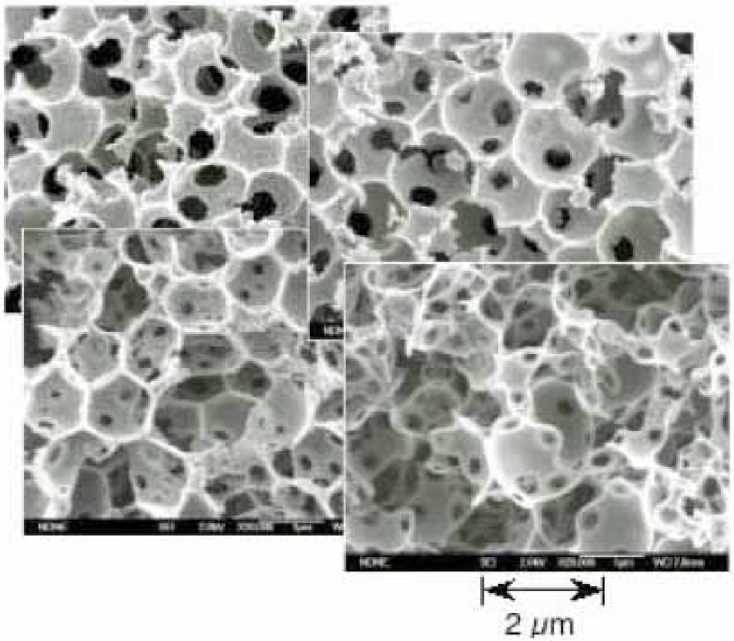






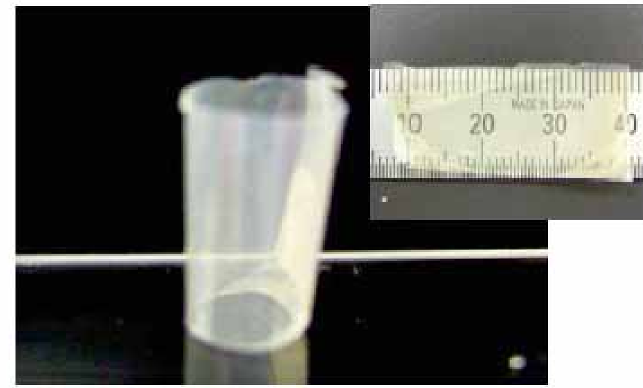
Fabrication of Sn-based low-density, mass-limited targets

Morphology controlled SnO_2



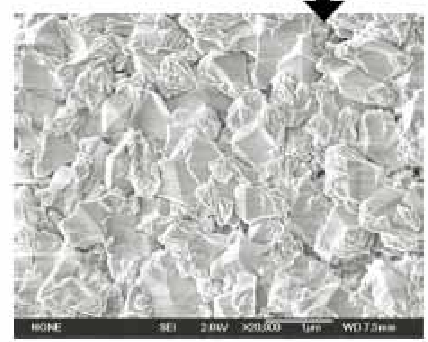
Density: 0.5 g/cc (7% of Bulk)

Tape (sheet) target



Polymer/Sn composite film

sintering



Density: $1.9 g/cm^3$
(28% of bulk SnO_2)
Nanocrystalline
Grain size: 10 nm

1) K. Nagai, et al. Trans. Mater. Res. Soc. Jpn, **29**(3), 943-946, (2004).
2) Q. Gu, et al. *Chem. Mater.*, **17** (5), 1115-1122, (2005).

Summary

Achieved performance

LPP

by YAG laser

- In-band Power 4.0 W (2%BW) at IF <Estimate>
- Conversion Efficiency 0.85 % @ 10Hz (2%BW, 2π sr)

by CO_2 laser

- Conversion Efficiency 0.6 % @ 10Hz (2%BW, 2π sr)
- Short Pulse 6kW CO_2 laser is under development ~ autumn, 2005

DPP

by Xe target

- In-band power 93 W (2%BW, 3.1 sr) at Primary Source
  19 W (2%BW) at IF
- Mirror lifetime $>1\times10^7$ shot (10% loss)

by Sn target

- In-band power 186 W (2%BW, π sr) at Primary Source <Estimate>
  47 W (2%BW) at IF <Estimate>

Main target for 2008 : 115 W (intermediate focus)

Acknowledgements

This work was performed under the management of the

Extreme Ultraviolet Lithography System Development Association

EUVA ,

a research and development program of

NEDO.