1st/2nd generation Laser-Produced Plasma source system for HVM EUV lithography

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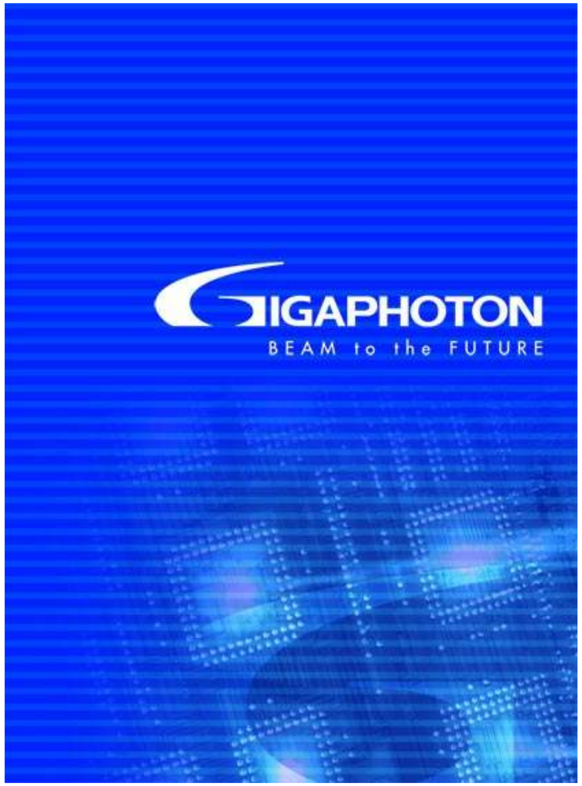

Outline

1. Introduction

2. Engineering Test source

- 1st Generation (ETS) device: System experiment
  - Operation Data

- 10Hz device: Critical issue experiment
  - Vaporization experiment
  - Ionization experiment
  - 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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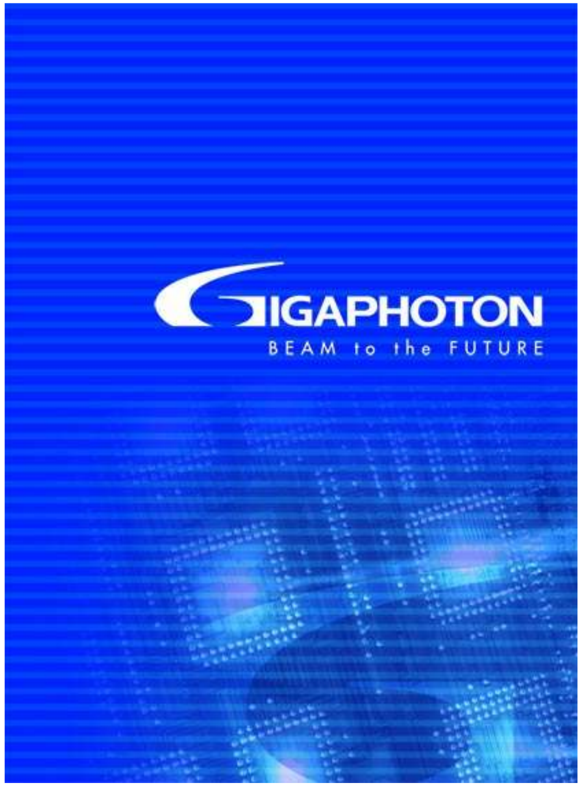

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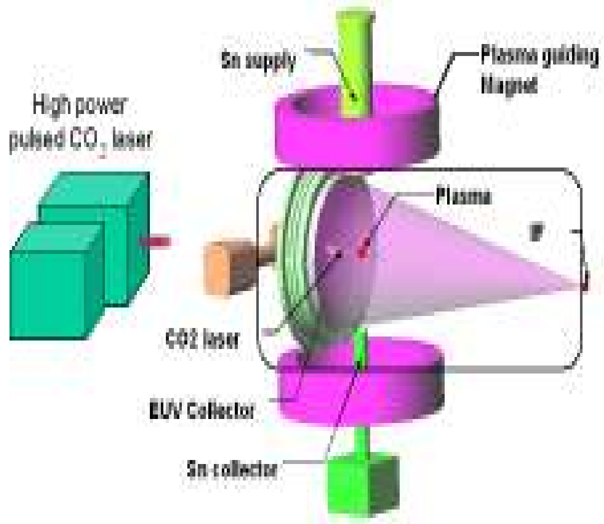
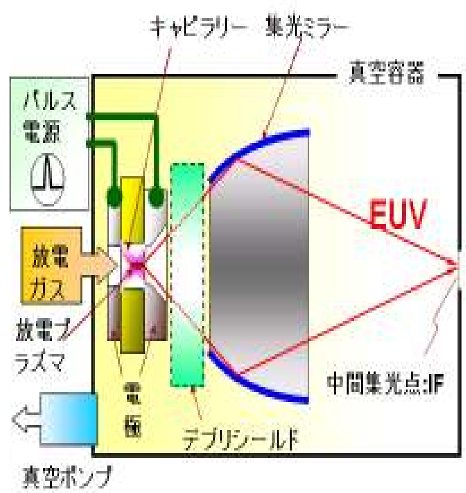
EUV sources

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

IRAI

System layout

■ Laser System

Oscillator	60W →	Pre-Amplifier	3 kW →	Main-Amplifier	→	13 kW

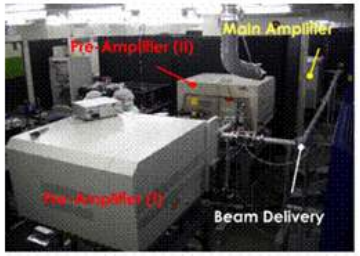
Oscillator
Wave length: 10.6um
Rep. rate :100kHz
Pulse width :20 ns (FWHM)

Pre-Amplifier
RF-excited CO2 laser

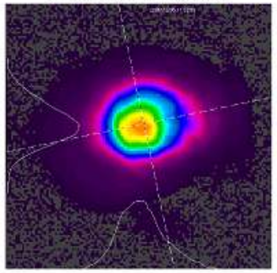
Main-Amplifier
RF-excited CO2 laser

13 kW

100 W at I/F equivalent

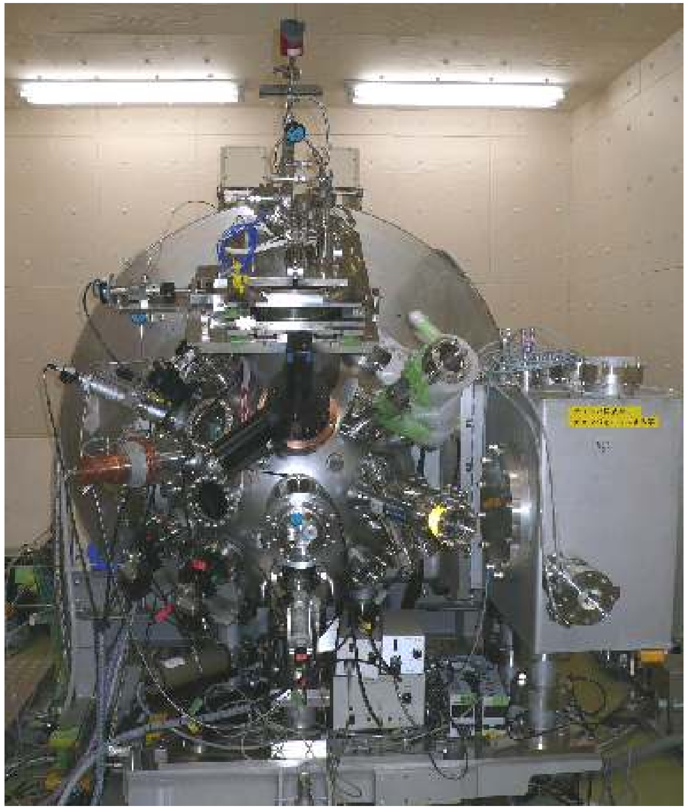


Laser beam profile



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

■ EUV chamber



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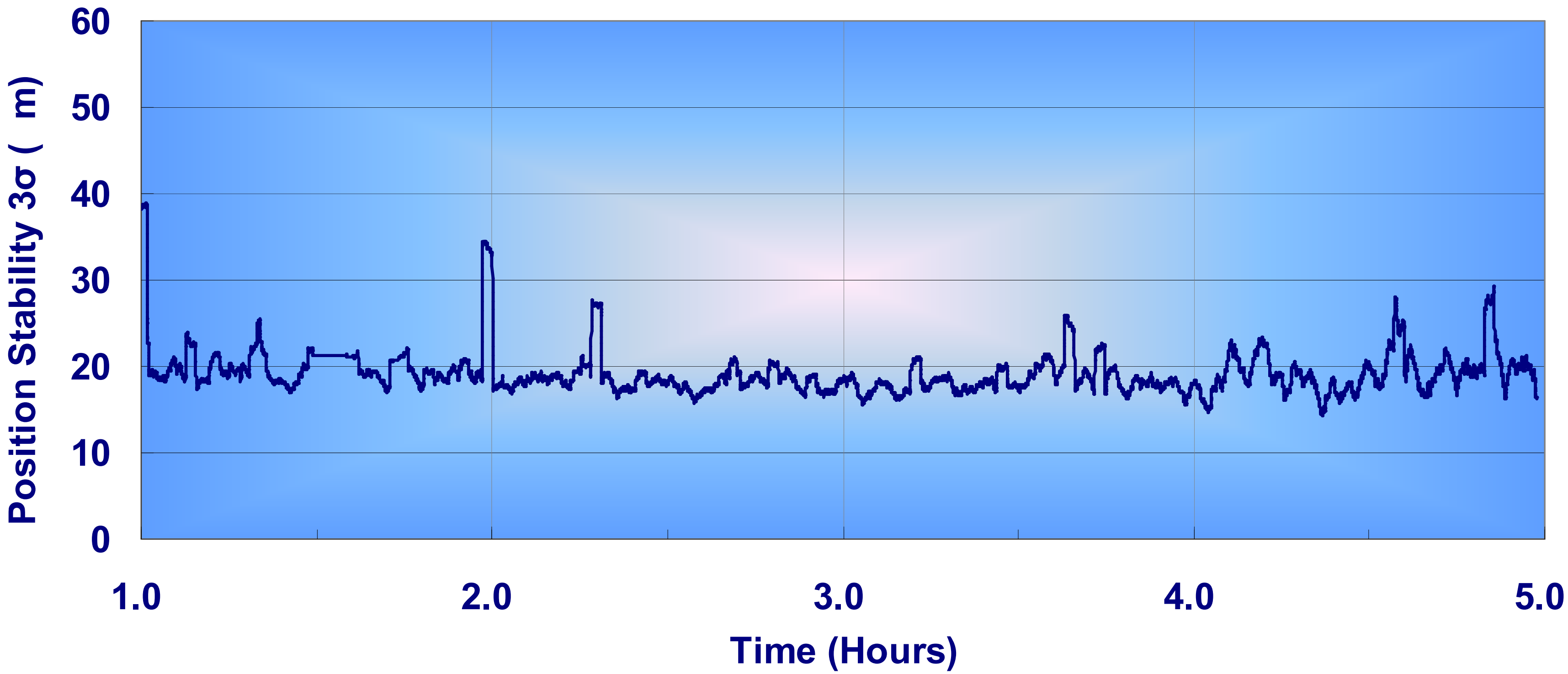
System operation Data (ETS device)

	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

Droplet generator lifetime improvement (φ30 μm)

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



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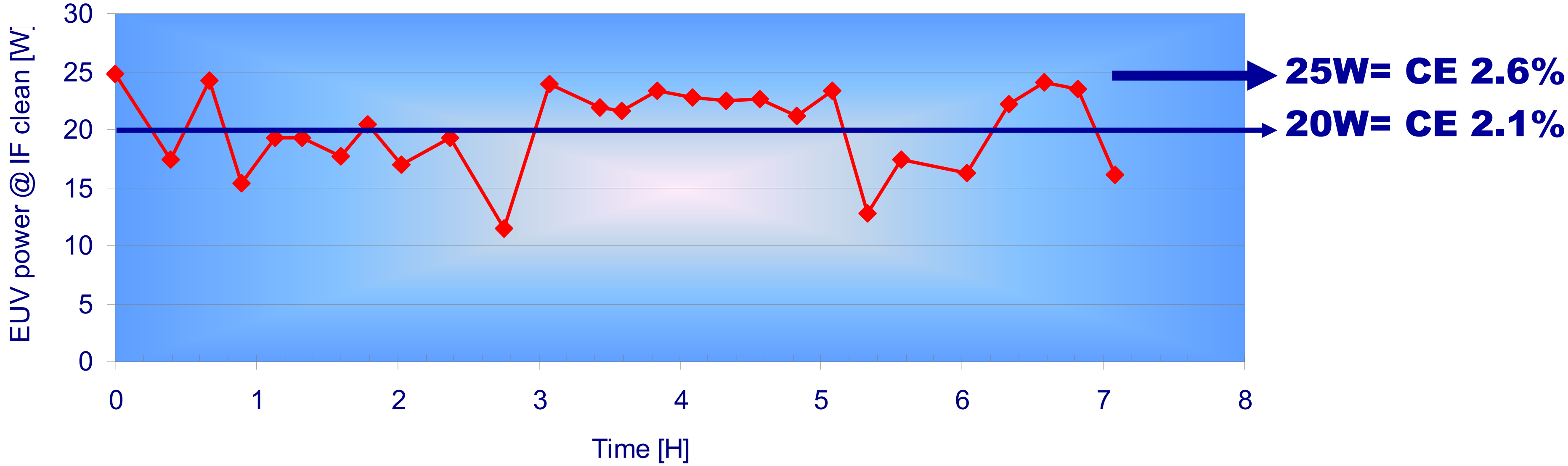
System operation result on ETS

- **Long time system operation demonstrated**
  - **Operation duration:** **7 hours**
  - **Droplet** **30 μm 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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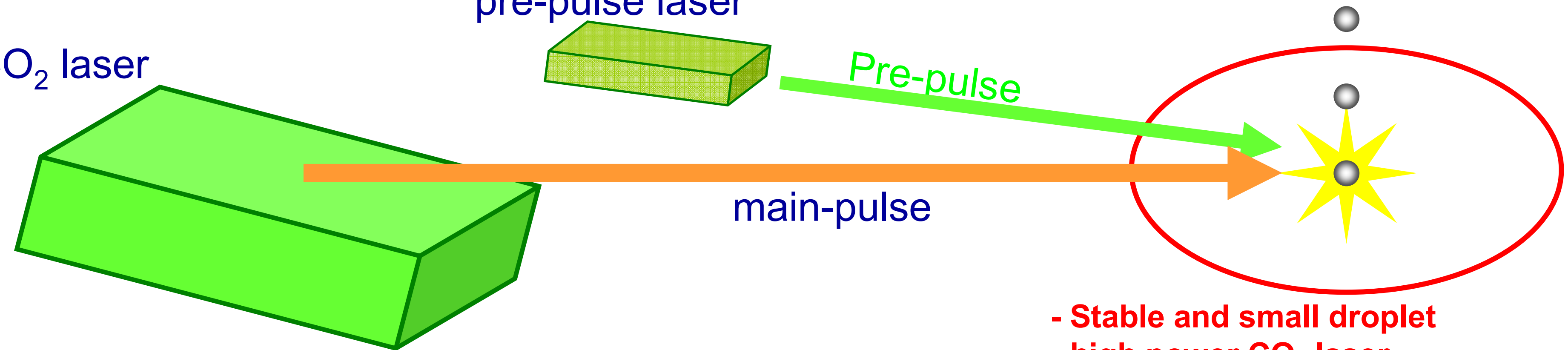
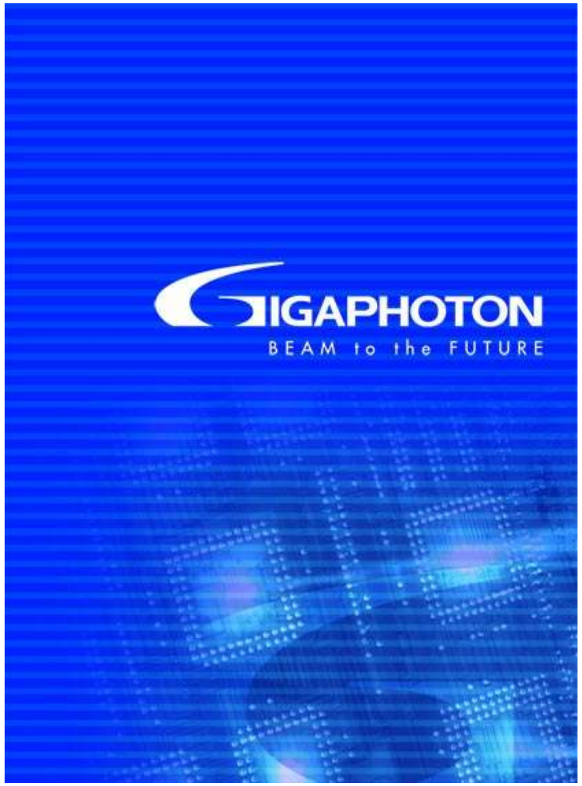
Conclusion of ETS device experiment

"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**



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



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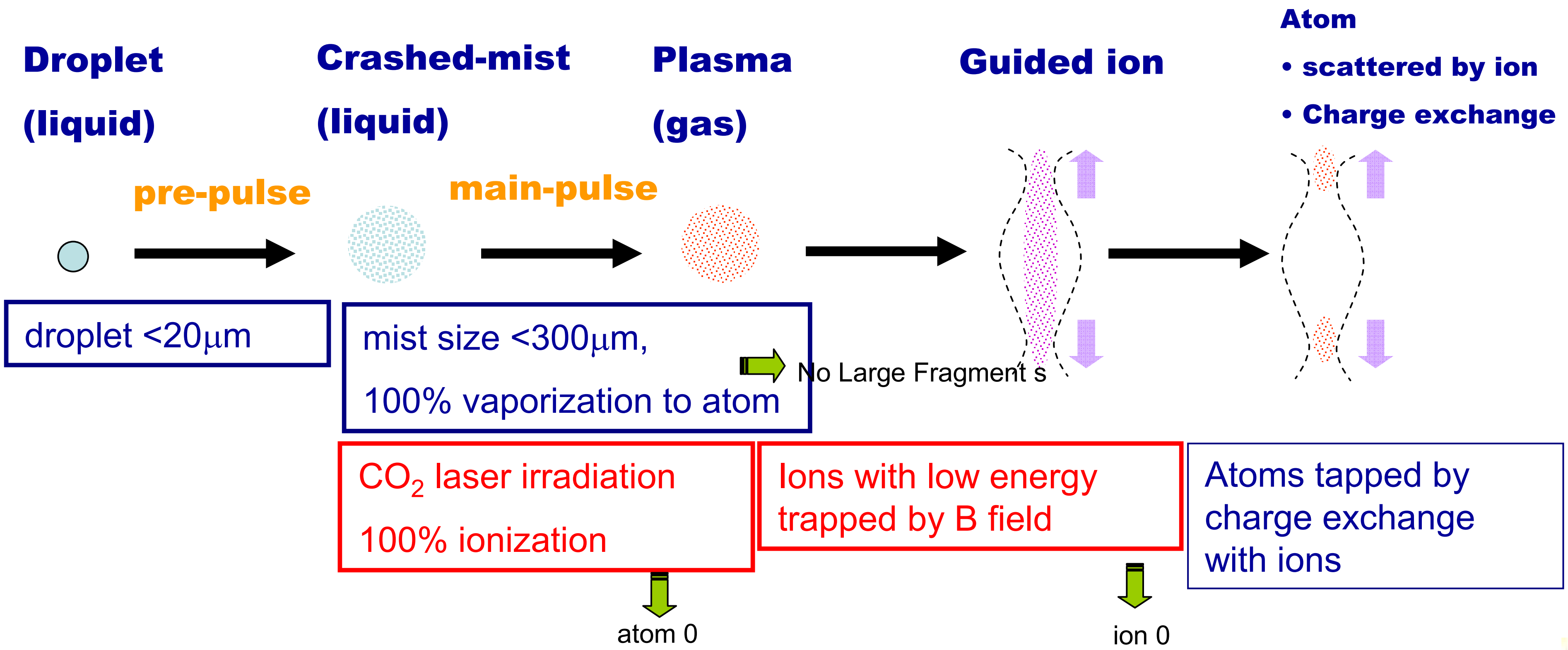
Collector mirror protect Concept

All Sn atoms should be ionized.

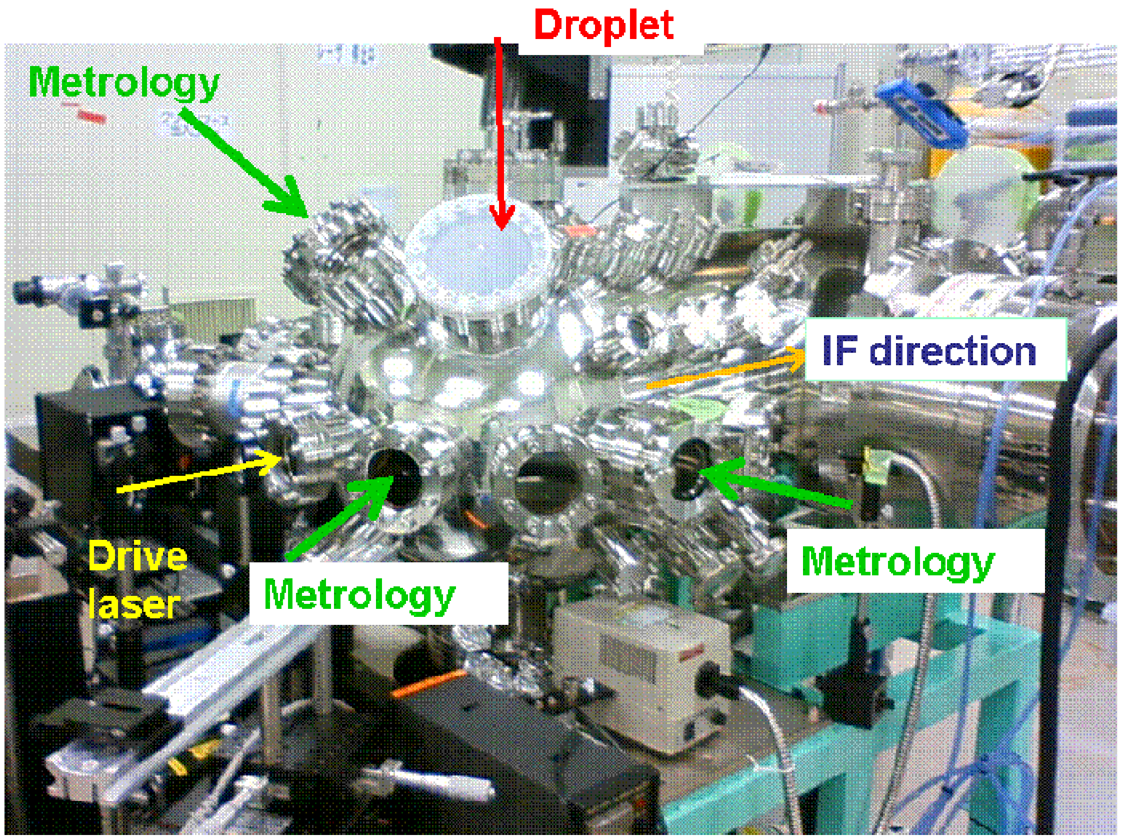
① Magnet field is effective for guiding ions not to going to mirror

② All Sn fragments and atoms are needed to be ionized

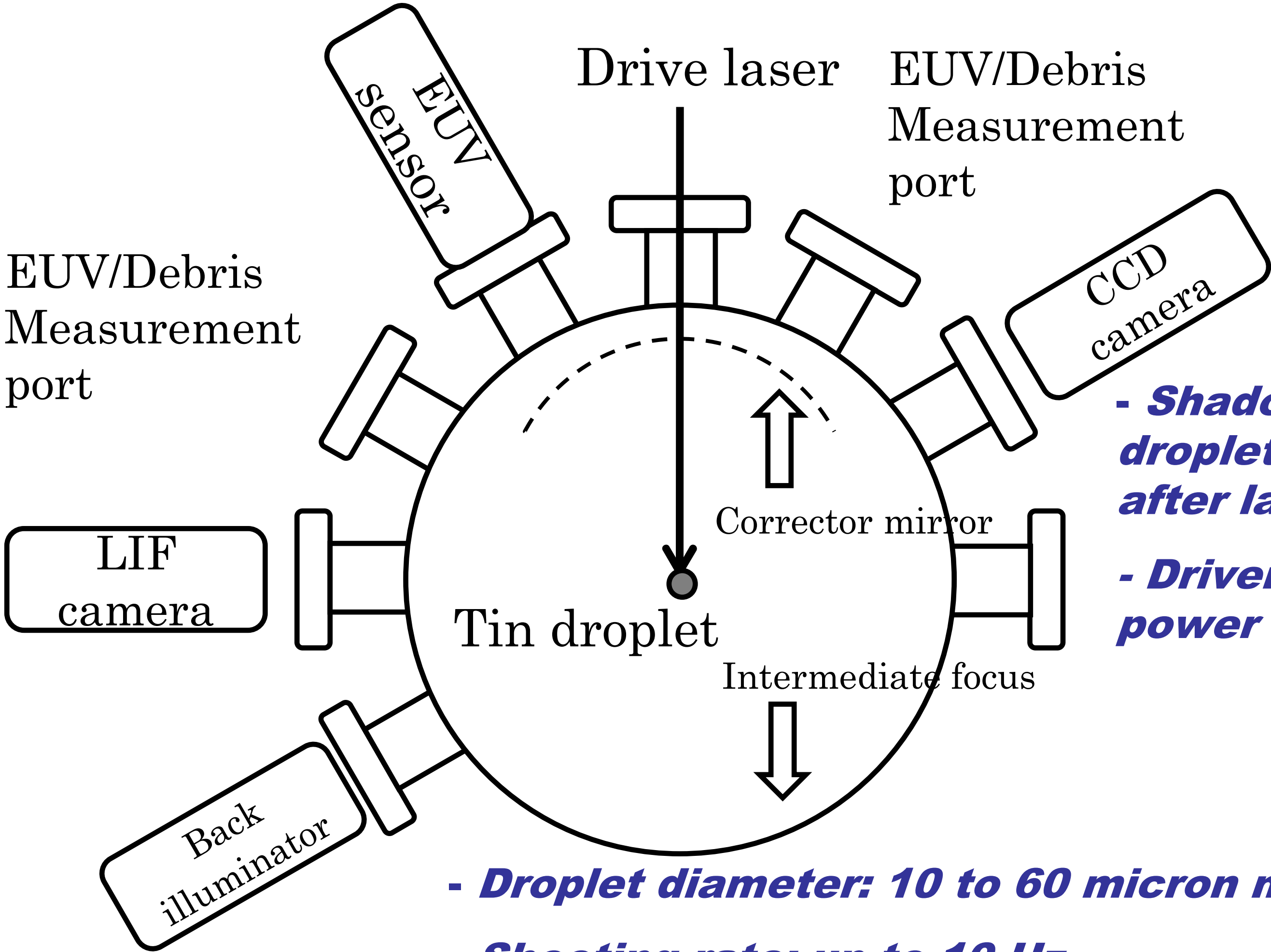


Critical issue investigation with 10Hz device

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



Setup configurations

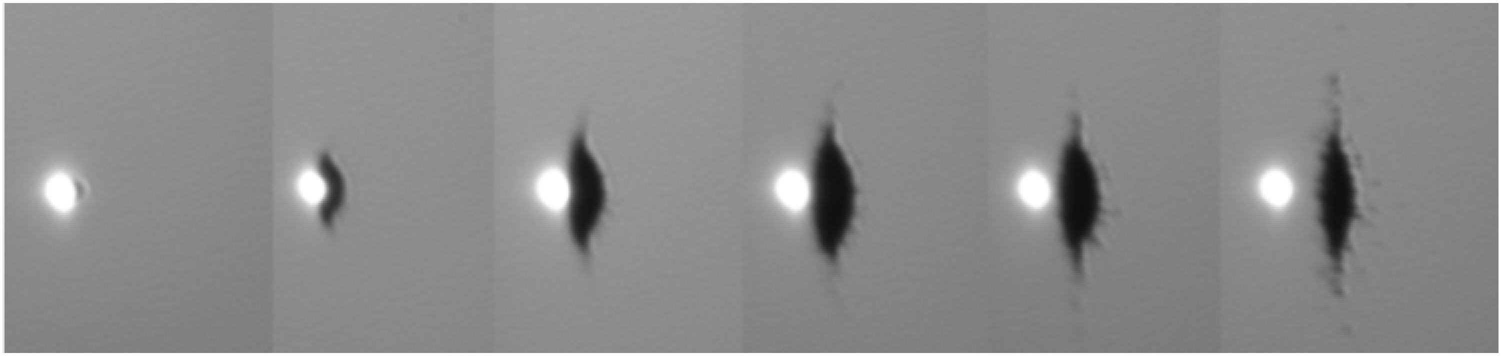


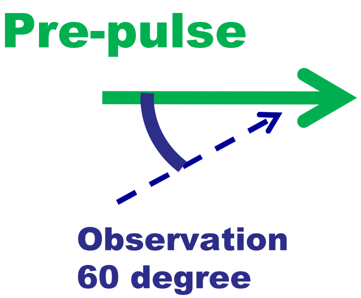
- ***Shadow camera & LIF: droplet & its behavior after laser shooting***
- ***Driver laser: refraction power & distribution***

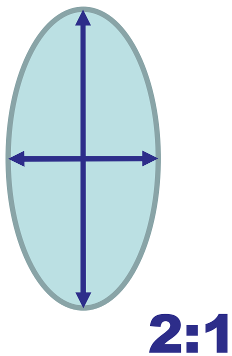
- ***Droplet diameter: 10 to 60 micron meter***
- ***Shooting rate: up to 10 Hz***
- ***Observe what's happen in the vessel?***

Droplet transformation by pre-pulse

Smaller fragments
Spread homogeneously







True circle looked like this ellipse in this configuration

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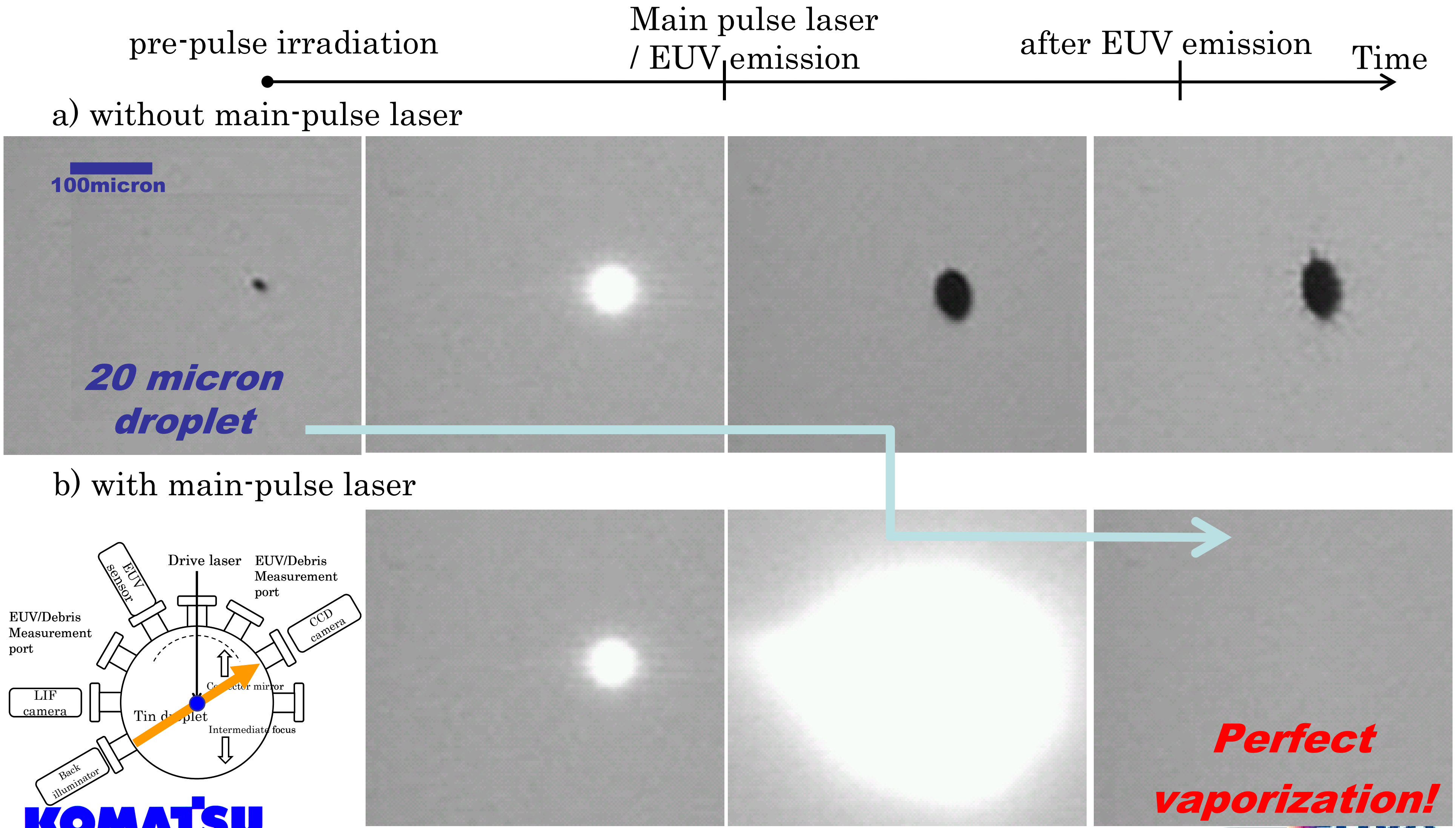
Droplet shooting scheme

Proper pre-pulse condition



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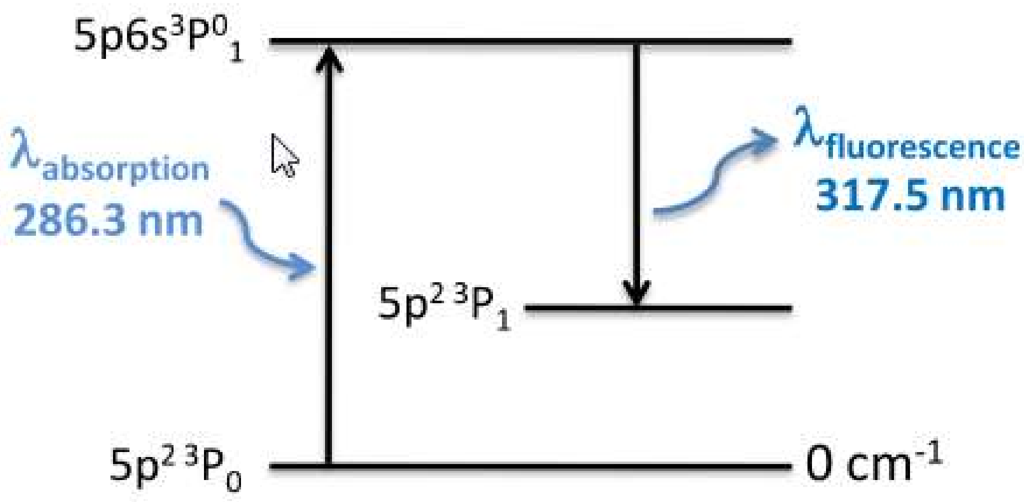
Laser induced fluorescence (LIF) imaging for tin atom

Advantages
- Spectrally selective pumping and observation
- High sensitivity
- Cross sectional imaging with a sheet laser beam

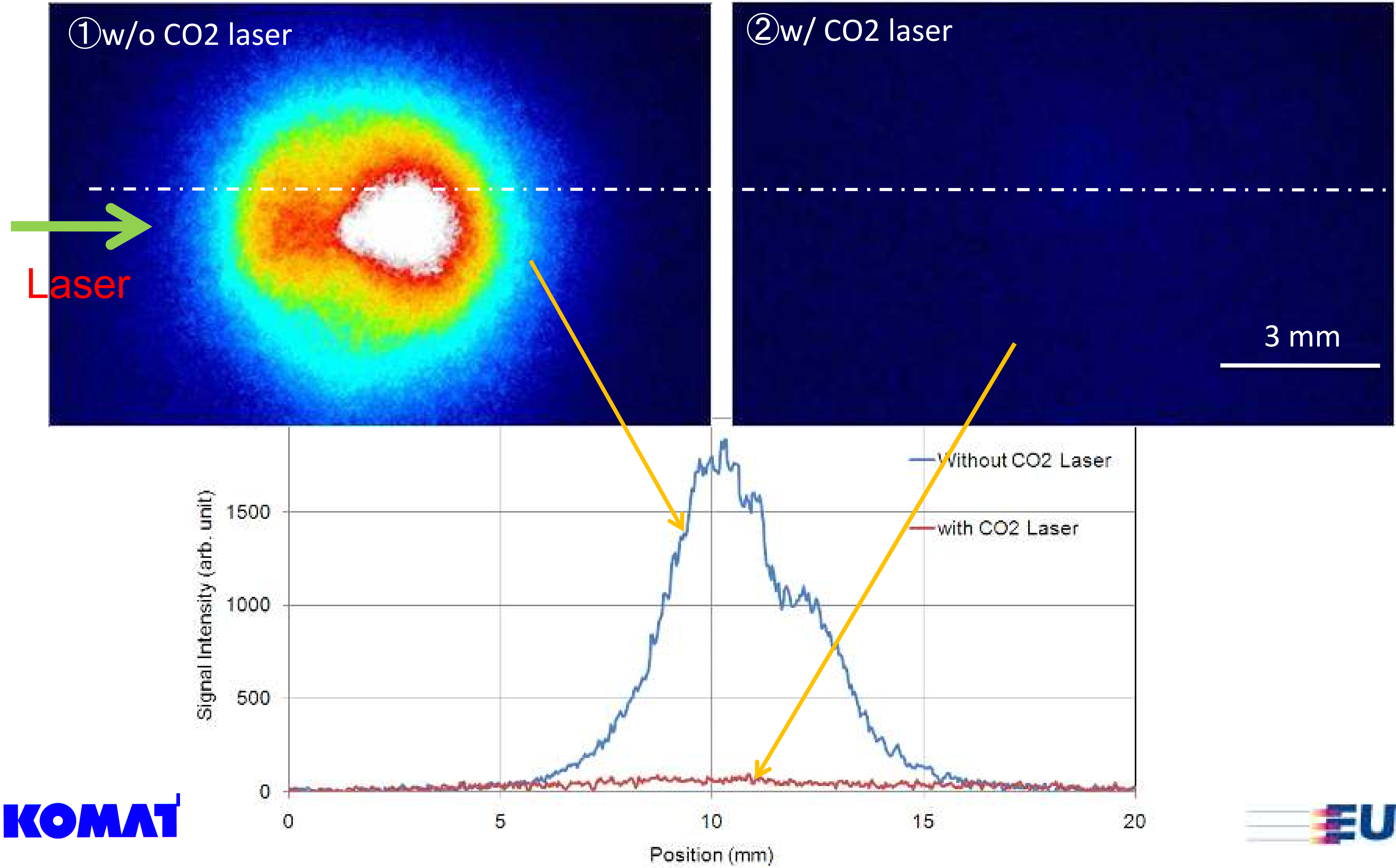
Principle of LIF



Grotrian diagram for tin atom

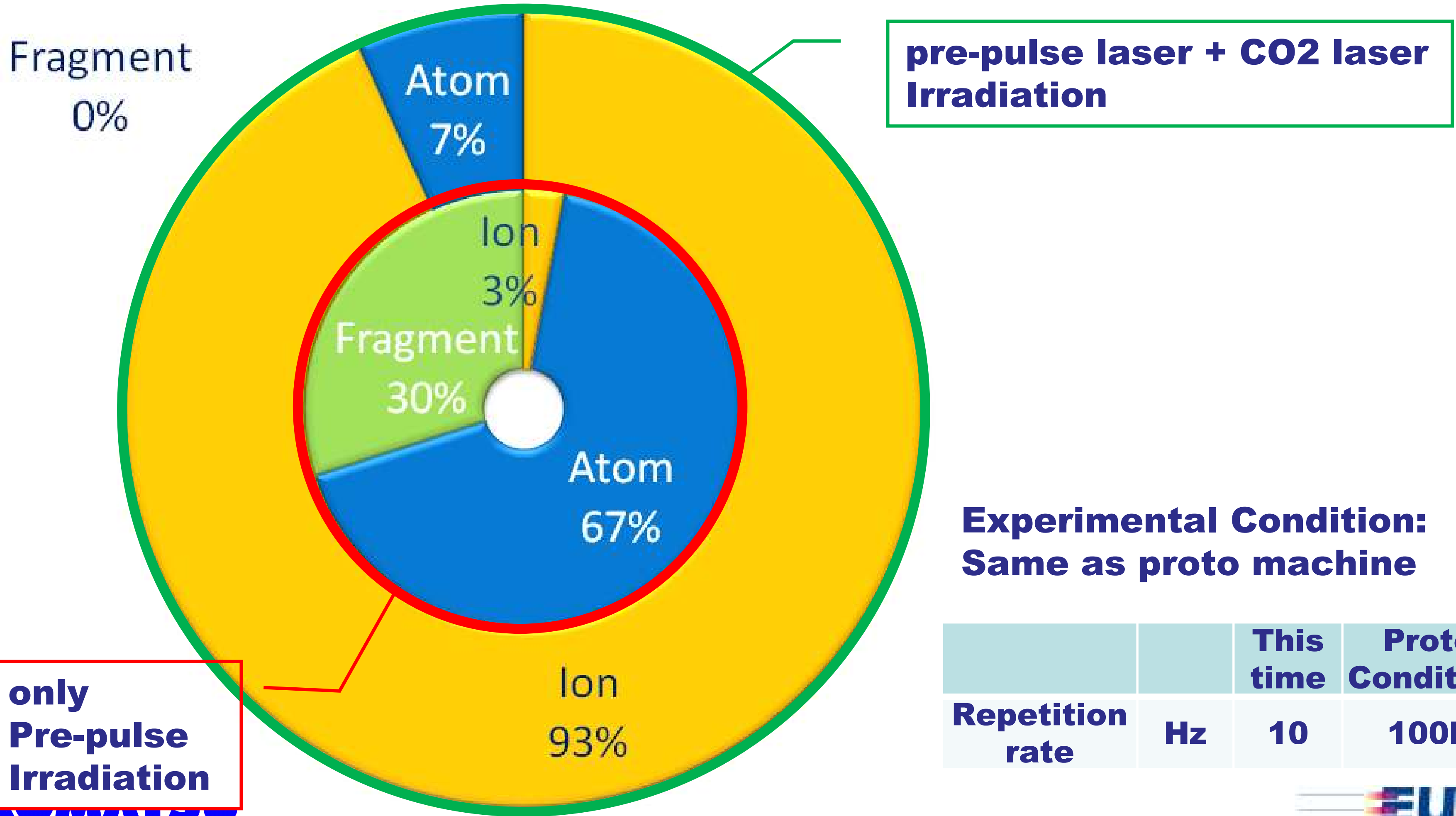
Atom measurement by LIF - 2

Remaining atoms was estimated by subtracting w/ CO_2 vs w/o CO_2 measurement



Results Summary

- Sn molecule measurement results
  - ✓ pre-pulse laser + CO_2 laser irradiation : ionized 93% of Sn
  - ✓ Only pre-pulse laser irradiation : ionized 3% of Sn



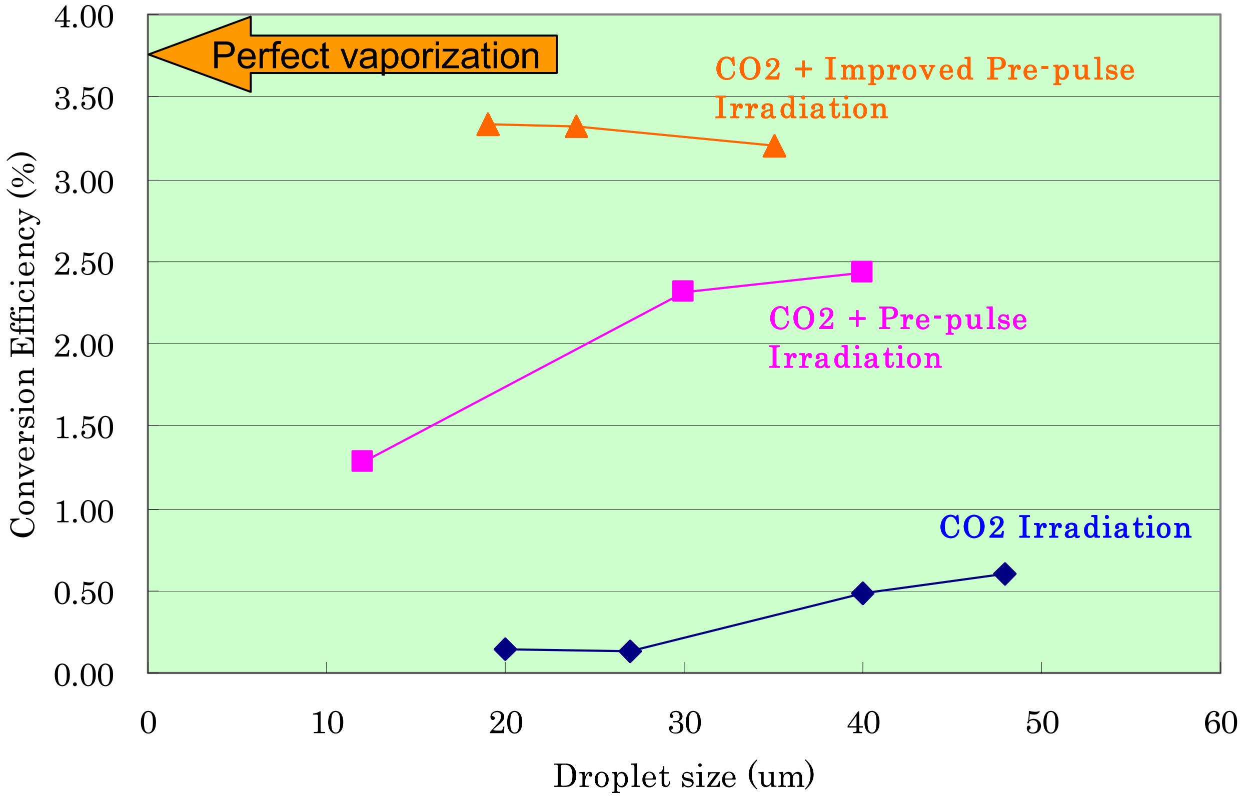
Experimental Condition:
Same as proto machine

		This time	Proto Condition
Repetition rate	Hz	10	100k

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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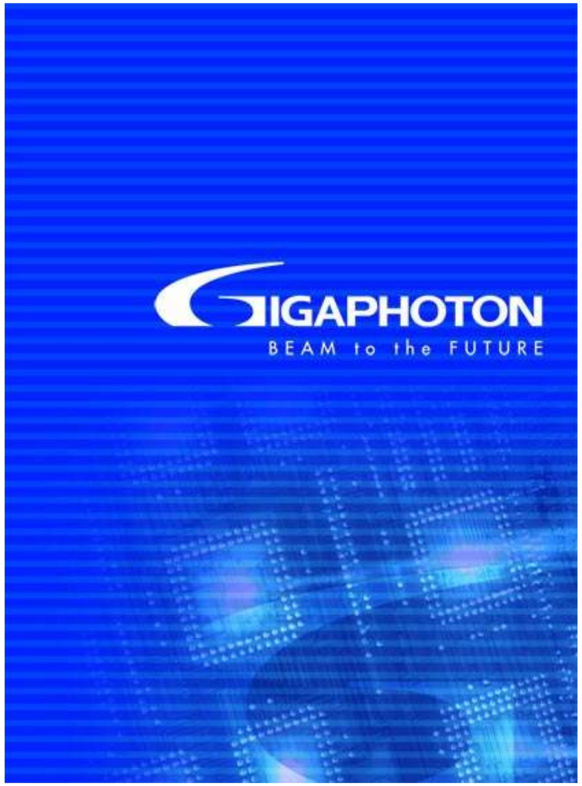

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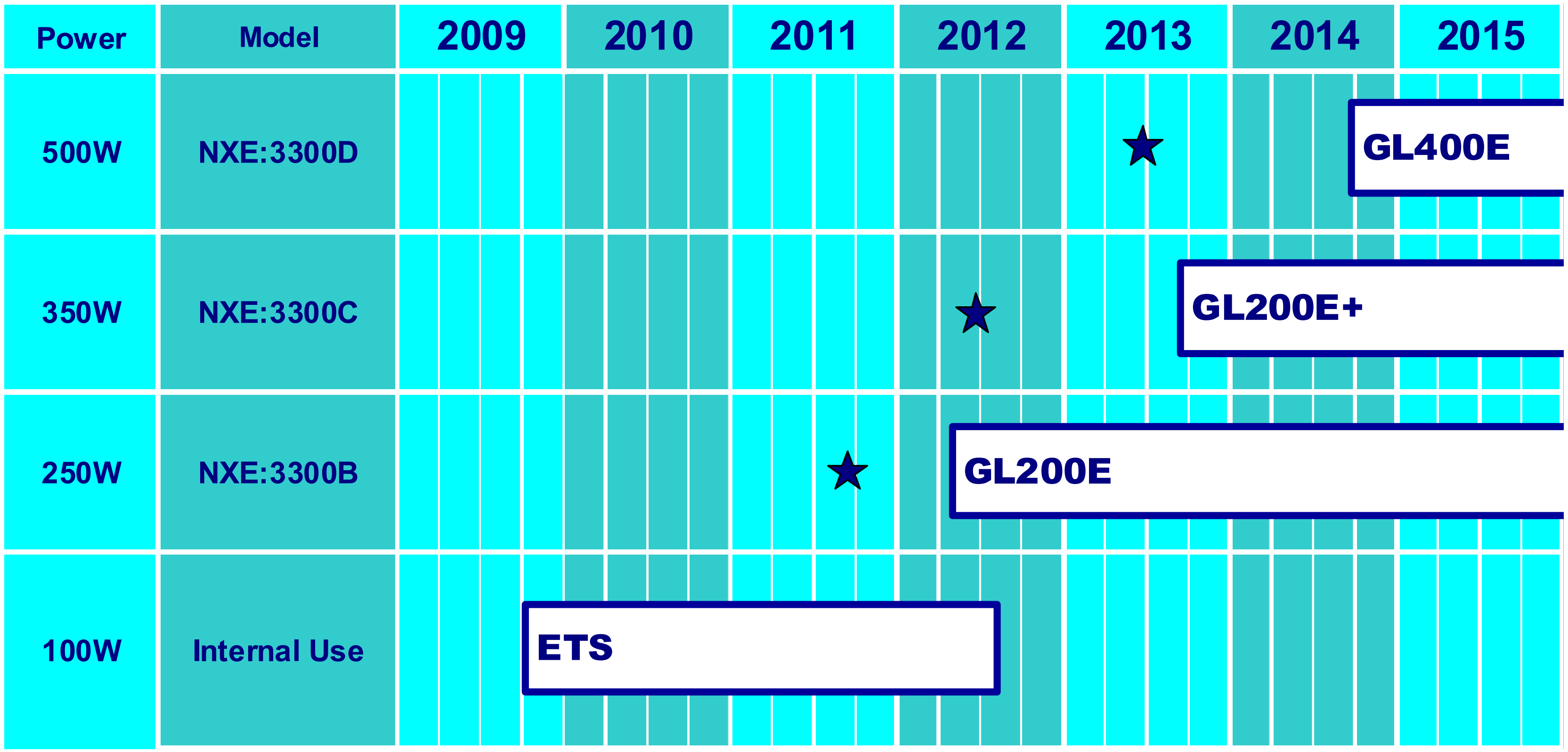
EUV product roadmap



★ 1st source delivery

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

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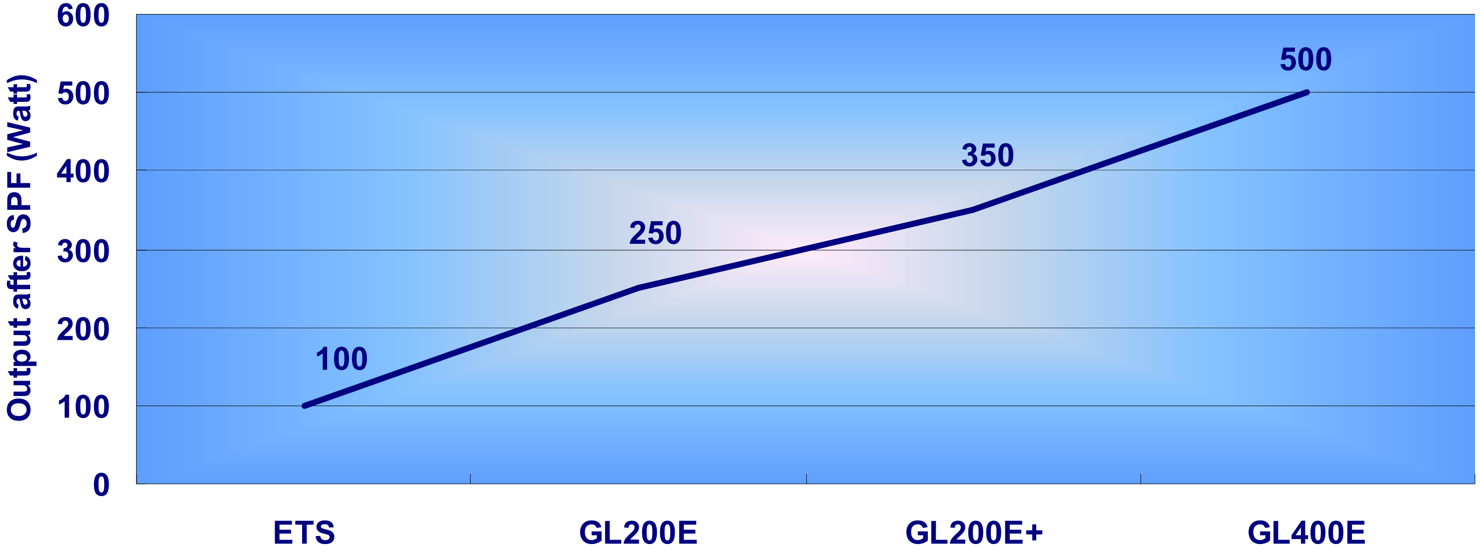
Clean power roadmap



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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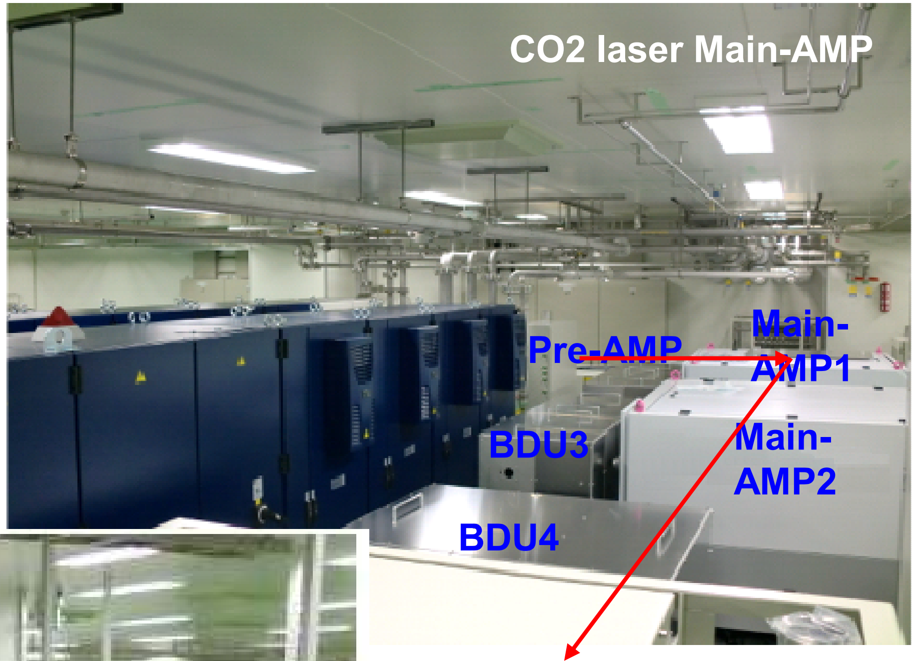
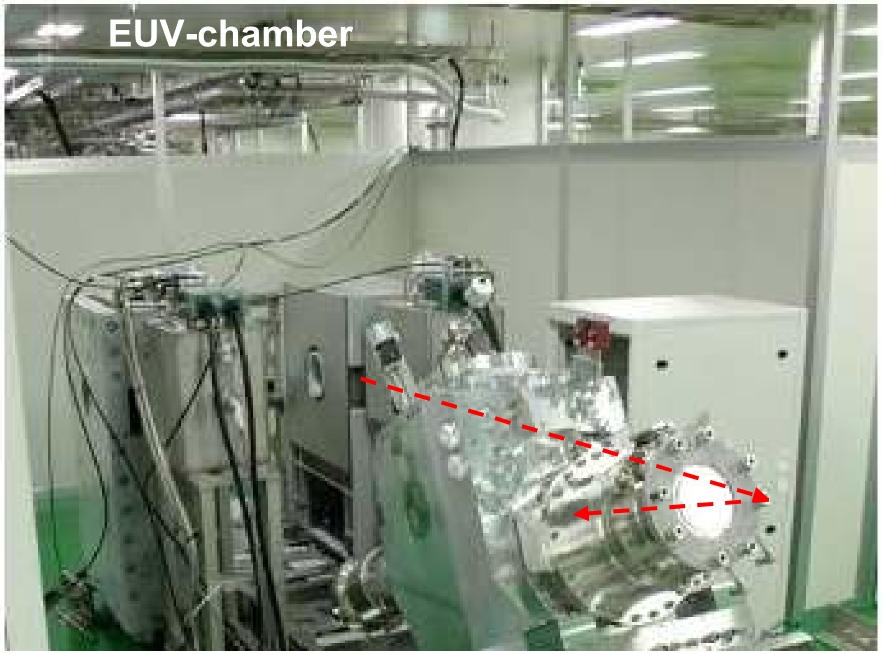
GL200E proto constructed at Hiratsuka facility





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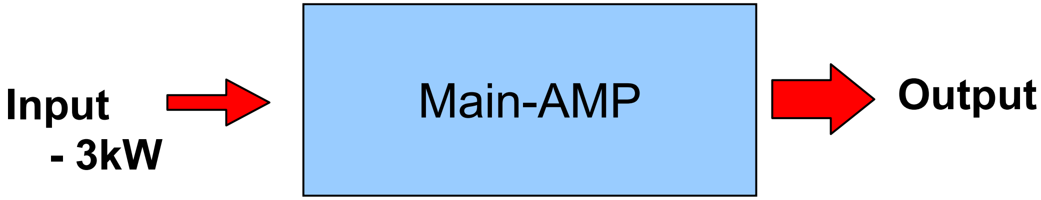
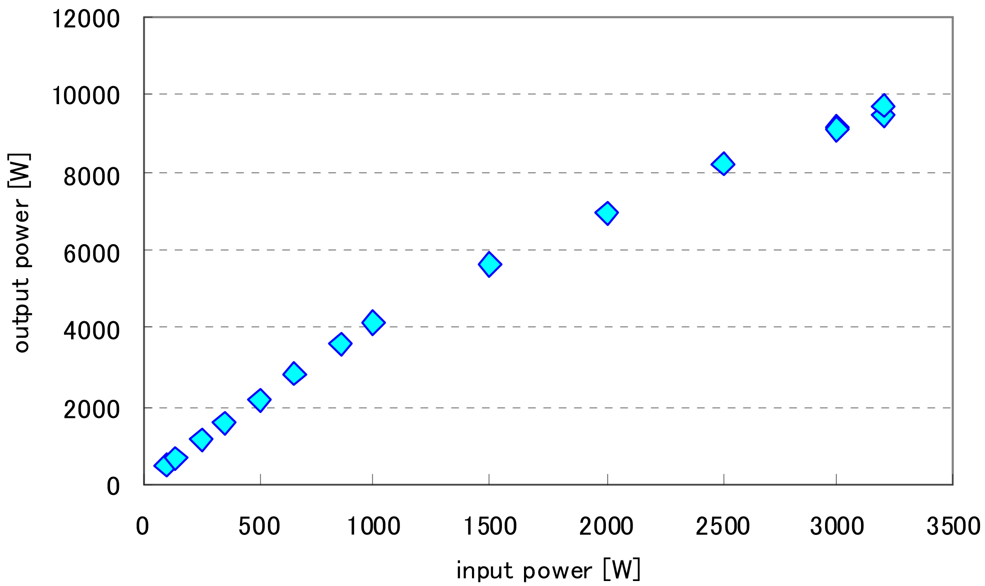
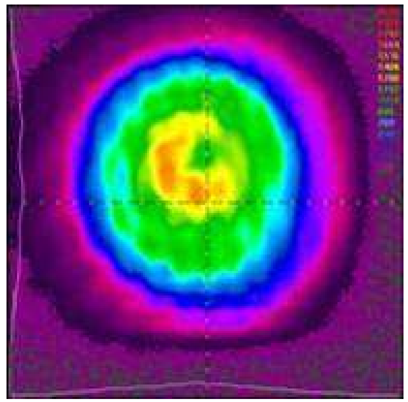
Main Amplifier performance

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



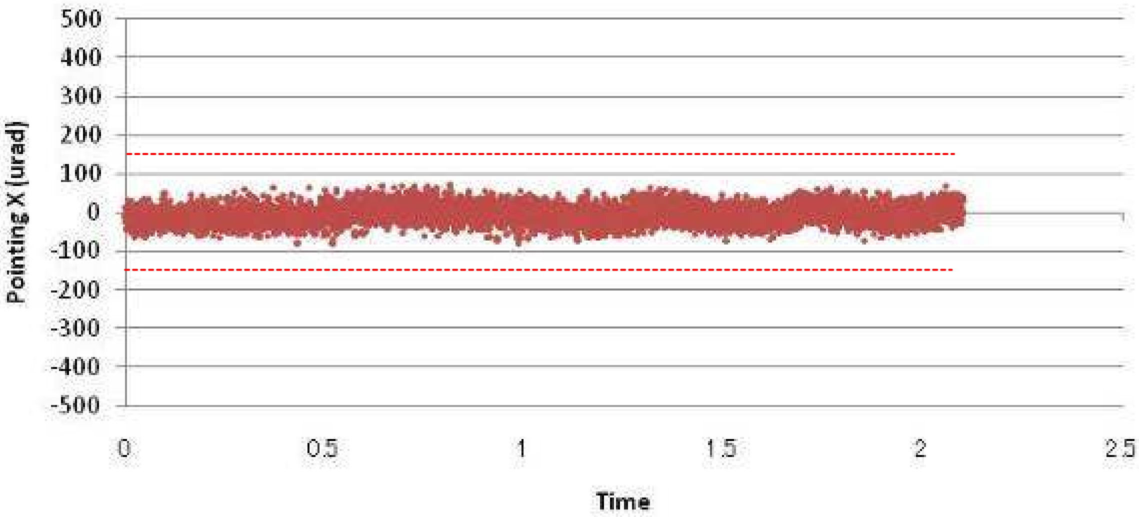


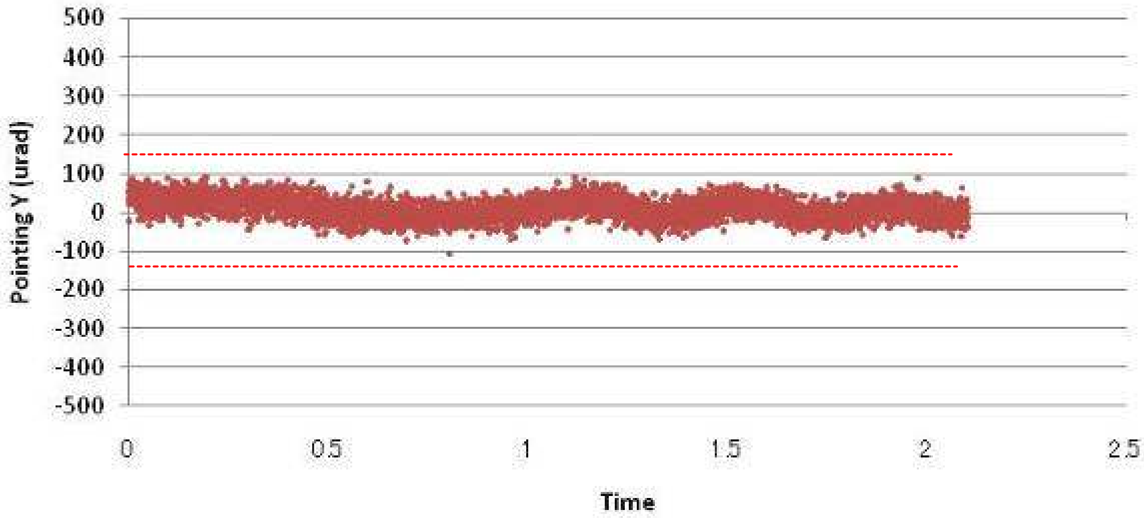
Output beam profile



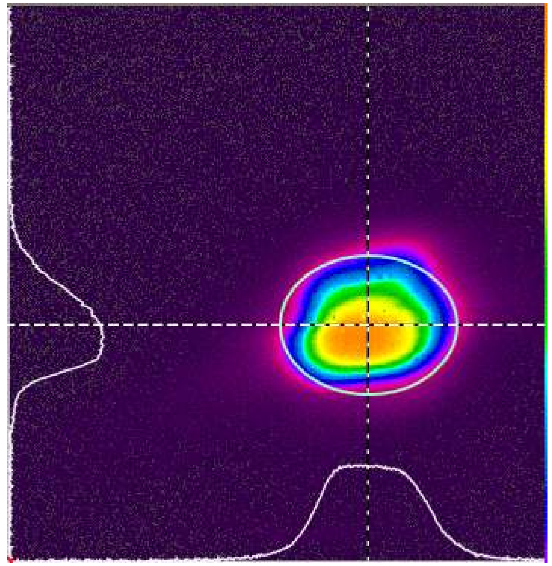
Pointing stability of CO2 laser

w/ control, duty cycle 30%





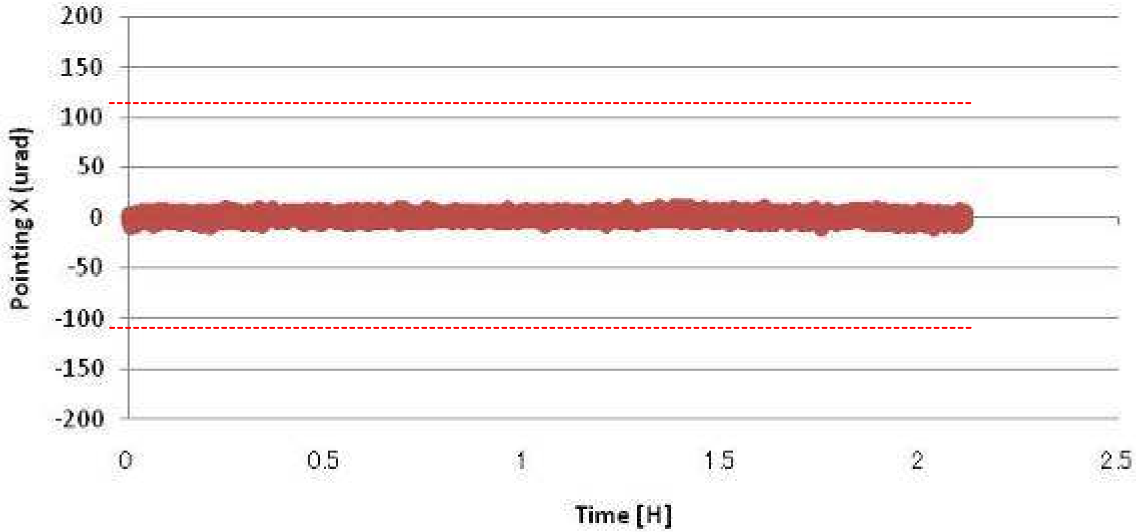
Beam profile

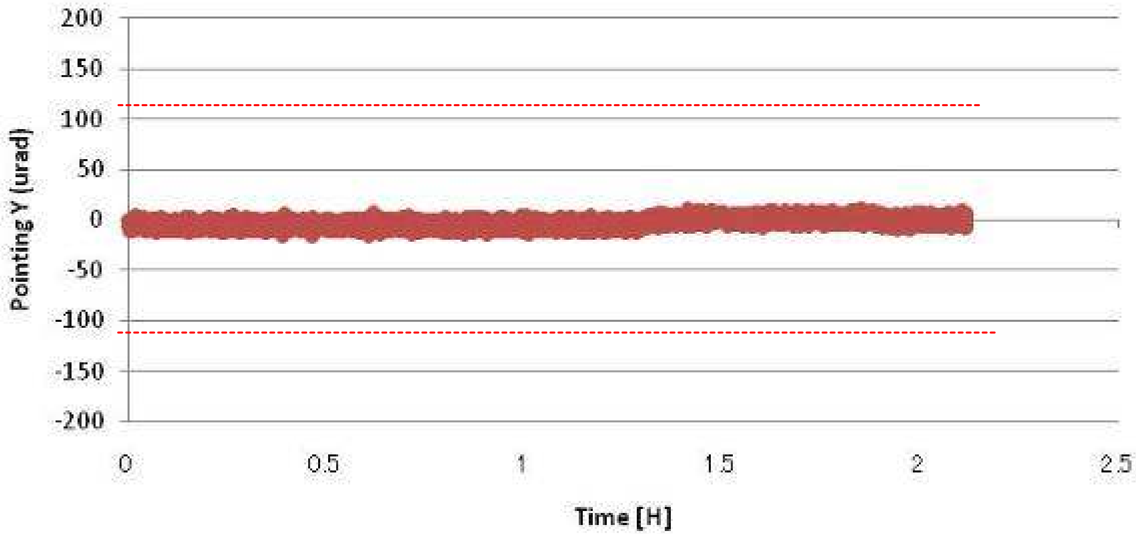


Operation conditions	
Rep. rate [kHz]	100
Duty [%]	30
ON pls [pulse]	30,000
OFF time [msec]	700
Testing time [min]	120

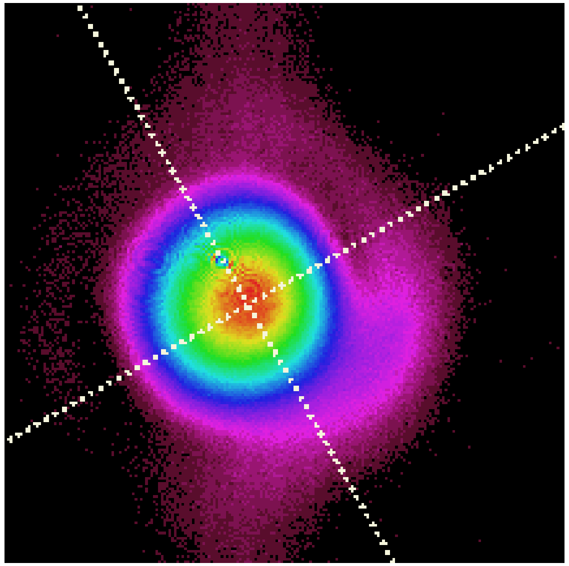
Pointing stability of Pre-Pulse laser

w/ control, duty cycle 30%





Beam profile



Operation conditions	
Rep. rate [kHz]	100
Duty cycle [%]	30
ON pls [pulse]	30,000
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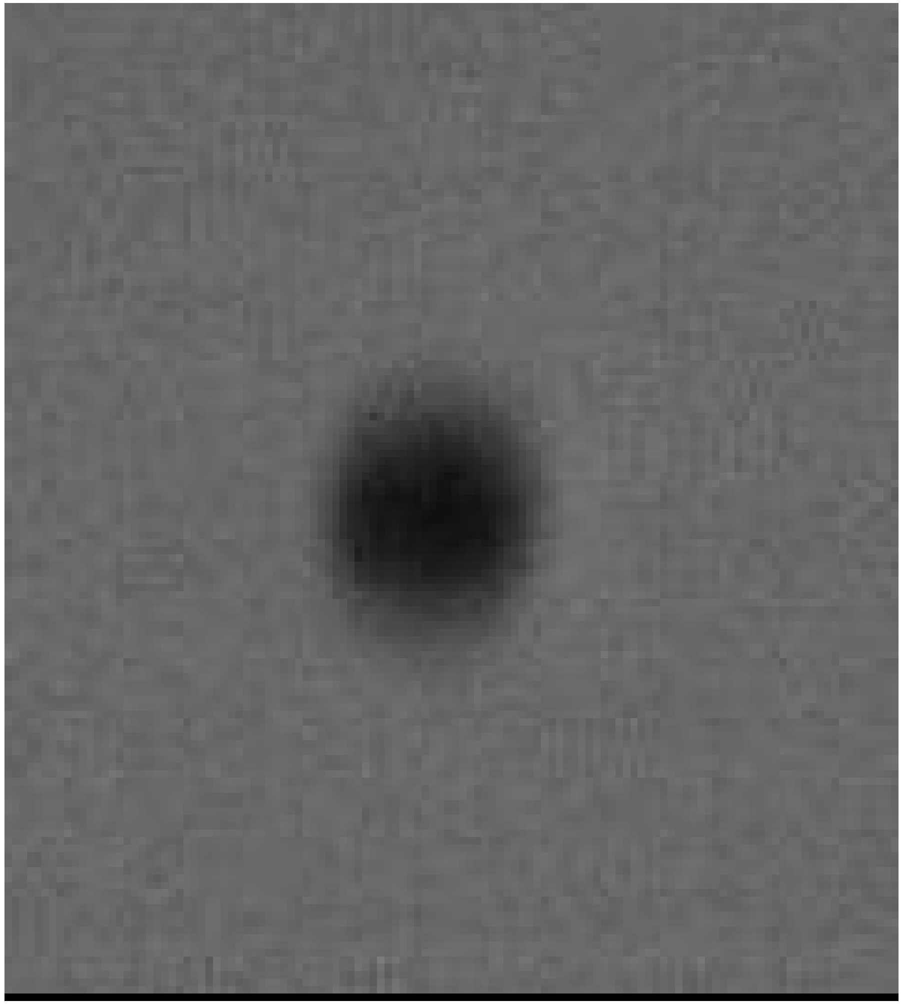
Droplet Generator for GL200E

Video

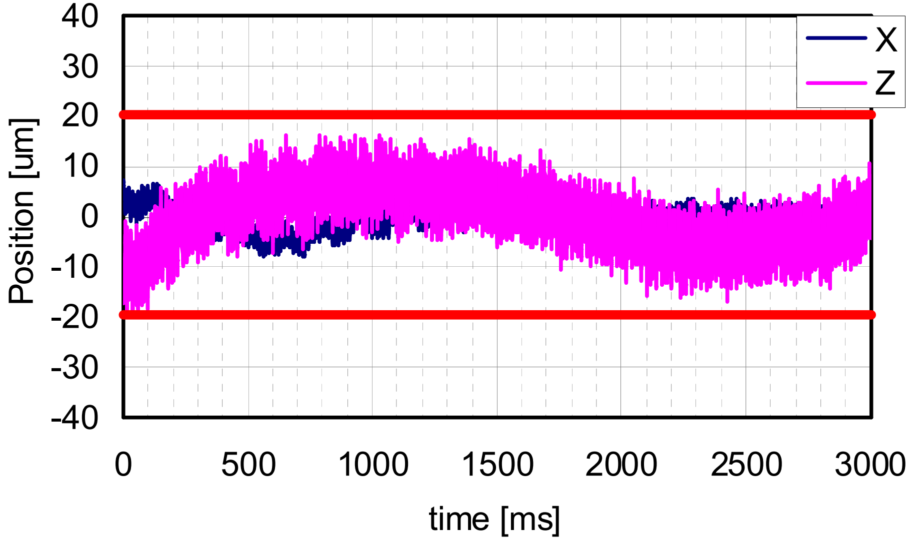
20 μm, 10kHz

Slow image @nozzle



Synchronized image @plasma point

Position stability at 10 kHz



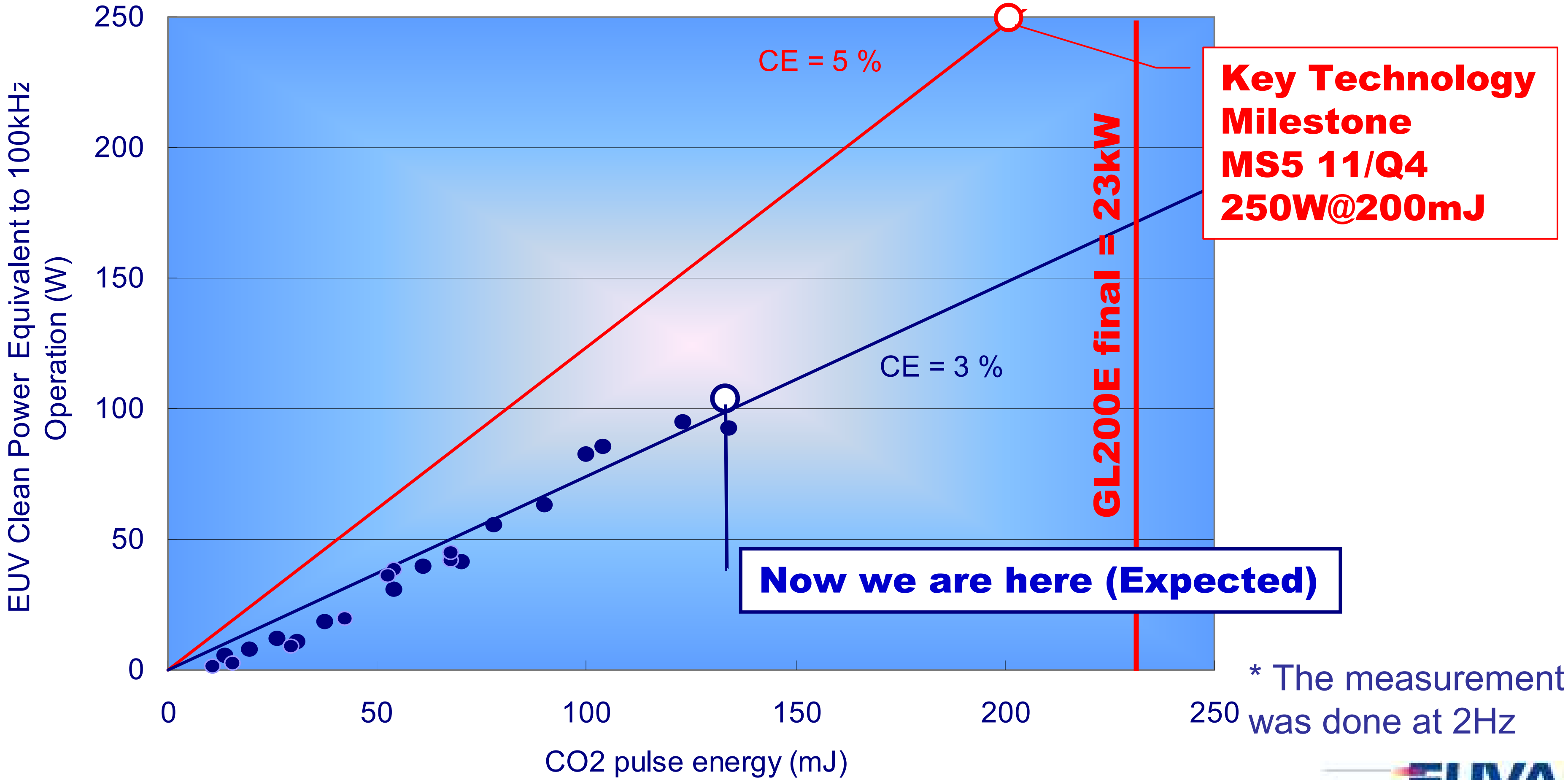
Sn droplet position variation at plasma point

Item	unit	target	result
position stability x	um	+/-20	7
position stability z	um	+/-20	18

- **Position stability is within specification for proto.**
- **Droplet generator on proto is working within spec.**

Scalability toward to 250W clean power

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

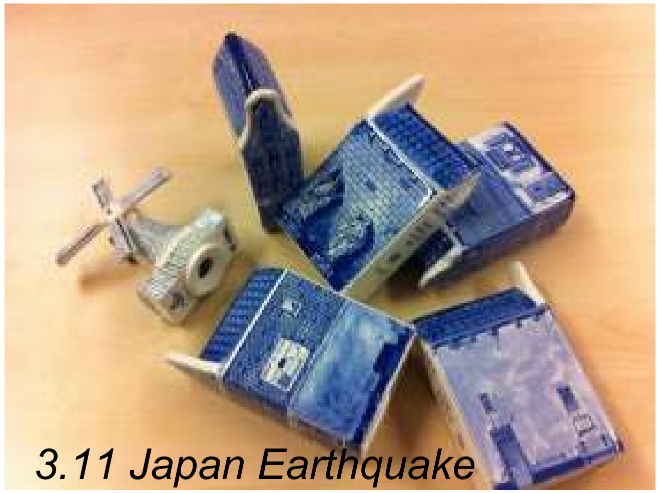


* The measurement was done at 2Hz

Research and development scenery

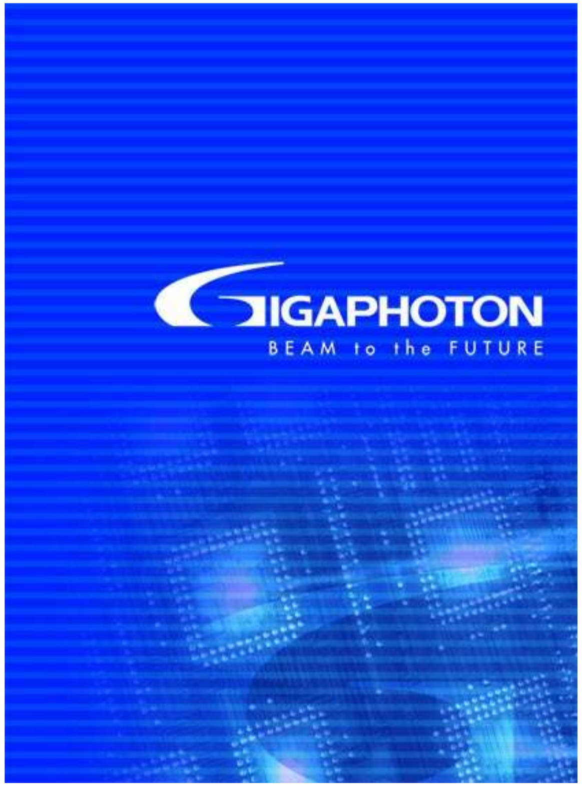
First light of GL200E will come very soon !

Presentation on 02 March @SPIE 2011 ↑



We delayed 3 months.
Now recovering !

Real first EUV light ...
High power and debris free light will come within a few weeks !



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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.
  - 10Hz experiment proved debris mitigation concept experimentally. That is; proper pre-inonization and main ionization make >93% ionization. This technology enables clean light source with combination with magnetic field.
  - 10Hz experiment clarify CE (Conversion Efficiency) improvement, 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 assembling and final engineering of components. The first light will be realized within a few weeks.

Acknowledgments

- *Thanks to fund*

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

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