GIGAPHOTON
BEAM to the FUTURE
www.gigaphoton.com

EUV Source Supplier Update, Gigaphoton

Hakaru Mizoguchi

EUV Source Workshop
6 May, 2007
Baltimore, MD, USA

Acknowledgments
A part of this work was performed under the management of EUVA in the NEDO's R&D Program.

Outline

- Introduction
  - LPP source roadmap and concept
- Update of CO_2 laser produced Sn plasma source
  - Laser output power
  - Sn deposition analysis
  - System scalability
- LPP/EUV future direction to HVM
- Summary

LPP Source Roadmap

	1st Mid term 2004/9	2nd Mid term 2006/3	EUVA Final 2008/3	HVM source-1 2010 planning
EUV Power (IF)	5.7W [1]	10W [1]	50W [2]	110W [2] /140W [3]
Stability	---	s<±10%	s <±5%	3s<±0.3%
Laser	YAG:1.5kW	CO_2:2.6kW	CO_2: 7.5kW	CO_2: 10kW
Laser freq.	10kHz	100kHz	100kHz	100kHz
CE (source)	0.9%	0.9%	2.5%	4%
Target	Xe-Jet	SnO_2 choroid liquid jet	Sn-Droplet	Sn-Droplet
	EUVA project			Gigaphoton

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) 28% with SPF
3) 36% without SPF

Light Source Concept

Requirement for EUV source for HVM

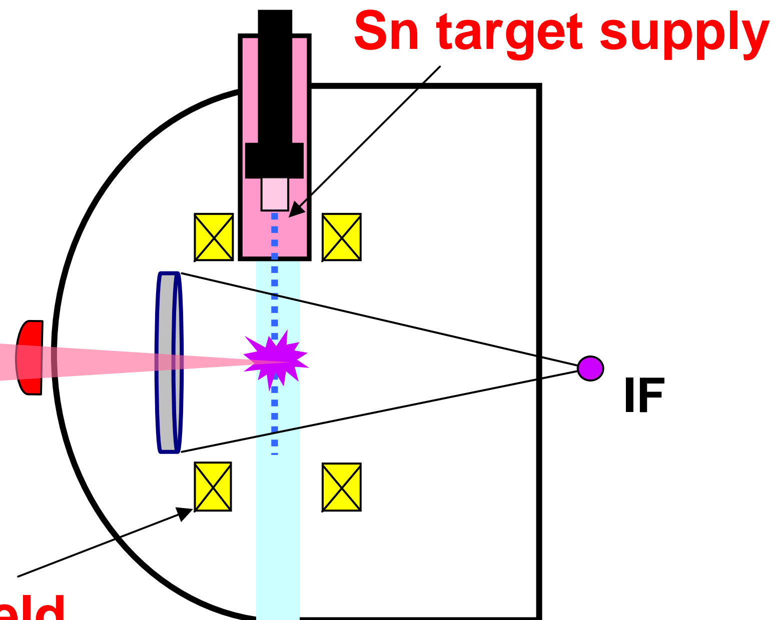
- High EUV power >115 W
- EUV Stability
- Collector mirror lifetime
- Low CoG / CoO

Original Concepts

CO_2 laser + Sn LPP light source + Magnetic field mitigation

High power pulsed CO2 laser system

Pulsed CO_2 Laser OSC+cw-CO2 laser AMP



History of technical concept proposal & technical demonstration

2001: Original Concept of CO_2 laser based LPP source.
(Patent applied in 2001)

Original Concept of MOPA CO_2 laser based LPP source.
(Patent applied in 2001)

2002 /09: EUVA light source project start with Gigaphoton, USHIO and Komatsu

2003: Original Concept of Magnetic field ion mitigation
(Patent applied in 2004)

2004 /09: EUV 5.7 W IF was demonstrated (Nd:YAG and Xe jet)

2006 /03: EUV 10 W IF was demonstrated (CO_2 and SnO_2 choroid liquid jet)

2007 /02: EUV 40 W IF was demonstrated (CO_2 and Sn target)

2007 /04: EUV 47 W IF was demonstrated (CO_2 and Sn target) ←This report

Outline

- Introduction
  - LPP source roadmap and concept
- Update of CO_2 laser produced Sn plasma source
  - Laser output power
  - Sn deposition analysis
  - System scalability
- LPP/EUV future direction to HVM
- Summary

Update of CO_2 laser produced Sn plasma source

Original concept:

CO_2 laser + Sn LPP light source for HVM EUVL

Update from *Feb. 2007 (Advanced Microlithography @ San Jose)*

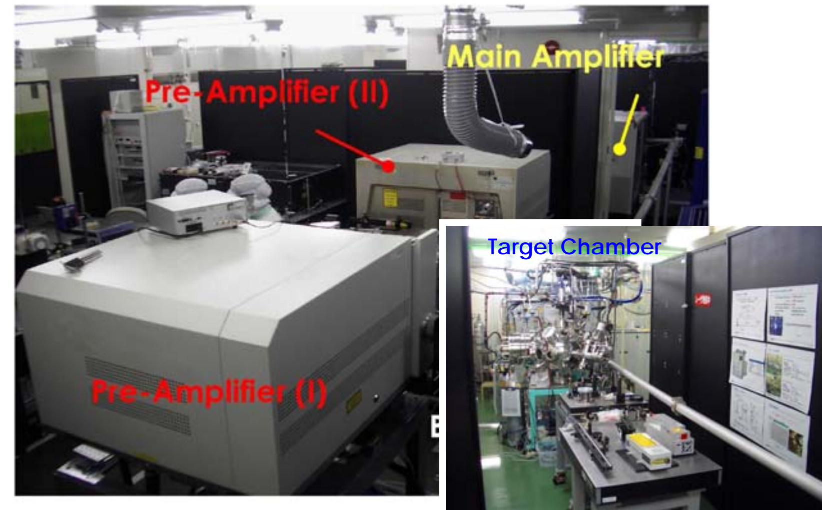
- Laser output power
  - CO_2 laser power 6.0 kW→ 7 kW ← Topic 1
- System scalability
  - 20-kW single line CO_2 system is scalable ← Topic 2
- Sn deposition analysis
  - Low density Sn deposition ← Topic 3

Experimental devices for EUV source development at EUVA

Component development is driven by two experimental devices.

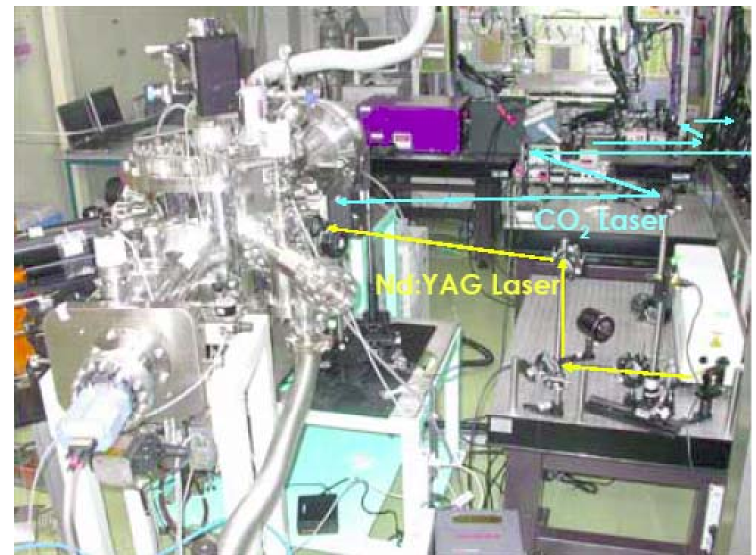
1. High power experiment device

- RF-CO_2 laser based system
- High power laser system development
- Target development
- High power EUV generation



2. Fundamental experiment device

- TEA-CO_2 laser based system
- CE experiment
- Debris analysis
- Mitigation system development



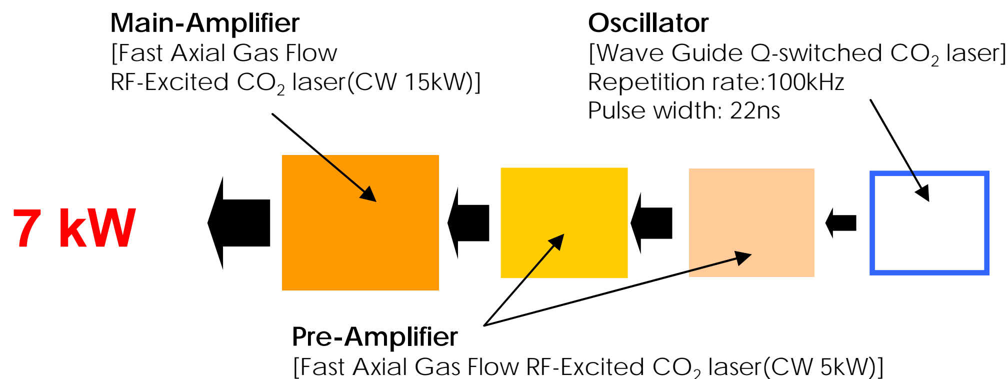
Topic 1 High Power CO_2 Laser MOPA System

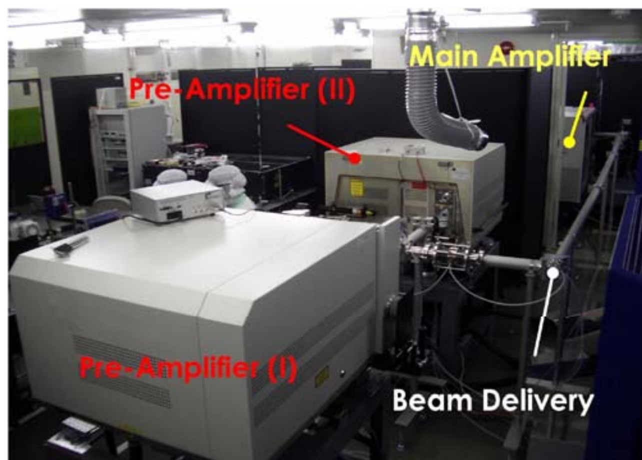
High power experiment device

- Performances

Laser Power :	**6kW → 7 kW**
Pulse Width :	**22 ns**
Repetition Rate :	**100 kHz**

- Laser System

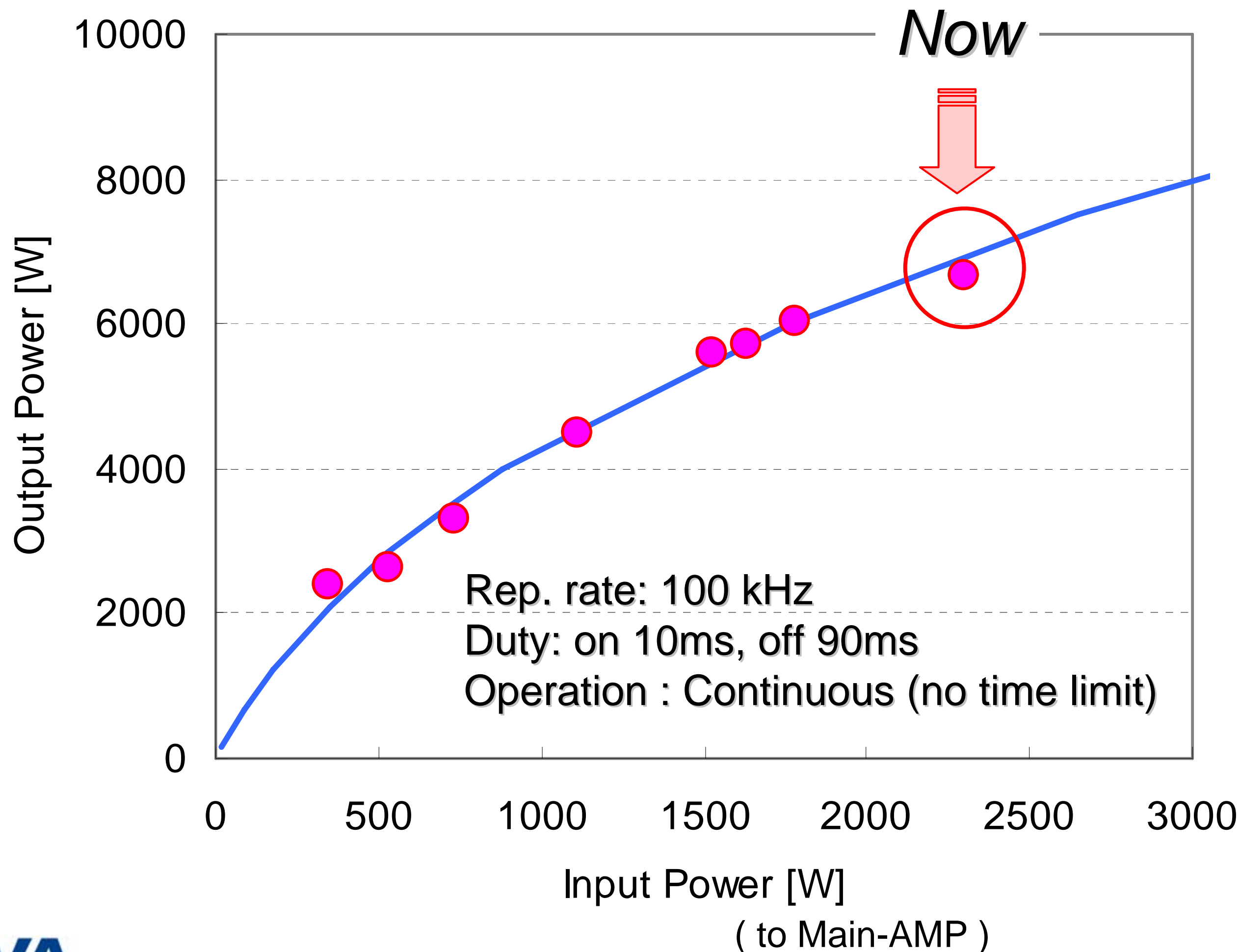




Topic 1 CO_2 Laser MOPA System Average Output Power

High power experiment device

➢ *Amplification Characteristic of Main - Amp*

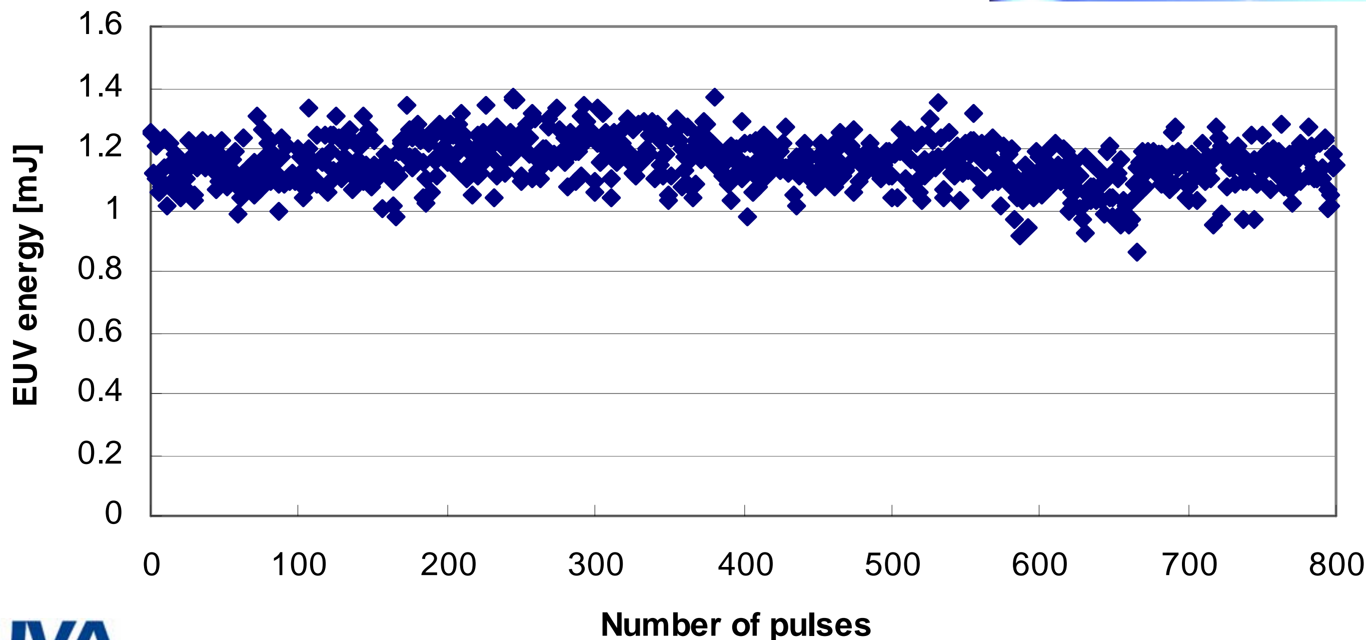


Topic 1 EUV from high power CO_2 laser produced Sn plasma

High power experiment device

EUV source power : 110 W (**130 W**) (2 πsr, 2%bw)

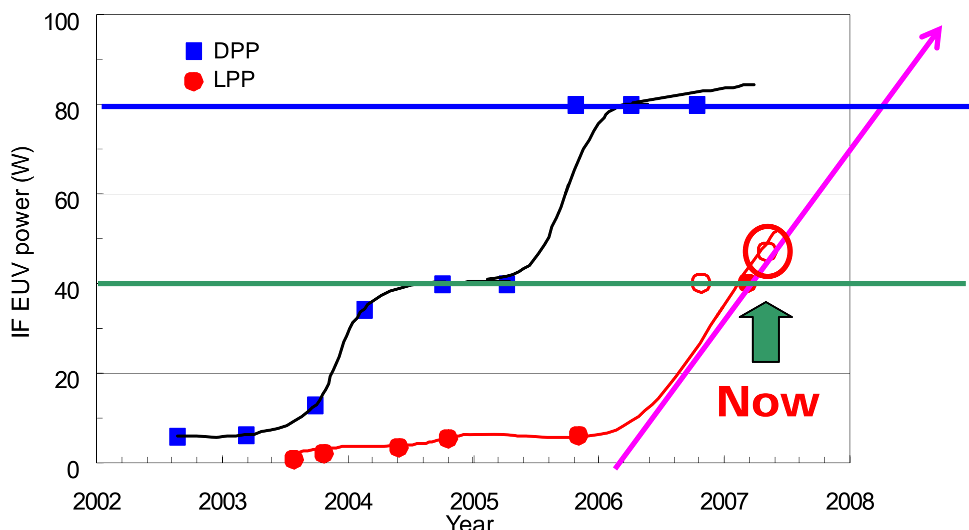
Target :	Rotating Sn plate
Laser irradiation power :	5 kW (→ **6 kW**)
Conversion efficiency (CE) :	2.2 %
EUV energy stability :	8% (3σ, 50 pulse)



Topic 1 LPP/ EUV Output Power

High power experiment device

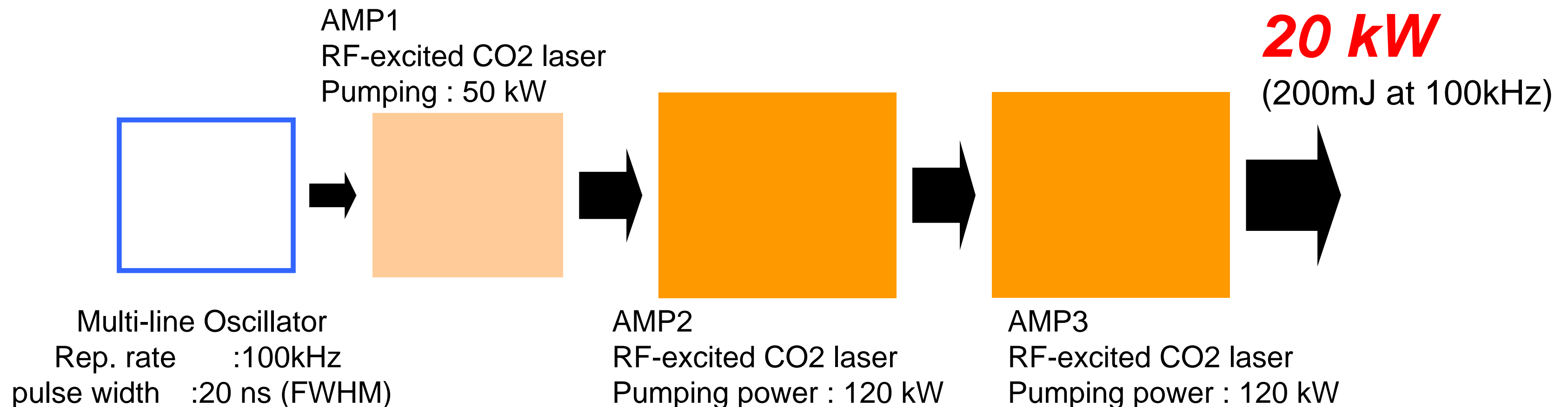
LPP IF EUV power caught up the 1st gen. Sn base-DPP power level !



Transmittance from primary to I/F	DPP		LPP	
Primary source EUV power (2pi sr, 2%bw)	616-702 W		110 W	(130 W)
Debris shield transmission	0.8		1.0	
Collection angle & collector transmission	0.28		0.38	(4 sr, R=0.6)
Aperture (etendue limit & SPF) transmission	0.45	0.09	1.0	0.36
Gas transmission	0.9		0.94	
Usable EUV power after IF	55-62 W		40 W	(47 W) w/o SPF

DPP data based on EUVA / DPP, October 2006

Topic 2 Multi 10 kW Short Pulse CO_2 laser MOPA system



One beam, 20 kW is reasonable estimate !!

Details will be discussed at ….

- Power Limitation
  - ***Damage of Optics***
    - ⇒ Short pulse damage threshold lower than CW threshold
  - ***Filling Factor***
    - ⇒ Laser beam diffraction
  - ***Saturation***
    - ⇒ Re-absorption from lower laser level (?)

Sn debris and mitigation

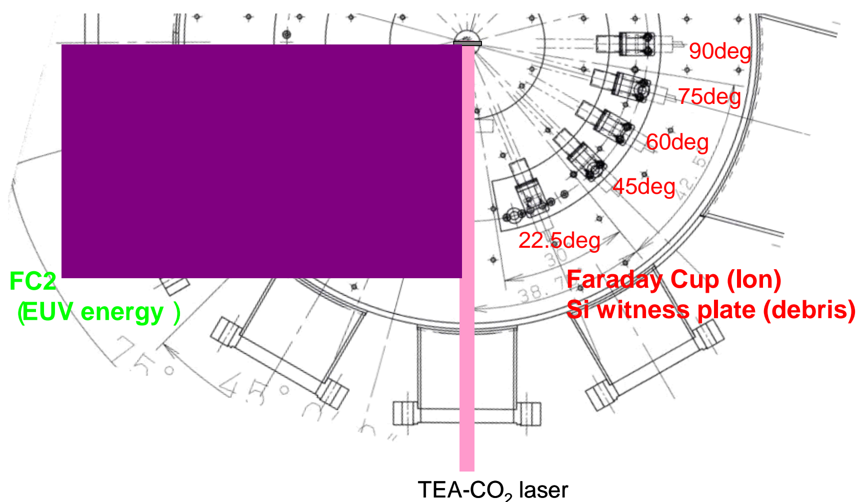
Fundamental experiment device

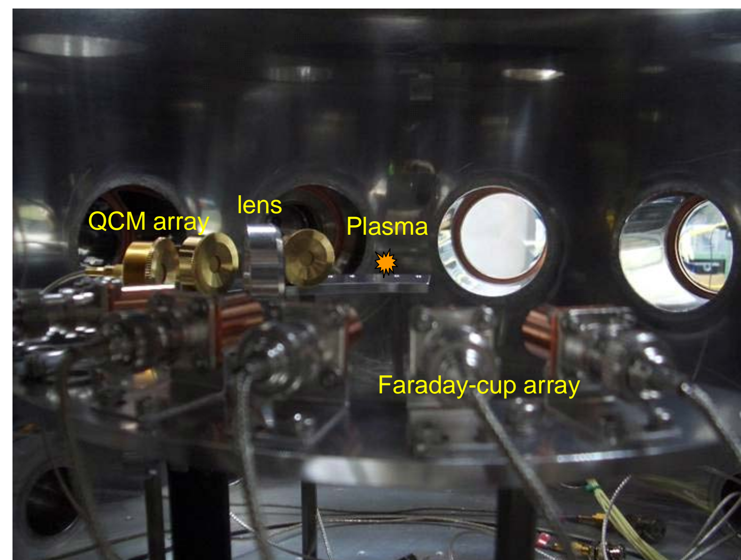
Debris from Sn laser plasma and mitigation

Droplet debris → **Deposition** ➡ **Minimized by CO_2 irradiation**
Sn neutral ↗

Fast ion → **Sputtering** ➡ Magnetic field mitigation

Experimental layout





Topic 3 CO_2 laser is clean LPP driver compared to YAG

Fundamental experiment device

Sputter / deposition rate measured by QCM

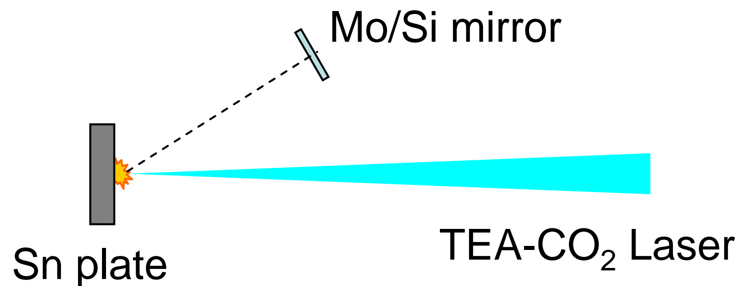
Deposition case

Topic 3 Mo/Si sample mirror test

Fundamental experiment device

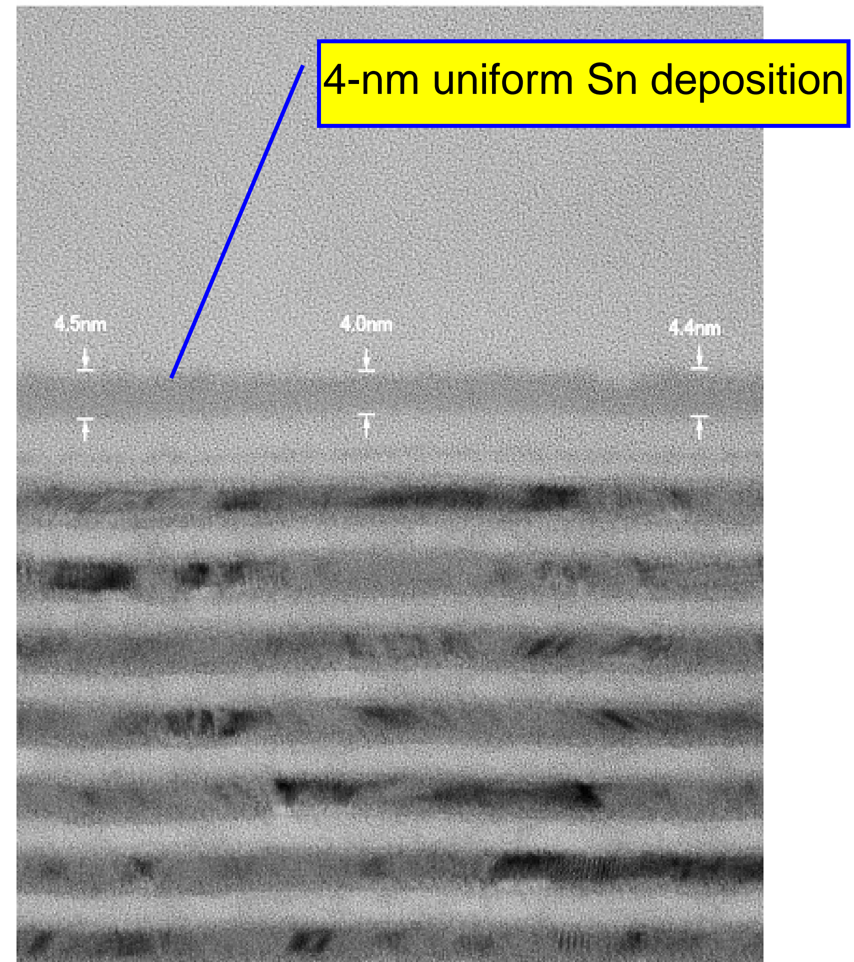
Experimental setup

- Mo/Si mirror sample :10 bilayer
- Distance from plasma: 120mm
- Angle to laser incidence: 30 degree
- Laser pulse energy: 15-25mJ
- Laser pulse number: 1.5×10^{5} pulse
- Chamber pressure: 5×10^{-2} Pa

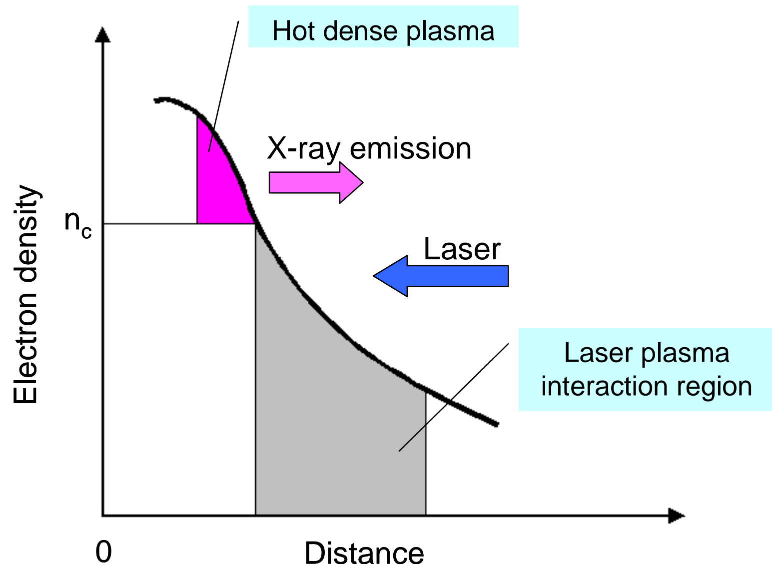


Low density Sn deposition; since the measured reflectivity change is much smaller than the calculated reflectance for 4nm solid Sn.

TEM class sectional image of the exposed Mo/Si



CO_2 laser is clean LPP driver compared to YAG

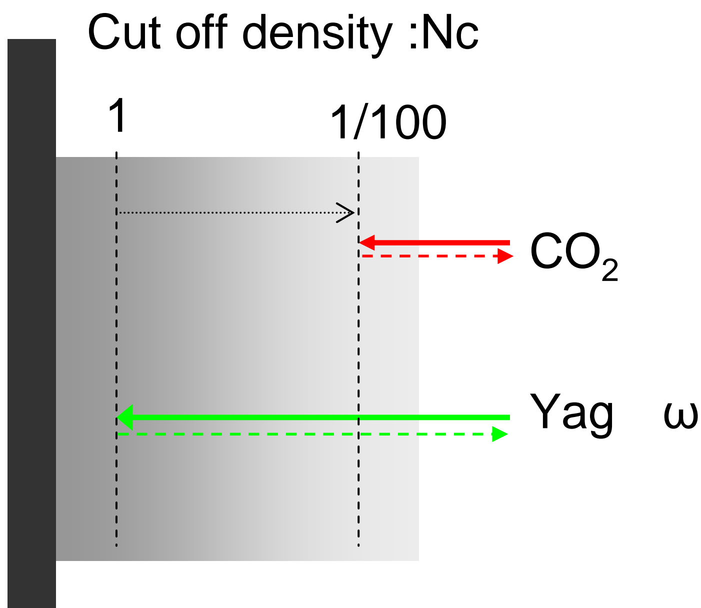


Fundamental experiment device

Efficient EUV is emitted from hot dense plasma near the electron critical density nc.

$$n_c = \frac{\varepsilon_0 m \omega^2}{e^2} = \frac{1.11\times10^{21}}{\lambda^2}(cm^{-3})$$

λ: wavelength in μm



Laser	Electron critical density (cm^{-3})
CO_2 (10.6um)	$1.0x10^{19}$
Nd:YAG (1.06um)	$1.0x10^{21}$

CO_2 laser light is efficiently absorbed by low density plasma, therefore thermal boiling of Sn (cause of Sn drops creation) is avoided.

Outline

- Introduction
  - LPP source roadmap and concept
- Update of CO2 laser produced Sn plasma source
  - Laser output power
  - Sn deposition analysis
  - System scalability
- LPP/EUV future direction to HVM
- Summary

LPP/EUV future direction to HVM (1)

EUV power estimation with laser power & CE

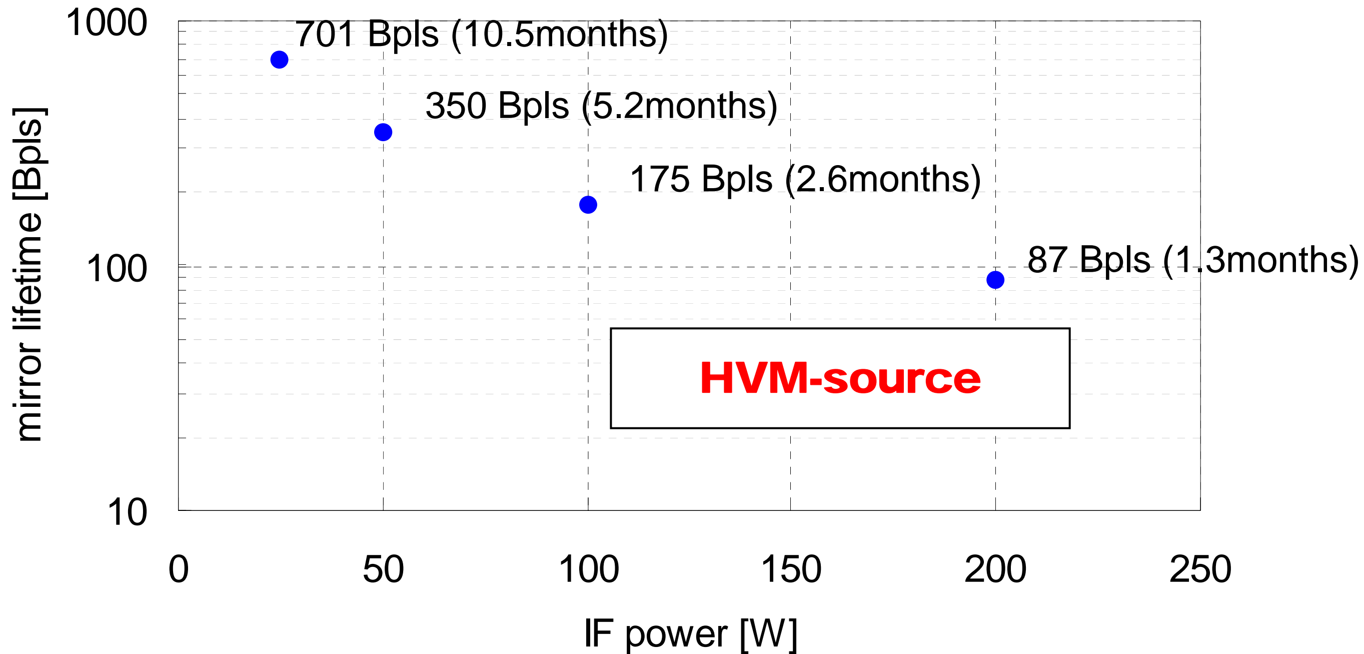
Laser kW \ CE %	2.0	2.2	2.5	3.0	3.5	4.0	4.5
2.5	14	15	18	21	25	28	32
	18	20	23	27	32	36	41
5.0	28	31	35	42	49	56	63
	36	40	45	54	63	72	81
7.5	42	46	53	63	74	84	95
	54	59	68	81	95	108	122
10.0	56	62	70	84	98	112	126
	72	79	90	108	126	144	162

HVM-source

Transfer efficiency from primary source to IF

	Total	Debris shield	Collectable angle	Reflectivity	T%	SPF
Case1	0.28	0.8	5sr	0.6	0.9	0.8
Case2	0.36	1	4sr	0.6	0.94	1

LPP/EUV future direction to HVM (2)



Lifetime requirements (12months) : 80Bpls@10kHz ⇒ 800Bpls@100kHz

Mirror lifetime estimation based on
Rep.rate : 100kHz, CO_2 laser w/o pre-pulse
Mirror : Mo/Si 250 bilayer , 22.5deg(worst place)
Plasma-mirror distance : 150mm
Magnetic field effect :×1000

Tool duty: 25%

7days 24H operation

LPP technology update summary

- LPP power by EUVA set up – (non-integrated setup)
  - ✓ ***40W@I/F is achieved at Q4 2006. Now 47W@I/F equivalent!***
    - ✓ By CO_2 laser (6kW→***7kW***) produced Sn plasma
    - ✓ Target: solid Sn disk
    - ✓ Source power 110 W→***130W***, 2p sr, 2%bw
  - ✓ ***20KW driver laser scalability is estimated.***
  - ✓ ***Easier debris mitigation of CO_2 laser produced Sn plasma***
    - ✓ 175 Bpls factor 1000 (detection limit)
      - *Estimated number by experimental setup.*
      - *Need proven data with system demonstration.*
    - ✓ ***Very small damage on collector mirror is observed***

- For next stage

  SD (System Demonstration)-SoCoMo is under planning

  90W (@ I/F) with CO_2 laser and Sn droplet + debris mitigation+ Collector mirror