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

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Acknowledgments
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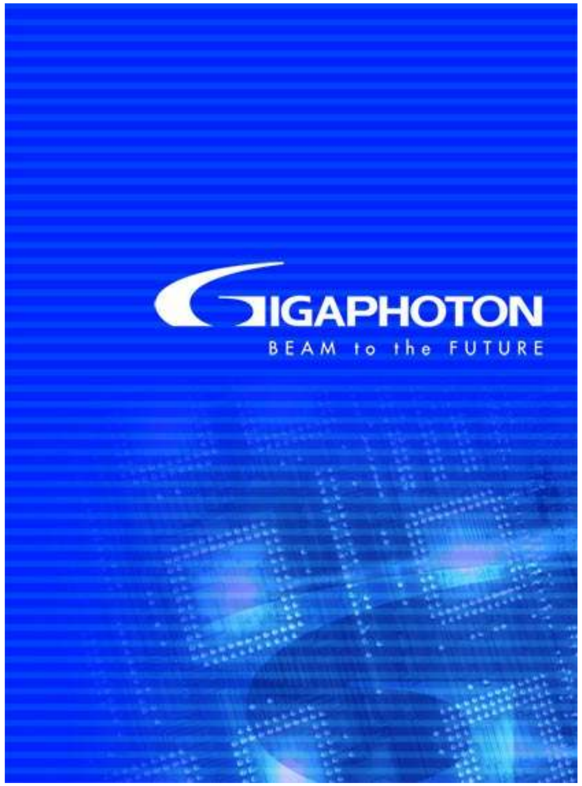


Outline

1. Introduction

2. Engineering Test source

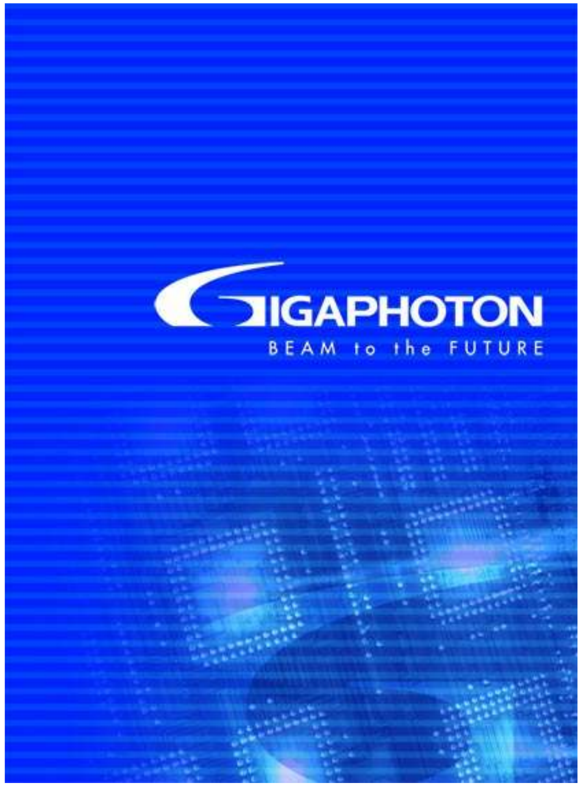
- **1st Generation (ETS) device: System experiment**
  - Latest experimental data
  - Critical issues
- **10Hz device: Critical issue experiment**
  - Perfect vaporization: Important step to magnetic mitigation
  - Pre-pulse and high CE

3. HVM EUV light source

- **Product roadmap**

- **2nd Generation device: Development status**
  - Configuration
  - Latest status

4. Summary



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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 ～
EUV Power (IF) Stability Laser Laser freq. CE (source) Target	5.7W 1) --- YAG:1.5kW 10kHz 0.9% Xe-Jet	10W 1) $\sigma<\pm10\%$ CO_2:2.6kW 100kHz 0.9% SnO_2 choroid liquid jet	50W 2) $\sigma<\pm5\%$ CO_2: 7.5kW 100kHz 2.5% Sn-Droplet	1st Generation (ETS) 110W 2) /140W 3) $3\sigma<\pm0.3\%$ CO_2: 10kW 100kHz 4% Sn-Droplet	2nd Generation (proto/GL200E) 250W (clean@IF) $3\sigma<\pm0.3\%$ CO_2: 23kW 100kHz 5% Sn-Droplet
	EUVA project-1			EUVA project-2	Commercial

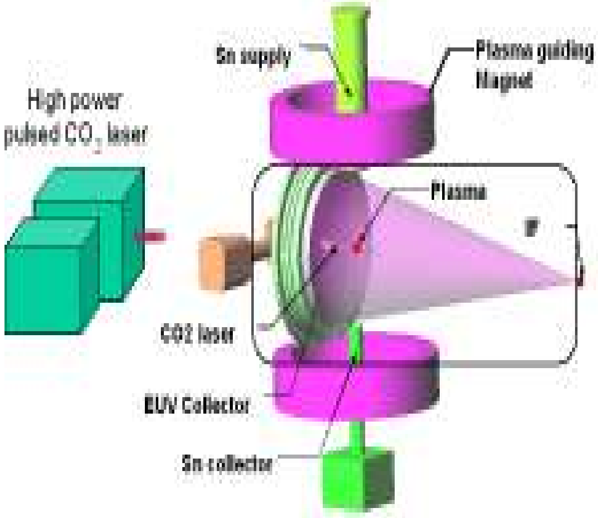
Note）
Primary source to IF EUV transfer efficiency：
1) 43%
2) 28% with SPF
3) 36% without SPF

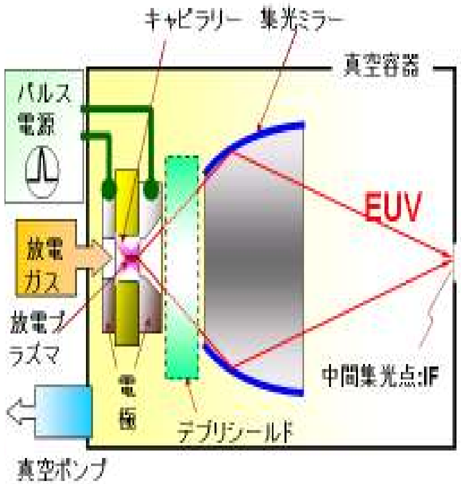
SPF: Spectral Purity Filter IF: Intermediate Focus

EUV sources

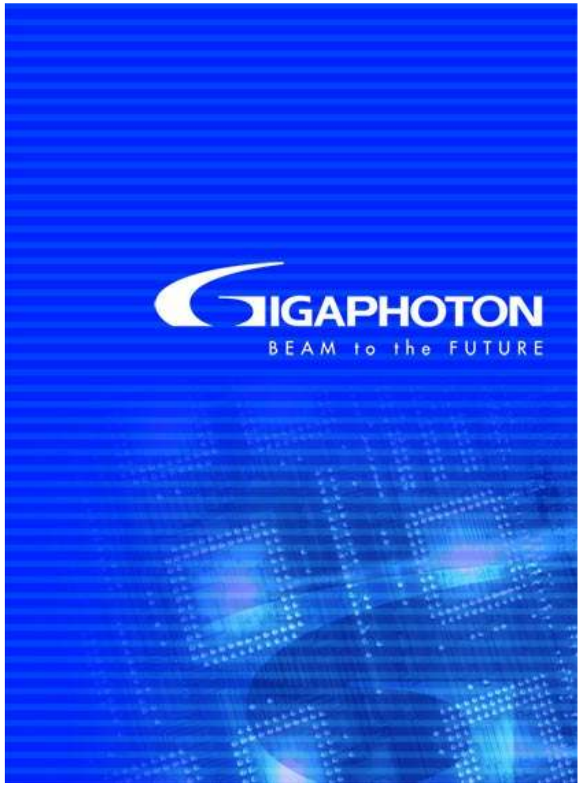
LPP：CO_2 laser and Sn source

- ✓ **High power pulsed CO_2 laser**
- ✓ **Magnetic field plasma mitigation**
- ✓ **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 works still to be done	･Trade off of power and lifetime	･Trade off of power and lifetime･ ･Trade off of power and beam quality



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ETS system configuration

System layout

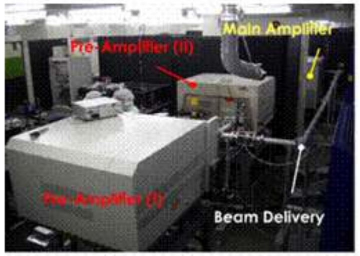
- Laser System

100 W at I/F equivalent

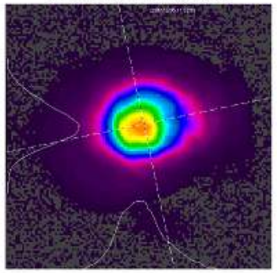
Oscillator
Wave length: 10.6um
Rep. rate :100kHz
Pulse width :20 ns (FWHM)

Pre-Amplifier
RF-excited CO2 laser

Main-Amplifier
RF-excited CO2 laser

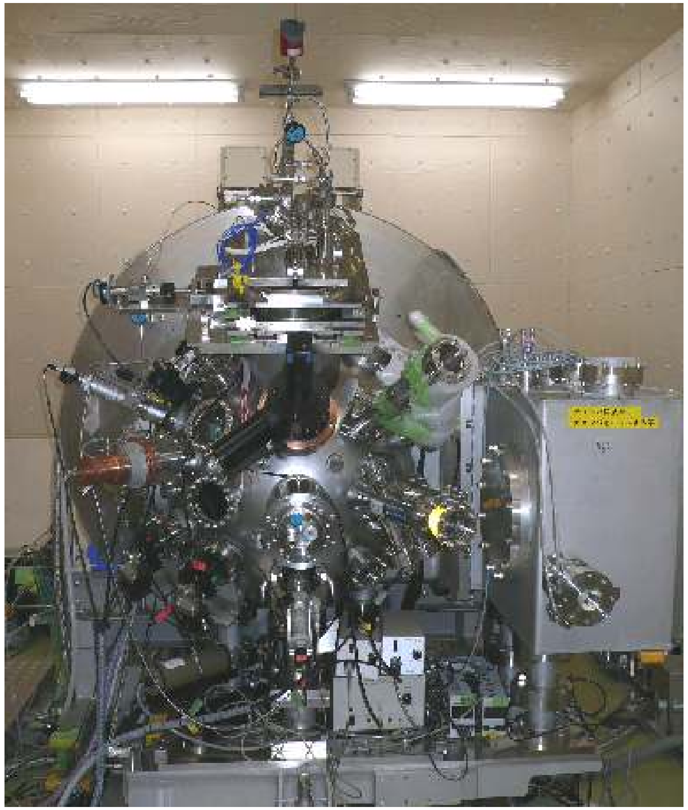


Laser beam profile



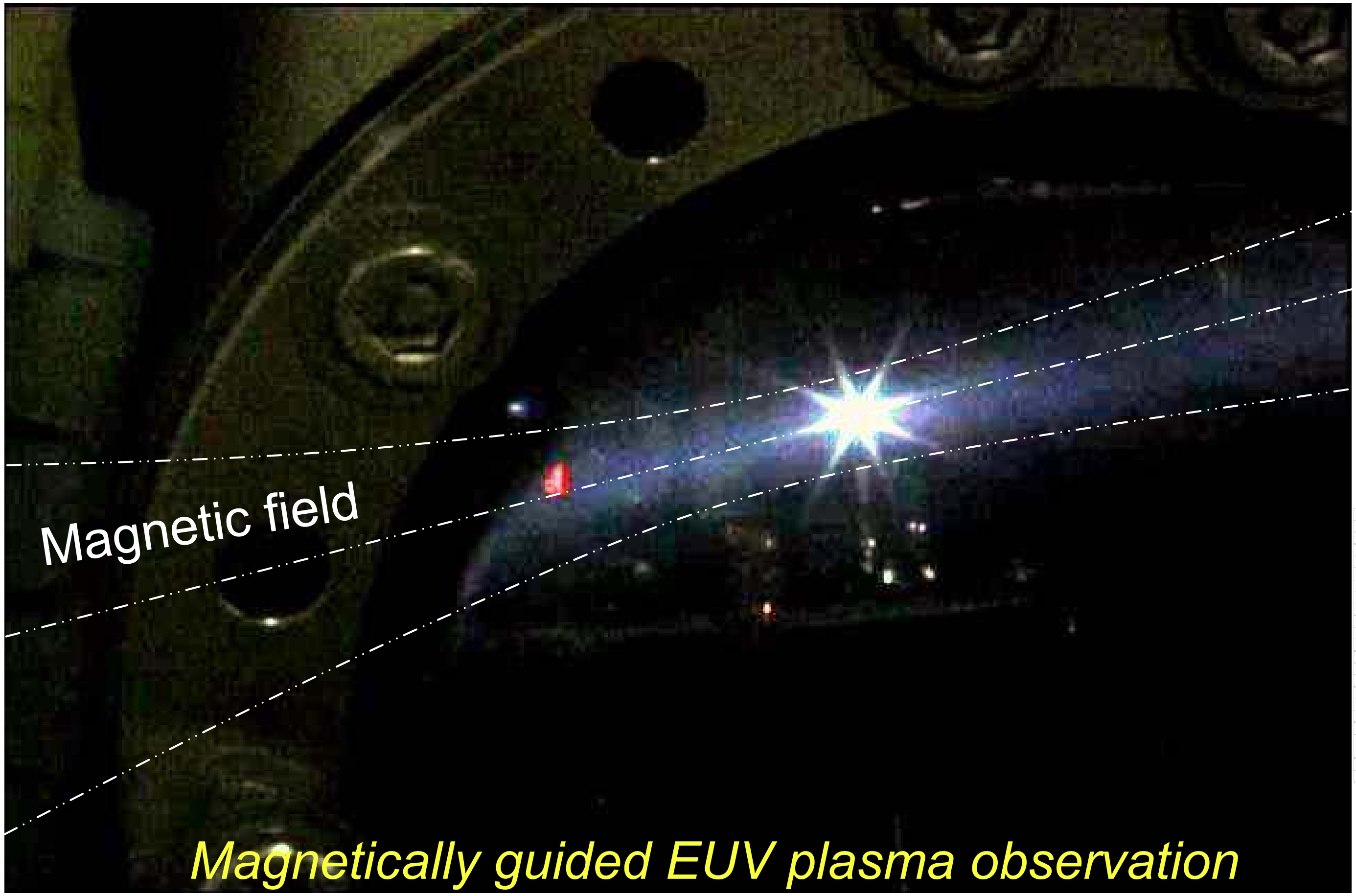
Laser Power:	13 kW
Pulse Width:	20 ns
Repetition Rate:	100 kHz
Pulse energy stability :	2% (3s, 500 pulses)

- EUV chamber



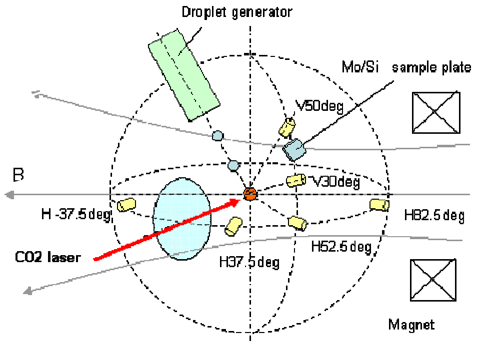
System operation data (ETS device)

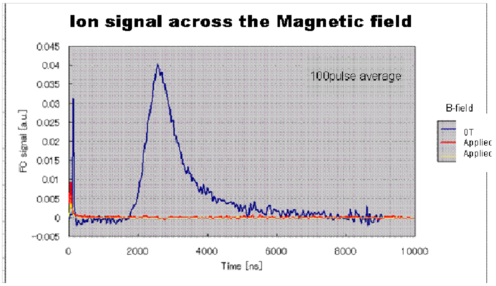
Fast Ions are perfectly shielded across magnetic field !



Magnetically guided EUV plasma observation

Ion measurement





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

System operation Data (ETS device)

	SPIE 2010 (Feb.2010)	EUV Symposium (Oct.2010)	Latest Data (Feb,2011)
EUV power (@ I/F)	69 W	104 W	42 W
EUV power (clean @ I/F)	33 W	50 W	20 W
Duty cycle	20 %	20 %	5%
Max. non stop op. time	>1 hr	<1 hr	>7 hr
Average CE	2.3 %	2.5 %	2.1%
Dose stability :simulation	(+/- 0.15%)		-
Droplet diameter	60μm	60μm	30μm
CO_2 laser power	5.6 kW	7.9 kW	3.6kW

Previous Experiment 60μm Liquid droplet experiment

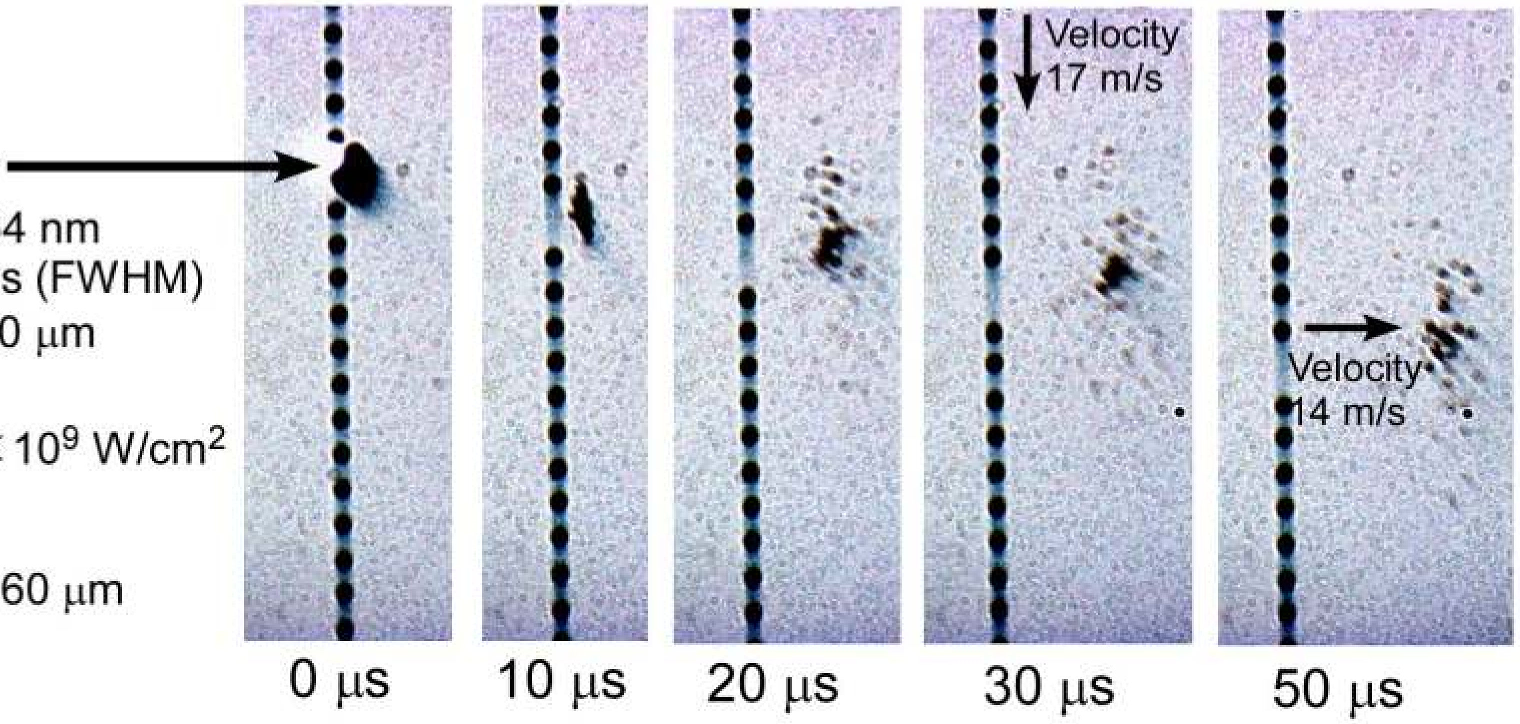
Shadowgraphs of the liquid droplet target

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

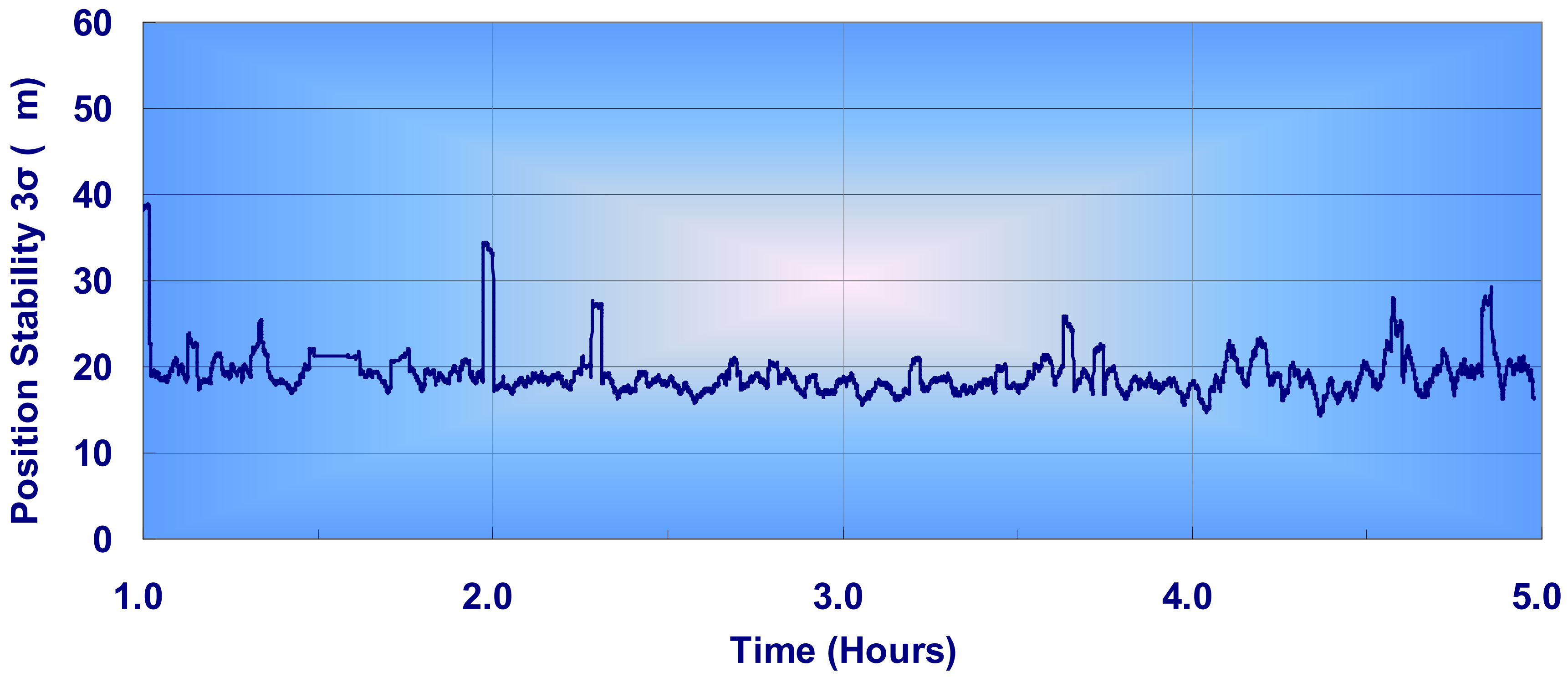


New data: Tin Liquid droplet 60μm -> 30 μm

Almost one order less fragment !

Droplet generator lifetime improvement (ϕ30 μm)

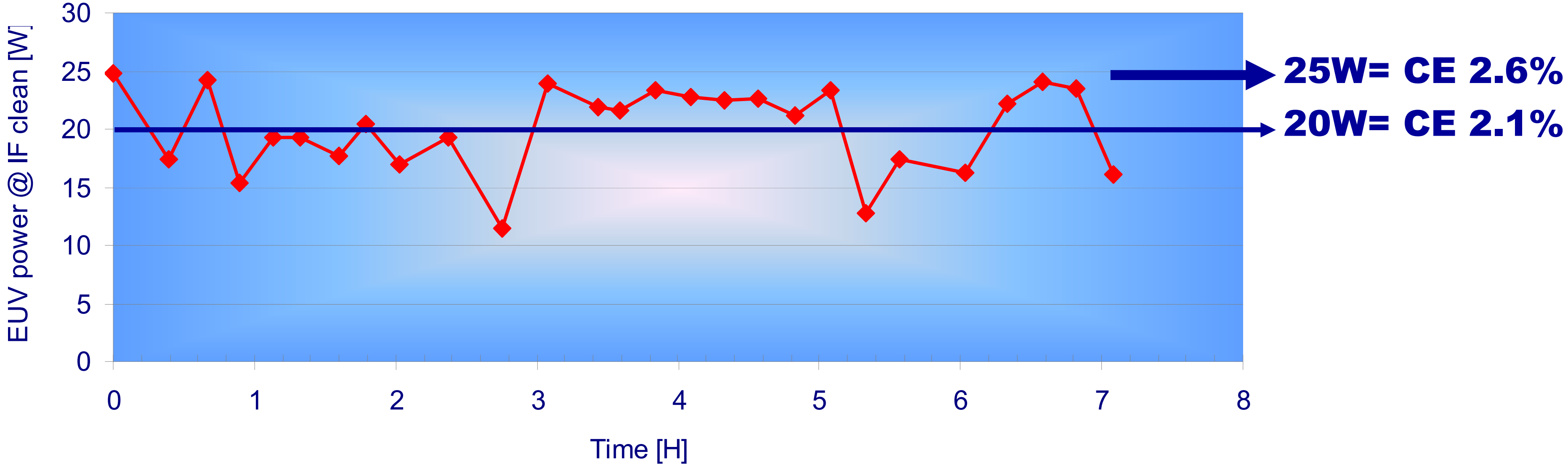
- **Operation time improved from <1 hour to >7 hours**



System operation result on ETS

➢Long time system operation demonstrated

➢ Operation duration:	7 hours
➢ **Droplet**	30 mm diameter
➢ Full repetition rate:	100 kHz
➢ In burst clean power:	20W (average) 25W (max)



Conditions;

Control: Droplet position control ON, EUV energy control OFF
CO_2 laser = 3.6kW @ 100kHz
Duty=5% (50msecON、950msecOFF)

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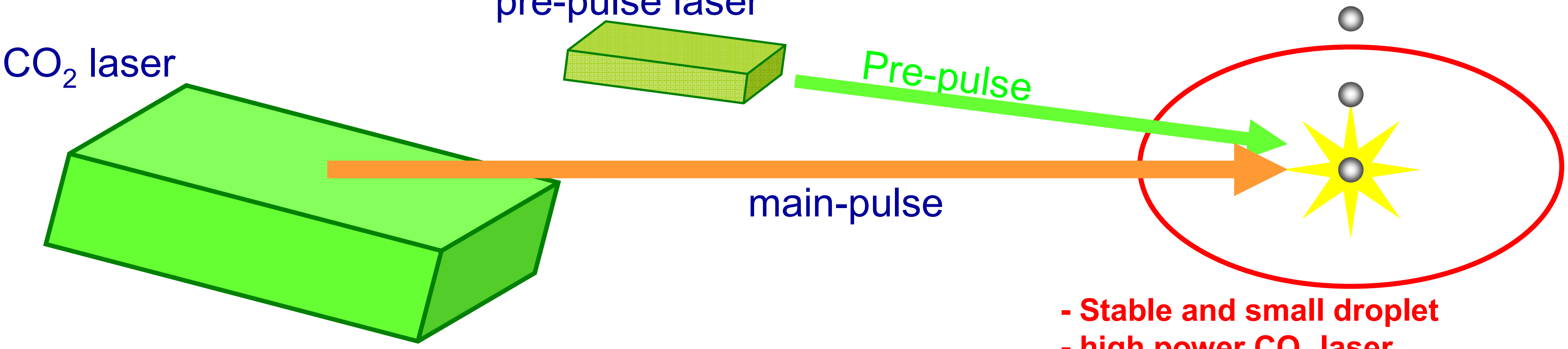
Conclusion of ETS device experiment

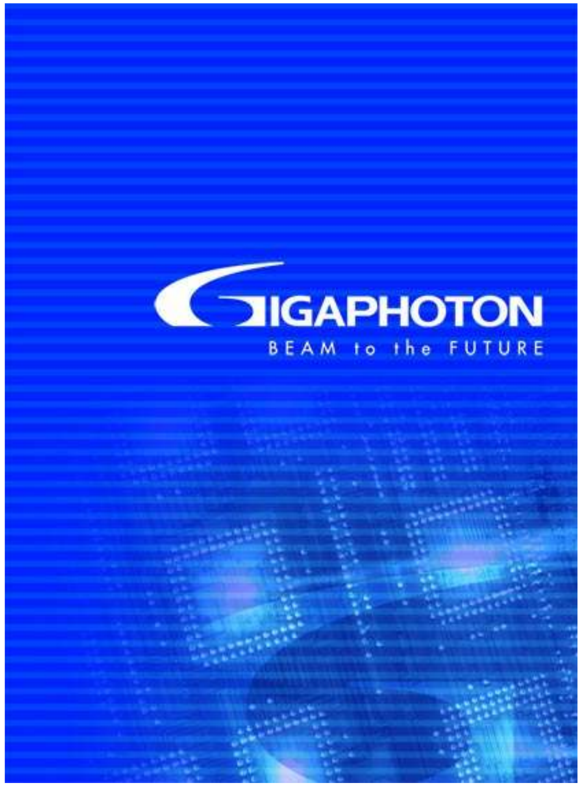
“ETS experiment clarified 3 key challenges are essential”

- ✓ **CE (Conversion Efficiency) improvement**
- ✓ **Debris mitigation = Stability and size of droplets**
- ✓ **CO_2 laser load = power x duty**

Droplet generator



- Stable and small droplet
- high power CO_2 laser
- the best plasma creation



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   - Product roadmap

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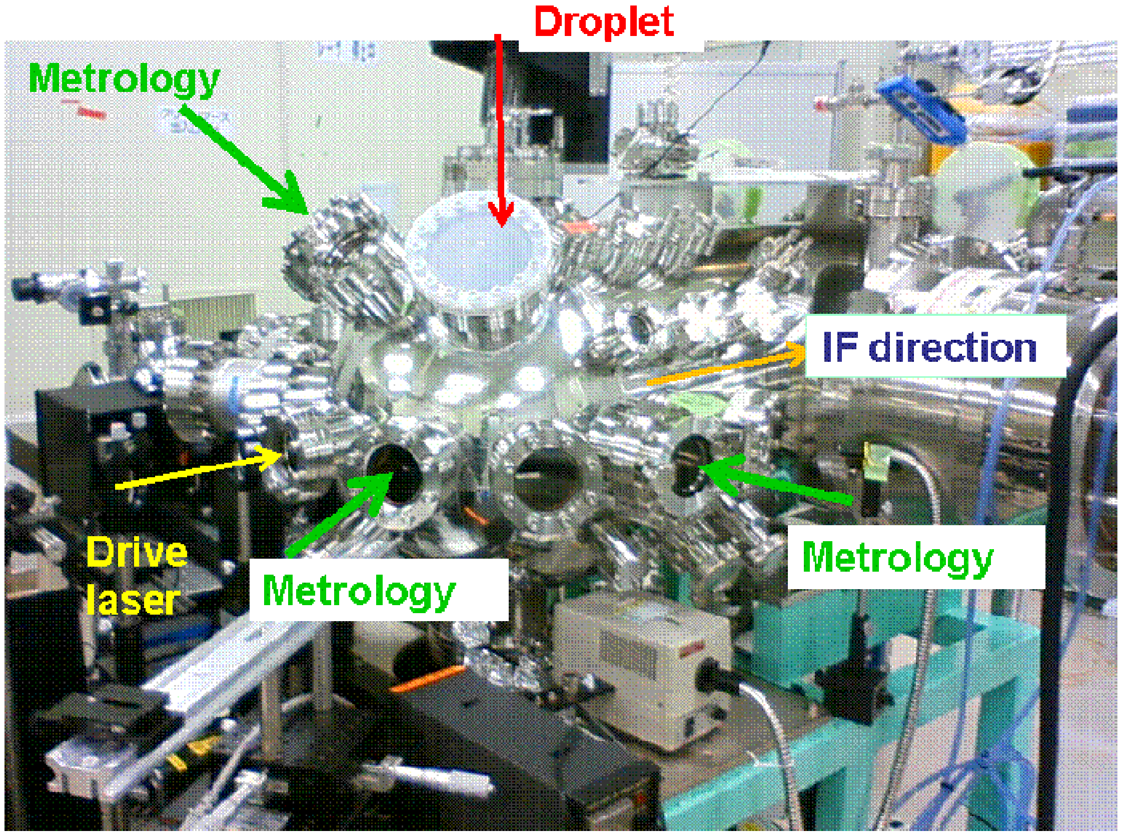
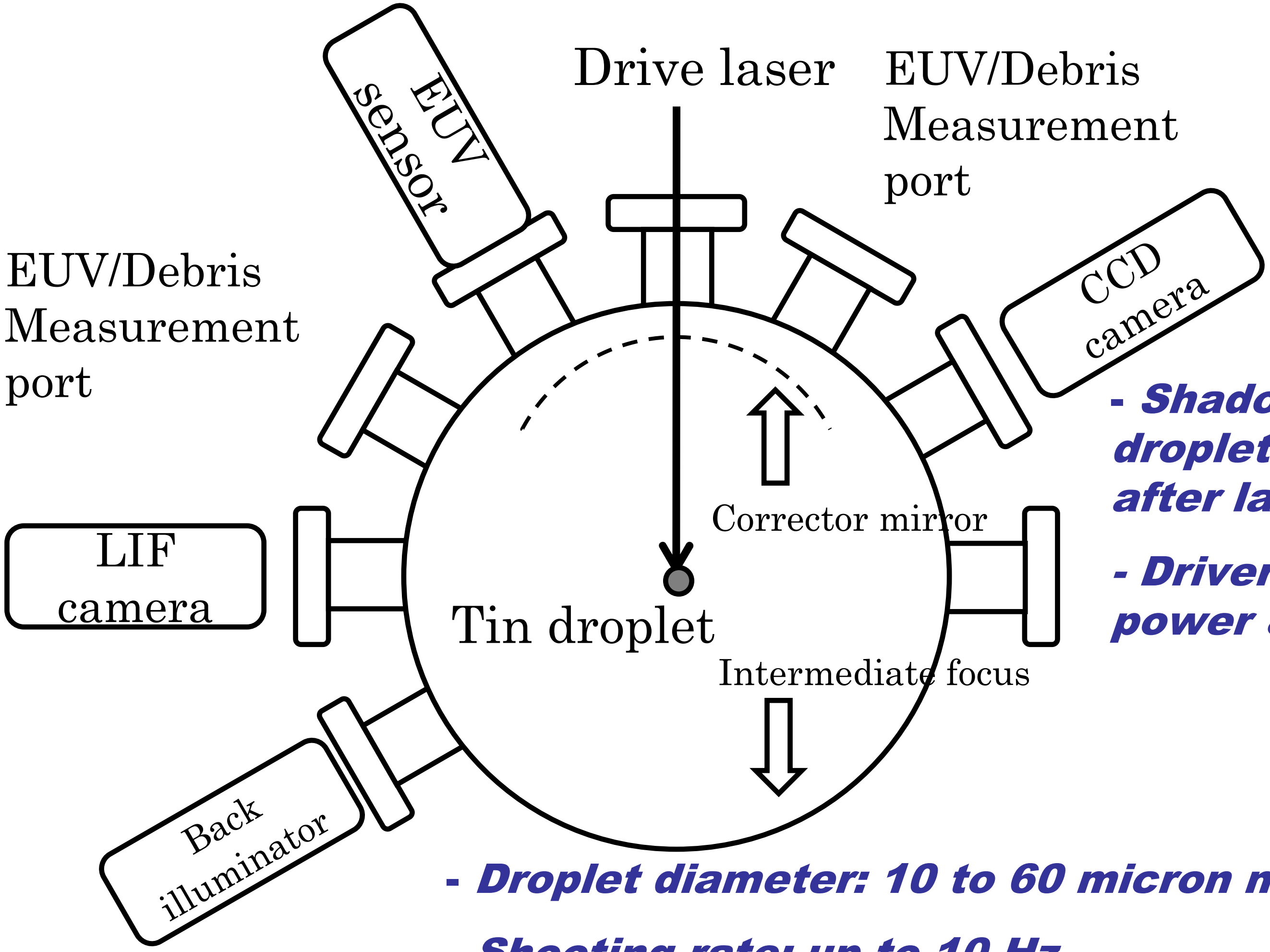
4. Summary

Critical issue investigation with 10Hz device

- *Double pulse optimization*
- *Debris mitigation mechanism*
- *Higher CE investigation*



Setup configurations

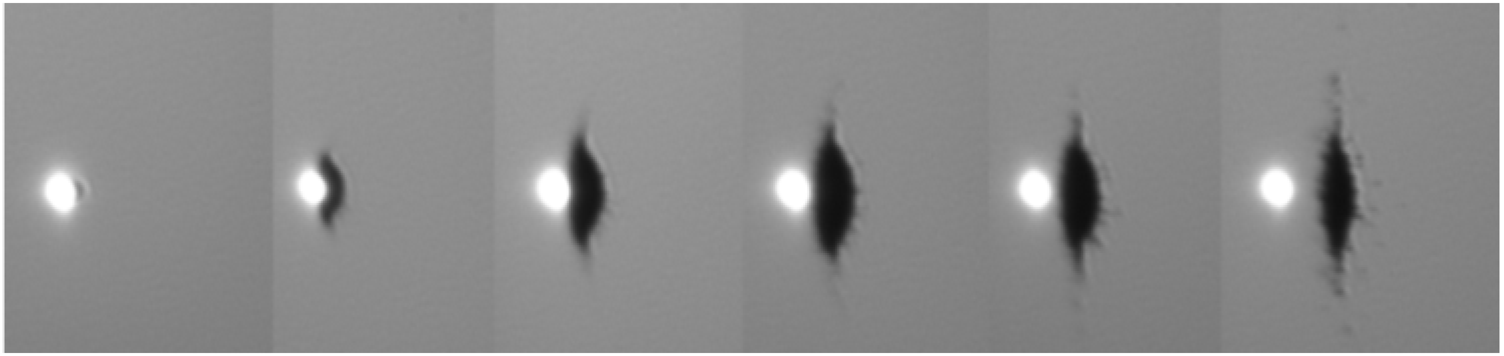


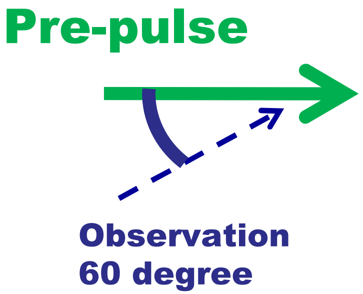
- ***Shadow camera & LIF: droplet & its behavior after laser shooting***
- ***Driver laser: refraction power & distribution***

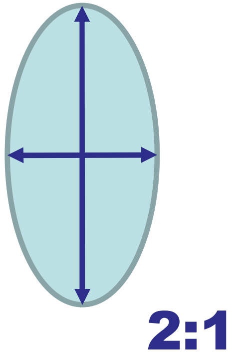
- ***Droplet diameter: 10 to 60 micron meter***
- ***Shooting rate: up to 10 Hz***
- ***Observe what's happen in the vessel?***

Droplet transformation by pre-pulse

Smaller fragments
Spread homogeneously







True circle looked like this ellipse in this configuration

Droplet shooting scheme

Improper pre-pulse condition; fragment size >>BIG

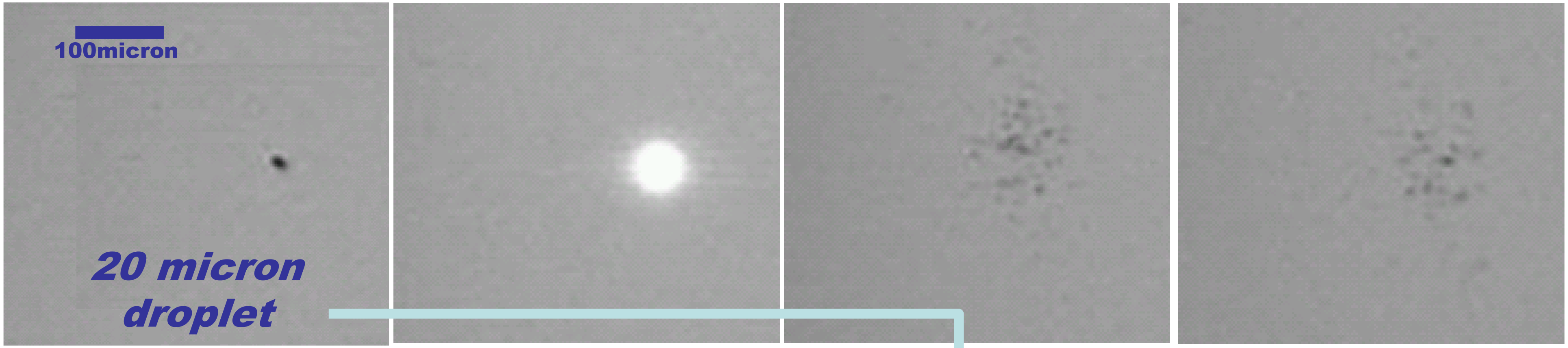
pre-pulse irradiation

Main pulse laser / EUV emission

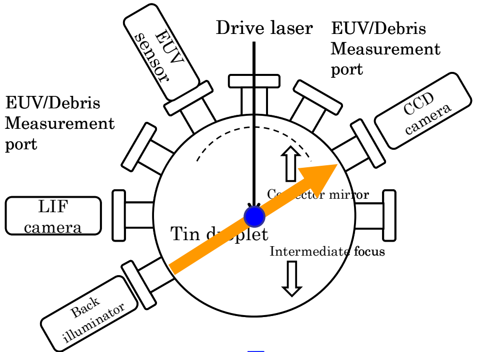
after EUV emission

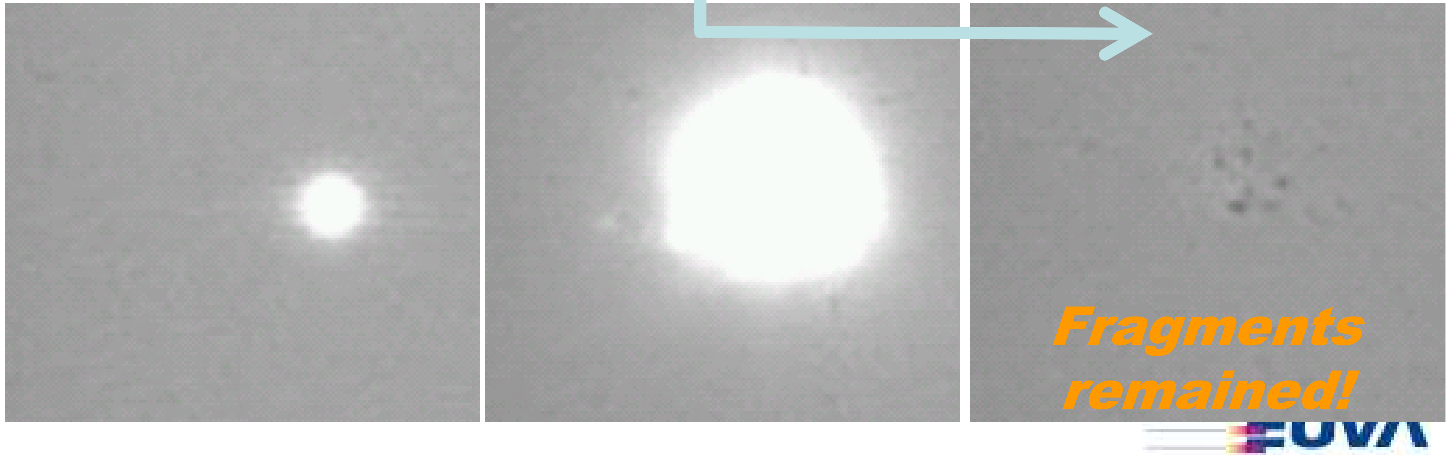
Time

a) without main-pulse laser



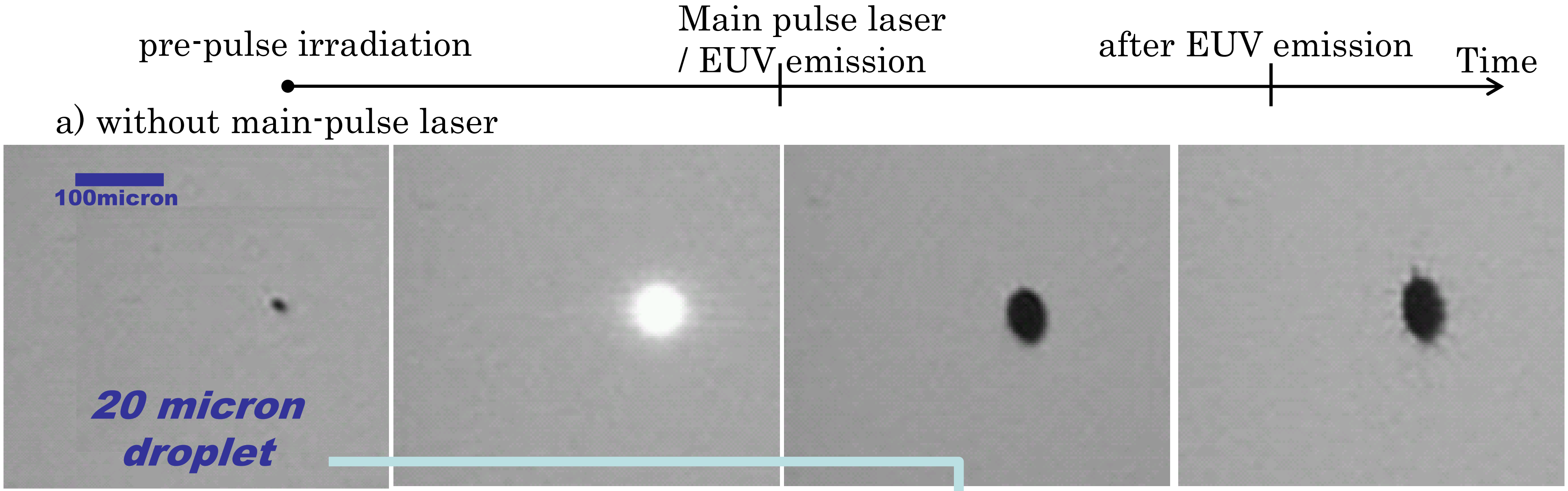
b) with main-pulse laser





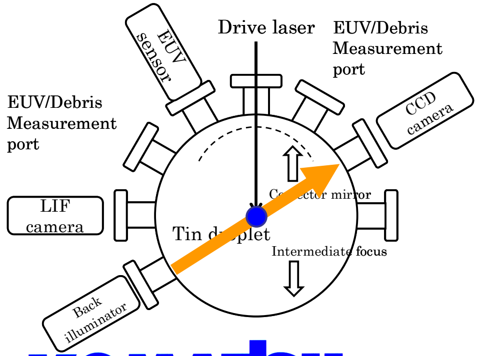
Droplet shooting scheme

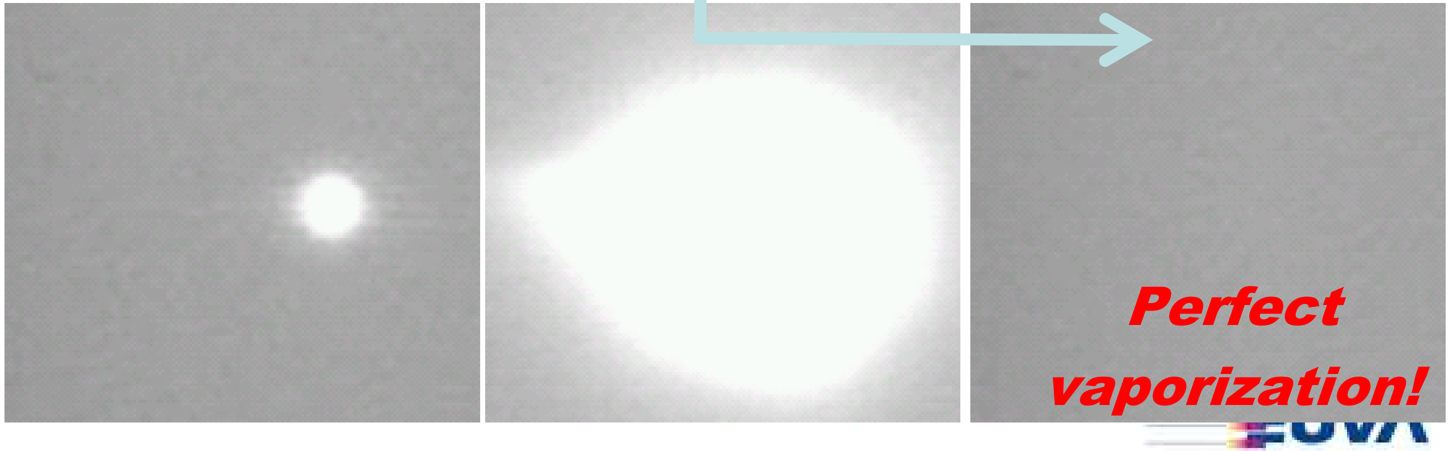
Proper pre-pulse condition



20 micron droplet

b) with main-pulse laser





Perfect vaporization!

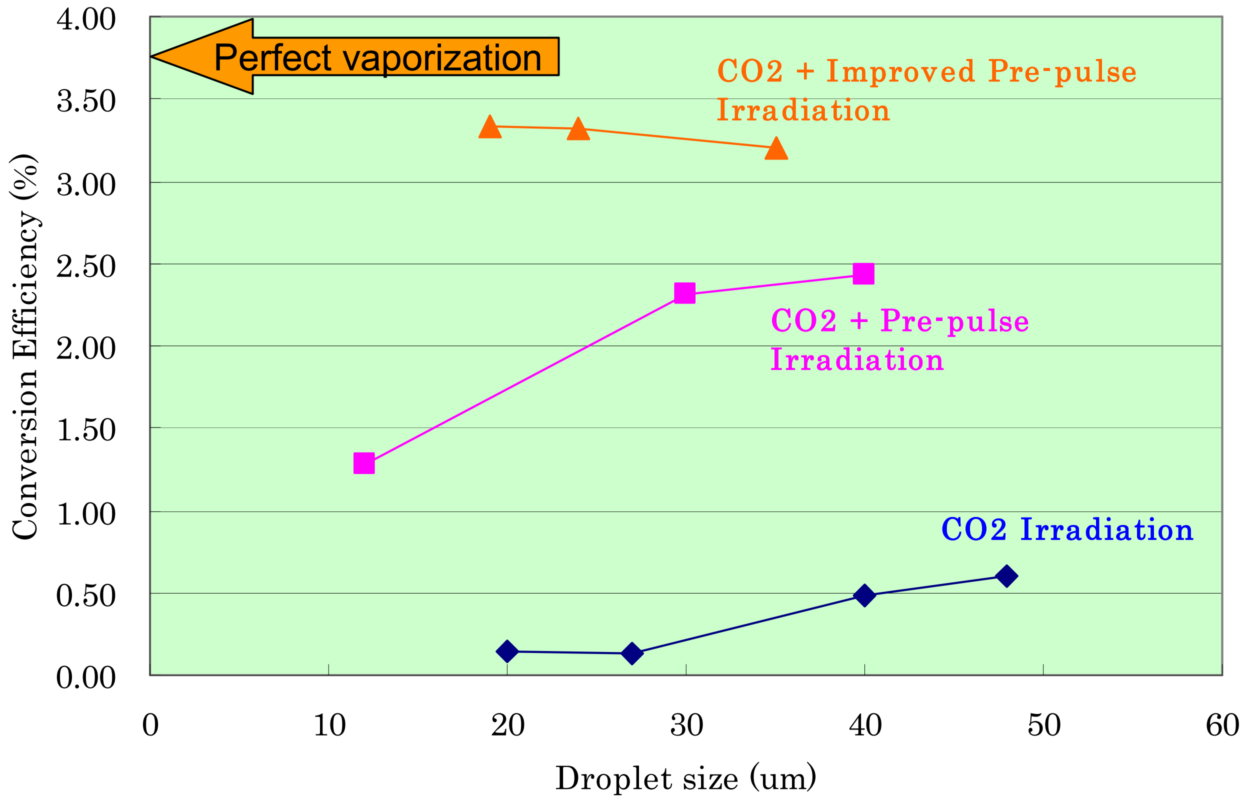
Target behavior with lasers shooting

10Hz Device: Fixed delay, Back light image, 1Hz sampling

Conclusion of 10Hz device experiment

"Even with smaller than 20μm droplet,

Ce=3.3% and perfect vaporization is simultaneously achieved"



-3.3% CE realized by 20 micron meter droplet

-pre-pulse is key to obtain higher CE

-This test was performed by 2 Hz operation

- CO_2 100 mJ, with/without pre-pulse

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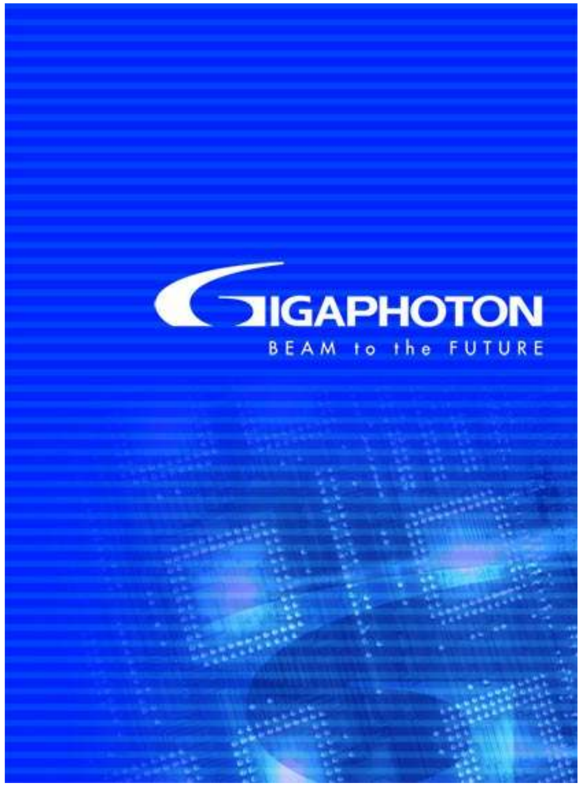

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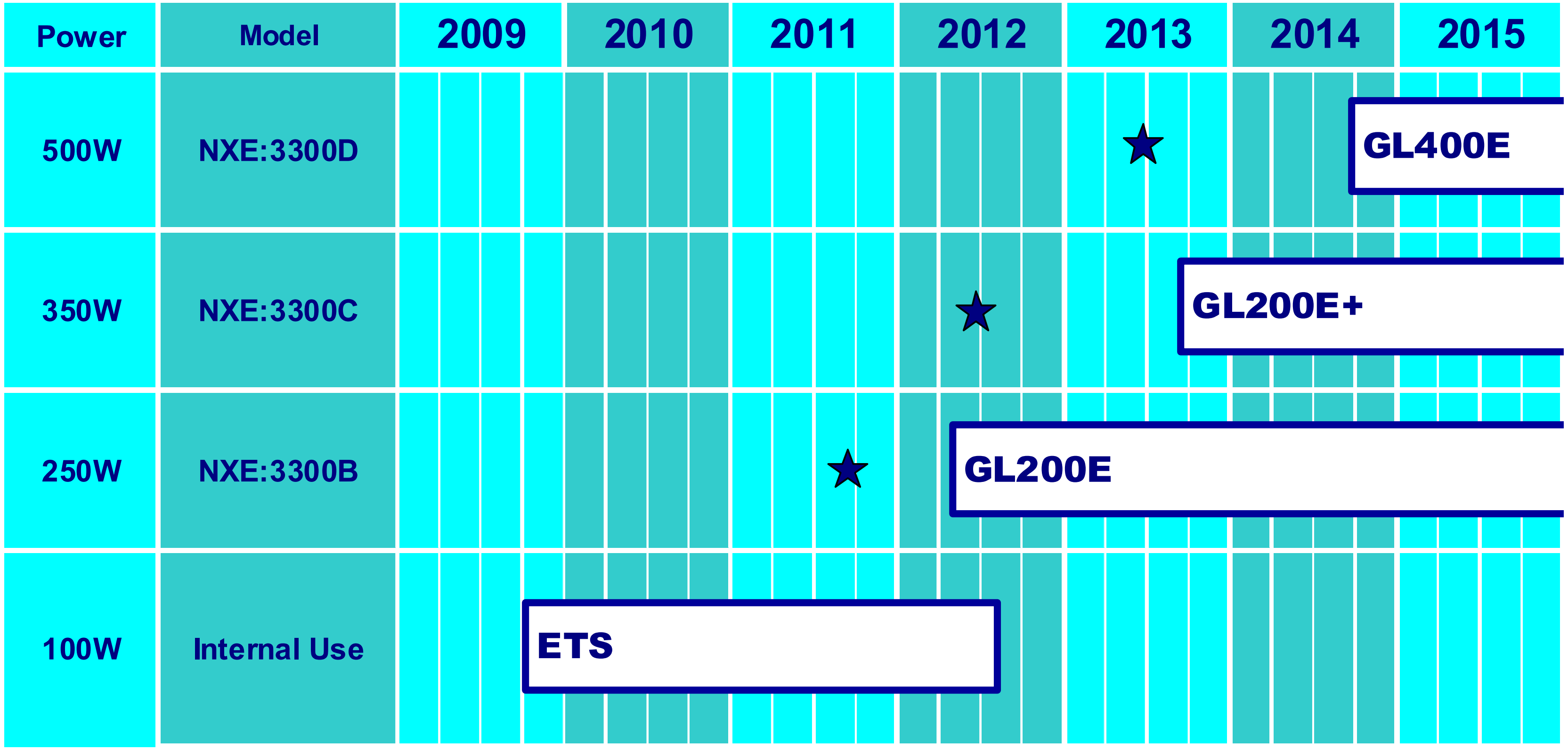
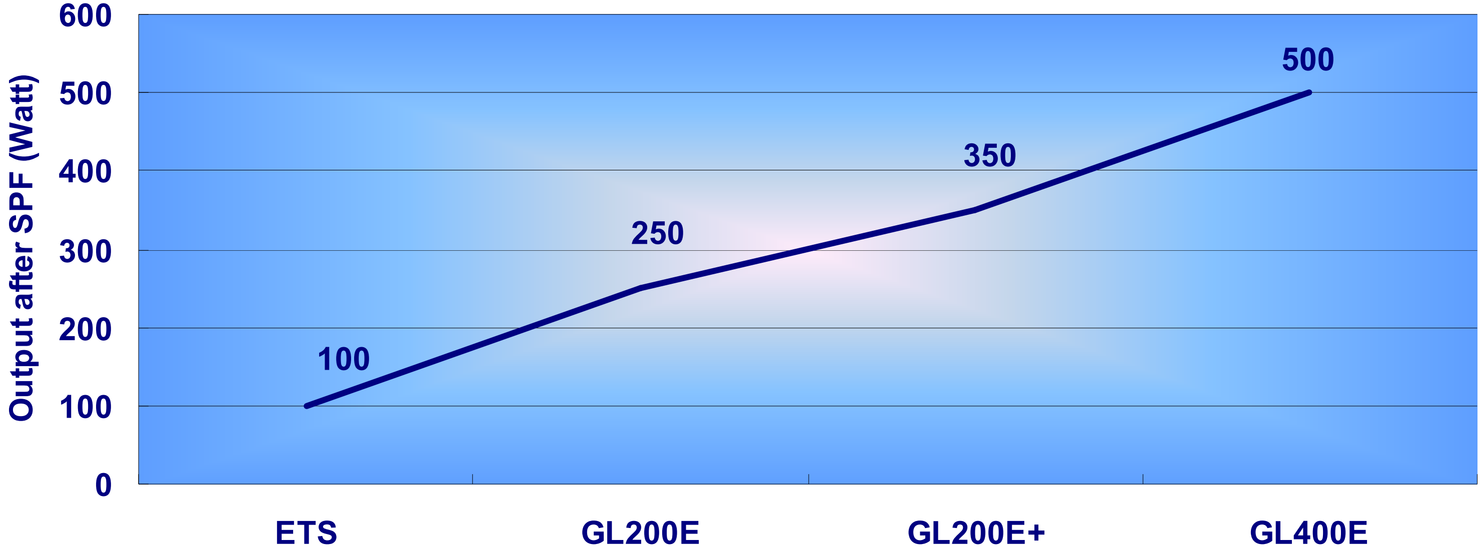
EUV product roadmap



★ 1st source delivery

- ➢ **GL200E will be delivered to scanner manufacture at Mid Y2011.**

Clean power roadmap



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

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* Against hemisphere (Calculation base)
** w/o SPF

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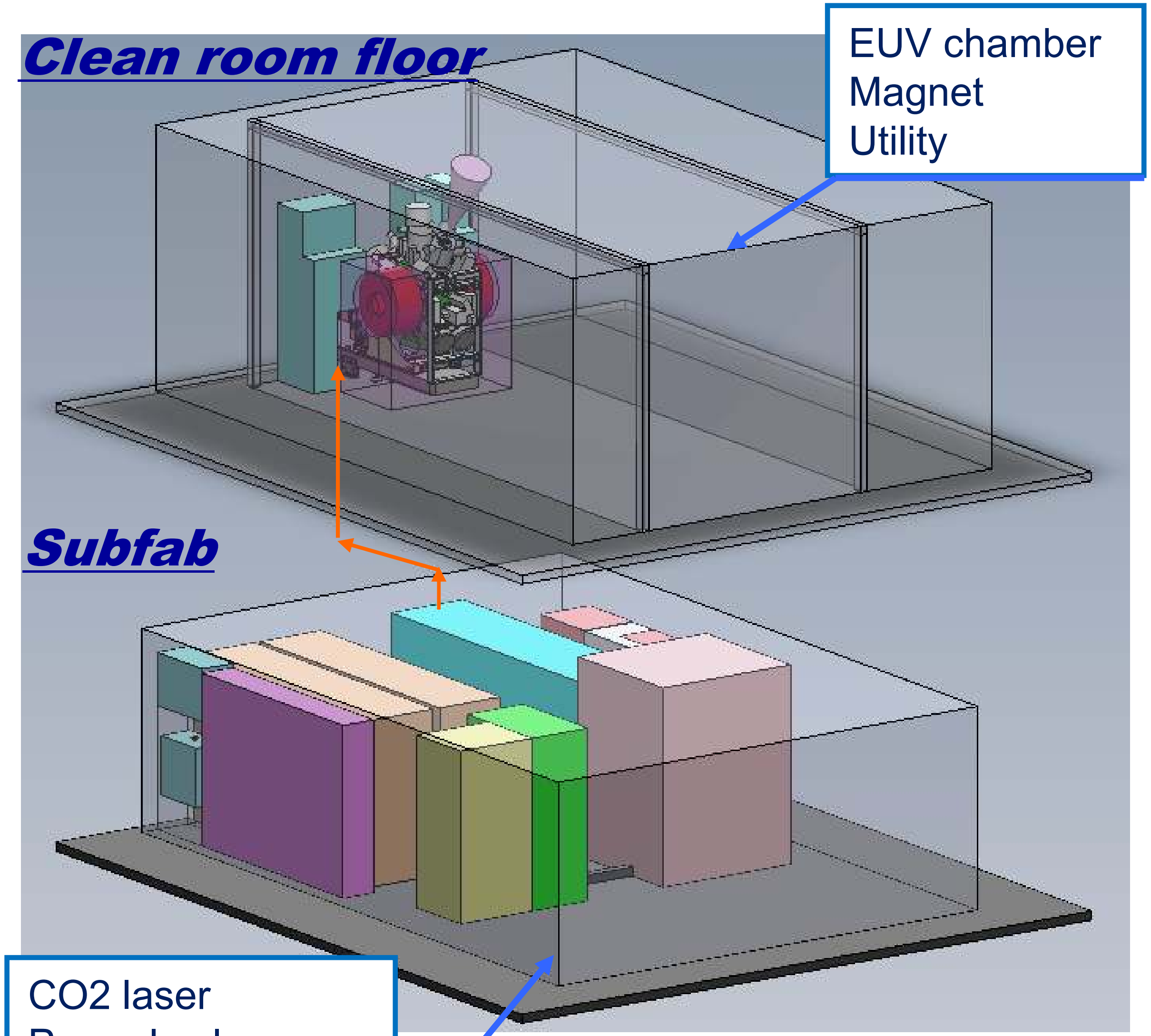
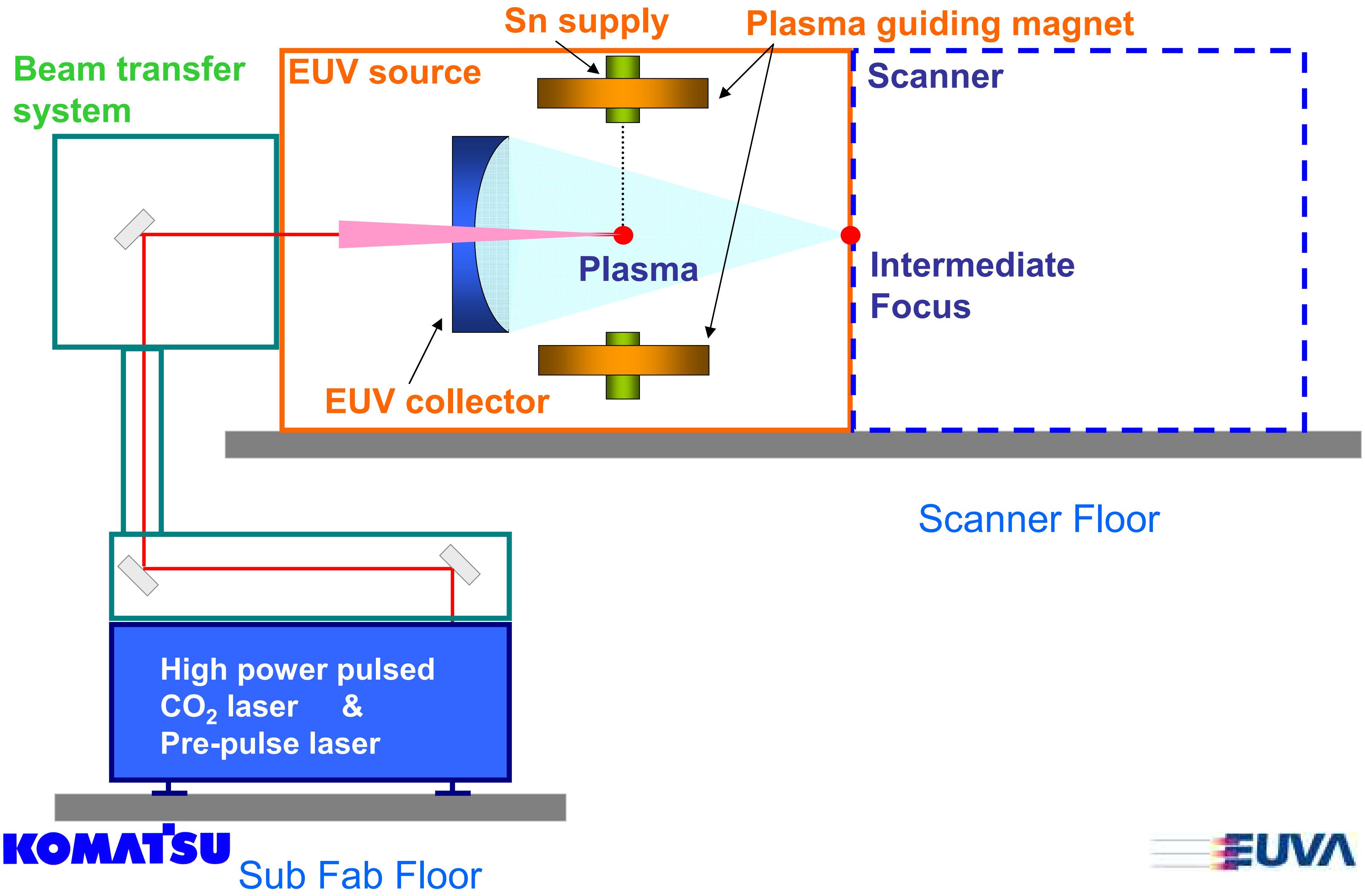
GL200E System layout in fab.



EUV chamber
Magnet
Utility

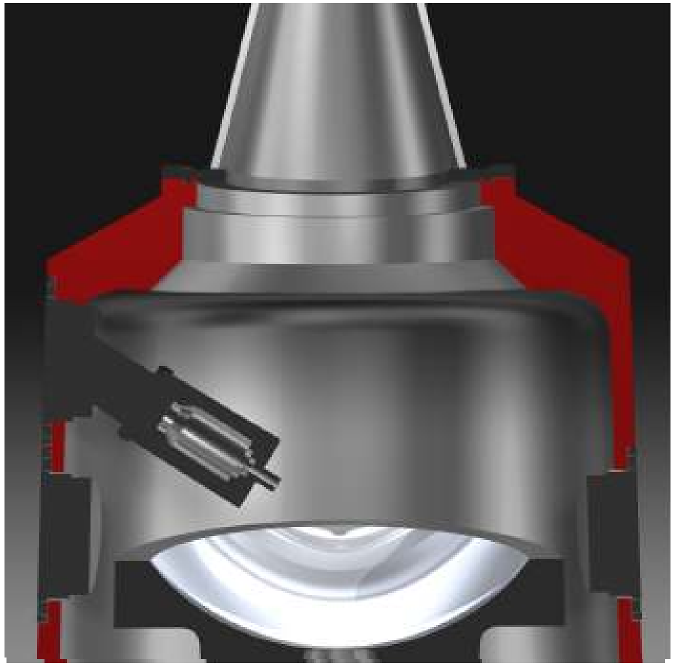
CO2 laser
Pre-pulse laser
Chiller

Scheme: LPP EUV light source



How it works

- Sn droplet comes in
- Shot by pre-pulse laser and then by CO_2 main pulse laser
- Plasma created
- Debris mitigation by magnetic field
- Clean operation completed



LPP-EUV Development Facility in Hiratsuka

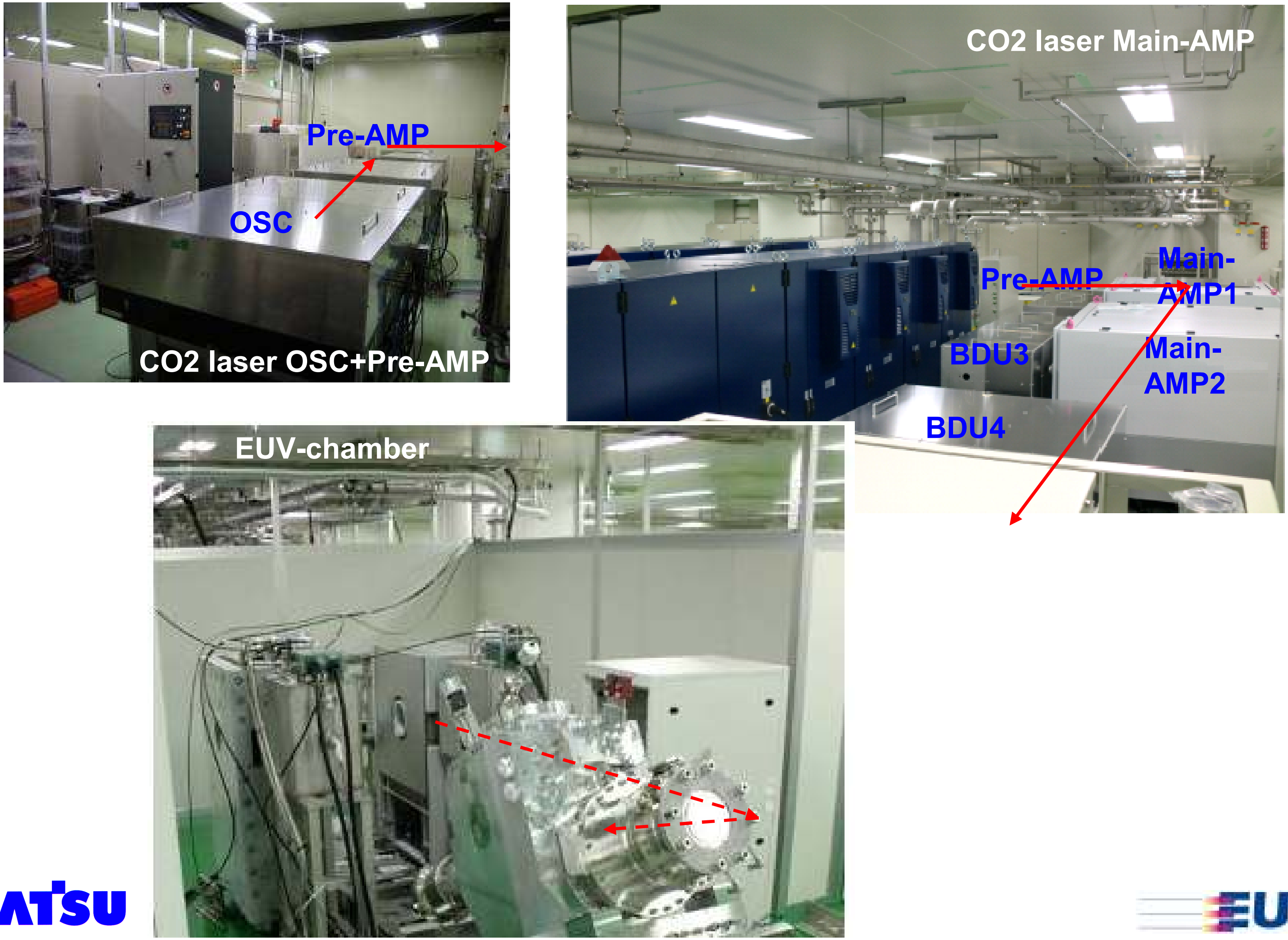

Overview


Building


Laboratory

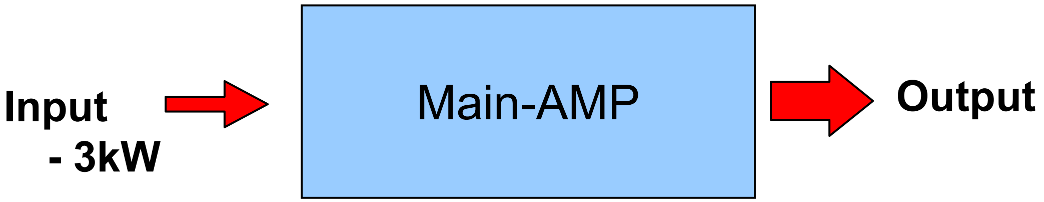

Utility

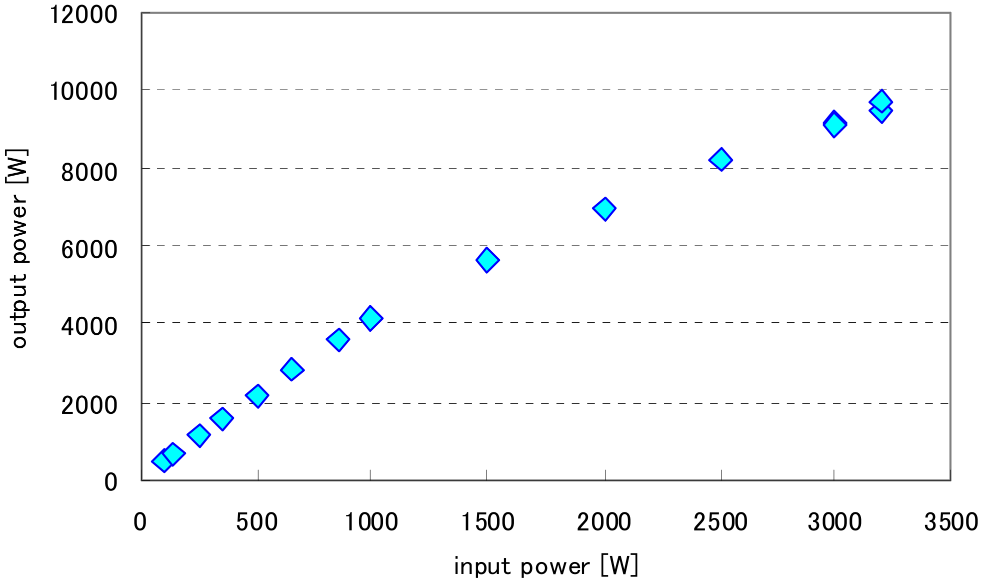
GL200E proto constructed at Hiratsuka facility



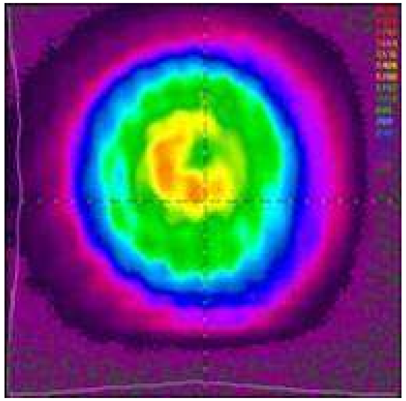
Main Amplifier performance

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


Input
- 3kW
Main-AMP
Output



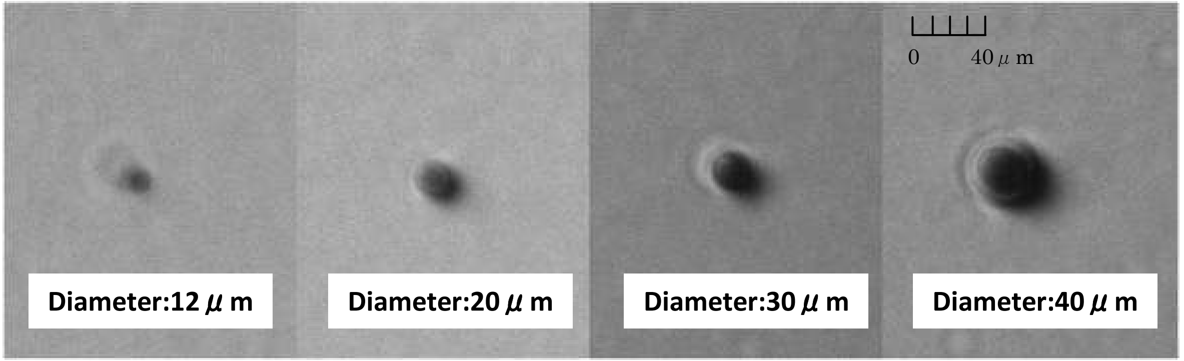
Output beam profile

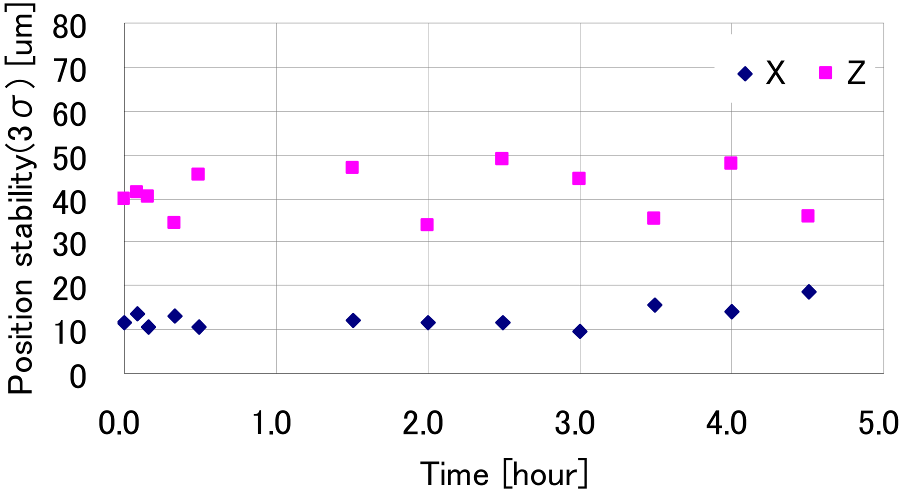


P30

Development of small diameter droplet

- 20mm droplet operate >10hrs
- 12mm droplet realized (champion data)





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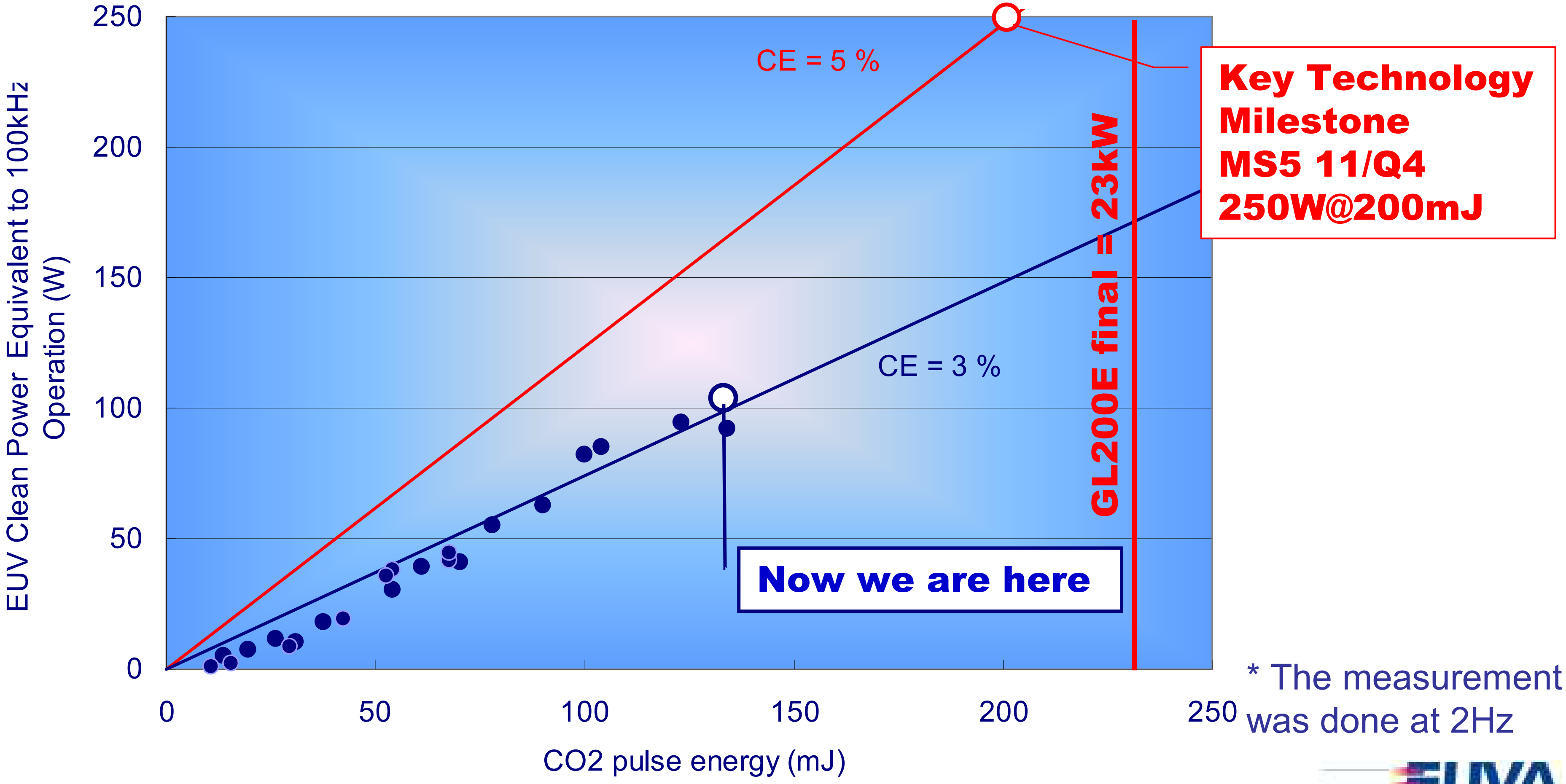
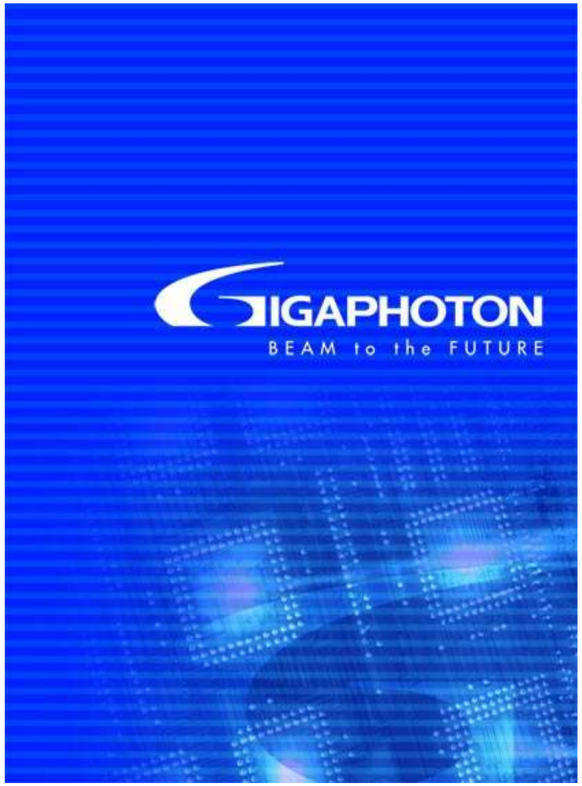
Scalability toward to 250W clean power

- 3.3% CE realized by 20 μm droplet
- It indicates ~100W clean power if operated at 100kHz*



* The measurement was done at 2Hz

First light of GL200E will come very soon !



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Summary

- **1st generation integrated setup LPP source (ETS) and 10 Hz device:**
  - One order smaller fragment (droplet size reduction from 60μm to 30 μm) extends operation time to 7 hours under 20W(clean power @I/F, 5%duty) level operation.
  - ETS experiment clarify 3 key engineering items are essential; CE (Conversion Efficiency) improvement, Debris mitigation = Stability and size of droplets and CO_2 laser load.
  - With <20μm droplet we found the region where Ce >3.3% and perfect vaporization are simultaneously possible.

- **2st generation LPP source (GL200E):**
  - Concept of design and outline is reported.
  - We already finished final assembling and just preparing operation of first light.

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Acknowledgments

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

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  - Osamu Wakabayashi, Hiroaki Nakarai, Junichi fujimoto

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