Development of LPP-EUV source for HVM EUVL

Junichi Fujimoto[*1], Toru Suzuki, Hiroaki Nakarai, Tsukasa Hori, Satoshi Tanaka, Yukio Watanabe, Yasufumi Kawasuji, Takeshi Ohta, Tamotsu Abe, Hakaru Mizoguchi[*1]

*1 *Gigaphoton Inc. :400 Yokokura shinden,Oyama, Tochigi,Japan*
Komatsu Ltd. : 3-25-1 Shinomiya, Hiratsuka, Japan

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

KOMATSU

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

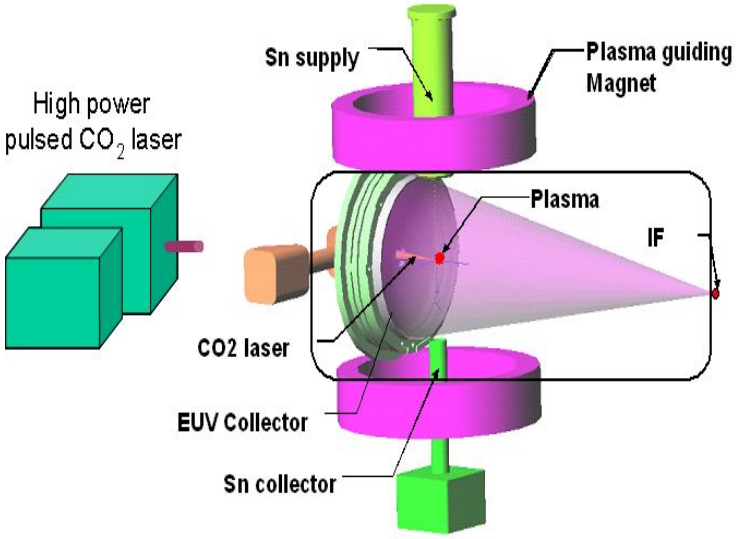
4. Summary

KOMATSU

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
Power (at present) peak/average	**104W/21W**
Plasma	**No electrode**
Mitigation	**Pre pulse + Magnet**
Life limitation	**(several 1000 hr)**
Remark	・Theoretically no limit ・Engineering works still to be done

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

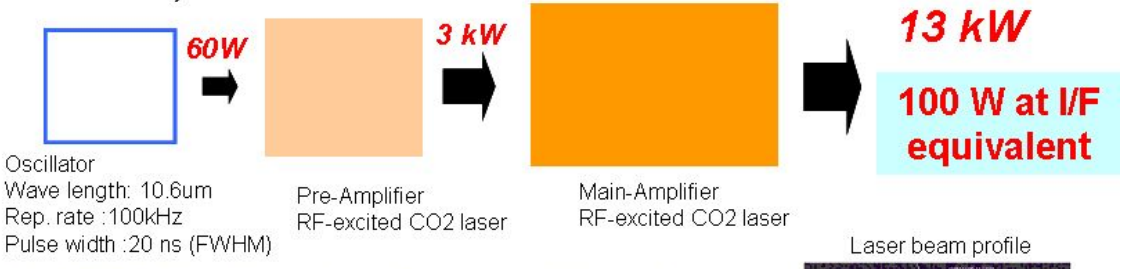
4. Summary

KOMATSU

ETS system configuration

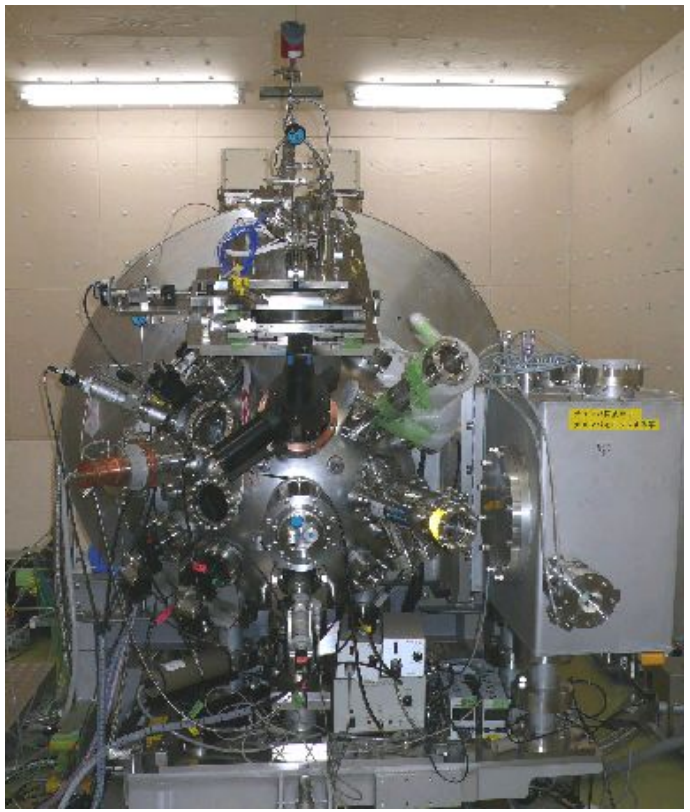
System layout

■ Laser System



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

■ EUV chamber



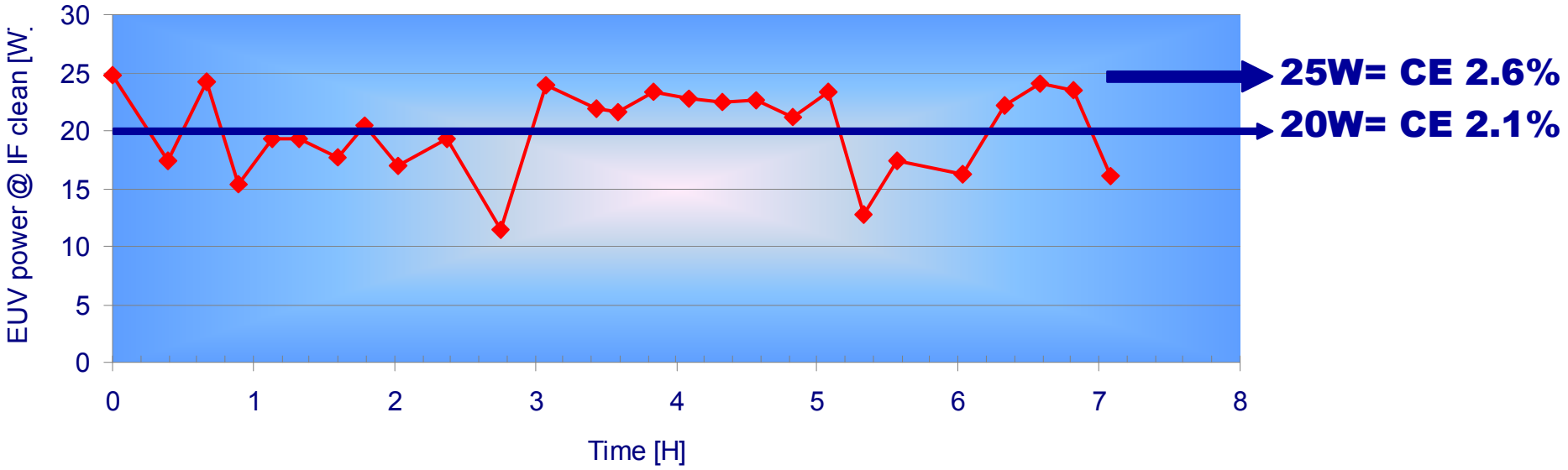
KOMATSU

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

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)



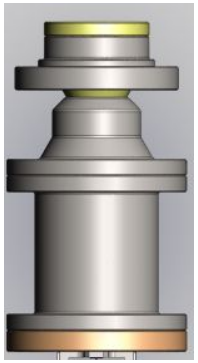
Conditions;
Control: Droplet position control ON, EUV energy control OFF
CO_2 laser = 3.6kW @ 100kHz
Duty=5% (50msecON、950msecOFF)

KOMATSU

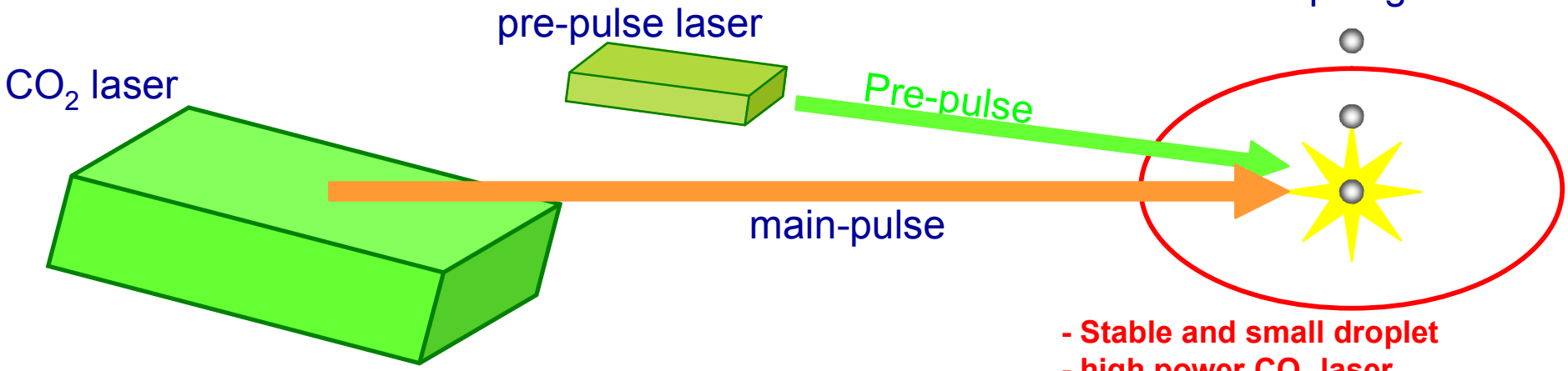
Conclusion of ETS device experiment

"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**

KOMATSU

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

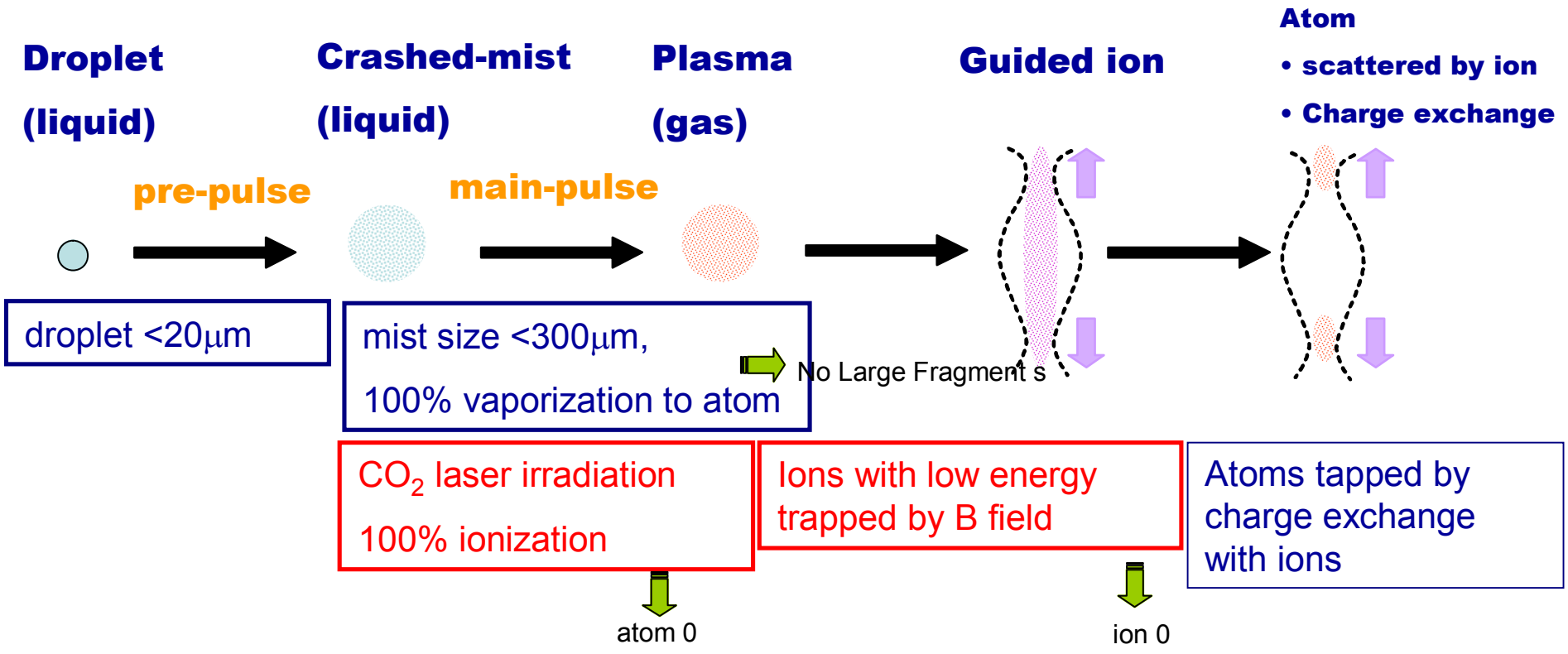
KOMATSU

Collector mirror protect Concept

All Sn atoms should be ionized.

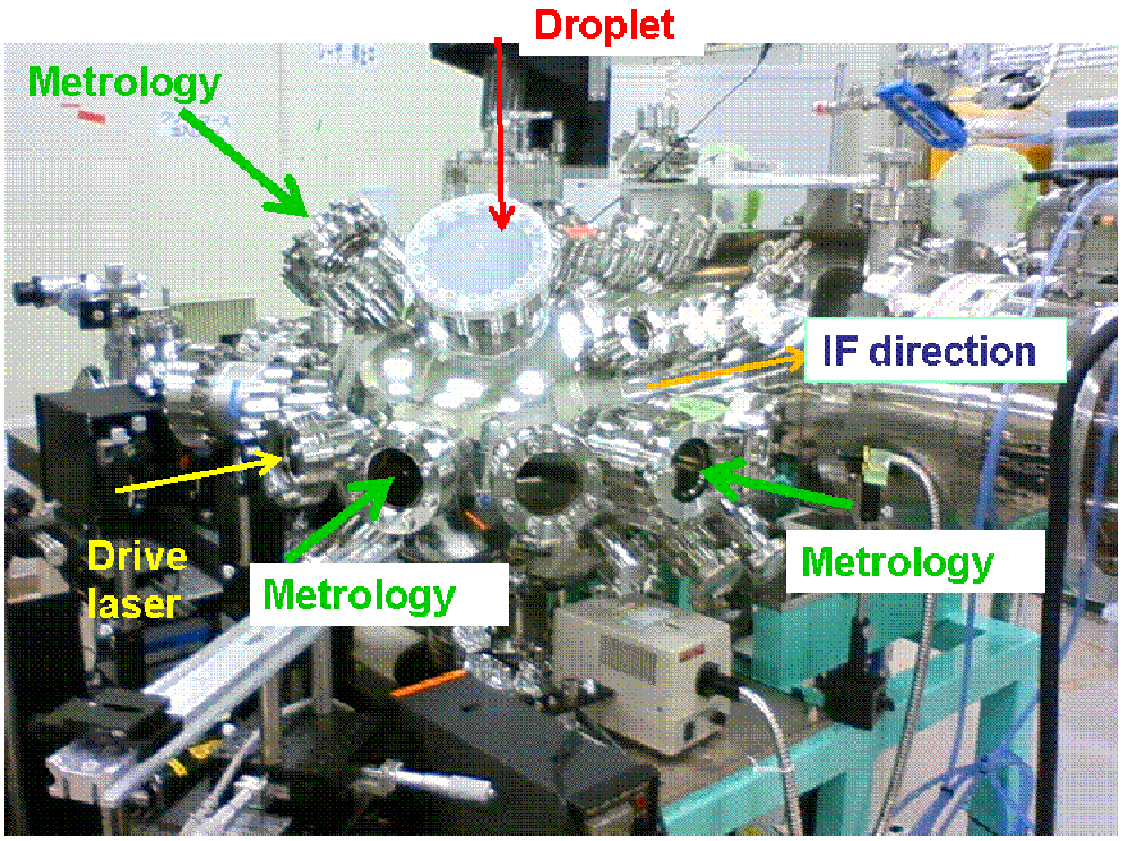
① Magnet field is effective for guiding ions not to going to mirror

② All Sn fragments and atoms are needed to be ionized



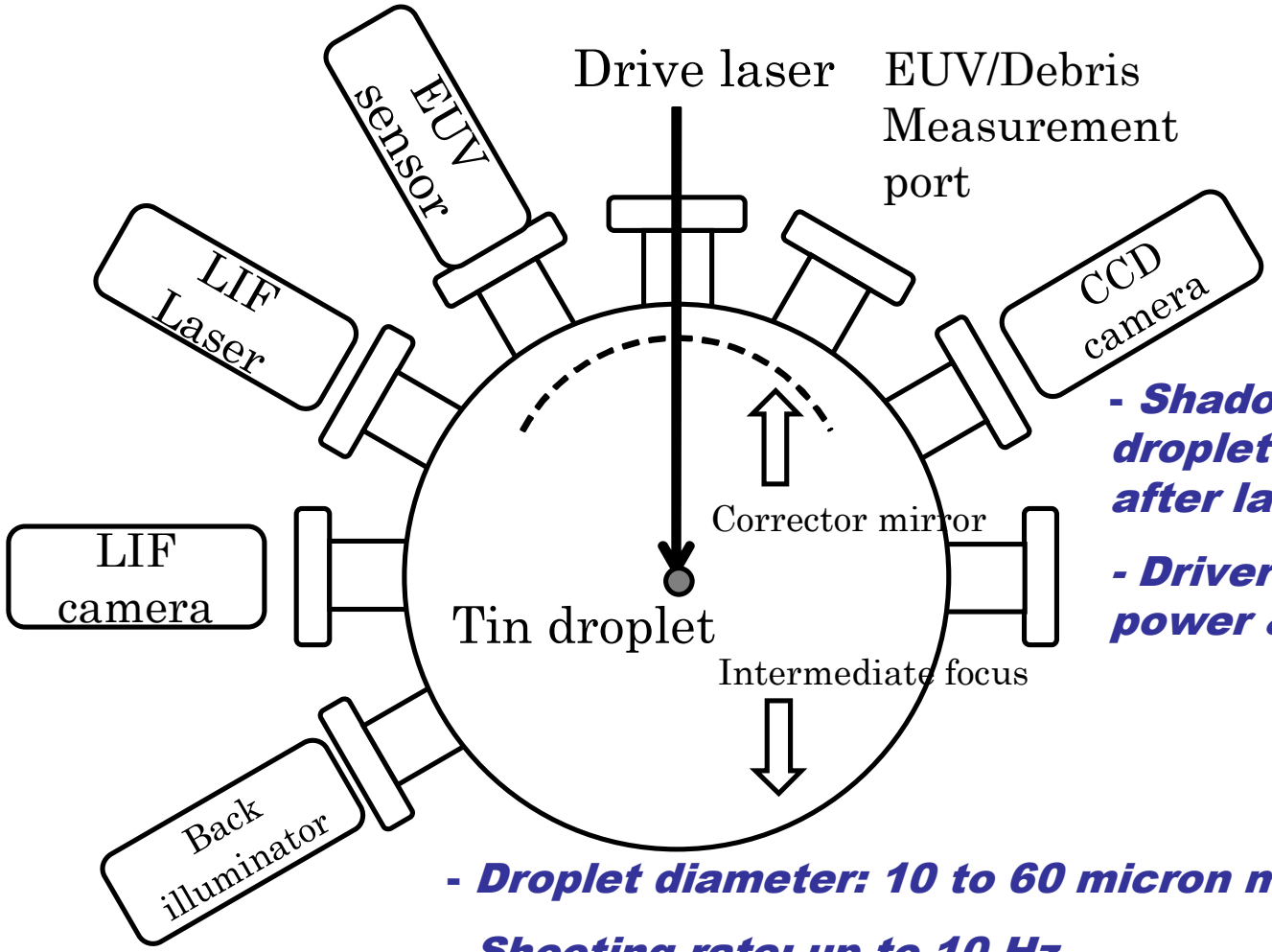
Critical issue investigation with 10Hz device

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



KOMATSU

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?***

KOMATSU

Droplet shooting scheme

Proper pre-pulse condition

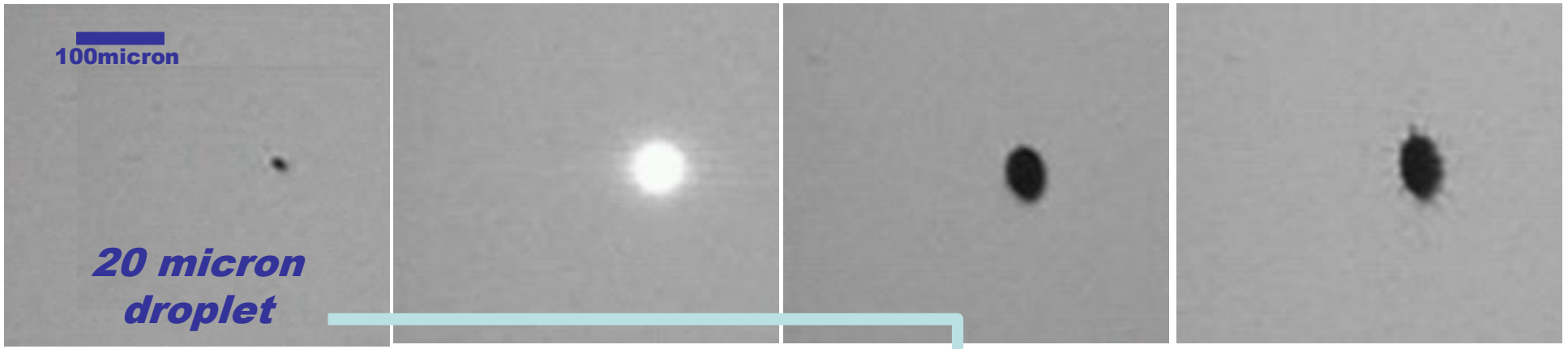
pre-pulse irradiation

Main pulse laser / EUV emission

after EUV emission

Time

a) without main-pulse laser

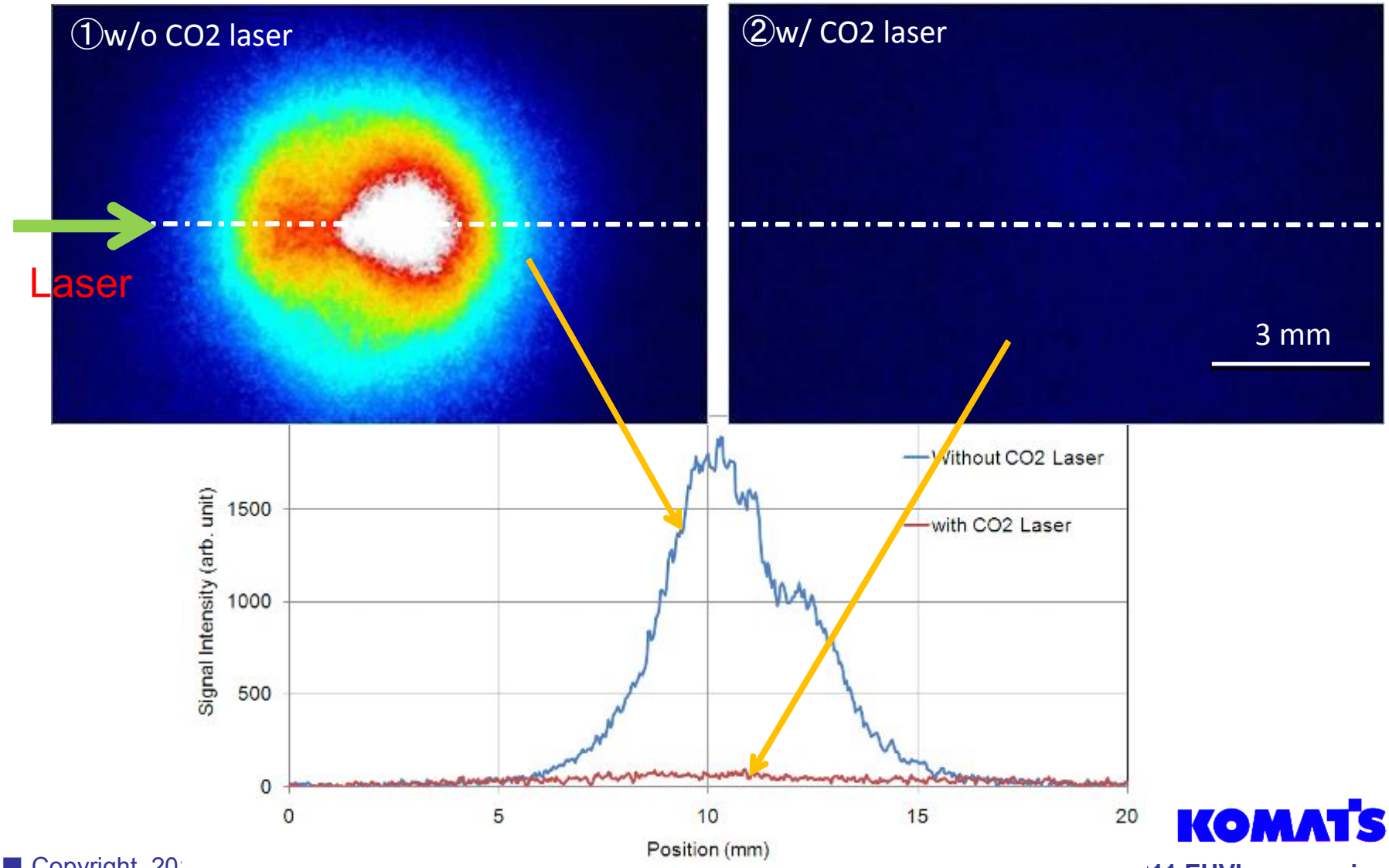


b) with main-pulse laser

KOMATSU

Atom measurement by LIF - 2

Remaining atoms was estimated by subtracting w/ CO2 vs w/o CO2 measurement

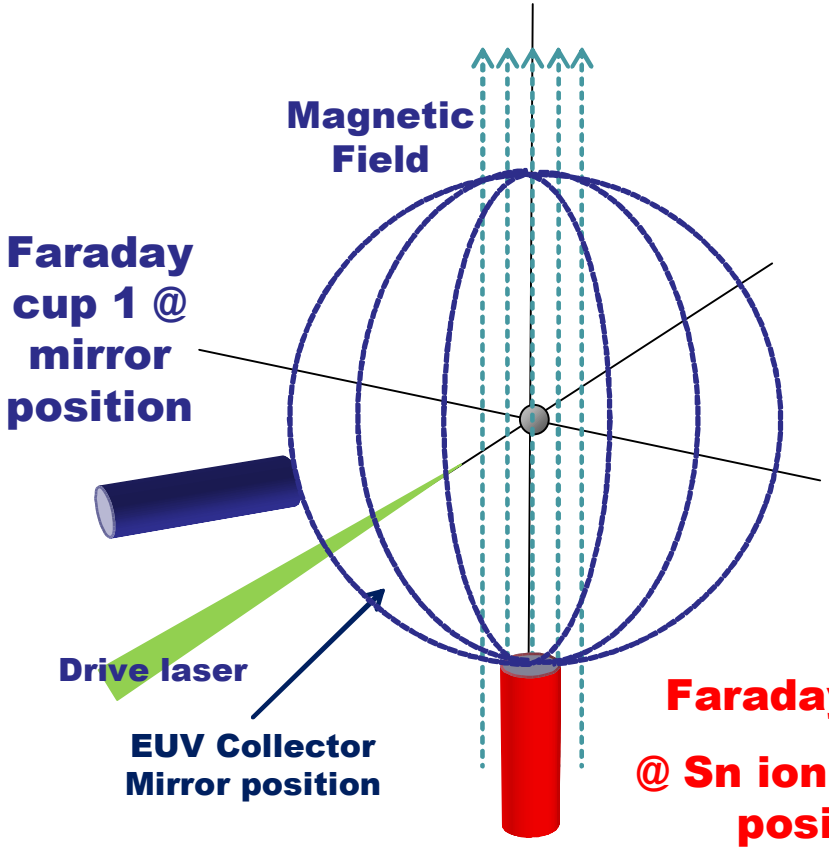


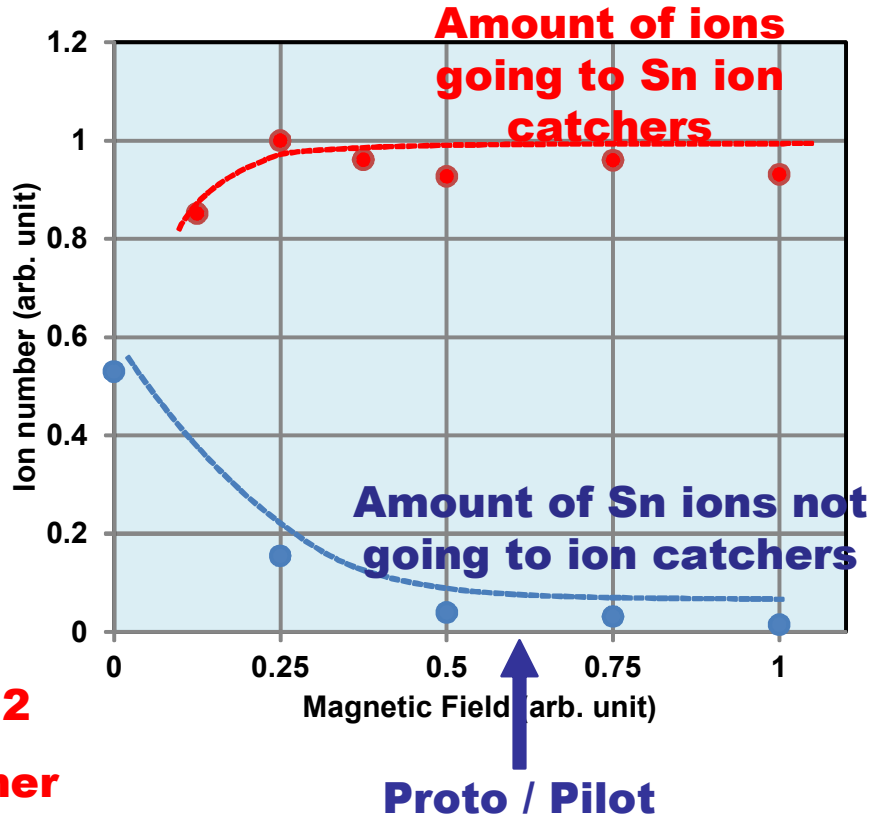
KOMATSU

Ion Measurements by Faraday cups

- Amount of ion is measured by Faraday cup

- *>99% Sn go to Sn ion catcher !!*

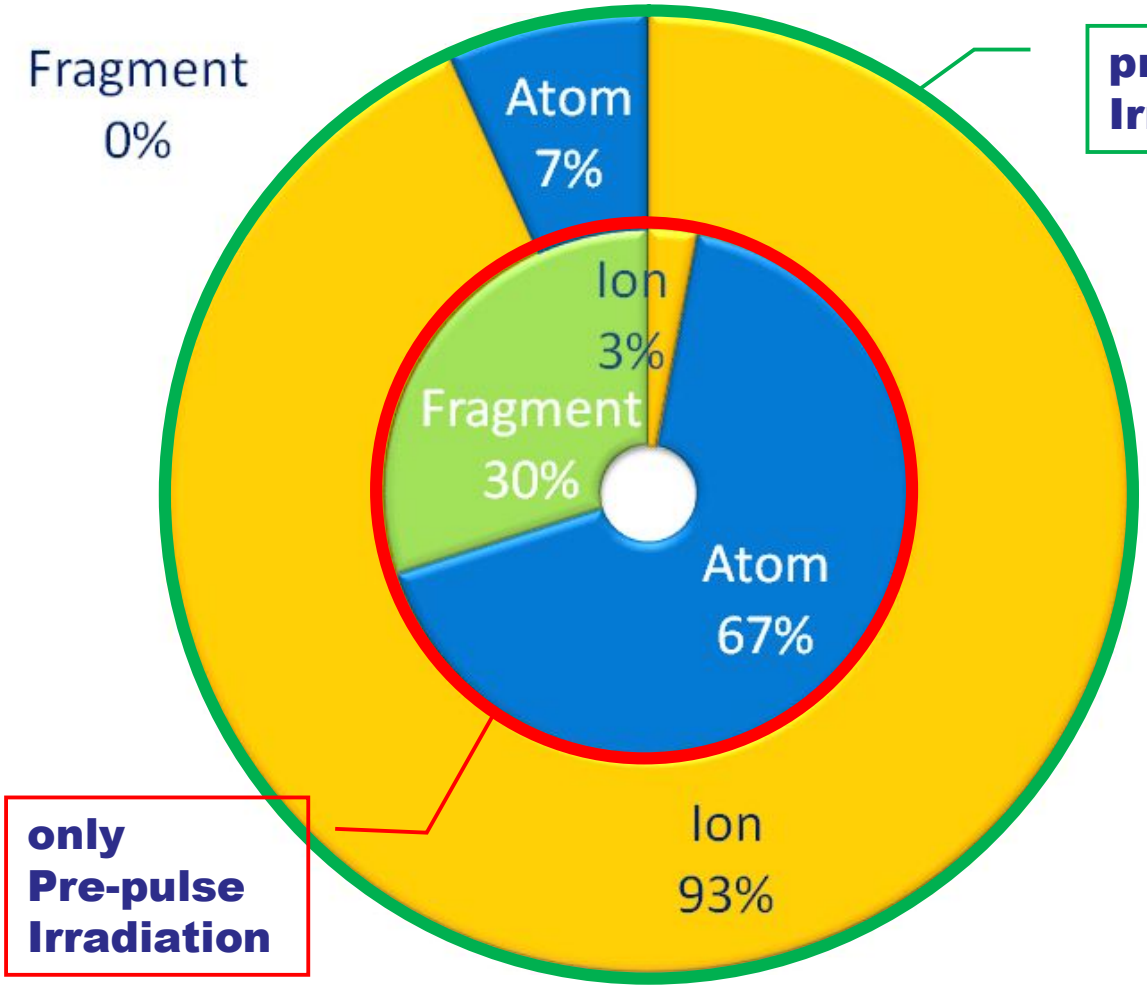




KOMATSU

Results Summary

- **Sn molecule measurement results**
  - ✓ **pre-pulse laser + CO2 laser irradiation : ionized 93% of Sn**
  - ✓ **Only pre-pulse laser irradiation : ionized 3% of Sn**



pre-pulse laser + CO2 laser Irradiation

only Pre-pulse Irradiation

Experimental Condition: Same as proto machine

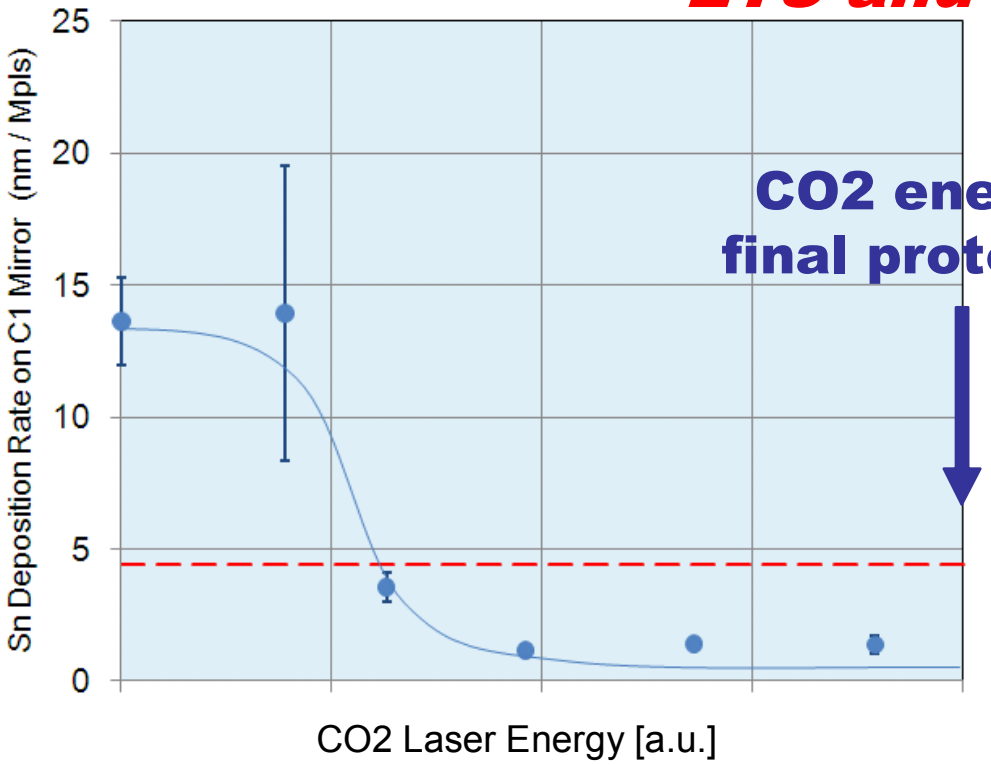
		This time	Proto Condition
Repetition rate	**Hz**	**10**	**100k**

KOMATSU

Clean operation feasibility proven

- **Estimated deposition and cleaning rates**
  - ✓ **Deposition rate: 1.2 nm / Mpls***
  - ✓ **Cleaning rate: 4.4 nm / Mpls****

Clean operation is proven by test data with ETS and 10Hz source



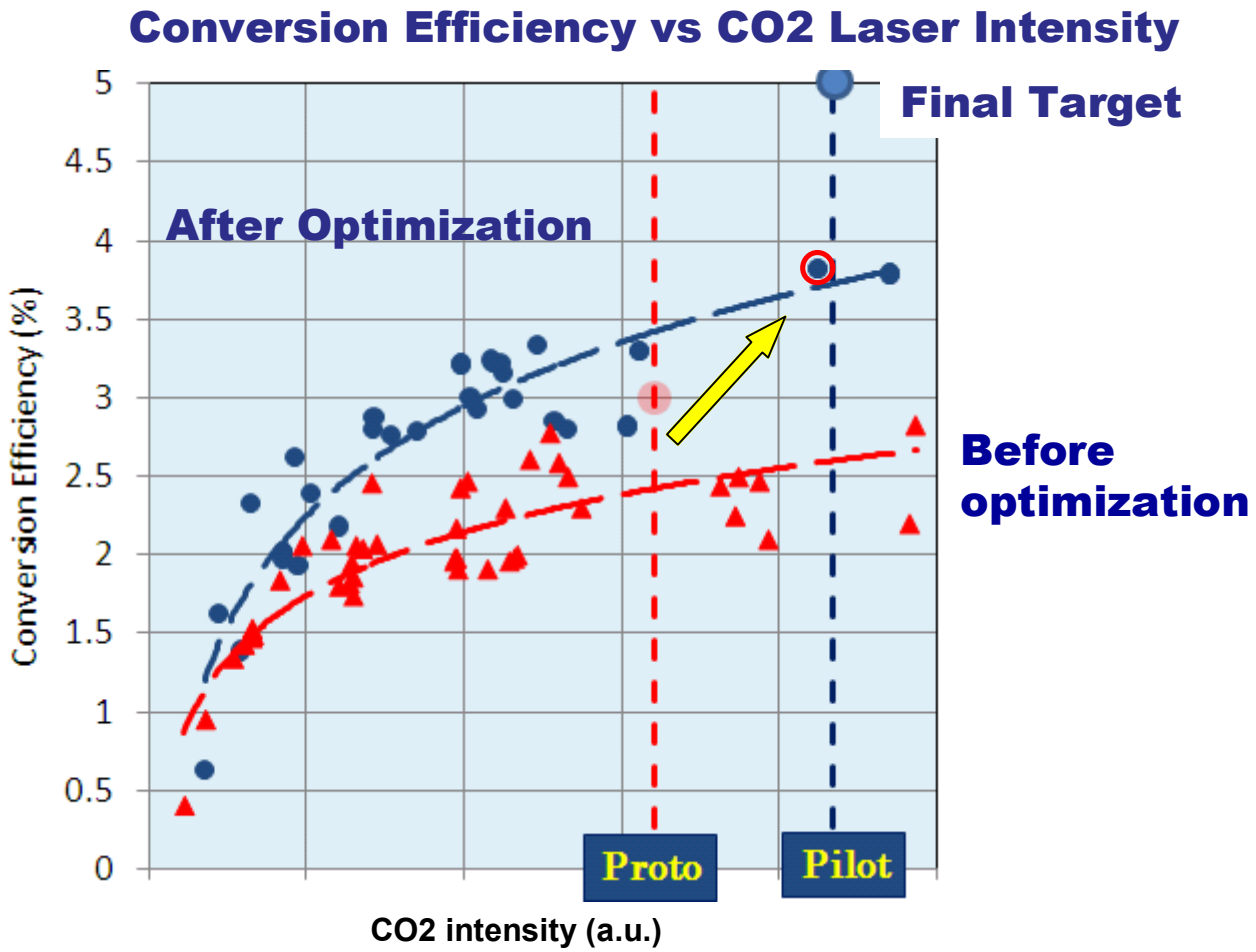
*Estimation of Sn atom dispersion : isotropic

** Estimation based on experimental data under pilot conditions

KOMATSU

New champion data of CE = 3.8% (Aug.2011)

- **After CE optimization**
  - ✓ 3.3% → 3.8% (@ pilot condition)



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

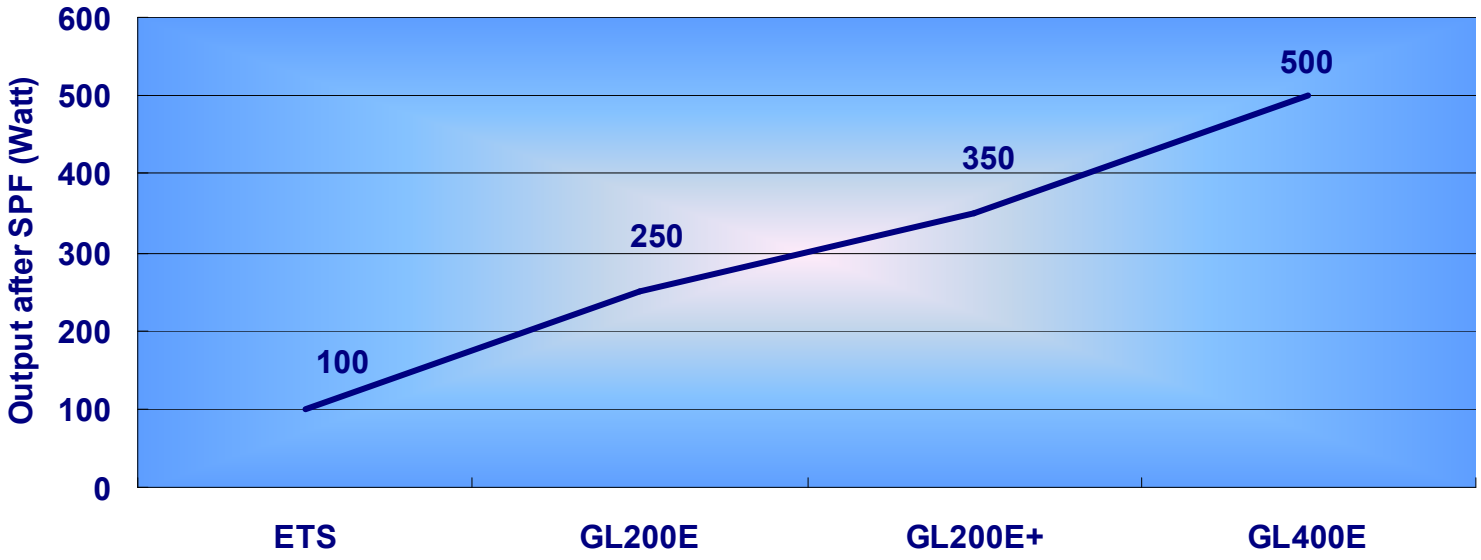
3. HVM EUV light source

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

4. Summary

KOMATSU

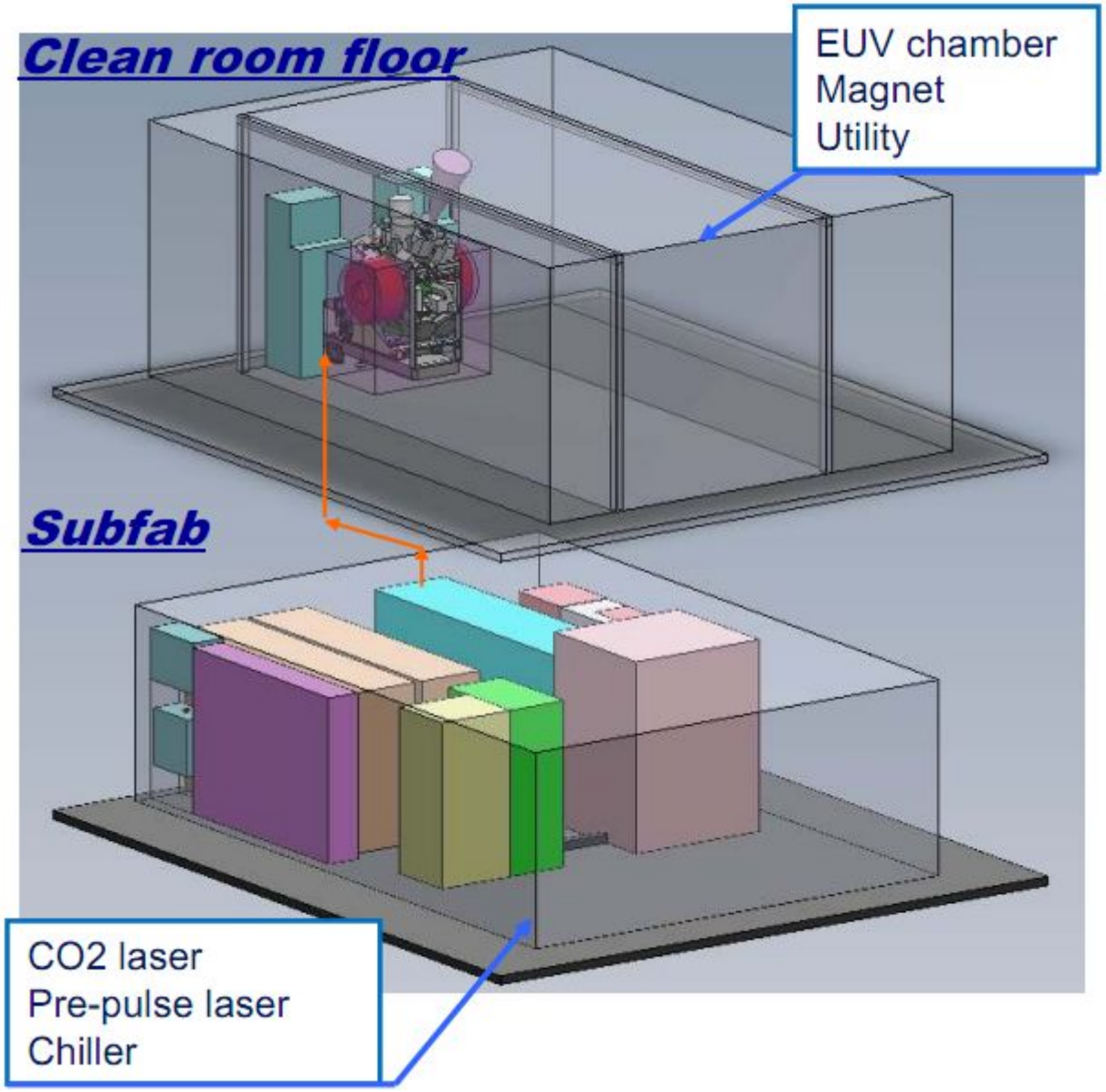
Clean power roadmap



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

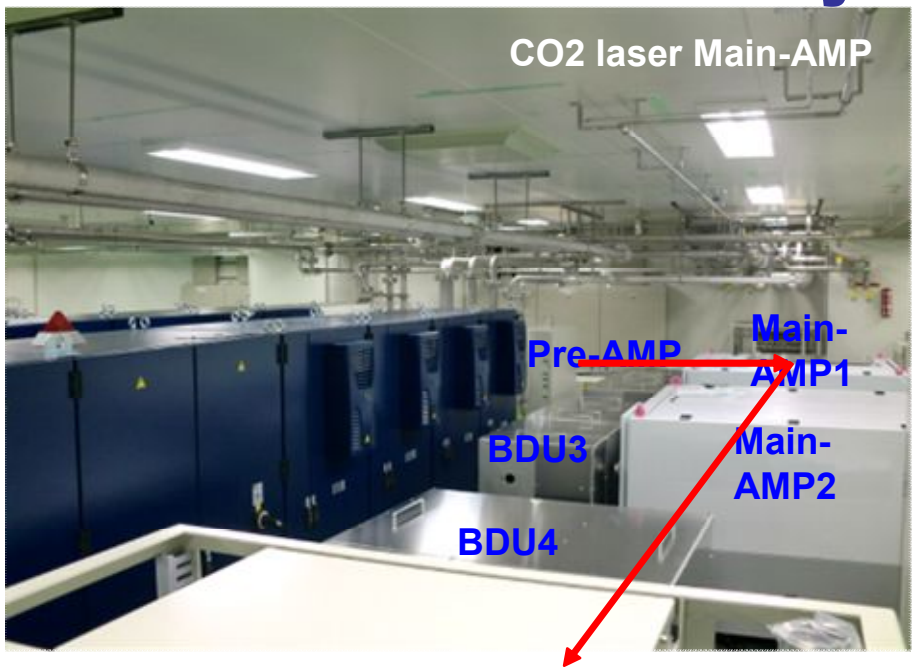
* Against hemisphere (Calculation base)
** w/o SPF

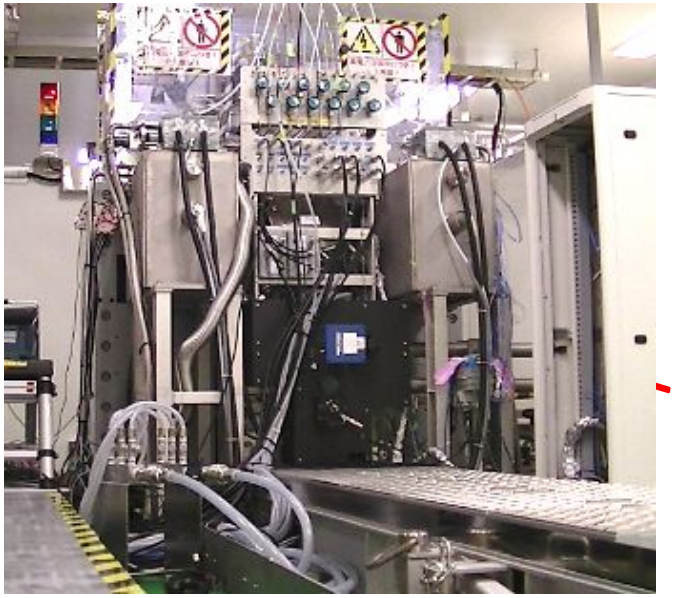
GL200E system overview

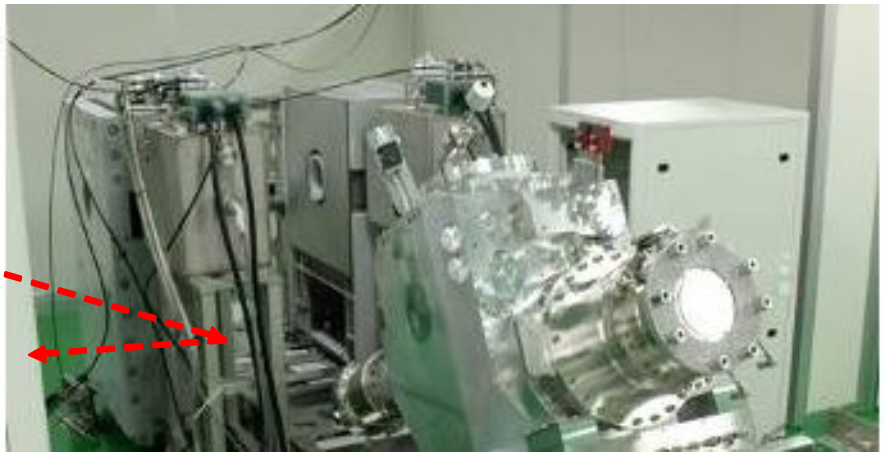


KOMATSU

GL200E proto constructed at Hiratsuka facility







KOMATSU

Real 1st EUV light was observed on proto !

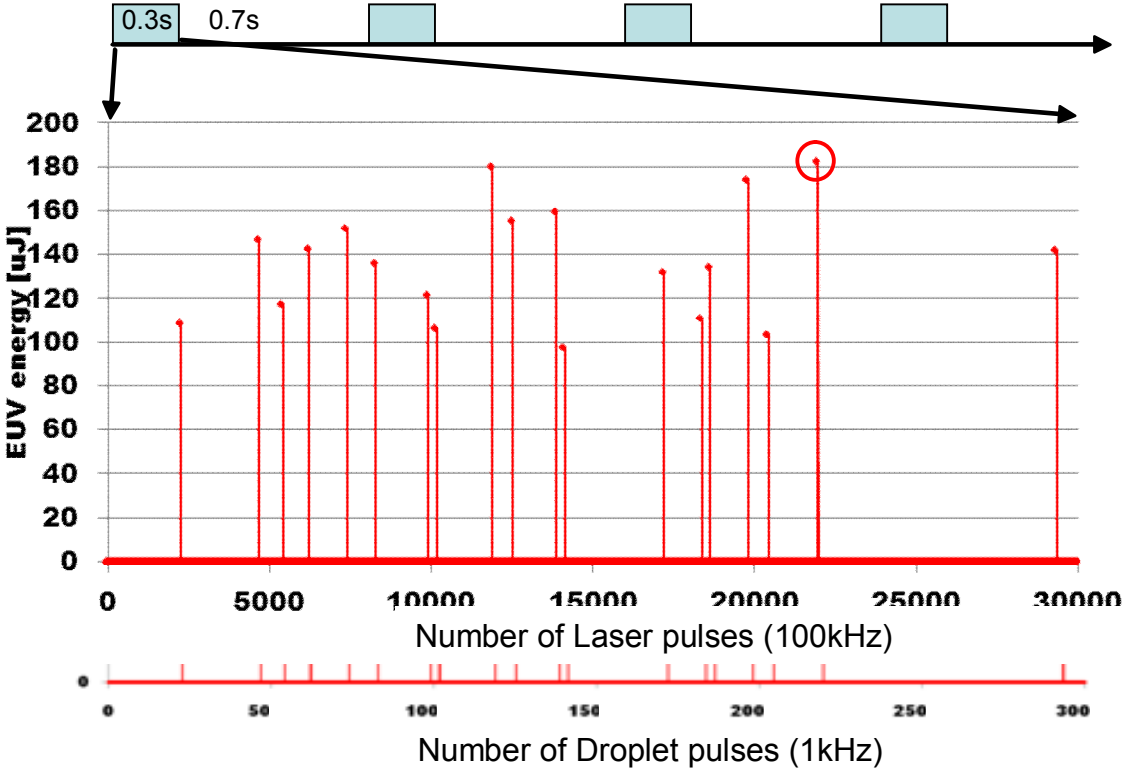
✓ **Max EUV energy =0.182mJ, CE=0.6% (Energy 18W equiv.@100kHz)**

Improvement with plasma shield

Rate of success hit

= 6.3% (=19 / 300)

Miss hit remain, seems by instability of DL acceleration voltage



Operation conditions

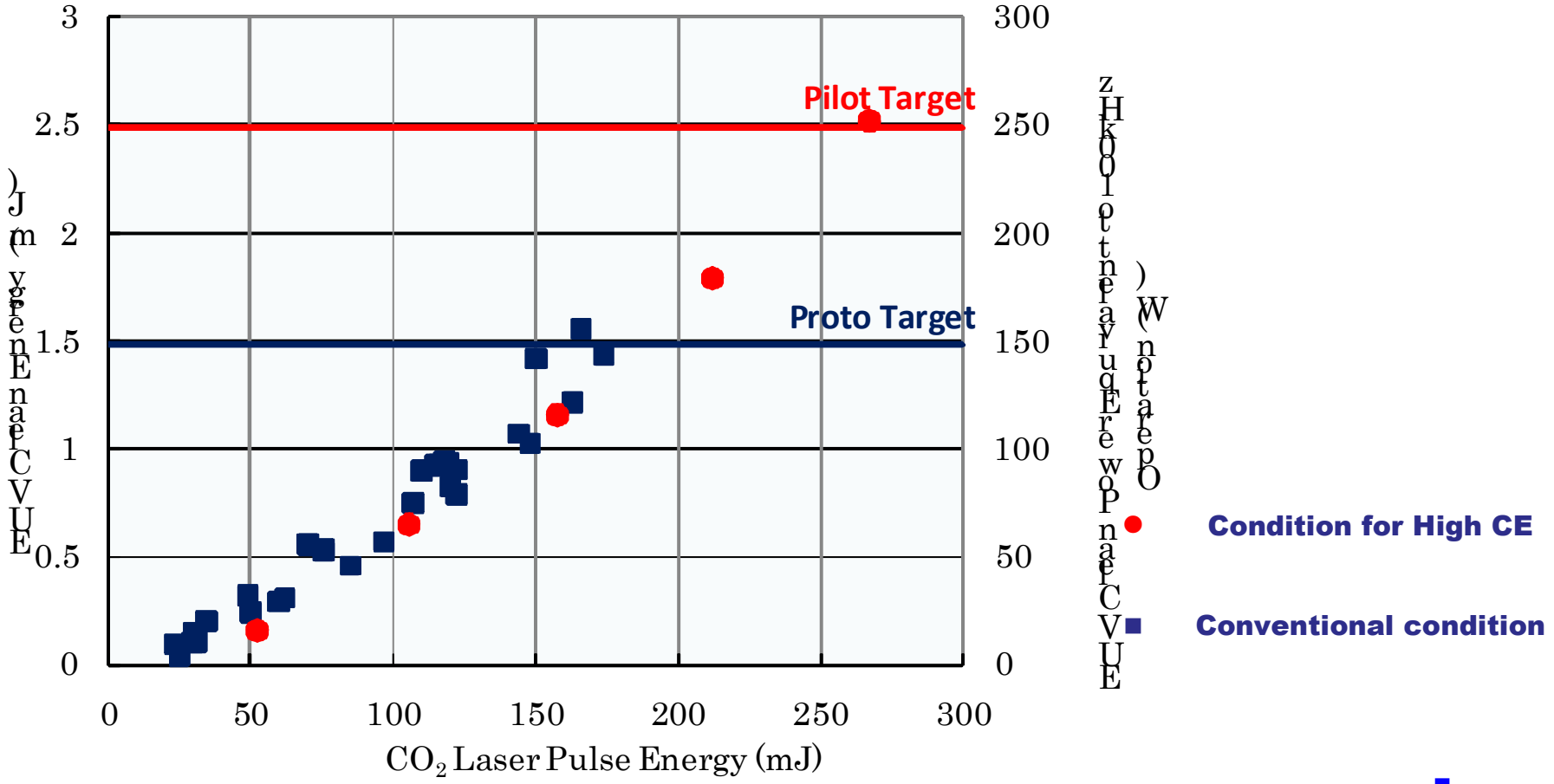
Duty=30% (0.3 sec ON (300pls DL / 30,000pls Laser) , 0.7sec OFF)

- CO2 laser power = 3.0kW 100kHz @ Plasma
- Pre-pulse laser power = 0.1kW 100kHz @ Plasma
- DLG = 33 μm 1kHz

KOMATSU

EUV Output Power vs CO2 Input Power

- **We achieved 2.5mJ EUV output which correspond to 250W clean power**



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

KOMATSU

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 >3.8% and perfect vaporization are simultaneously possible.

- **2st generation LPP source (GL200E):**
  - Concept of design and outline is reported.
  - Our final goal of GL-200E is 250W and the feasibility is supported by high CE experimental data.
  - We observed 1st EUV light on proto source with 18W equivalent level at present. Next target is 50W level demonstration until 1Q 2012.

KOMATSU

Acknowledgments

Thanks to fund

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

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