1st generation Laser-Produced Plasma 100W source system for HVM EUV lithography

Hakaru Mizoguchi

Gigaphoton (Japan)
400 Yokokura shinden, 323-8558,Oyama, Tochigi, Japan

2010 International Workshop on EUV Sources
University College Dublin, November 13-15, 2010

Outline

- **Introduction**
  - Concept of Gigaphoton LPP source
- **1st Generation system data**
  - Latest data
  - Critical issue and experimental data
- **2nd generation system development**
  - Design
  - Status of construction
- **Roadmap update and New facility**
- **Looking through 6.6nm**
- **Summary**

Outline

- **Introduction**
  - Concept of Gigaphoton LPP source
- **1st Generation system data**
  - Latest data
  - Critical issue and experimental data
- **2nd generation system development**
  - Design
  - Status of construction
- **Roadmap update and New facility**
- **Looking through 6.6nm**
- **Summary**

KOMATSU

EUVA

EUV sources

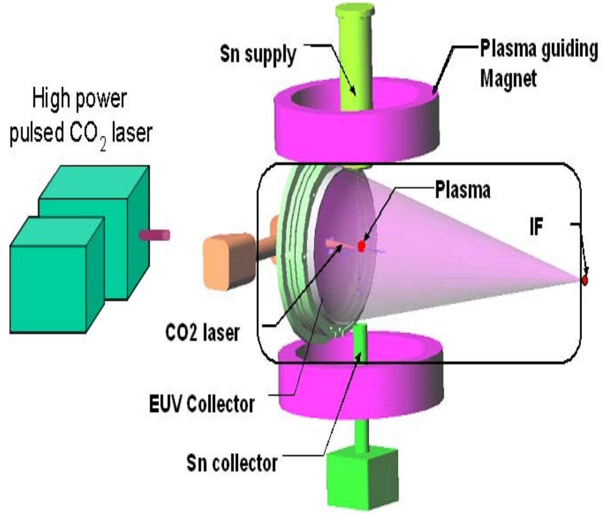
Original technologies

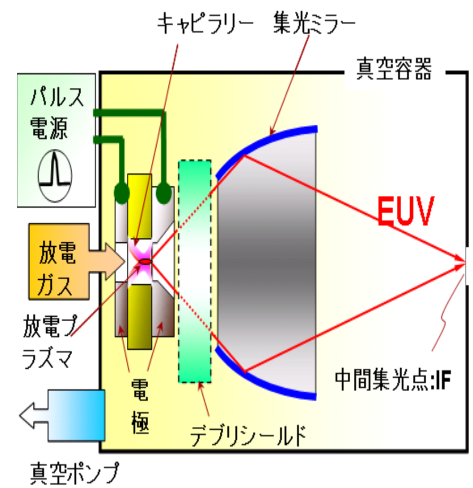
LPP :CO_2 laser and Sn source

① High power pulsed CO2 laser

② Magnetic field plasma mitigation

③ Pre-Pulse plasma technology





Type	LPP		DPP
Maker	**Gigaphoton**	*Company A*	*Company B*
Size	*Large*	*Very Large*	***Small***
Power (at present)	**104W/21W**	90W/20W	*34W/34W*
Plasma	**No electrode**	No electrode	Disc electrode
Mitigation	**Pre pulse + Magnet**	Gas	Gas＋mechanical shutter
Life limitation	**(several 1000 hr)**	Several 10 hr	Several 10 hr
Bottle neck	-	Mirror	Electrode/Mirror
Remark	・Theoretically no limit ・Engineering items are lot	・Trade off of power and lifetime	・Trade off of power and lifetime・ ・Trade off of power and beam quality

EUVA Project (LPP)

	1st Mid term 2004/9	2nd Mid term 2006/3	EUVA -1 final 2008/3	EUVA-2 final ～ 2011/3	Gigaphoton 2011/4 ～
				1st Generation (ETS)	2nd Generation (proto/GL200E)
EUV Power (IF)	5.7W 1)	10W 1)	50W 2)	110W 2) /140W 3)	250W (clean@IF)
Stability	---	σ<±10%	σ <±5%	3σ<±0.3%	3σ<±0.3%
Laser	YAG:1.5kW	CO_2:2.6kW	CO_2: 7.5kW	CO_2: 10kW	CO_2: 23kW
Laser freq.	10kHz	100kHz	100kHz	100kHz	100kHz
CE (source)	0.9%	0.9%	2.5%	4%	5%
Target	Xe-Jet	SnO_2 choroid liquid jet	Sn-Droplet	Sn-Droplet	Sn-Droplet
	EUVA project-1			EUVA project-2	Commercial

Note）
Primary source to IF EUV transfer efficiency：
1) 43%
2) 28% with SPF
3) 36% without SPF

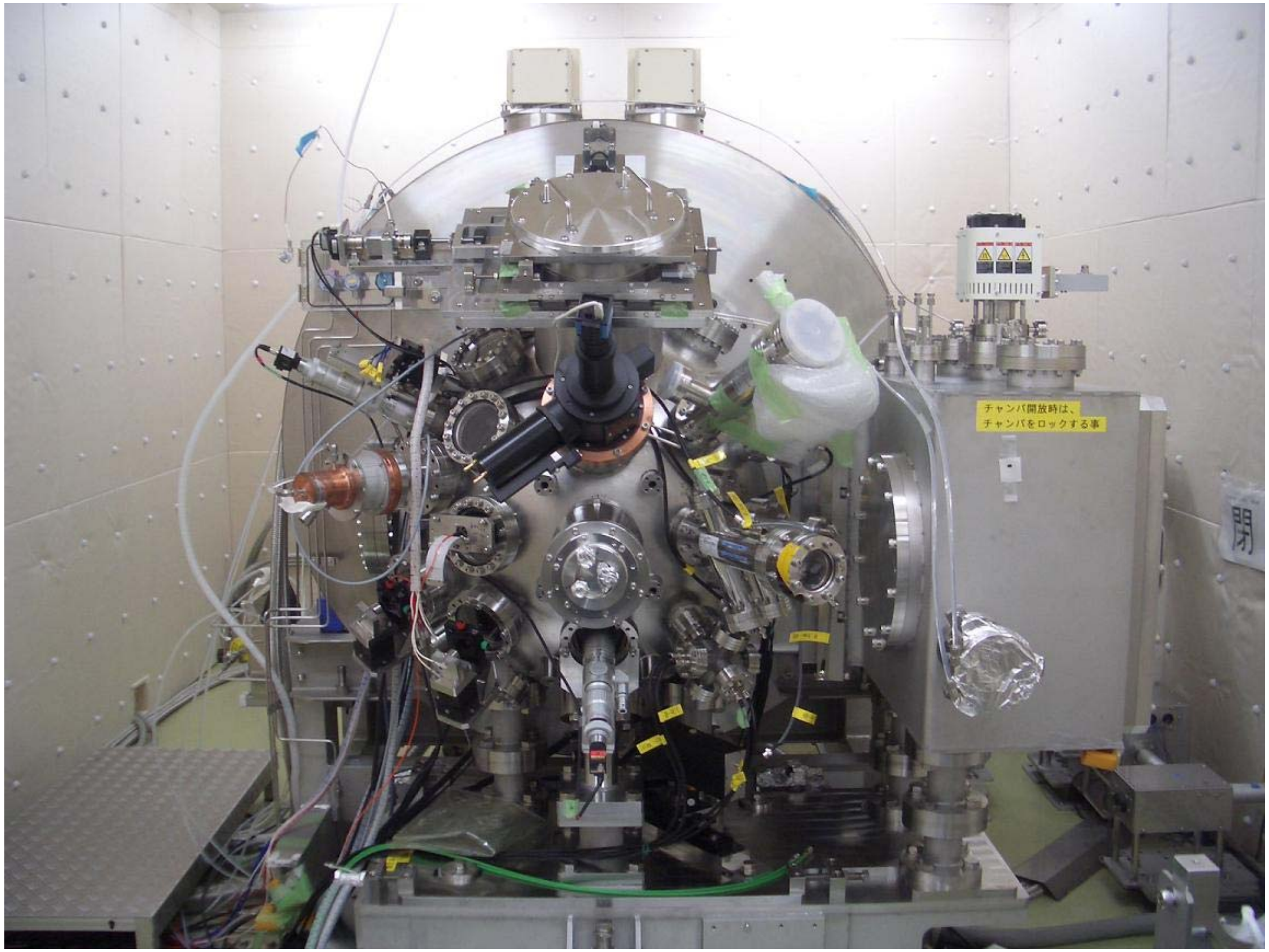
SPF: Spectral Purity Filter IF: Intermediate Focus

KOMATSU EUVA

Outline

- **Introduction**
  - Concept of Gigaphoton LPP source
- **1st Generation system data**
  - Latest data
  - Critical issue and experimental data
- **2nd generation system development**
  - Design
  - Status of construction
- **Roadmap update and New facility**
- **Looking through 6.6nm**
- **Summary**

1st generation system (ETS device)



System operation Data (1)

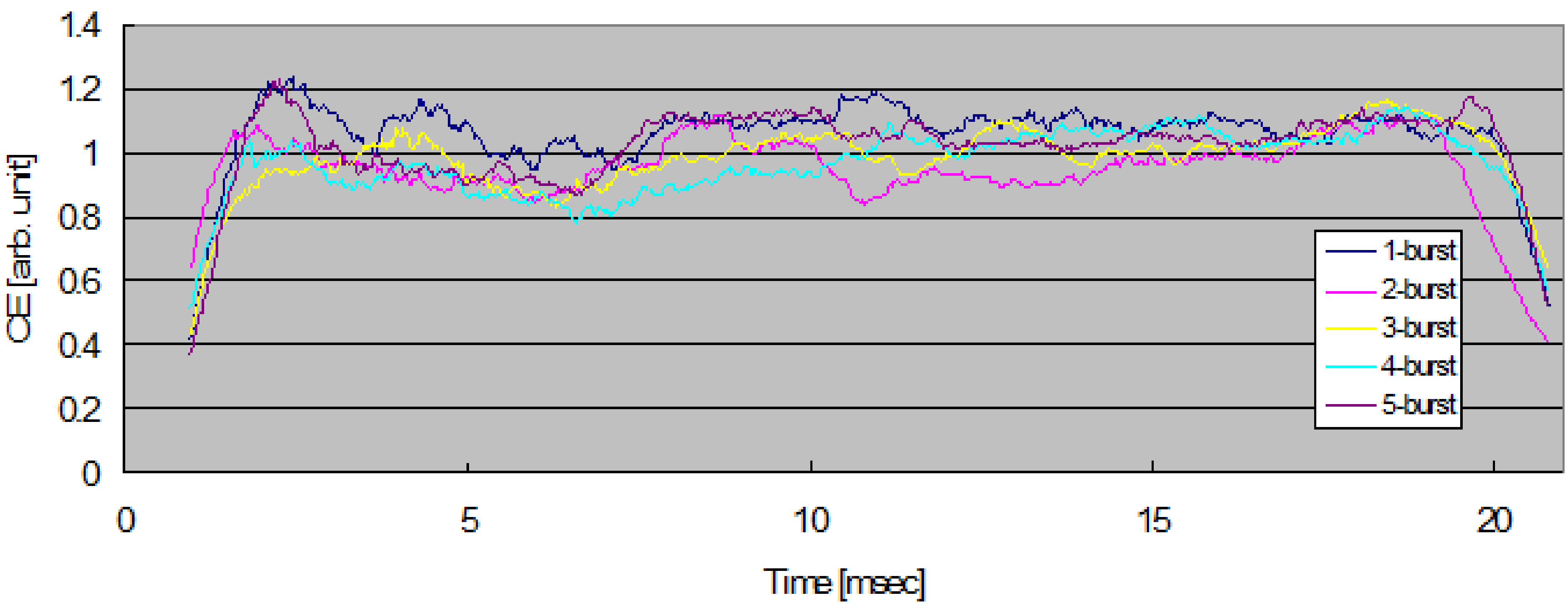
	Last data (SPIE 2010)	Present
Average power (@I/F)	14 W	21 W
Brightness (@I/F)	69 W	104 W
Duty cycle	20 %	20 %
Max. non stop op. time	>1 hr	<1 hr
Average CE	2.3 %	2.5 %
Dose stability (simulation)	(+/- 0.15%)	(+/- 0.15%)
Droplet diameter	60μm	60μm
CO_2 laser power	5.6 kW	7.9 kW

KOMATSU

EUVA

System operation Data (2)

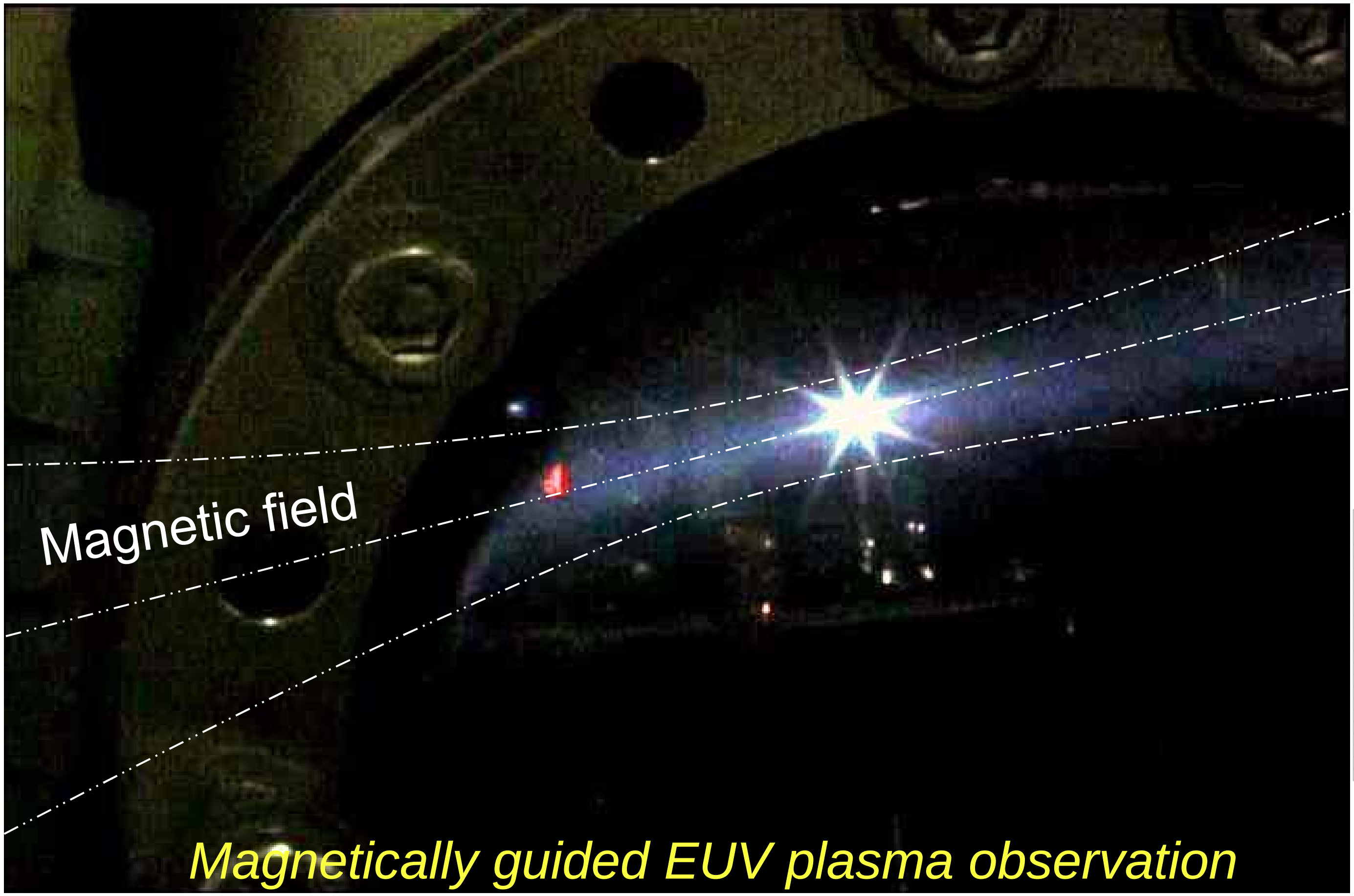
- Burst stability data (70W open loop)



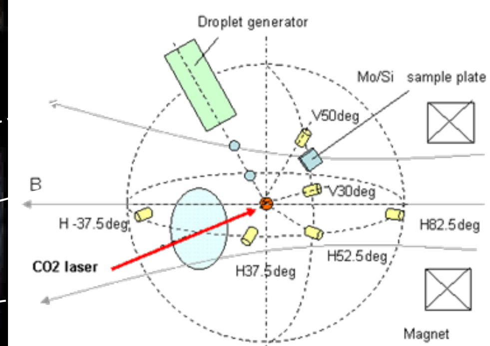
KOMATSU EUVA

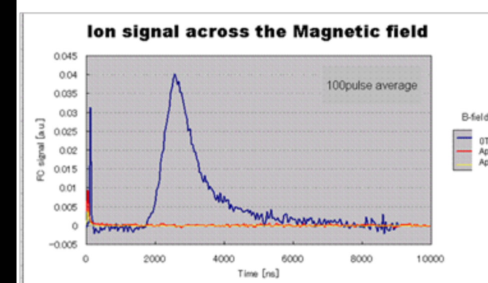
System operation data (3)

Fast Ions are perfectly shielded across magnetic field !



Ion measurement



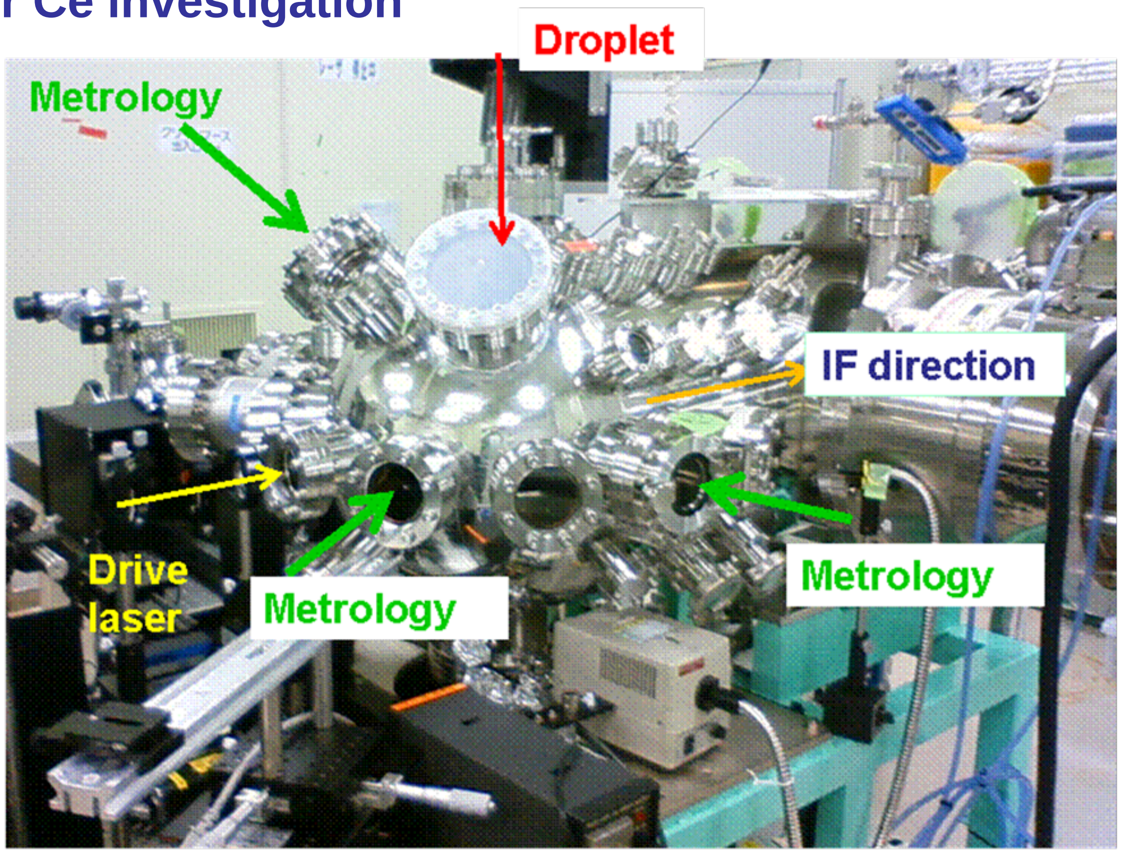


- ✓Laser power 5kW
- ✓Duty 20% (ON 200msec:OFF 800msec)

Critical issue investigation

(Experiment with research device 10Hz experiment)

- Double pulse optimization
- Debris mitigation mechanism
- Higher Ce investigation



Liquid droplet experiment

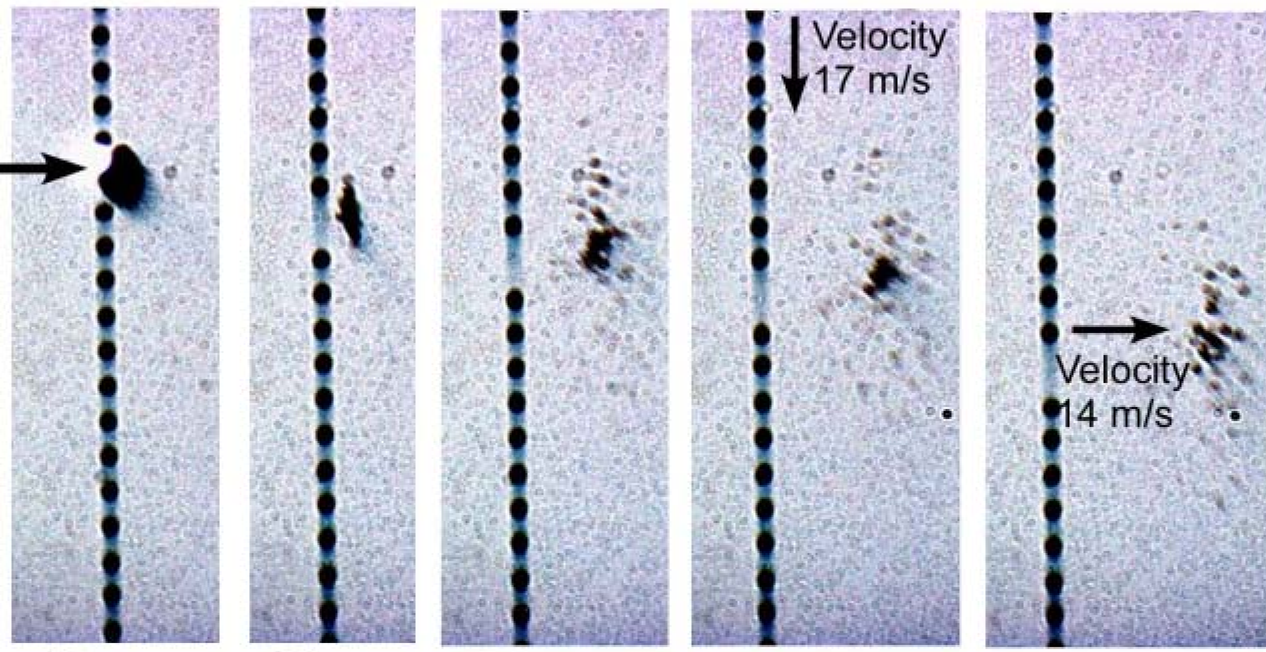
Shadowgraphs of the liquid droplet target

Nd:YAG Laser

Wavelength : 1064 nm
Pulse length : 5 ns (FWHM)
Spot size : ~ Φ100 μm
Laser intensity
: ~ 1.6×10^{9} W/cm^{2}

Target

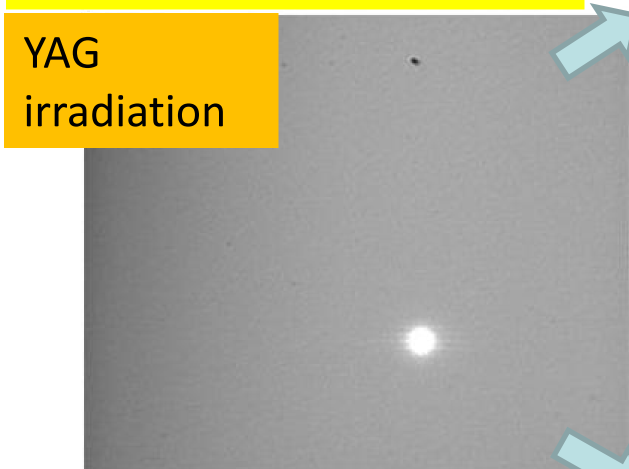
Liquid droplet : Φ60 μm

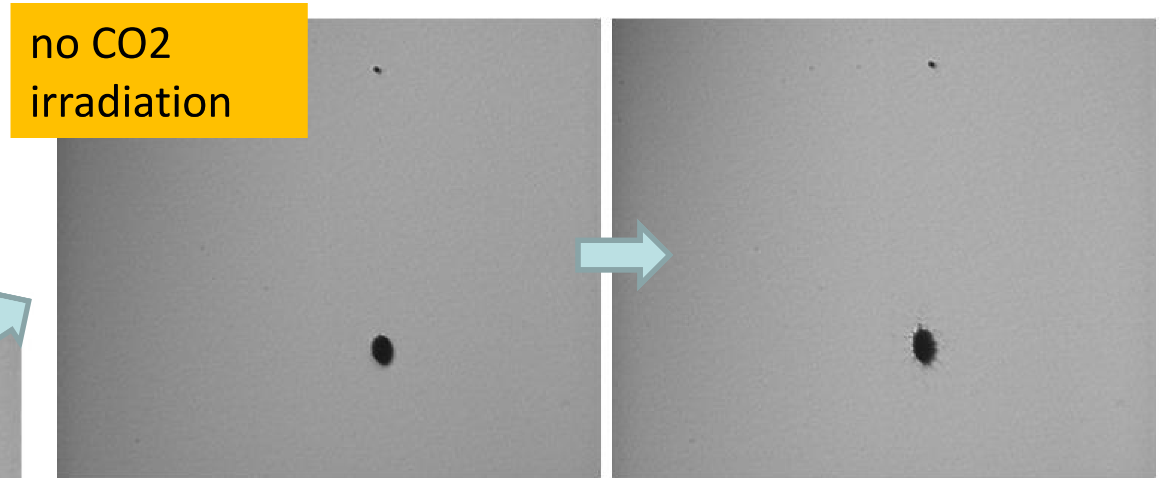


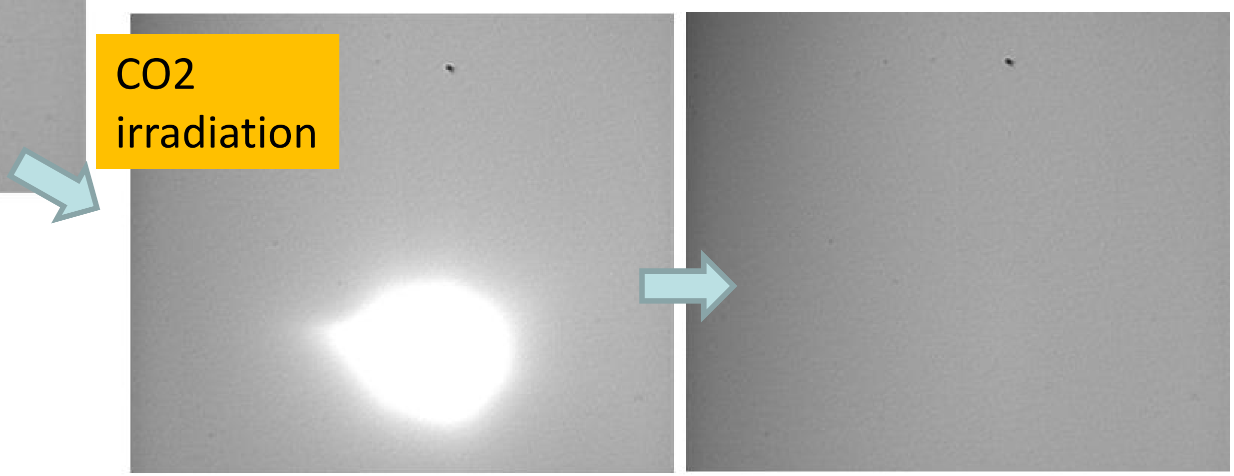
0 μs | 10 μs | 20 μs | 30 μs | 50 μs

Liquid droplet experiment with double-pulse

Perfect evaporation and high Ce(=2.2%) with double pulse irradiation at around 20 micron Tin droplet is demonstrated.







SO-04 **T. Hori "Investigation on high conversion efficiency and tin debris mitigation for LPP EUV light source.**

SO-P15 **A. Sunahara "Radiation Hydrodynamic Simulation of laser produced Tin plasma."**

Outline

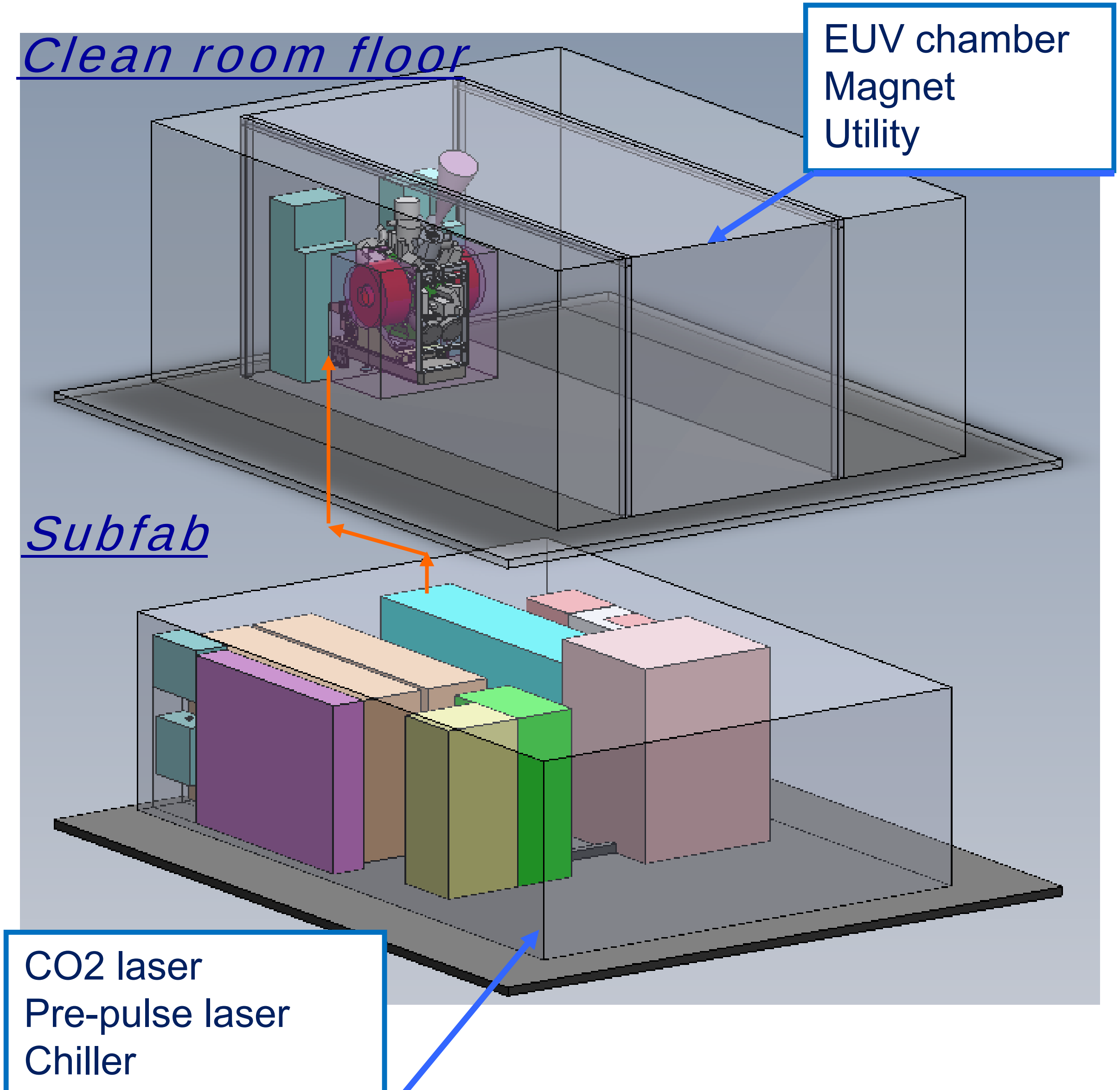
- **Introduction**
  - Concept of Gigaphoton LPP source
- **1st Generation system data**
  - Latest data
  - Critical issue and experimental data
- **2nd generation system development**
  - Design
  - Status of construction
- **Roadmap update and New facility**
- **Looking through 6.6nm**
- **Summary**

EUV Light Source Major Specifications

2nd generation GL-200E-proto is under development !

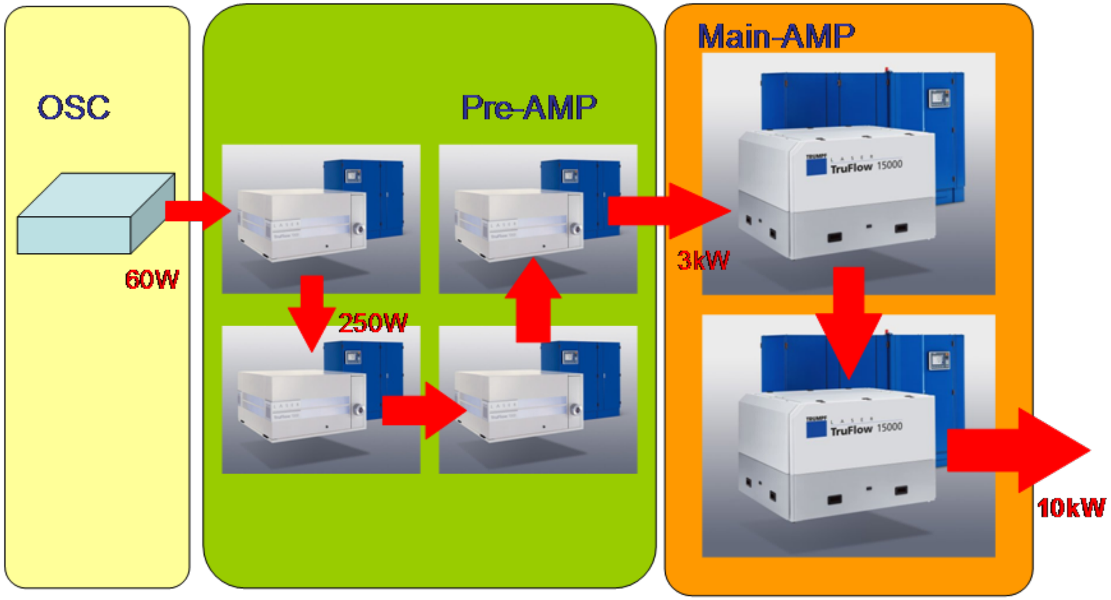
		1st generation	2nd generation	
EUV model		**ETS**	**GL200E proto**	**GL200E**
Power	**W**	**100**	**>100**	**>250**
Pulse energy	**mJ**	**1**	**>1**	**>2.5**
Max rep rate	**kHz**	**100**	**100**	**100**
Max Duty Cycle	**%**	**75**	**>75**	**>75**
Sub systems				
Target Material and Shape		**Sn droplet**	**Sn droplet**	**Sn droplet**
Droplet Diameter	**micro meter**	**60**	**10**	**10**
Debris Mitigation		**Magnet and cleaning**	**Magnet and cleaning**	**Magnet and cleaning**
Collector Mirror Lifetime	**Bpls**	**11**	**>200**	**>1250**
Tool Interface		**No**	**Yes**	**Yes**

GL200E-proto System Overview

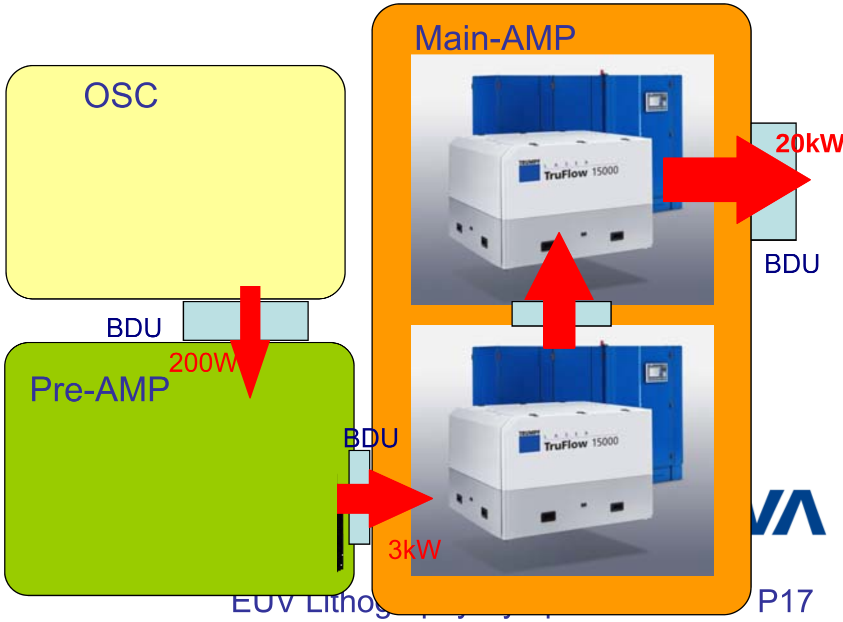


2nd gen. high power pulsed CO_2 laser system

- 1st gen. laser system



- **2nd gen. laser system**
  - *- Compact: footprint -> <50%*
  - *- Efficient: Plug in eff. x2*
  - *- Higher power: 10kW-> 20kW*

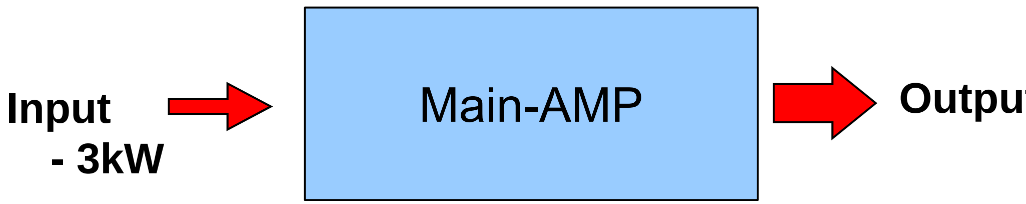


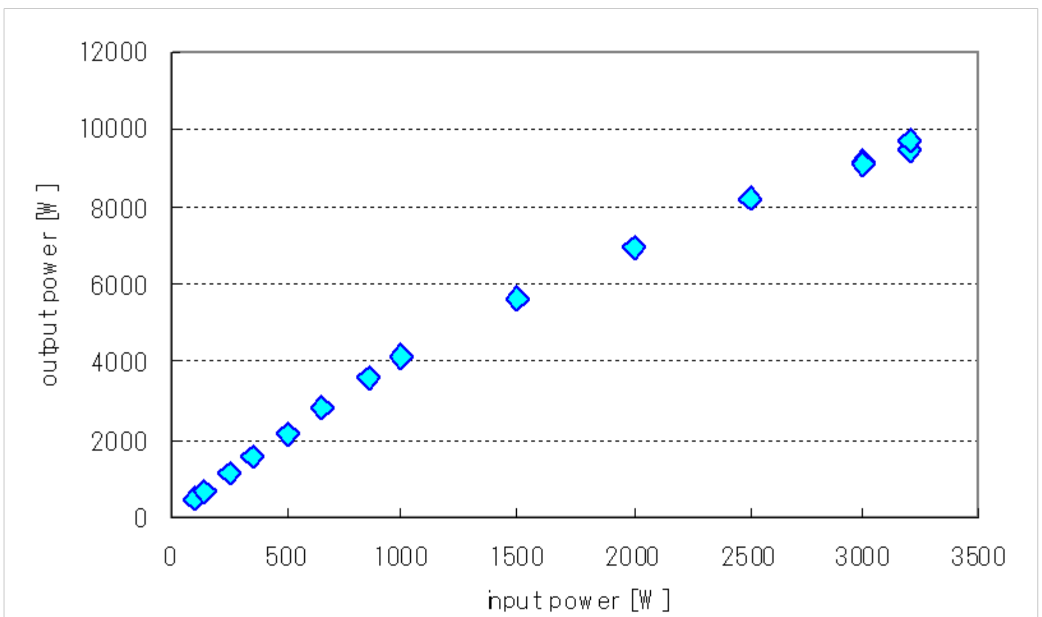
KOMATSU

2nd Gen. CO_2 laser system is under construction

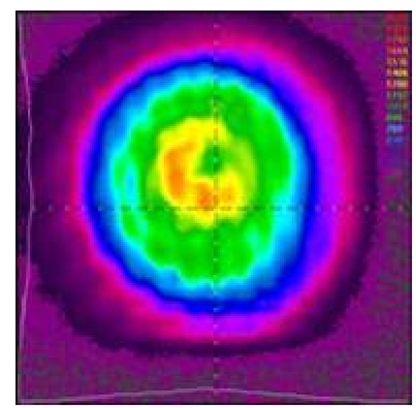
Main Amplifier performance

- Main amplifier characteristics : experimental results
  - ✓ ~10kW output achieved at 3kW input power
  - ✓ Good beam quality: $M^2<2.0$





Output beam profile



SO-PO3 **T. Ohta "Improving efficiency of pulsed CO2 laser system for LPP EUV light source."**

2nd Gen. Magnet system is under construction

Outline

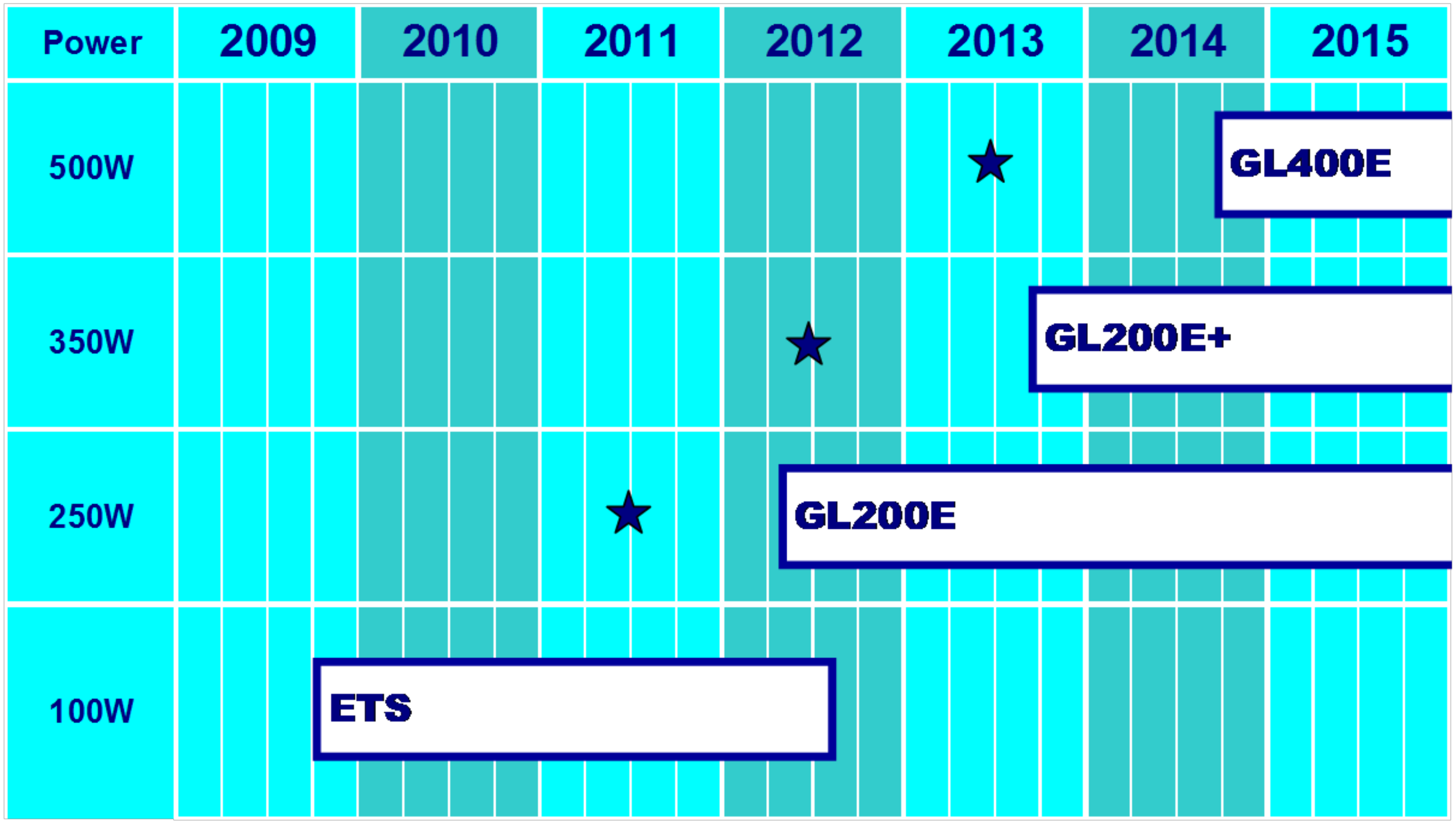
- **Introduction**
  - Concept of Gigaphoton LPP source
- **1st Generation system data**
  - Latest data
  - Critical issue and experimental data
- **2nd generation system development**
  - Design
  - Status of construction
- **Roadmap update and New facility**
- **Looking through 6.6nm**
- **Summary**

GIGAPHOTON BEAM to the FUTURE

KOMATSU

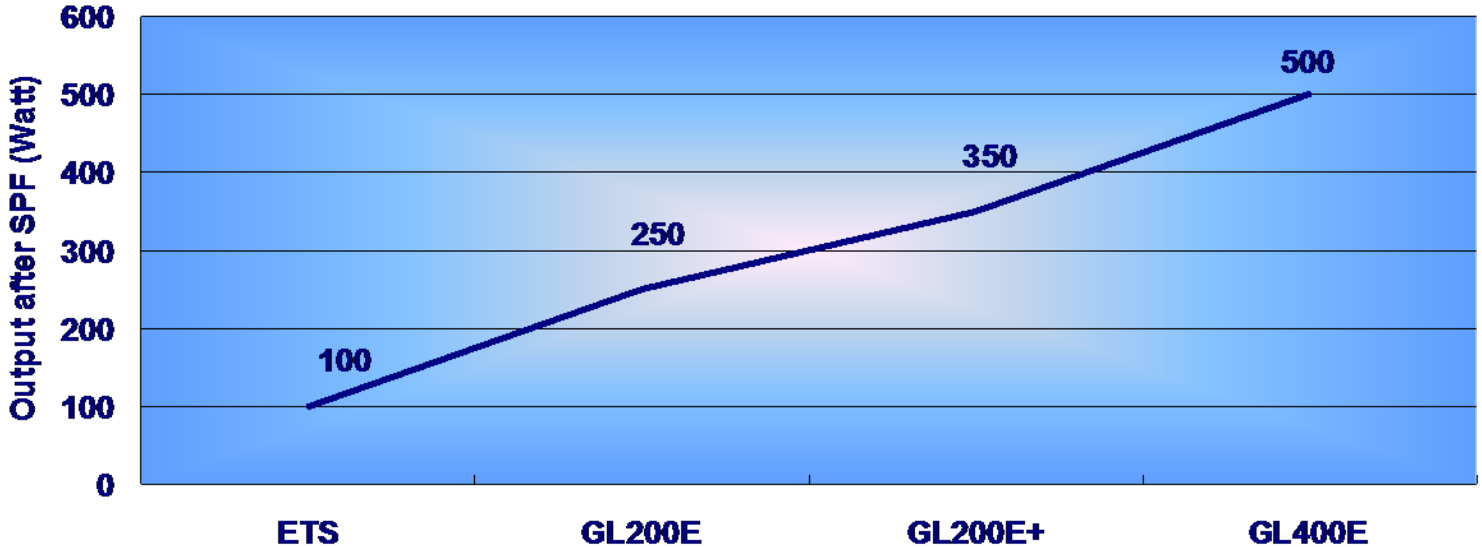
EUVA

Gigaphoton EUV roadmap



★ 1st source delivery

Power roadmap (Clean EUV Power)



EUV model		ETS	GL200E	GL200E+	GL400E
Drive laser power	kW	10	23	33	40
Conversion efficiency	%	3.0	5.0	5.0	6.0
C1 mirror collector angle	sr	5.5	5.5	5.5	5.5
efficiency*	%	74	74	74	74
C1 mirror reflectivity	%	(50)	57	57	57
Optical transmission	%	95	95	95	95
SPF (IR, DUV)	%	N/A**	62	62	62
Total EUV power (after SF	W	100	250	350	500

LPP-EUV Development Facility (1)

- ✓ Shinomiya, Hiratsuka (60km south-west from Tokyo)
- ✓ In industry park of Hiratsuka beside the Sagami river
- ✓ Production capacity is up to 4 units/year (at present)
- ✓ Building is extendable to surrounded open space

LPP-EUV Development Facility (2)

Outline

- **Introduction**
  - Concept of Gigaphoton LPP source
- **1st Generation system data**
  - Latest data
  - Critical issue and experimental data
- **2nd generation system development**
  - Design
  - Status of construction
- **Roadmap update and New facility**
- **Looking through 6.6nm**
- **Summary**

Looking through 6.6nm

Base line

- For 1/2 shorter wavelength generation, 2x higher plasma temperature is needed. On the other hand LPP based on free standing plasma, plasma temperature may not showstopper of EUV generation.

Engineering issue

- Fundamental study of Gd, Tb plasma is important. Also conversion efficiency investigation on the plasma is important for system design.

- 2x higher exciting power intensity by LPP driver laser.

- Gd,Tb has similar property with Tin except melting point. (→ next table)

  Around 10 micron droplet generation of very high temperature (>1000 ° C) materials is key technology.

EUV emission materials

Physical properties		Tin	Gadolinium	Terbium
EUV wavelength		13.6nm	6.5-6.7nm	
Density (near r.t.)	$g \cdot cm^{-3}$	7.365	7.90	8.23
Liquid density at m.p.	$g \cdot cm^{-3}$	6.99	7.4	7.65
Melting point	°C (°F)	231.93 (449.47)	1312 (2394)	1356 (2473)
Boiling point	°C (°F)	2602 (4716)	3273 (5923)	3230 (5846)
Heat of fusion	$kJ \cdot mol^{-1}$	7.03	10.05	10.15
Heat of vaporization	$kJ \cdot mol^{-1}$	296.1	301.3	293
Specific heat capacity (25°C)	$J \cdot mol^{-1} \cdot K^{-1}$	27.112	37.03	28.91
Ionization energies	$kJ \cdot mol^{-1}$	1st: 708.6 2nd: 1411.8 3rd: 2943.0	1st: 593.4 2nd: 1170 3rd: 1990	1st: 65.8 2nd: 1110 3rd: 2114
EUV Conversion Efficiency	%	**3.2 (max.8.0)**	?	?

Outline

- **Introduction**
  - Concept of Gigaphoton LPP source
- **1st Generation system data**
  - Latest data
  - Critical issue and experimental data
- **2nd generation system development**
  - Design
  - Status of construction
- **Roadmap update and New facility**
- **Looking forward 6.6nm**
- **Summary**

Summary

- **ETS-2 (1^{st} generation integrated setup LPP source)**
  - Latest operation data is reported
    - 104W at duty cycle of 20% (i.e. average power = 21W)
    - Stability under burst operation <+/- 0.23% (dose simulation)
  - Investigation of critical issue is in advance at research device.
    - Under 20 μm Tin droplet evaporated perfectly with double pulse method.
- **2^{nd} generation LPP source**
  - Construction of 1^{st} proto machine is on going.
    - CO_2 laser operate with good beam quality around 10kW 30% duty.
    - Super conductive magnet is installed.
- **Product roadmap and new facility**
  - Target spec.and schedule of Gigaphoton LPP source product is updated.
  - New EUV facility is introduced.

- **Looking forward 6.7nm**
  - Basically LPP-scheme is applicable even on 6.6nm.
  - Fundamental study of Gd, Tb plasma, conversion efficiency investigation is important.
  - 2x higher exciting power intensity by LPP driver laser.
  - Around 10 micron droplet generation of very high temperature (>1000 ° C) materials is key technology.

Acknowledgments

■ *Thanks to funding*

This work was partly supported by the New Energy and Industrial Technology Development Organization -NEDO- Japan.

■ *Thanks to co-workers*

- *Tamotsu Abe, Yukio Watanabe, Takanobu Ishihara, Takeshi Ohta, Tsukasa Hori, Akihiko Kurosu, Hiroshi Komori, Kouji Kakizaki, Akira Sumitani*

EUVA/Komatsu (Japan): 1200 Manda, Hiratsuka, Kanagawa, 254-8567, Japan

- *Osamu Wakabayashi, Hiroaki Nakarai, Junichi Fujimoto*

Gigaphoton (Japan): 400 Yokokura shinden, Oyama, Tochigi,323-8558 Japan

- *Akira Endo (Present address)*

Forschungszentrum Dresden-Rossendorf, 01328 Dresden, Germany

KOMATSU EUVA

Gigaphoton's mission is to be the No.1 provider of advanced technology and quality products, and to contribute to society as the industry leader.

We at Gigaphoton aim at being a team of professionals who can build a strong relationship of mutual trust, both within and outside of the company.

GIGAPHOTON

http://www.gigaphoton.com