Development Status of HVM Laser Produced Plasma EUV Light Source

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EUVA

(Extreme Ultraviolet Lithography System Development Association)

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Outline

- Background and development roadmap
- EUV light source by CO_2 laser driven Sn droplets
  - High-power CO_2 laser
  - Sn droplet target
  - Characterization of Sn debris
- Latest result and summary

LPP Source Roadmap

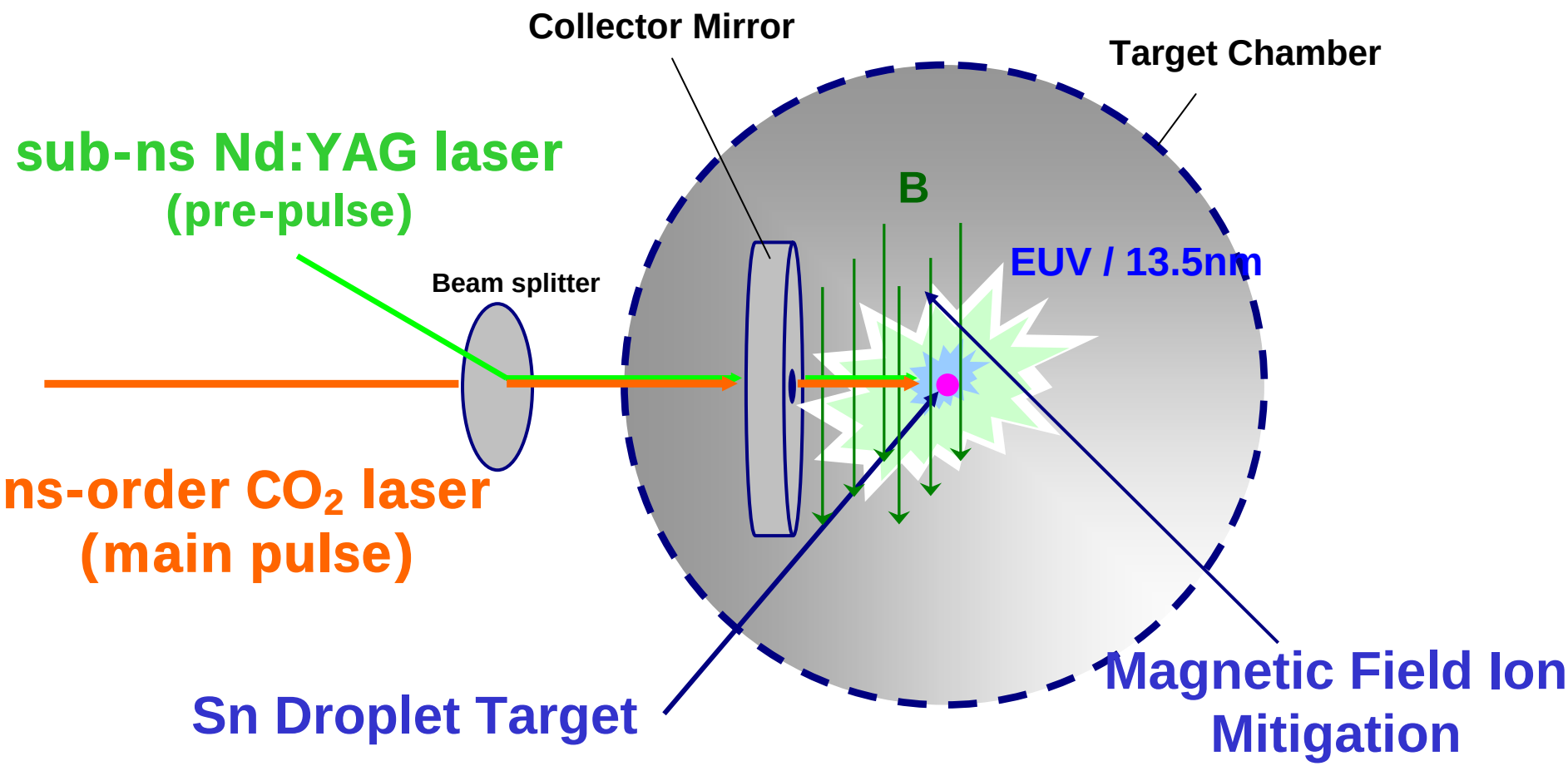
	1st Mid term 2004/9	2nd Mid term 2006/3	EUVA Final 2008/3	Commercial Machine(2009)
EUV Power (IF)	5.7W 1)	10W 1)	50W 2)	115W 2)
Stability	---	$\sigma<\pm10\%$	$\sigma<\pm5\%$	$3\sigma<\pm0.3\%$
Laser	YAG:1.5kW	CO_2*:2.6kW	CO_2*: 10kW	CO_2*: 17kW
Laser freq.	10kHz	100kHz	100kHz	100kHz
CE (source)	0.9%	0.9%	2.5%	3.5%
Target	Xe-Jet $\phi30\mu m$	SnO_2 choroid liquid jet	Sn-Droplet $\phi10\mu m$	Sn-Droplet $\phi10\mu m$

Technology for <10W
Nd:YAG Laser, Liquid Xe jet

Technology for 115-200W
CO2 Laser, Sn droplet target
Magnetic field mitigation

Note)
Primary source to IF EUV transfer efficiency :
1) 43%
2) 20%
***with Pre-Pulse YAG Laser**

CO_2 laser based EUV system

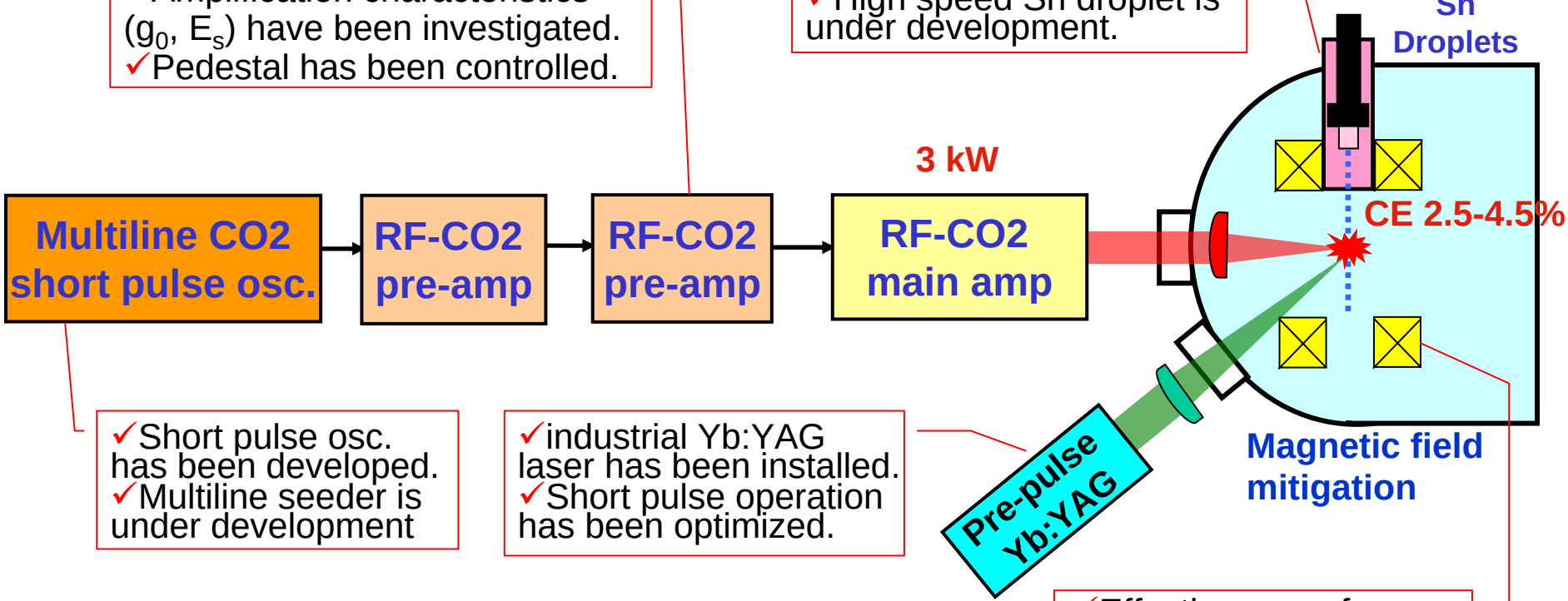


Conversion Efficiency (CE) of
2.5 – 4.5 % has been achieved with Sn wire w/o pre-pulse

CO_2 laser based EUV system development status

✓Industrial RF-CO2 lasers have been installed.
✓Amplification characteristics (g_0, E_s) have been investigated.
✓Pedestal has been controlled.

✓Sn droplet has been generated.
✓High speed Sn droplet is under development.



✓Short pulse osc. has been developed.
✓Multiline seeder is under development

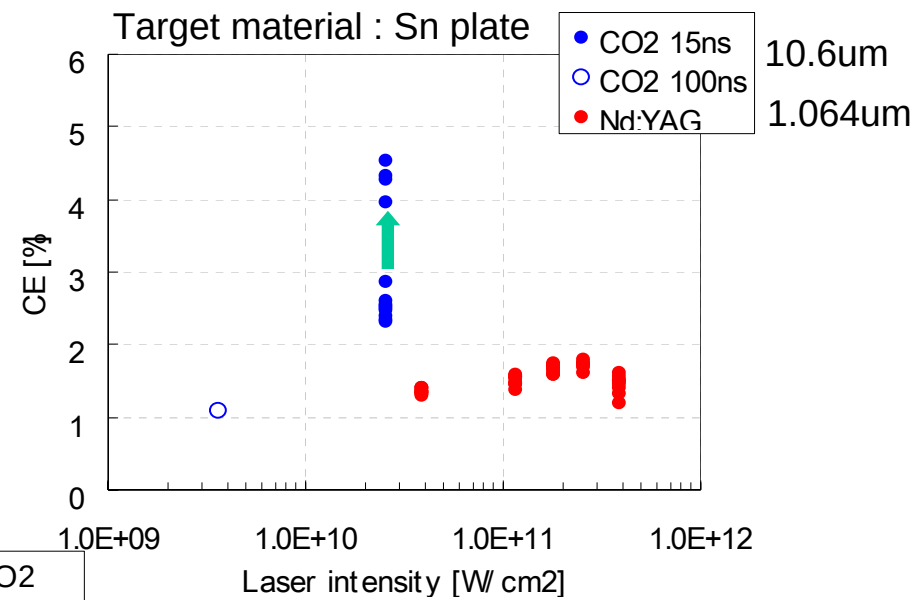
✓industrial Yb:YAG laser has been installed.
✓Short pulse operation has been optimized.

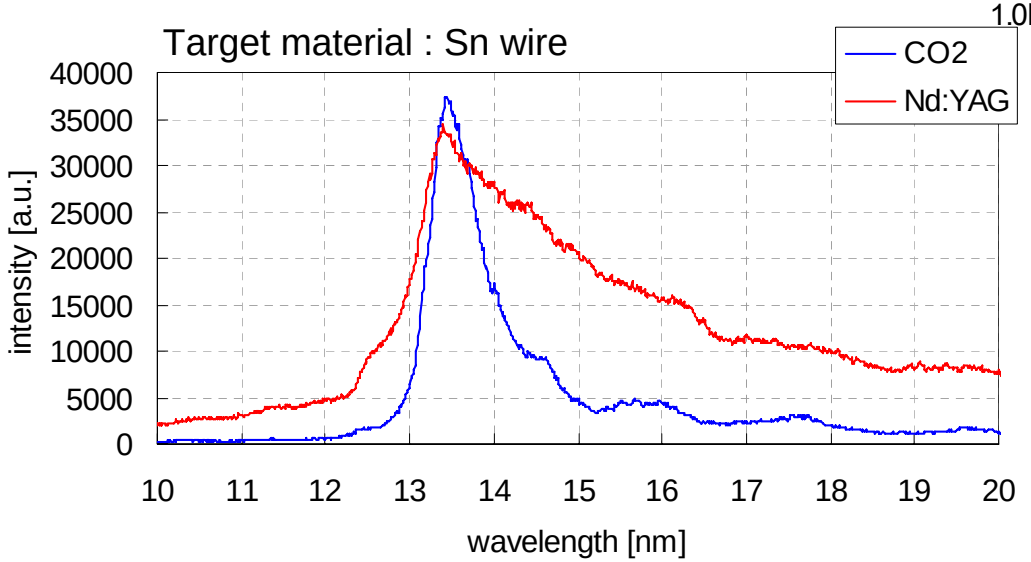
✓Effectiveness of magnetic field mitigation has been confirmed for pre-pulsed CO2.

EUV from TEA-CO_2 laser produced Sn plasma

Conversion efficiency dependence on the laser intensity

CE: 2.5% - 4.5% with CO2 laser
Laser intensity : 3×10^{10} W/cm^2
*energy:30mJ
*Pulse width:11ns
*Spot size: d=100um





EUV spectra from Sn plasma

Narrow in-band spectrum with CO2 laser

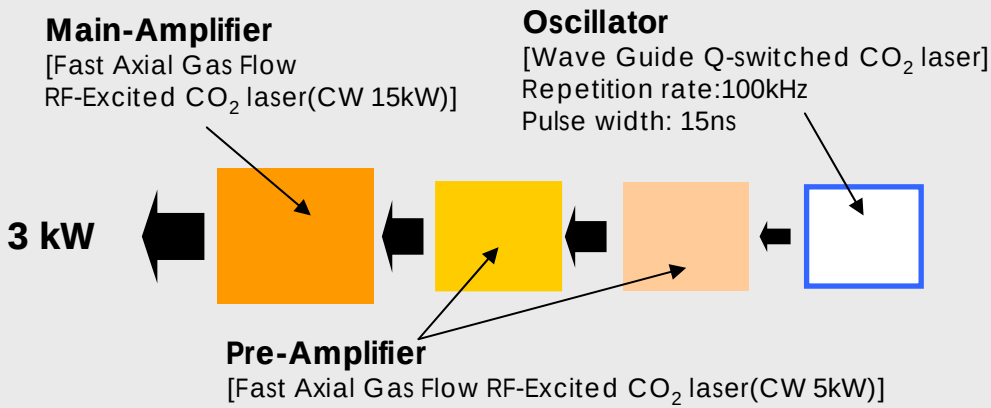
General Performance Summary

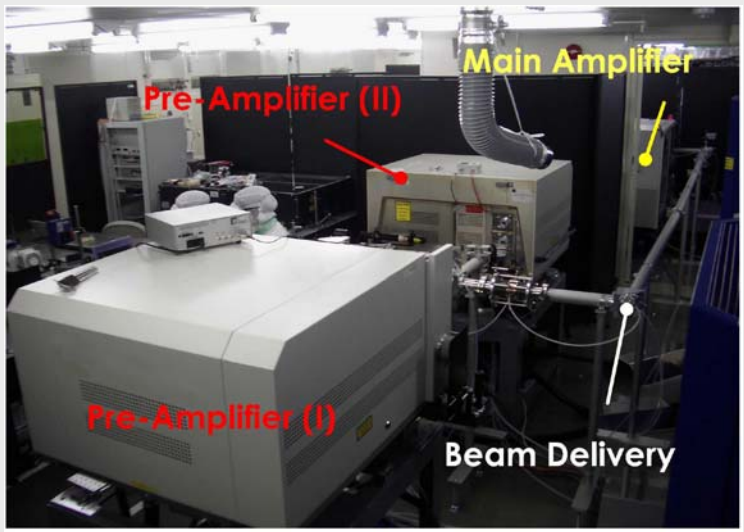
Target material: Sn

Items	CO2		Nd:YAG
CE	2.5 - 4.5%		1.5 - 2.5%
In band spectral bandwidth (nm, FWHM)	0.8		2.5
Debris		<	
Fast ion	1	:	2
Out-of-band		<	
Cost			
Initial	1	:	2 - 3
CoO (exclude electricity)	1	:	5
Mo/Si reflectivity at laser wavelength	> 90%		30%

High repetition rate CO2 MOPA laser system

- **MOPA laser system**

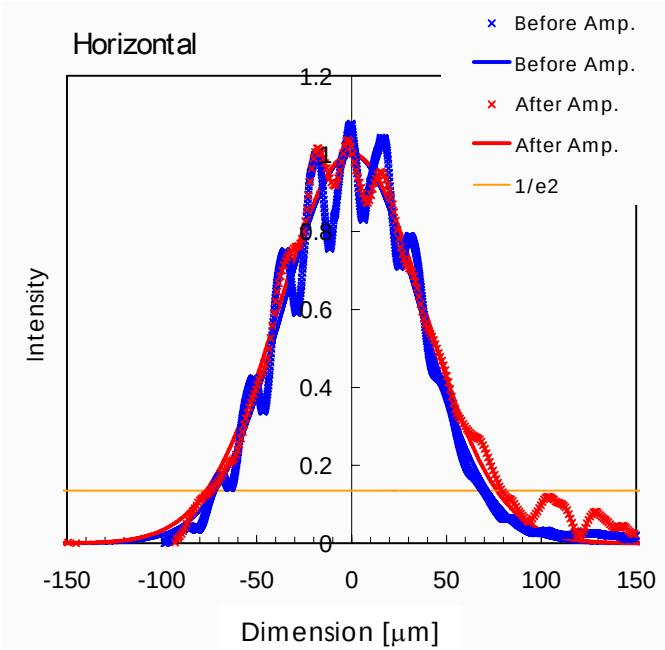


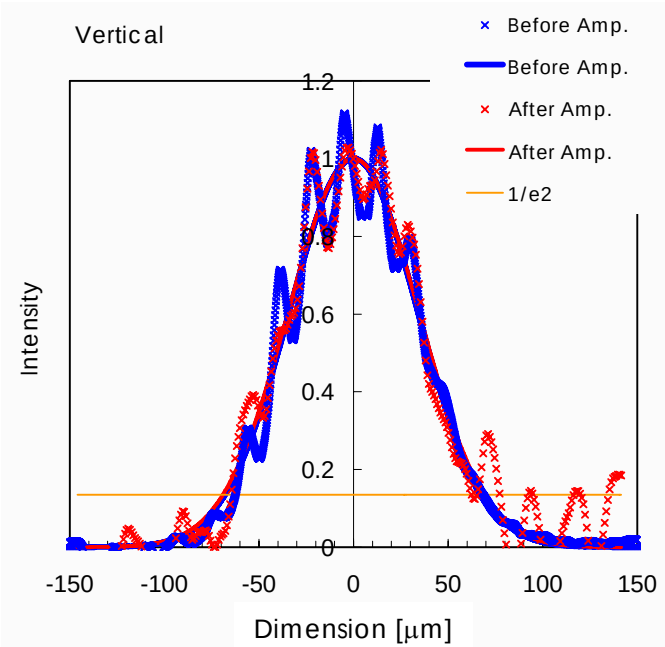


Focusability of amplified CO_2 laser beam

No significant degradation in focusability after amplification

(Focusing lens f=127 mm)





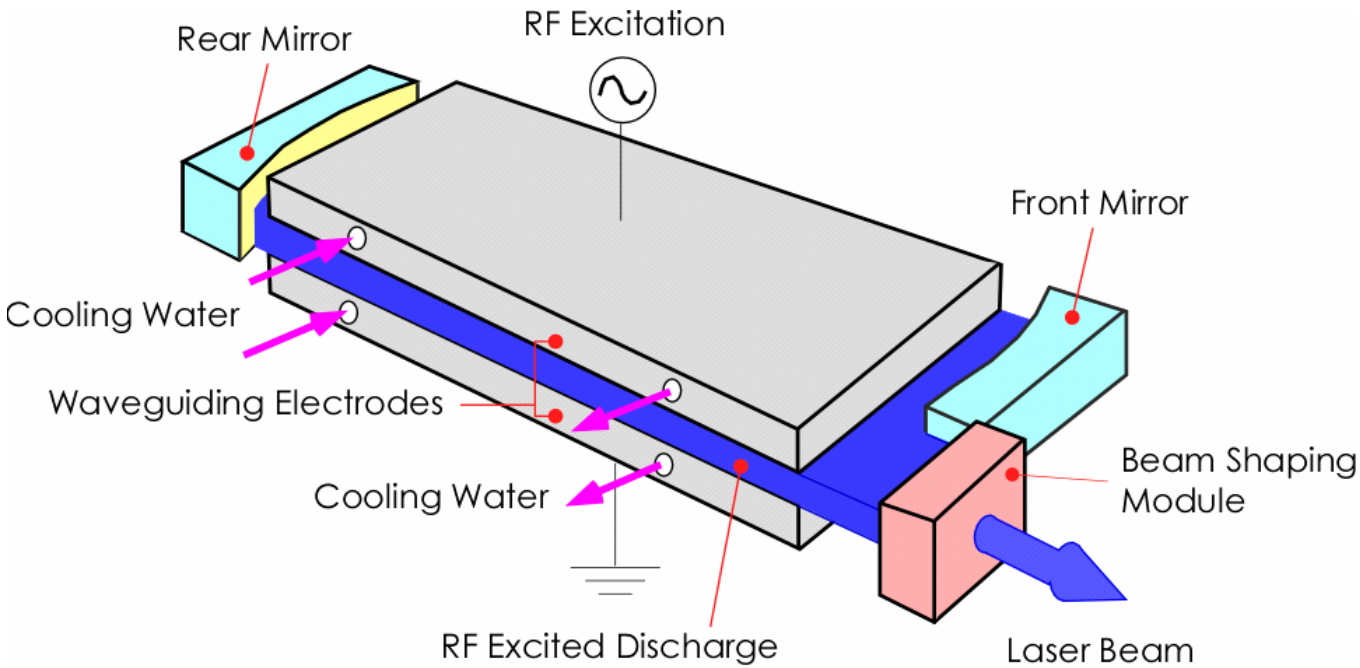
- Focal spot size after amplification ($1/e^2$) -

Horizontal: 153μm

Vertical: 138μm

Principle of Slab CO_2 Laser

✓ Schematic Diagram of Slab CO_2 Laser

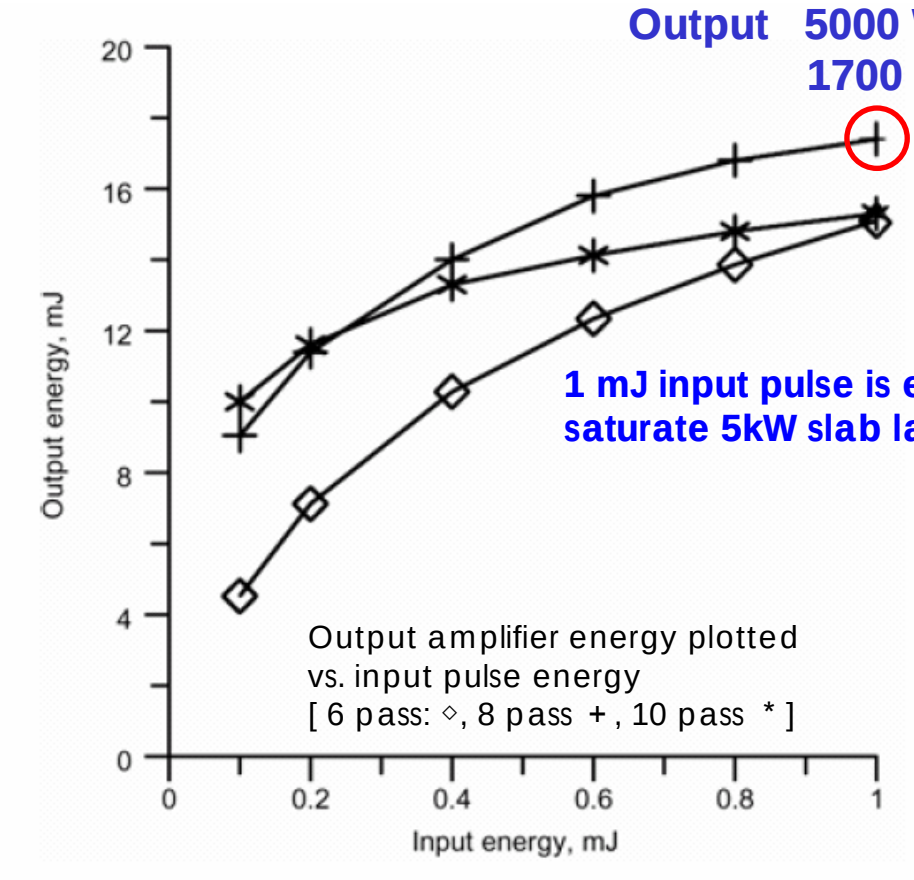


- Excitation of the laser gas takes place in the RF field between the water-cooled electrodes.
- The heat generated in the gas is dissipated by the water-cooled electrodes (**Diffusion-Cooled**).

→ **Gas circulation systems are not required and compact!**

Estimation of extraction energy from a slab amplifier

Output 5000 W : CW oscillator
1700 W : 100kHz amplifier



1 mJ input pulse is enough to saturate 5kW slab laser.

Extraction Efficiency : 34% (= 1.7kW/5kW)

This work was preformed with Research Institute for Laser Physics [V.E. Sherstobitov]

Comparison of Fast Axial Flow and Slab Laser

		RF Fast Axial Flow	RF Slab
CW Output Power [W]		5000	5000
Size	Head Size [mm]	1185x1150x650	2100x850x853
	Control Unit Size [mm]	2000x800x2000	800x600x1900
Volumetric capacity of Laser System [m^3]		**4.1**	**2.4**
Power Consumption [kW]		60	68
Max. Extraction Energy as an Amplifier [KW]		1	1.7
Max. Extraction Energy Efficiency as an Amplifier		** Experiment* 20.0%	** Calculation* 34.0%
Plug in Max. Extraction Energy Efficiency as an Amplifier		**1.7%**	**2.5%**

Slab is 60% of fast Axial Flow

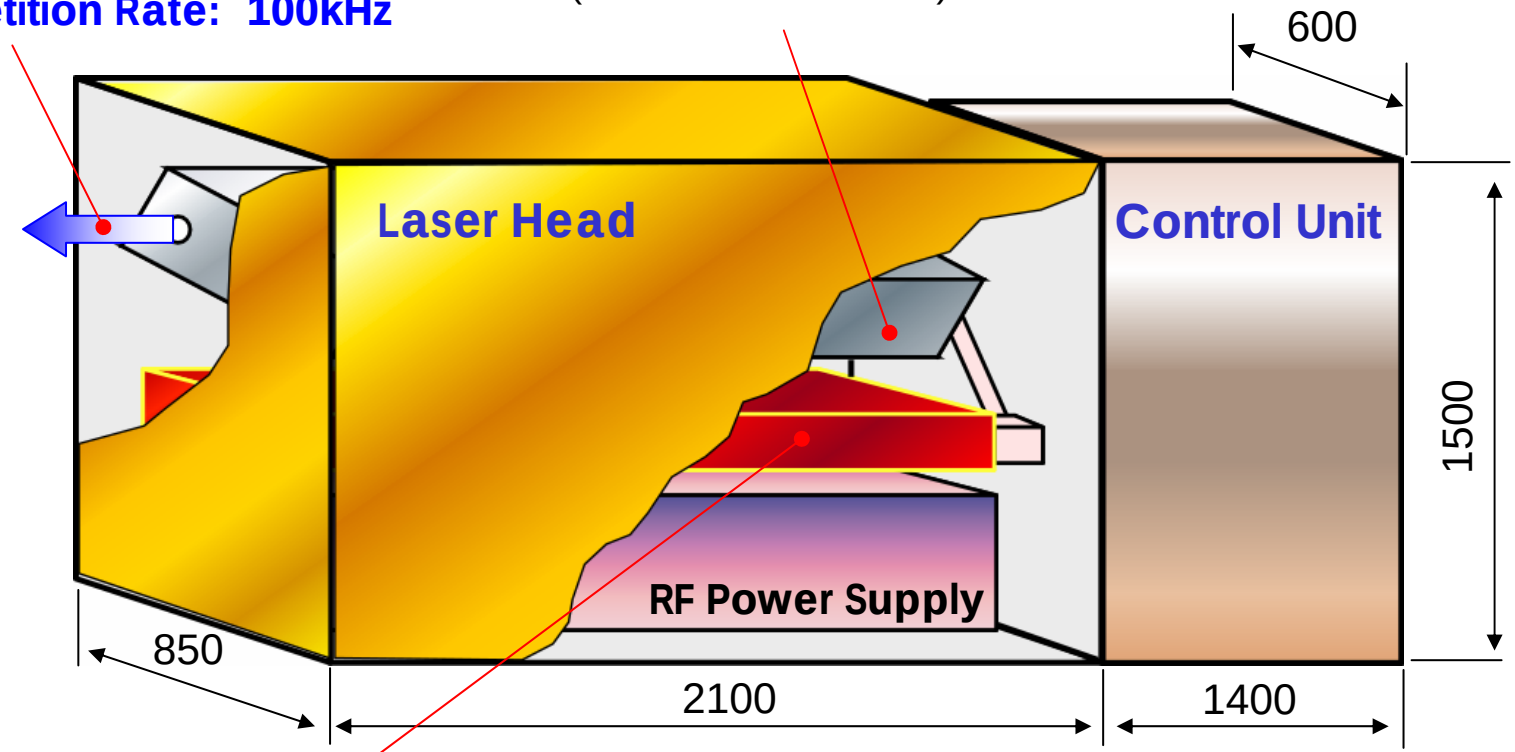
Slab is 150% of fast Axial Flow

CO_2 Laser Module for HVM EUV Lithography

*without cooling unit

- ✓**Average Power: 2.5 kW**
- ✓**Pulse width: 15ns**
- ✓**Repetition Rate: 100kHz**

Slab Amplifier
(CW 8 kW Slab Laser)



Short Pulse Oscillator
(Average Power 100W, Pulse width 15ns, Repetition Rate 100kHz)

Approximate Initial Cost (at volume manufacturing)
2.5 kW Laser Module : US$ 1million

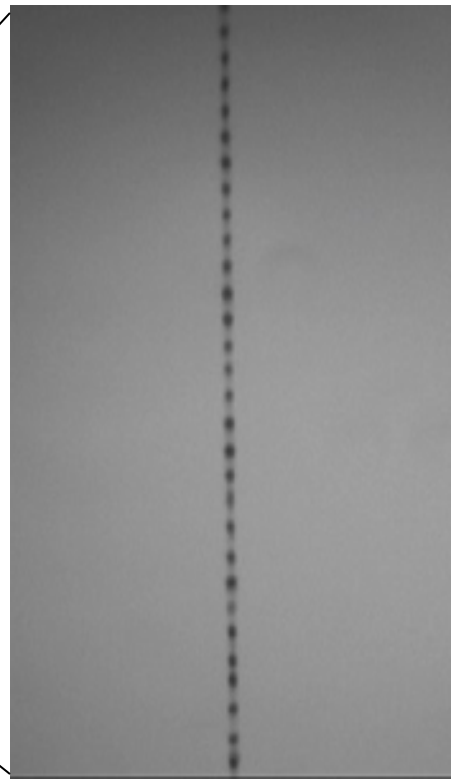
Approximate Running Cost of Slab Laser

Laser Gas:	US$ 1.5/hour
Electricity:	US$ 9/hour
Spare Parts:	US$ 4/hour
Maintenance & Service:	US$ 26000/Year

High speed droplet target supply

- Sn droplet

Item	Demonstrated	Goal
Droplet speed	16 m/s	100 m/s
Diameter	75 um	20 um (tentative)
Repetition rate	100 kHz	100 kHz



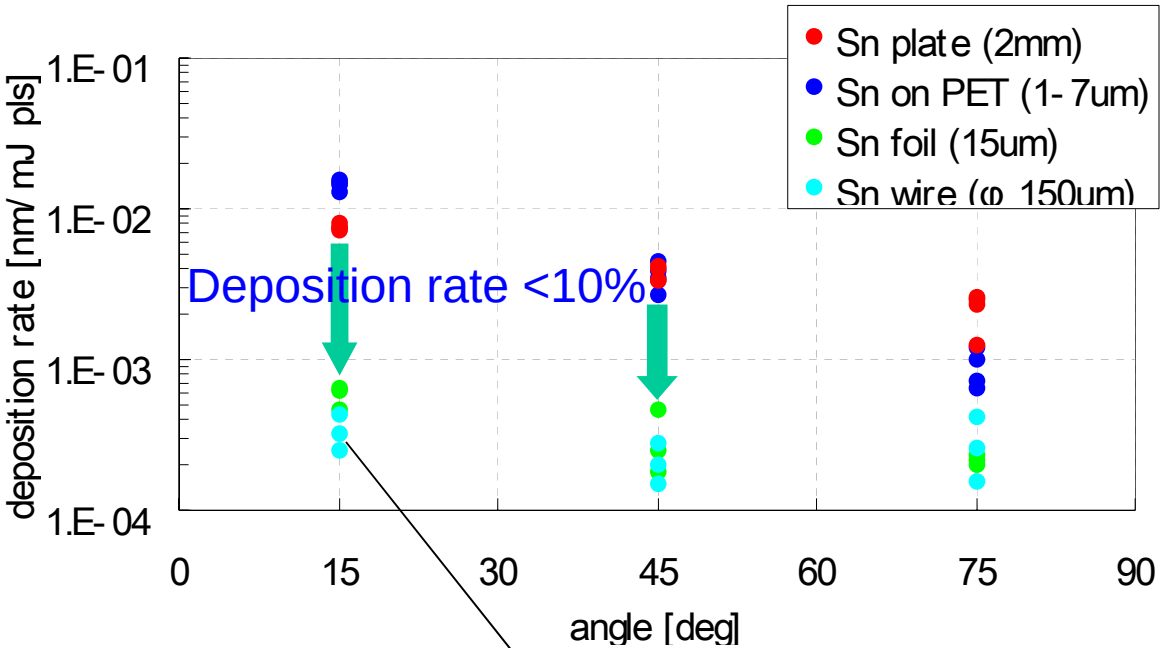
16 m/s, 100 kHz

Sn debris evaluation

Sn debris evaluation by QCM measurement

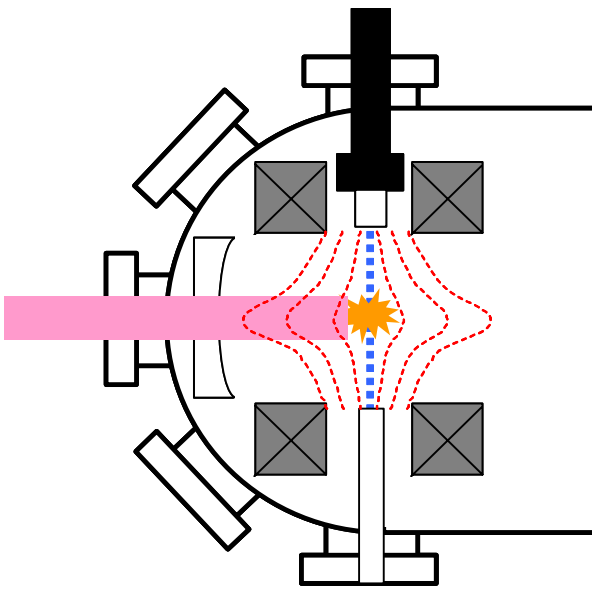
- Laser: Nd:YAG, 35 mJ, spot size 100um
- EUV pulse energy : 0.4-0.45mJ
- Target: Sn Plate (t = 2mm), Sn on PET(Cu), (t = 1-7um/40um)
  Sn foil (t = 15um, free-standing), Sn wire (d = 150um)

Angular dependence of debris deposition for various Sn target



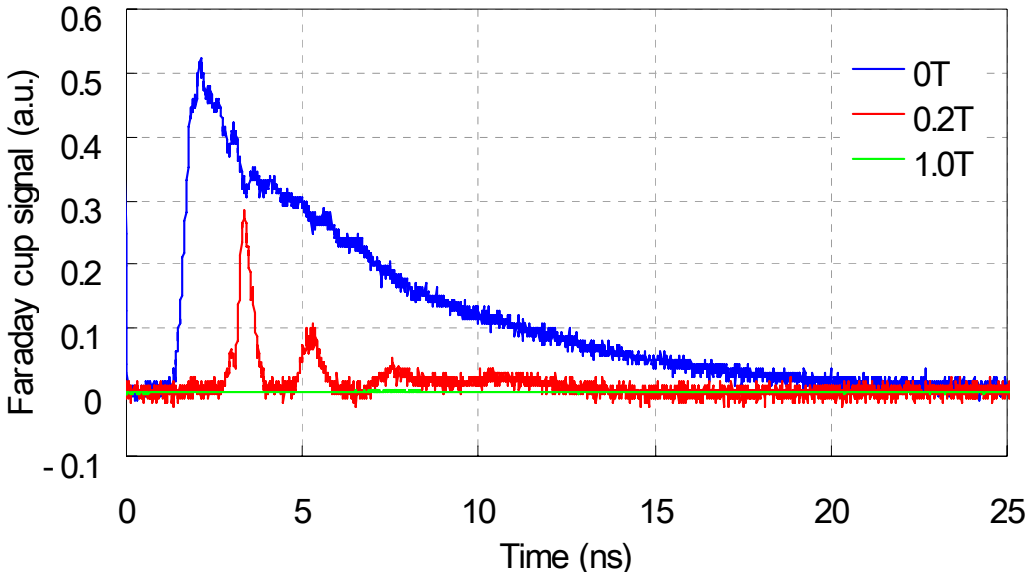
Sn wire : Mass limit

Fast ion mitigation with magnetic field



EUV energy: 0.4mJ
Chamber pressure: 4E-4Pa
Target : Sn (d=6mm Rod)
Faraday cup location: 15deg

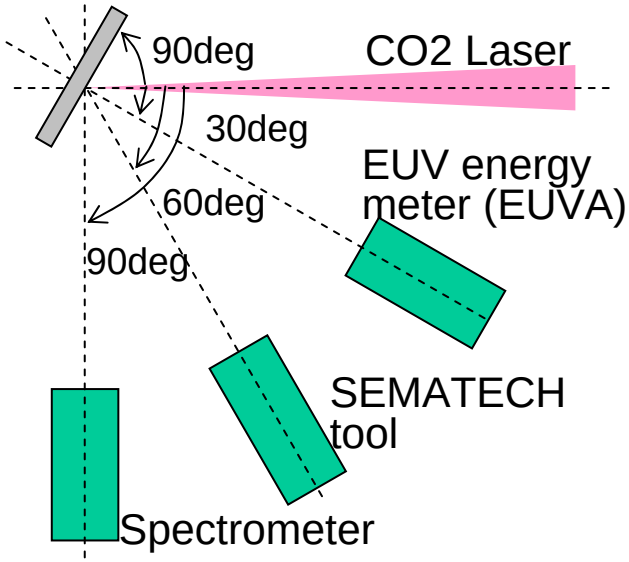
Faraday cup signal



Fast ion signal decreased < 0.1% with 1 T magnetic flux density

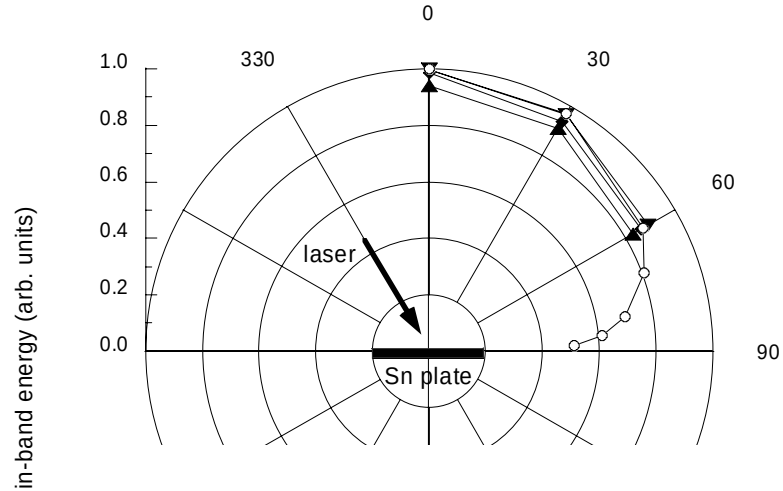
Source measurement with SEMATECH standard tool

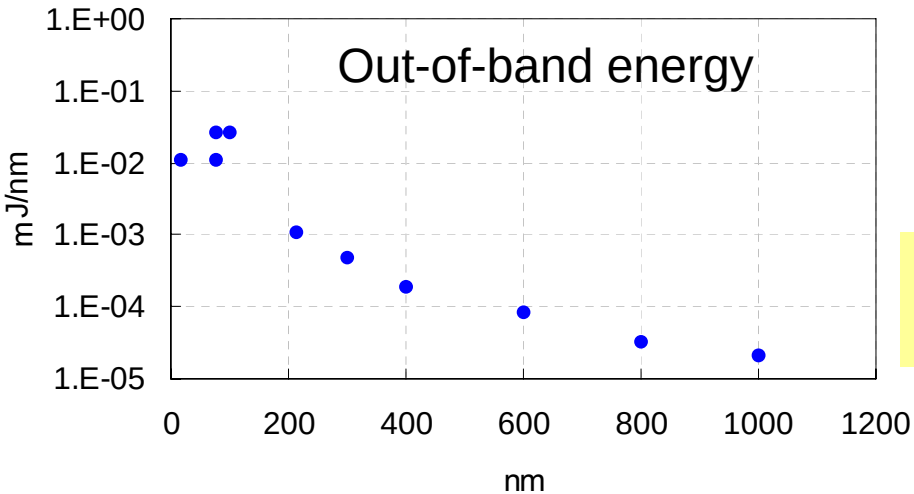
Configuration



Laser: TEA CO2 (25 mJ, 10-15 ns)
Target: Sn plate
Measurement: in band, out-of-band energy.

EUV angular distribution





- CE : 2.8 - 4% (2πsr, 2%BW)
- Out-of-band energy (>200 nm): < 0.2 mJ

Estimated EUV IF power

Now

Calculated IF Power

Laser Power \ CE	Xe	Sn			
	0.5%	2.5%	3.0%	3.5%	4.0%
2.5kW	3.5W	17.5W	21.0W	24.5W	28.0W
5.0kW	7.0W	35.0W	42.0W	49.0W	56.0W
7.5kW	10.5W	52.5W	63.0W	73.5W	84.0W
10.0kW	14.0W	70.0W	84.0W	98.0W	112.0W

Primary source to IF EUV transfer efficiency: 28%

EUVA goal

HVM source

Summary

Achievement

CO2 LPP light source:

- CE 2.5% - 4.5% with Sn
- EUV source power 100 W (2 πsr, 2% BW, Calculated)
- CO2 laser output power 3 kW
- Sn droplet target 16 m/s, d = 75 um, 100 kHz
- Fast ion mitigation < 0.1% with 1 T magnetic flux density
- Sn debris < 10% by using mass limit target

CO2 drive laser system:

- HVM laser system will be based on slab amplifier modules.