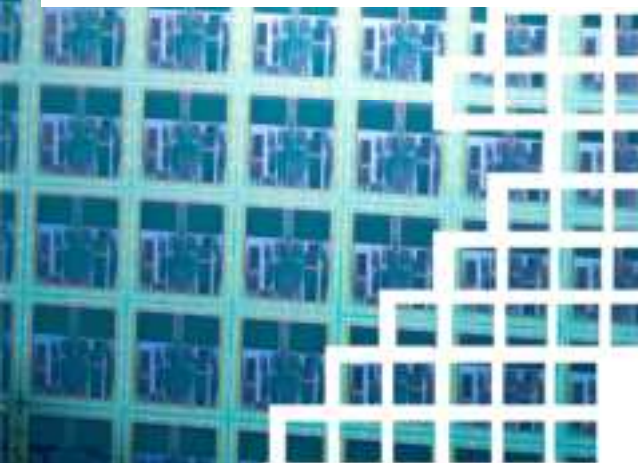

GIGAPHOTON

S2

# UPDATE OF >300W HIGH POWER LPP-EUV SOURCE CHALLENGE IV FOR SEMICONDUCTOR HVM



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# Agenda

## Introduction

- New Trend of Semiconductor Manufacturing Technology
- New DUV laser processing for Middle End Semiconductor Packaging

## EUV Source development for Lithography

- Concept and key technologies
- 330W EUV Source System
- System Operation Data
- Lifetime Extension of Collector Mirror
- Extendibility toward >800W of EUV power

## Summary & Acknowledgement

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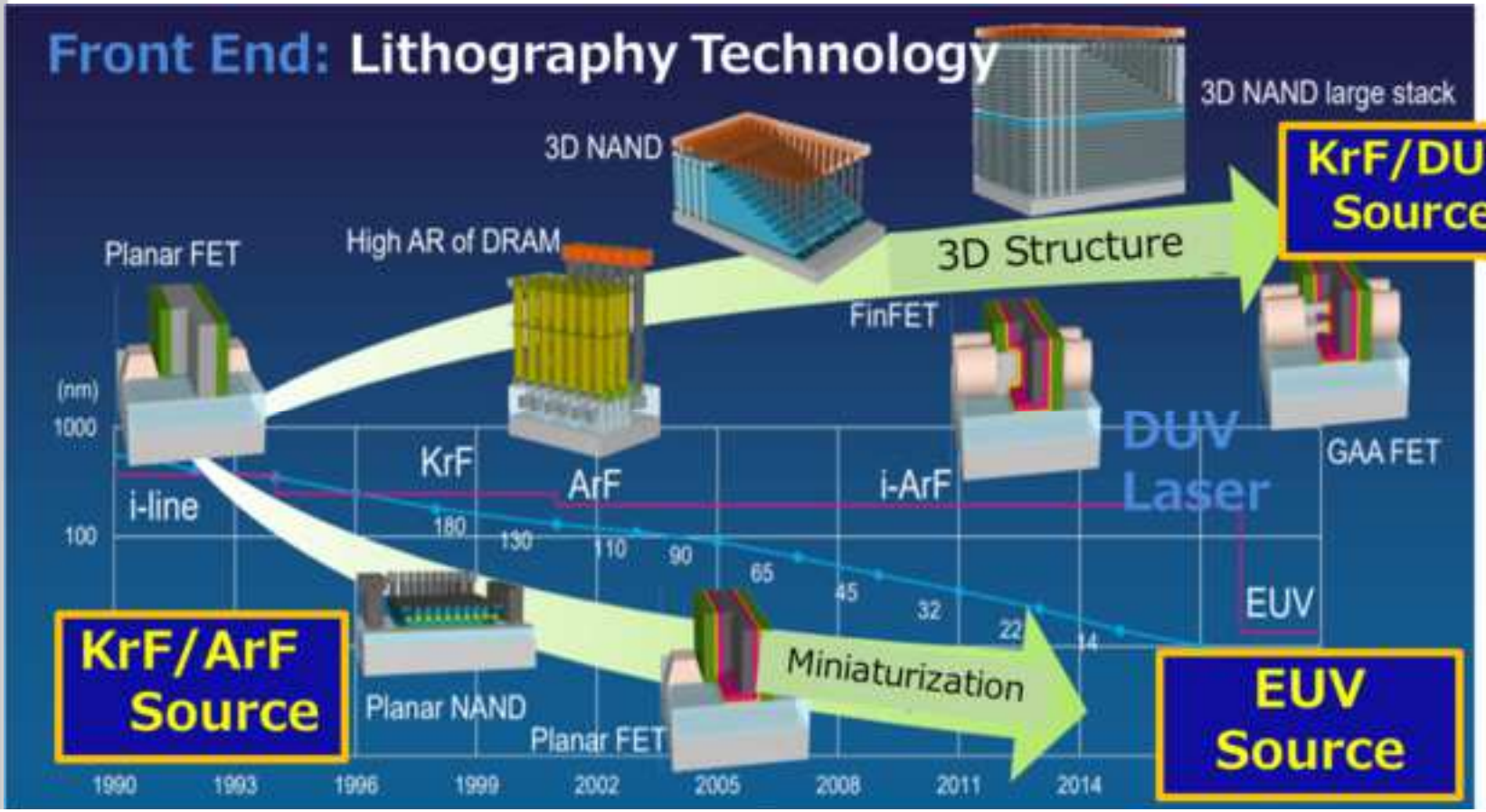
# New Trend of Semiconductor Manufacturing Technology

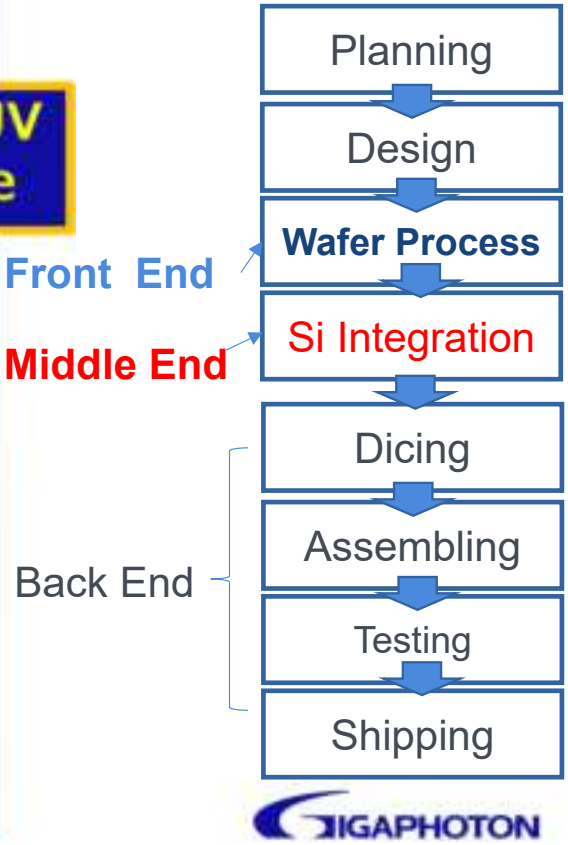
***New Trend***

*3D structure, Minimization by EUV lithography and Packaging are three key direction.*

*EUV lithography is now rump up. Huge investment are on going all over the would.*

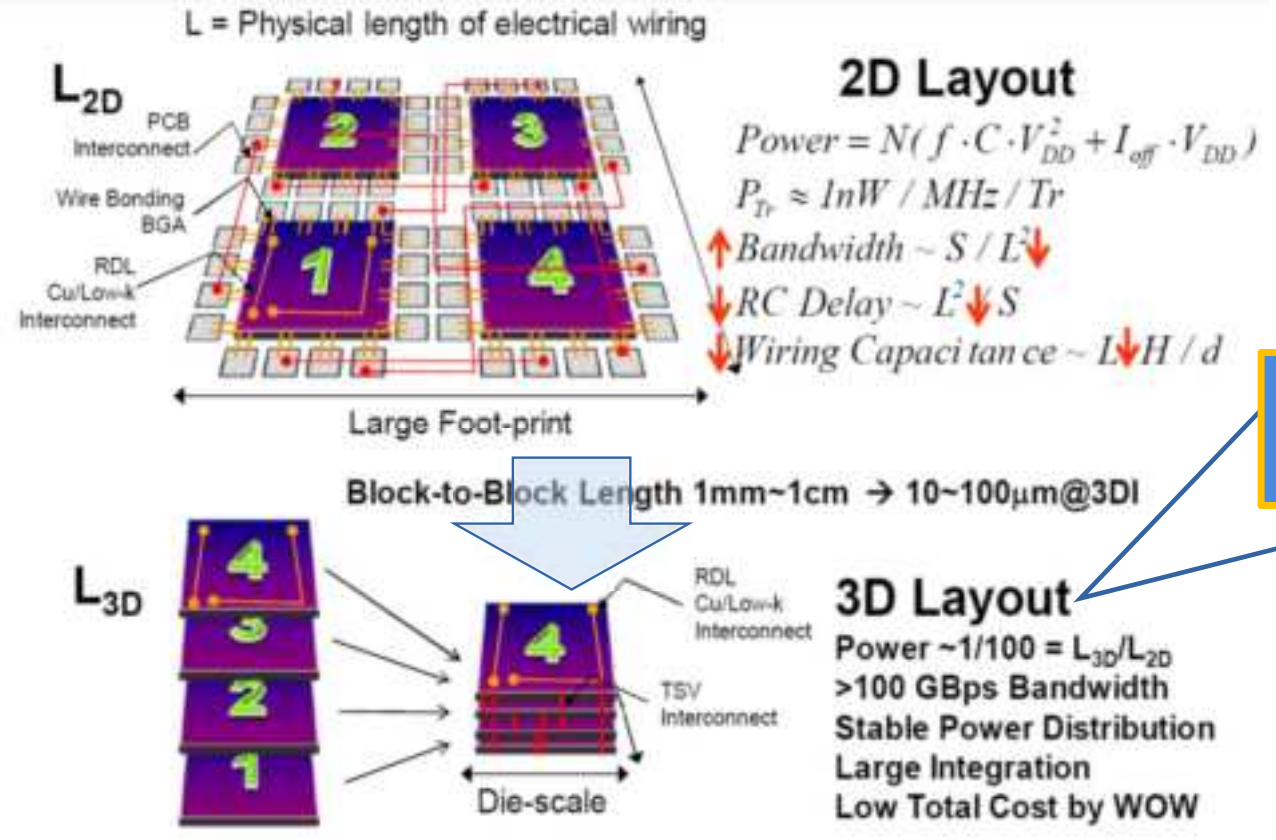


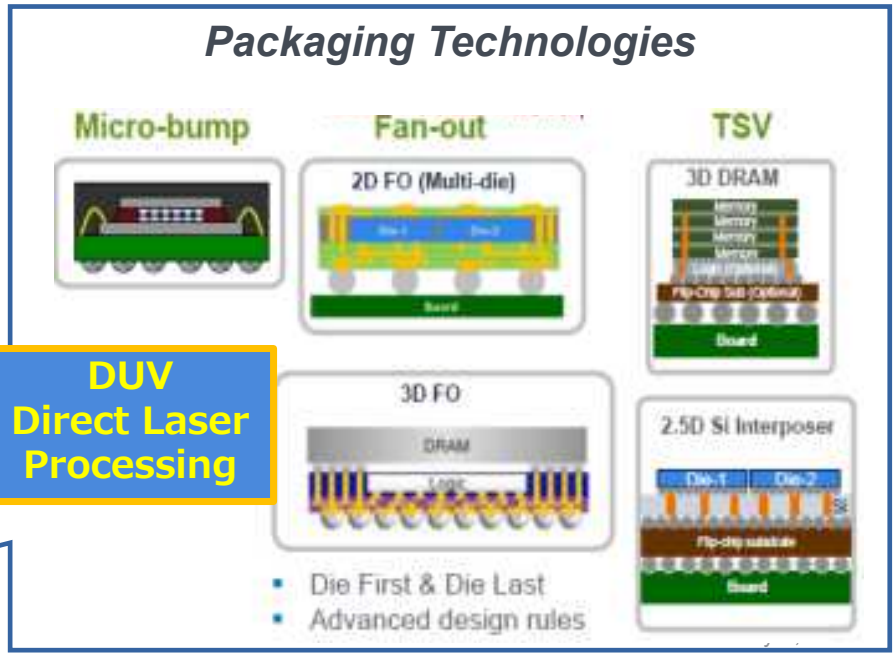

Semiconductor Manufacturing Flow



# Development of Material Processing for Packaging (1)

## Package Layout dominate performance of Chip



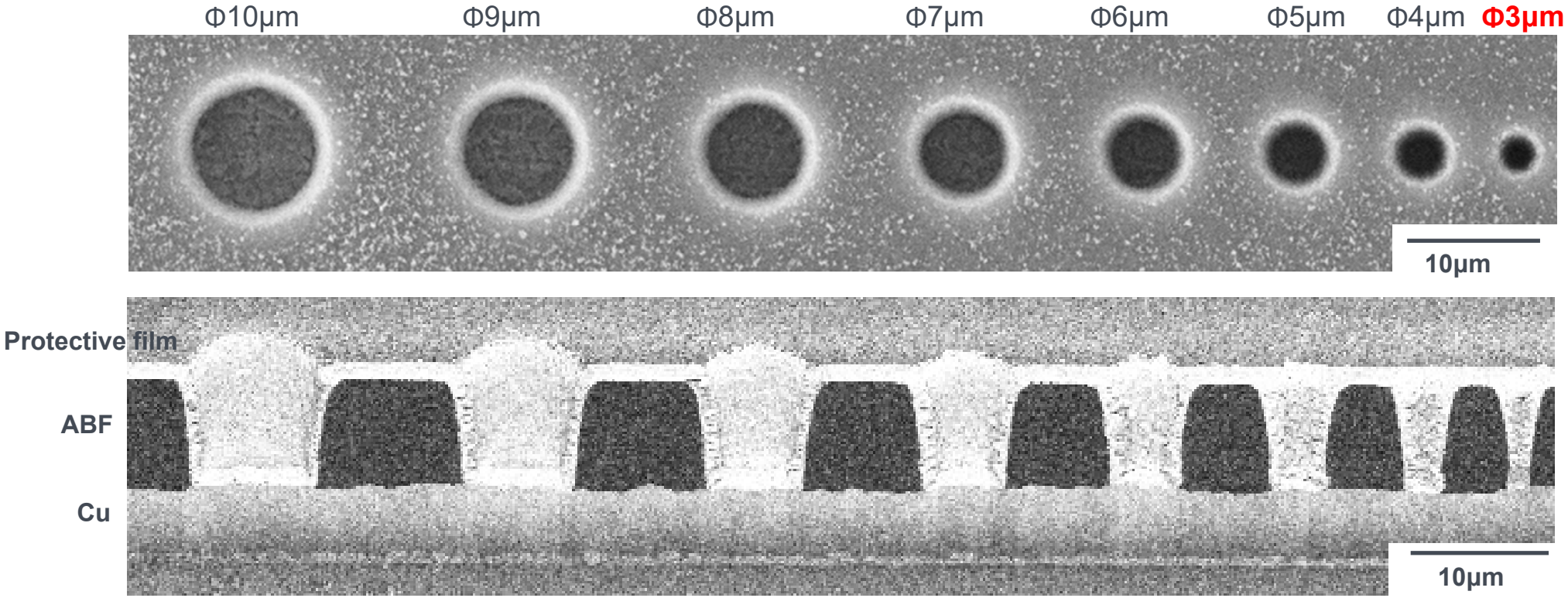

DUV Direct Laser Processing

Ref.
Takayuki Ohba Laboratory, Laboratory for Future Interdisciplinary Research of Science and Technology, Tokyo Institute of Technology,

http://www.wow.pi.titech.ac.jp/research01_e.html

# Development of Material Processing for Packaging (2)

## Fine via on ABF ( Plastic and ceramic compound ): cross-sectional SEM image




Cross-sectional SEM image (Inclination 52°)

- **KrF excimer laser can process via of Φ3 μm with GY50**
- **There was no damage on the Cu film**

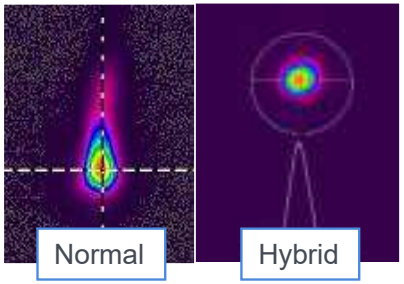
# Development of Material Processing for Packaging (3)

## *Hybrid Laser for Advanced Material Processing*

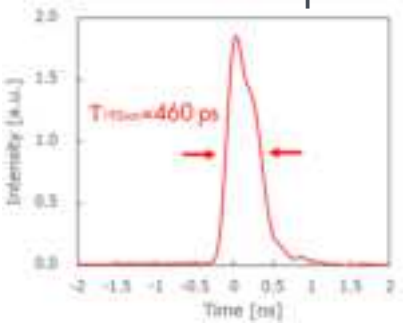
**New laser Processing PJT of NEDO : 2017-2022**

Gigaphoton Developed
Hybrid ArF laser for Advenced Material Processing

Focused spot profile




Pulse shape





Hybrid ArF Excimer laser in TACMI Kashiwa Lab.

- Short wavelength
  - Precise micromachining
- High photon energy
  - Direct cutting of atomic / molecular bonding
- High average power
  - Fast processing rate
- Good beam quality
  - Further precise micromachining
  - Achievement of higher energy fluence
- Short pulse duration
  - Reduction of heat affected zone (H

NEDO
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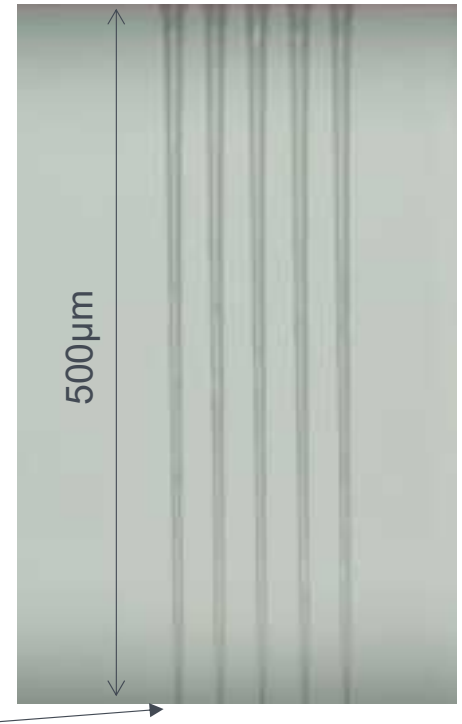
# Development of Material Processing for Packaging (4)

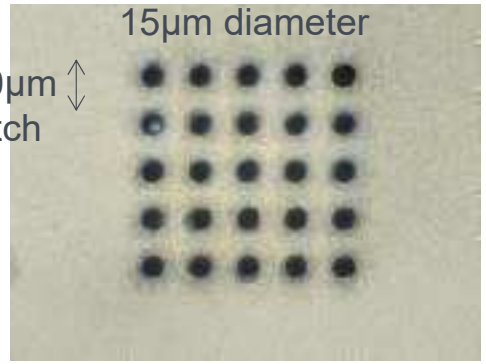
## *Advanced Laser Processing by using DUV Laser on Difficult Materials*

**Glass Material : Eagle XG ( CORNING )**
**500μm thickness**
Light Source : GT600K ( Gigaphoton )

Side view



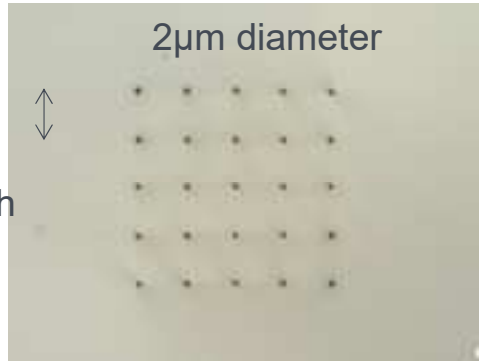

Top view( irradiation side)




Hole diameter :15μm
Hole Pitch :30μm
No Cracks on surface
(No post processed after laser via drilling)

Aspect ratio : 33 ( = 500/15 )
No Cracks inside

Bottom view




Hole diameter : 2μm
Hole Pitch :30μm
No Cracks on surface

# Development of Material Processing for Packaging (5)

## Excimer Laser Light Source for Material Processing

■ Product

Gigaphoton have developed
the commercial laser
**G300K** and **GT600K**
for material Processing.

■ Key performances

- Short wavelength ( 248nm )
- High power (300W, 600W)
- High frequency (4000Hz, 6000Hz)


| Model | G300K | GT600K |
|---|---|---|
| Wavelength (nm) | 248 | |
| Output light power (W) | **300** | **600** |
| Output light energy (mJ/pulse) | 75 | 100 |
| Output light Repetition frequency(Hz) | 4000 | 6000 |
| Body size (mm) | 1975 x 800 x 1950 | 2,800 x 820 x 2,120 |
| Body weight (kg) | 1600 | 3400 |

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## Summary & Acknowledgement

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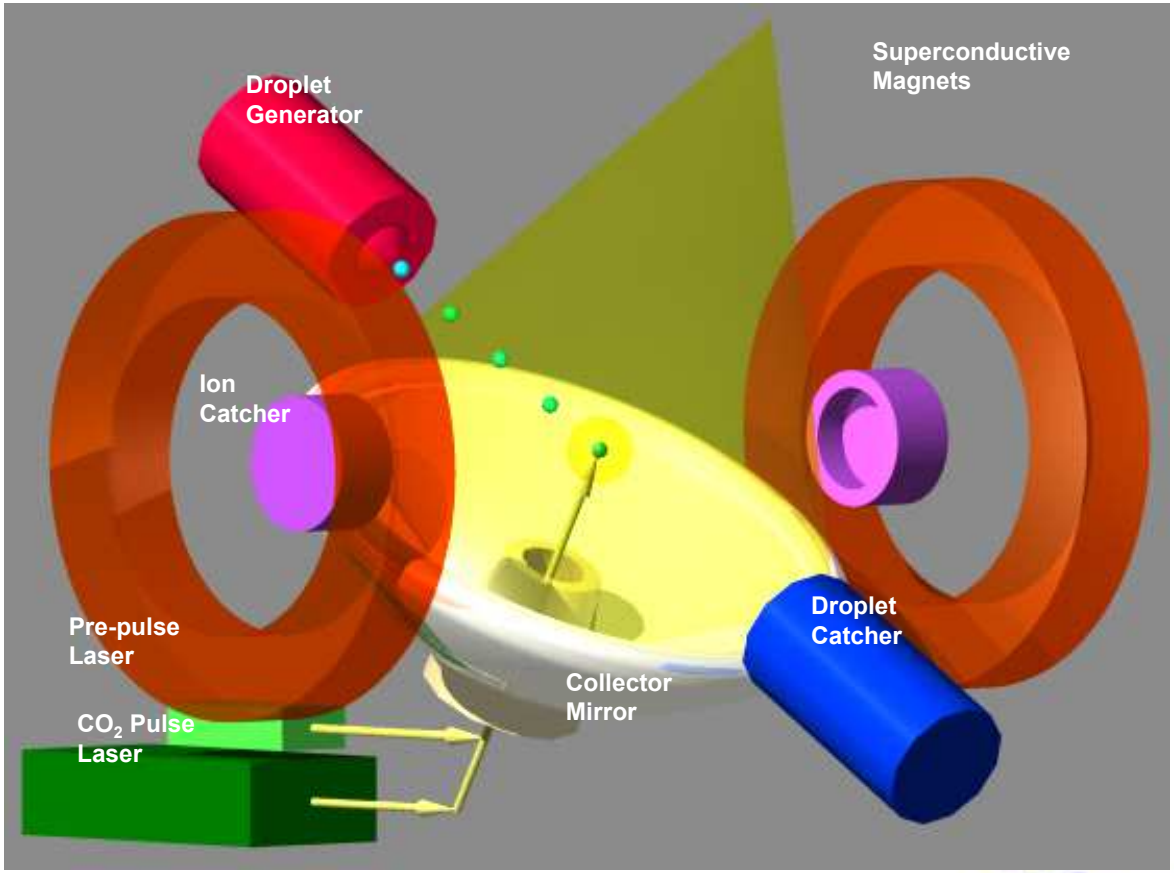
# ■ Gigaphoton LPP Source Concept (1/3)

## State of Art Gigaphoton LPP Source Configuration* was Established in 2007 *several patented

1. High ionization rate and CE EUV tin (Sn) plasma generated by dual-wavelength shooting via $CO_2$ and pre-pulse solid-state lasers
2. Hybrid $CO_2$ laser system with short pulse high repetition rate oscillator and commercial cw-amplifiers
3. Tin debris mitigation with a super conductive magnetic field
4. Accurate shooting control with droplet and laser beam control
5. Highly efficient out-of-band light reduction with grating structured C1 mirror

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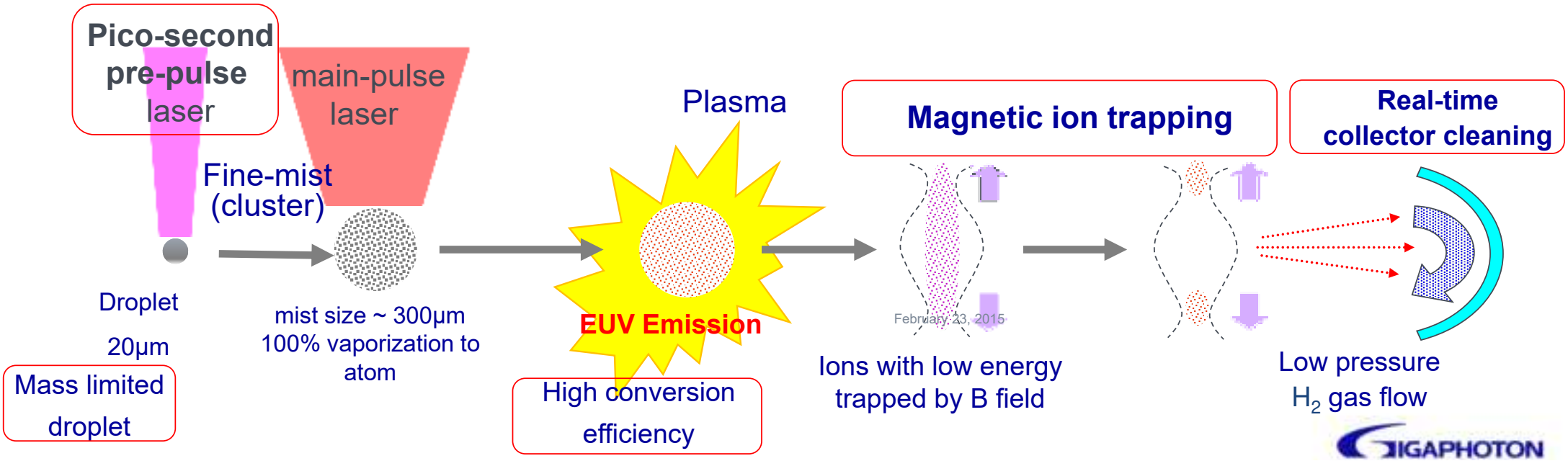
# ■ Gigaphoton LPP Source Concept (2/3)

## Pico-second pre-pulse + Magnetic mitigation technology was established in 2012

- **Mass limited 20μm droplets**
- **Pico-second pre-pulse laser** produce **high conversion efficiency**
- Super conductive magnets and ion catchers enable **Magnetic Ion trapping**
- Low pressure $H_2$ gas flow enable **real-time collector cleaning**.



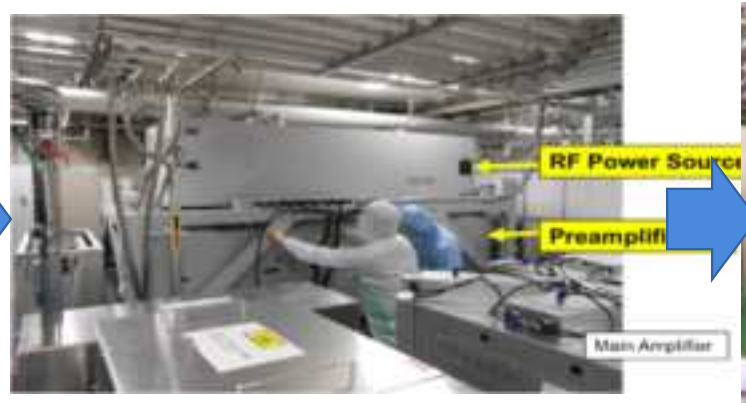
# ■ Gigaphoton LPP Source Concept (3/3)

*<Configuration & History of Amplifier development>*

*Collaborated with* MITSUBISHI ELECTRIC

| OSC | PA1 | MA1 | MA2 | MA3 | Plasma Point |
|---|---|---|---|---|---|
| OSC → Pre-Amp → Pre-Amp | AMP | AMP | AMP | AMP | → |
| ***For 330W EUV*** 100W | 5kW | 10kW | 20kW | 30kW | **27 kW** |

*Basic Experiment in 2013*




*1st Amplifier installation in 2015*

*Amplifier system installation in 2016*

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# Extremely High gain Amplifer technology was supplied by Mitsubishi Electric since 2012

## Parameter Study

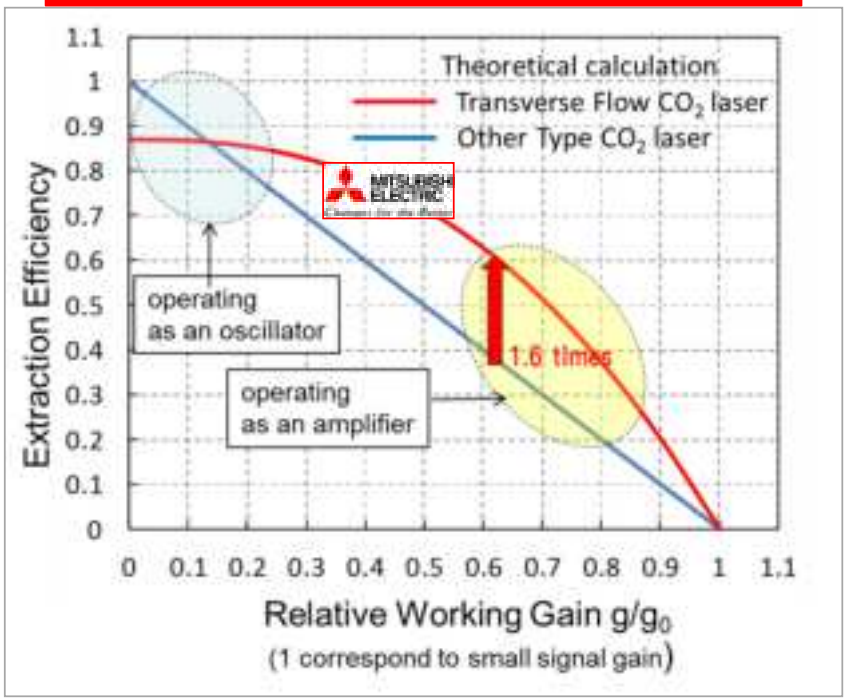
- With a classical model: $P = P_s\left(g_0 L + \ln\sqrt{1-r}\right)^*$
- Transverse-flow : Higher gain → Higher amplification efficiency
- Wider gas flow channel → Lower gas pressure → Higher gain

| | Transverse-flow (4 kW) | Axial-flow (5 kW) |
|---|---|---|
| Gas flow cross-section | 700 cm² | 40 cm² |
| Gas pressure | 7 kPa | 20 kPa |
| Small signal gain | 3.7 | 2.2 |
| Multi-fold path | Possible | Impractical |

(*) $P$: Power, $P_s$: Saturation power, $g_0 L$: Small signal gain, $r$: Loss

2013 International Symposium on Extreme Ultraviolet Lithography

Higher extraction efficiency at amplifier condition




Ref. Koji Yasui et. al., " Scalability of CO2 amplifiers to generate stable 500W extreme ultraviolet (EUV) beams" , 2017 International Workshop on EUV lithography, https://www.euvlitho.com/2017/P12.pdf

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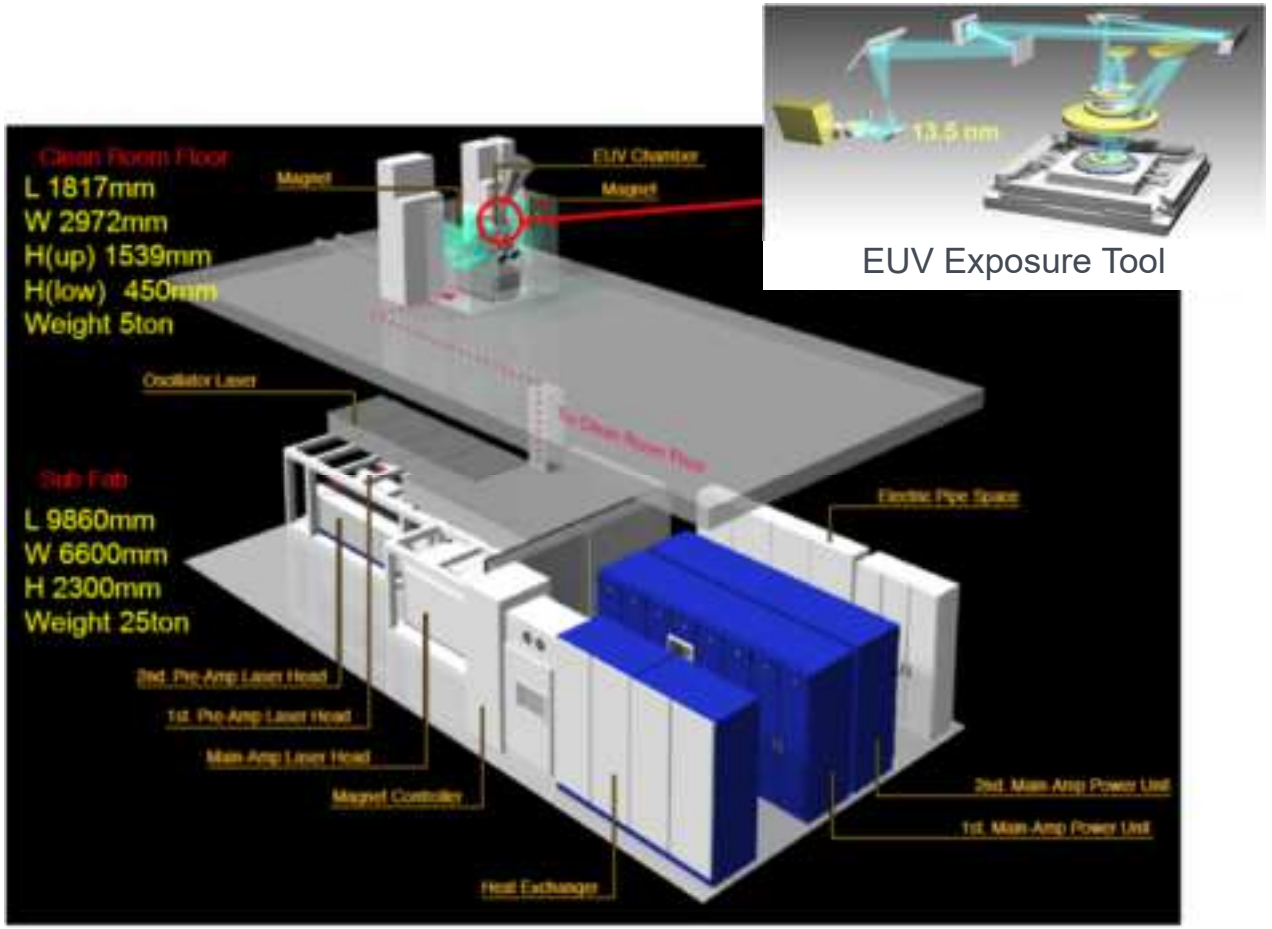
# Layout of >330W EUV Light Source Pilot #1

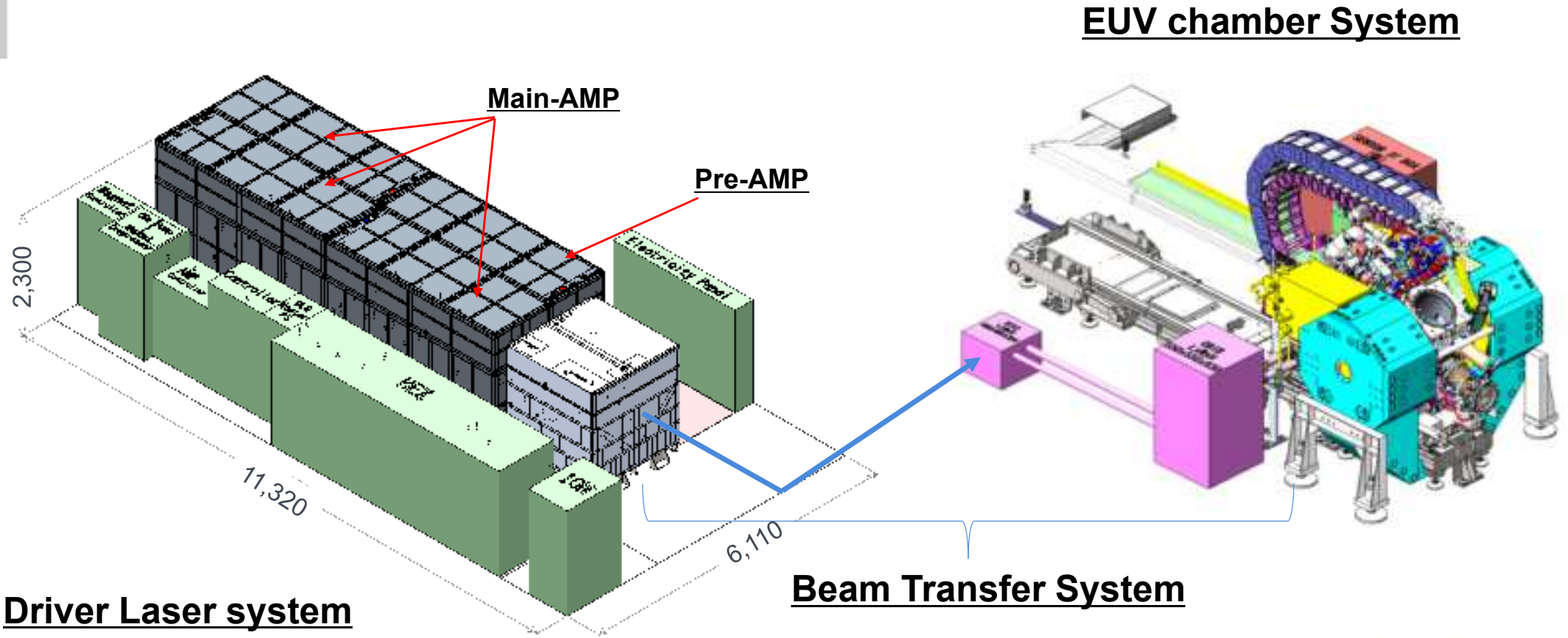
## First HVM EUV Source

- Original design was 250W EUV source
- **>330W Power Challenge with Upgraded Hardware**

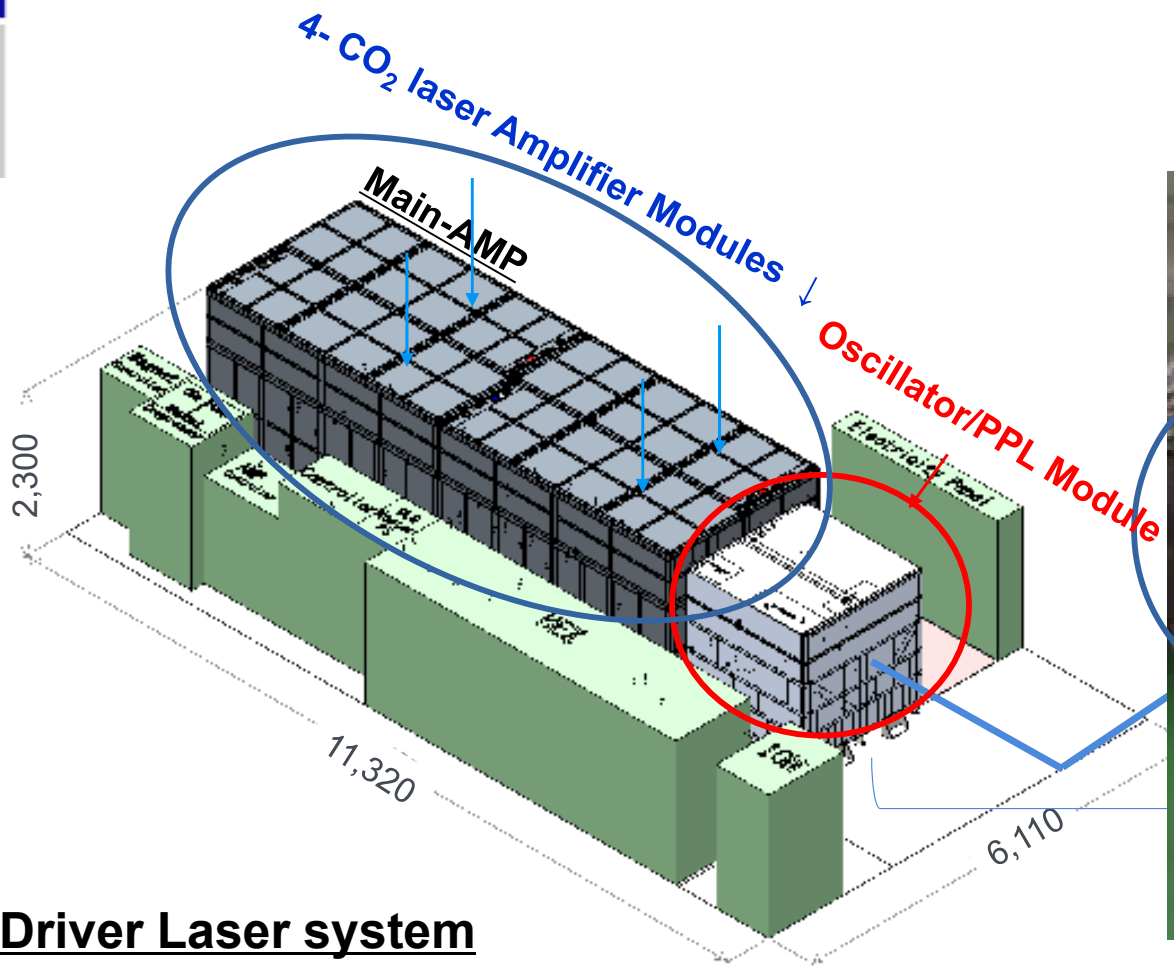
| Operational specification (Target) | | | HVM Source |
|---|---|---|---|
| Performance | EUV Power | | > 330W |
| | CE | | > 5.5-6.0% |
| | Pulse rate | | 100kHz |
| | Availability | | > 90 % |
| Technology | Droplet generator | Droplet size | < 20 micron |
| | CO2 laser | Power | > 27 kW |
| | Pre-pulse laser | Pulse duration | ~10 ps pulse duration |
| | Debris mitigation | Magnet, Etching | >3 months |

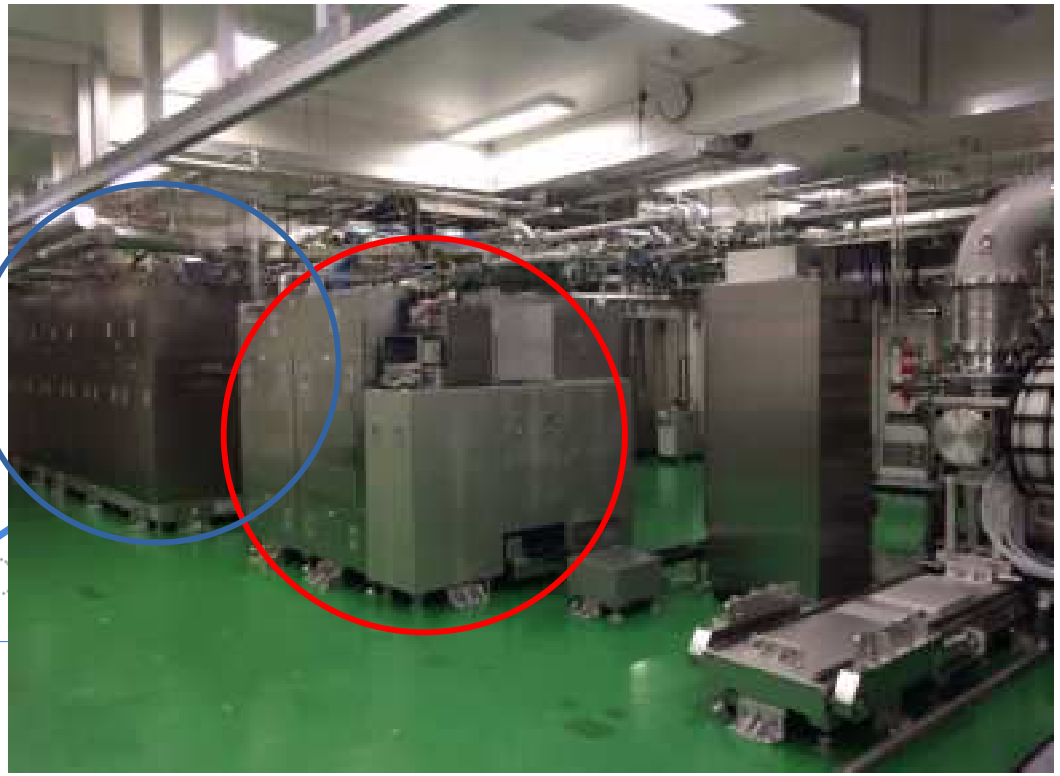


# Pilot #1: High Power EUV Source for HVM



# Pilot #1: Driver laser & PPL system (1)



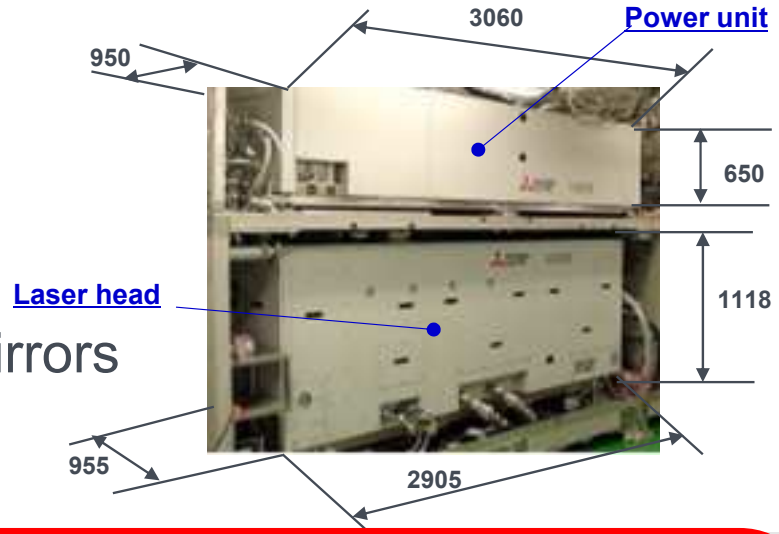



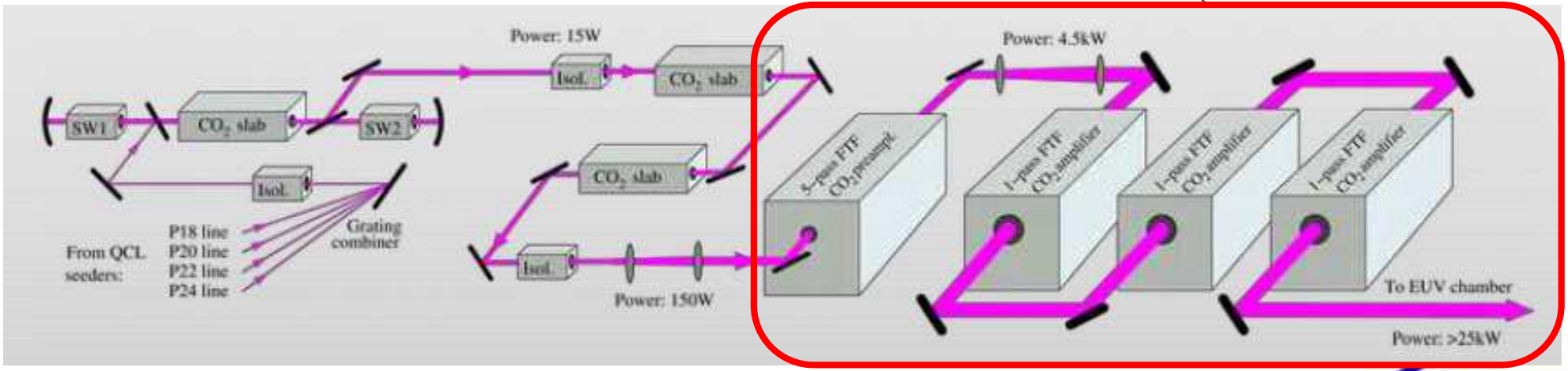
**Driver Laser system**

# Pilot #1: Driver laser & PPL system (2)

## Amplifier laser

- Power unit :
  - Common for both PA and MA
- Laser head:
  - PA has multi optical pass with internal mirrors
  - MA has single optical pass

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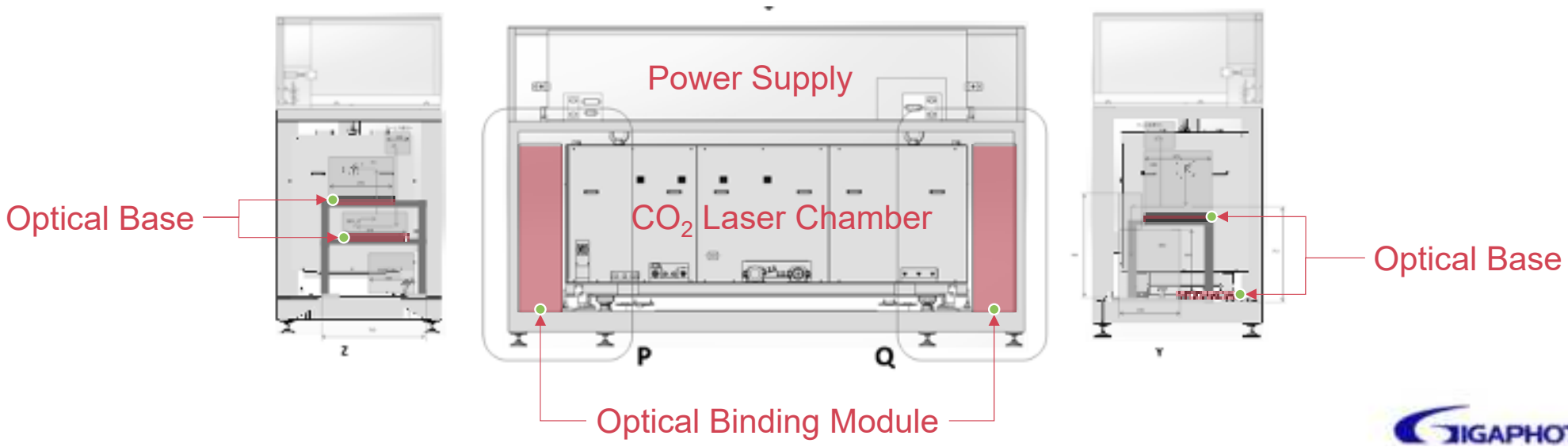
# Pilot #1: Driver laser & PPL system (3)



## CO2 Laser: Arrangement

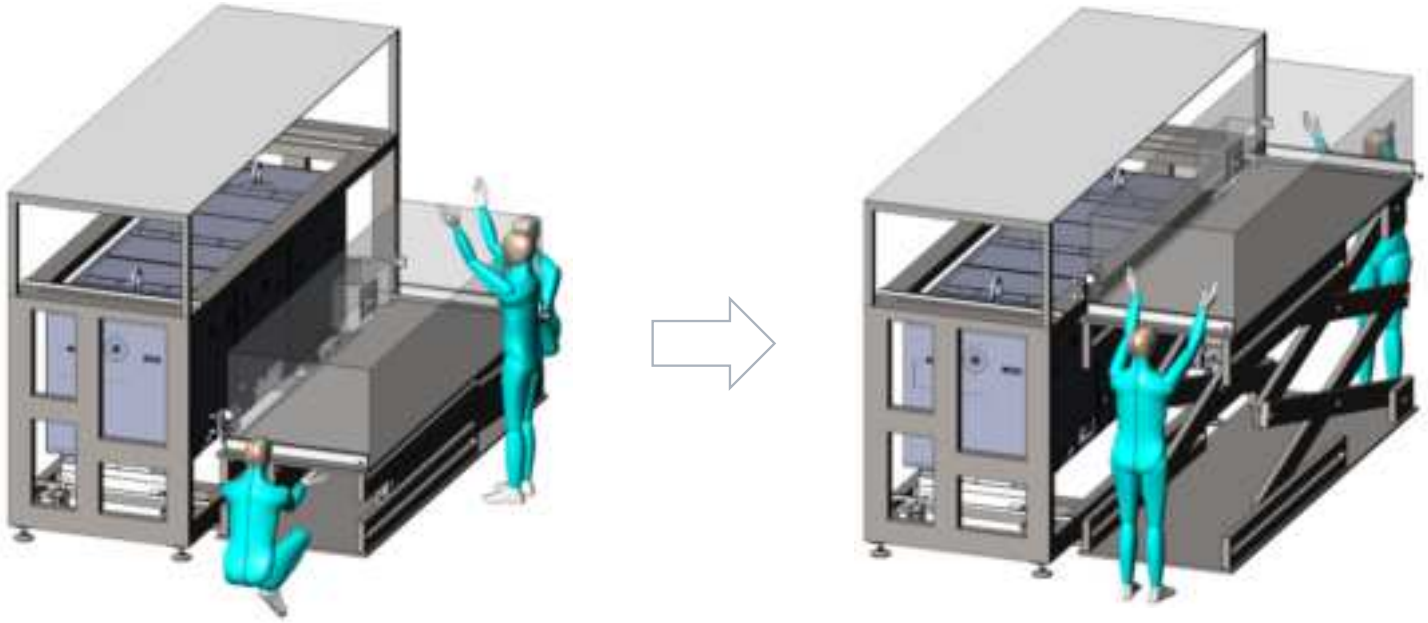
- Optical Binding Module is isolated from the $CO_2$ Lase Chamber and Power Supply
- This allows chamber replacements to occur without axis realignment



# Pilot #1: Driver laser & PPL system (4)

## CO2 Laser: Maintenance

- Today chamber replacements occur once every two years ( scheduled maintenance ) or unexpected trouble.
- After $CO_2$ laser chamber replacements at maintenance or replacement, there is no beam axis adjustment necessary.
- Safe and easy procedures allow efficient maintenance with few people.



# Beam axis control

**Configuration of Beam transfer system**


***EUV chamber***

***PPL/CO2 combiner***

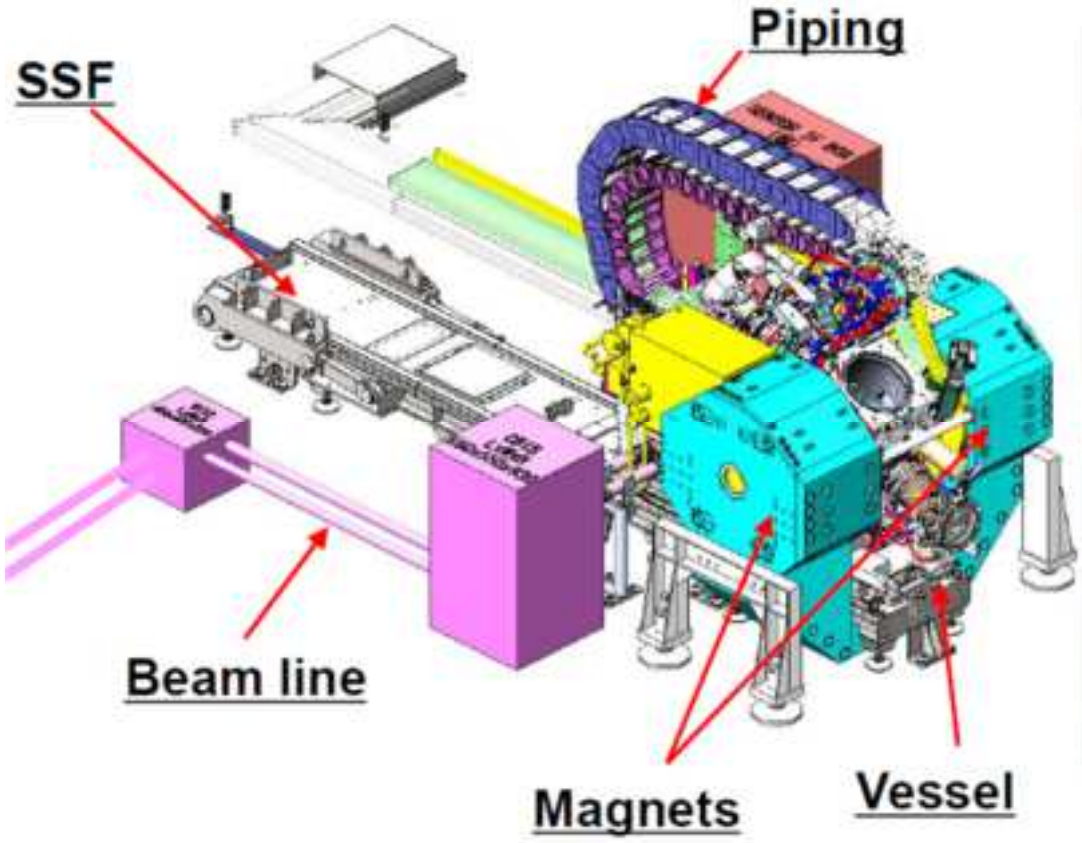
CO2

***PPL Guide laser***
・λ=600 nm

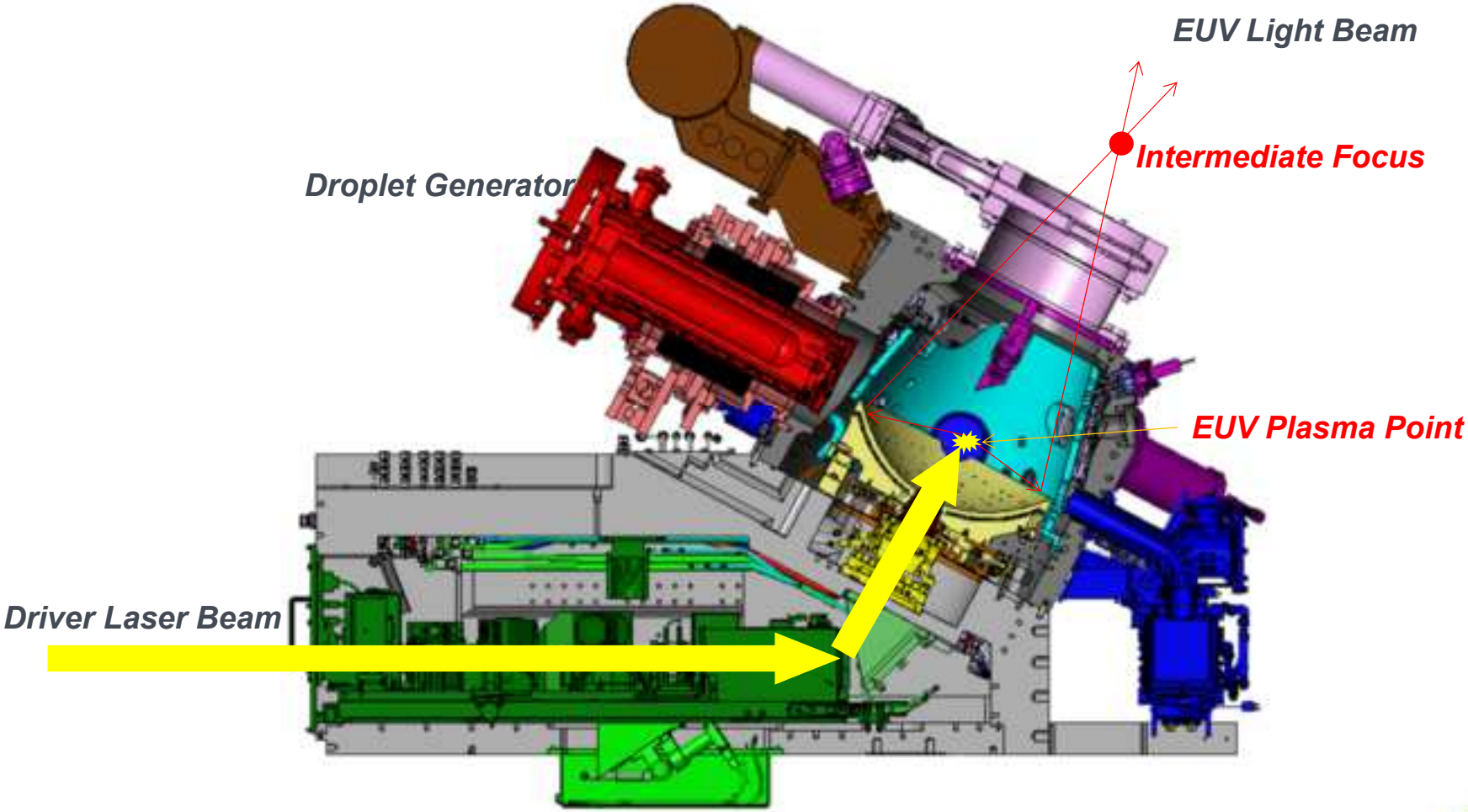
***PPL laser***
・λ=1060 nm

# Pilot #1 : EUV Chamber System (1)

## EUV chamber system

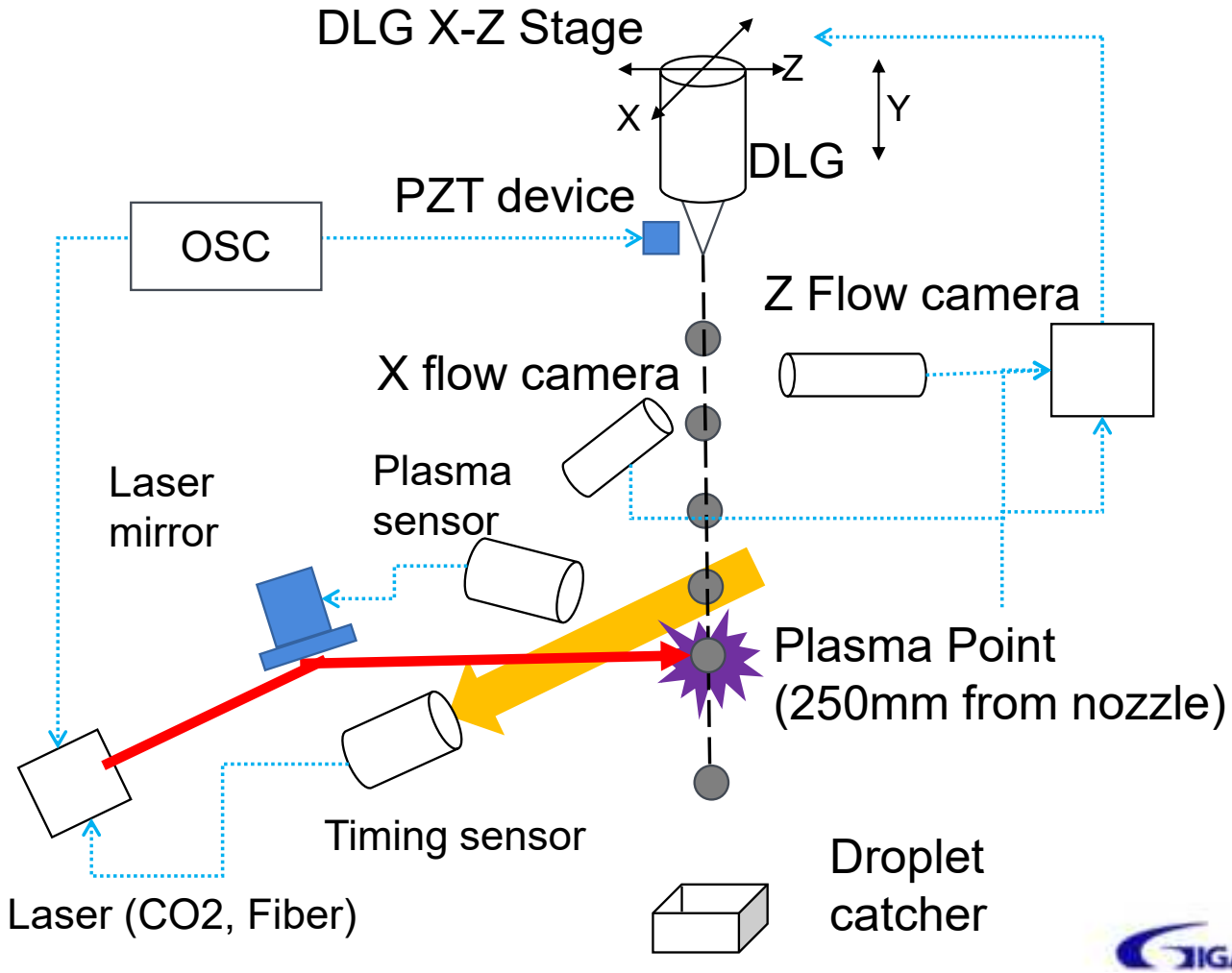



# Pilot #1 : EUV Chamber System ( 2 )



# Pilot #1 : EUV Chamber System (3)

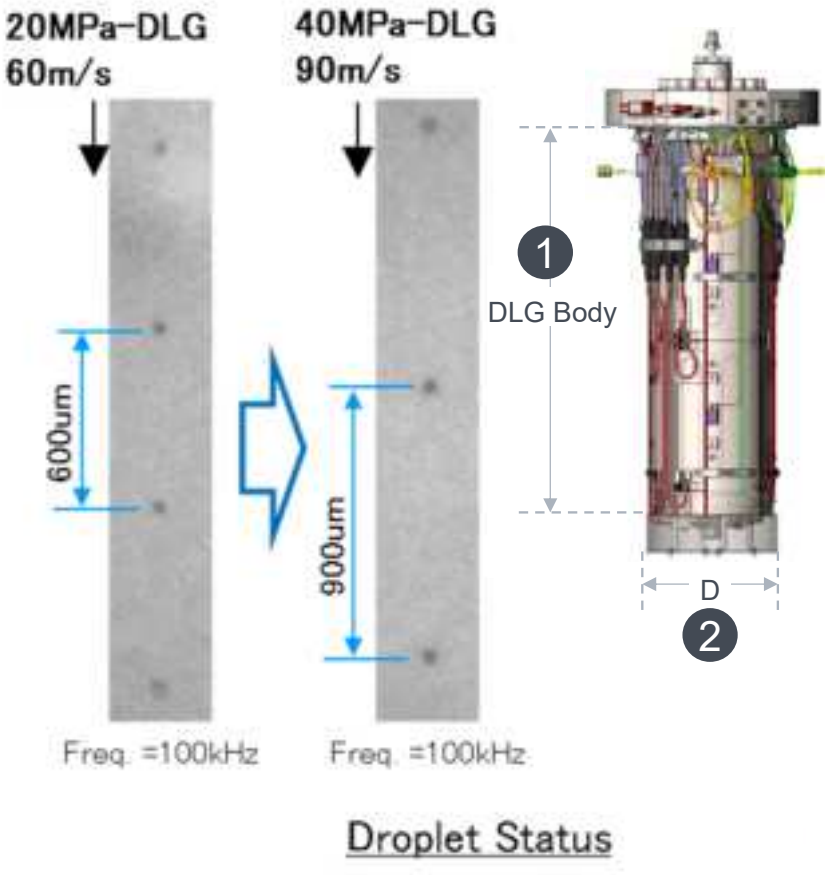
LPP EUV Source :
Shooting Control System



# Pilot #1 : EUV Chamber System (4)

- High speed droplet generator was successfully released to Proto system

| | | Proto#1 | Proto#2 | Proto#2 | Pilot#1 |
|---|---|---|---|---|---|
| Droplet speed | m/s | 45 | 60 | **90** | **100** |
| Back pressure | MPa | 12 | 20 | **40** | **50** |
| Max Repetition rate | kHz | 50 | 80 | 100 | 100 |
| | | | | | |




Droplet Status

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## Summary & Acknowledgement

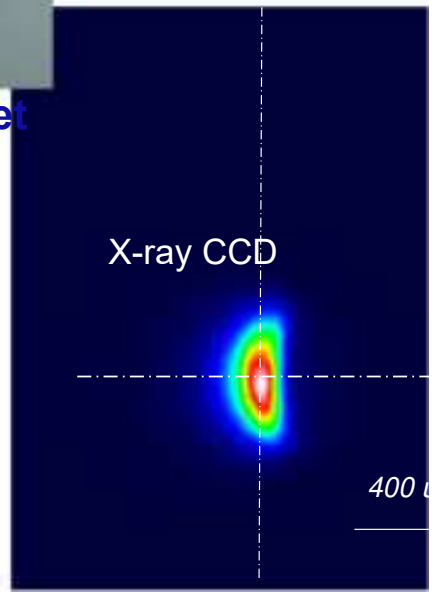
# Pilot#1 system is in Operation.

# CE Improvement with Pre-pulse Optimization

- Gigaphoton found **>50% advantage of conversion efficiency** by pico-second pre-pulse.

**Pre-pulse (nano-second)**


**'Disk' like target**

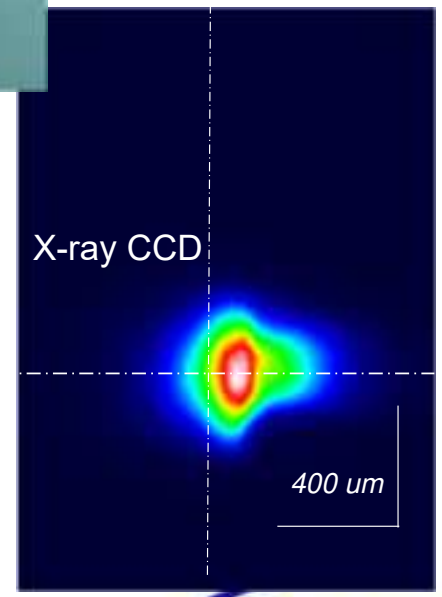


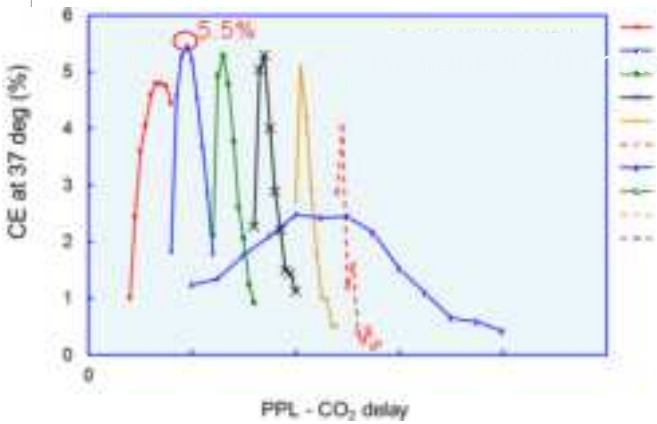

**Pre-pulse(pico-second)**


Very short pulse duration with 1um wavelength laser

Same optical path between pre-pulse and main

**Ideal 'Dome' like target**



# Direct measurement EUV **Sn** parameters by Tomson Scattering

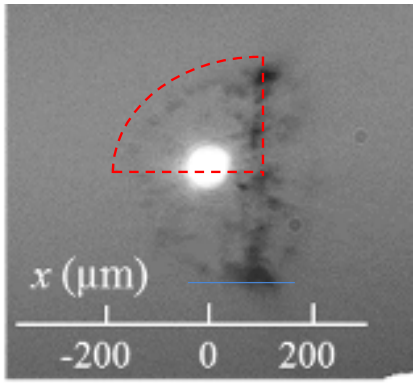
## Previous results (*Sci. Rep. 2017*)

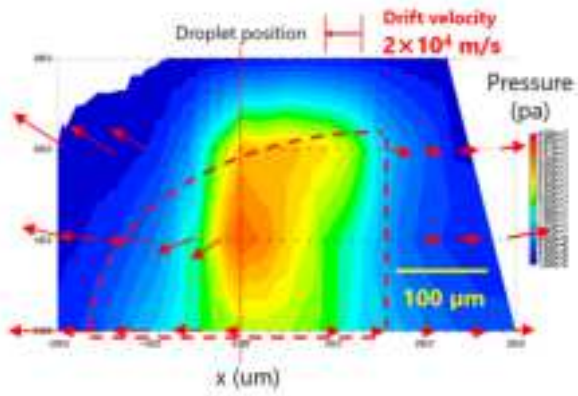
Electron density ($n_e$) and electron temperature ($T_e$) of the EUV source plasma can be clarified using TS.

EUV emissivity ($\eta_{EUV}$) was theoretically calculated using $n_e$, $T_e$, and atomic model.

*Kentaro Tomita et.al. "Recent Diagnostic results of EUV Source and EUV induced plasma ",P42-EUV Source Workshop (2020)*

2D velocity field in EUV plasma




Dr. Kentaro Tomita

北海道大学 HOKKAIDO UNIVERSITY

九州大学 Kyushu University

*Now Dr. Kentaro Tomita working in Hokkaido University since June 2020*

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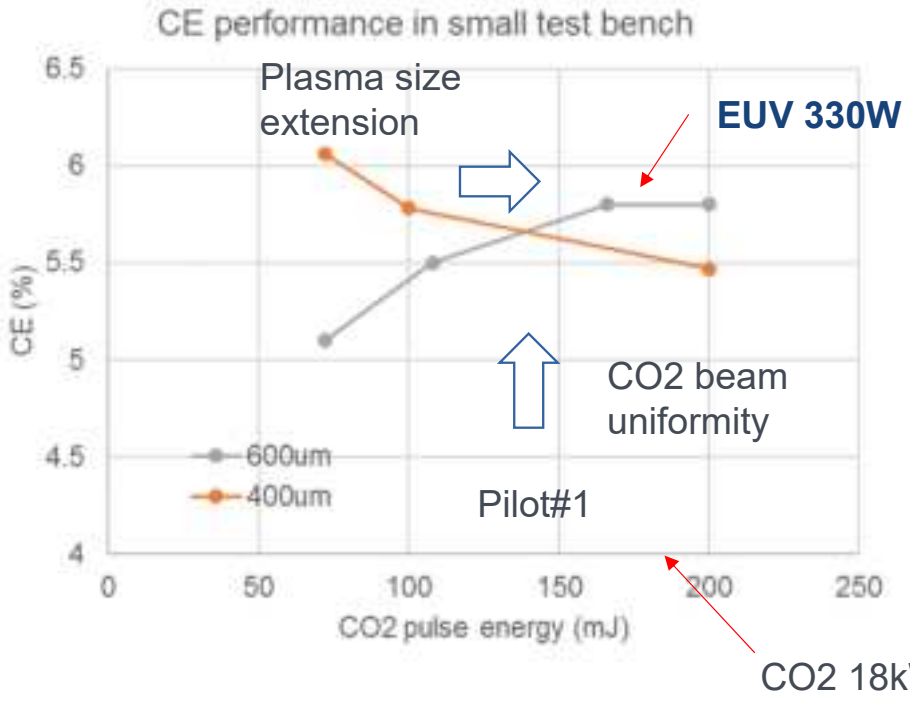
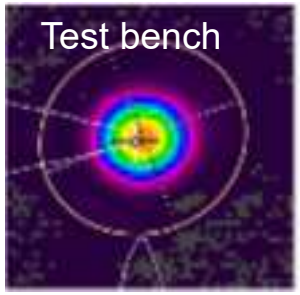
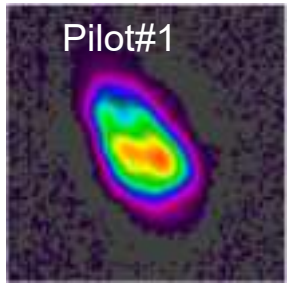
# Plasma - Beam Matching for Higher CE

- 5.8% CE at 180mJ was already confirmed in **small test bench** by increased plasma size.
- CO2 beam non-uniformity of Pilot#1 due to beam expander design is improved.



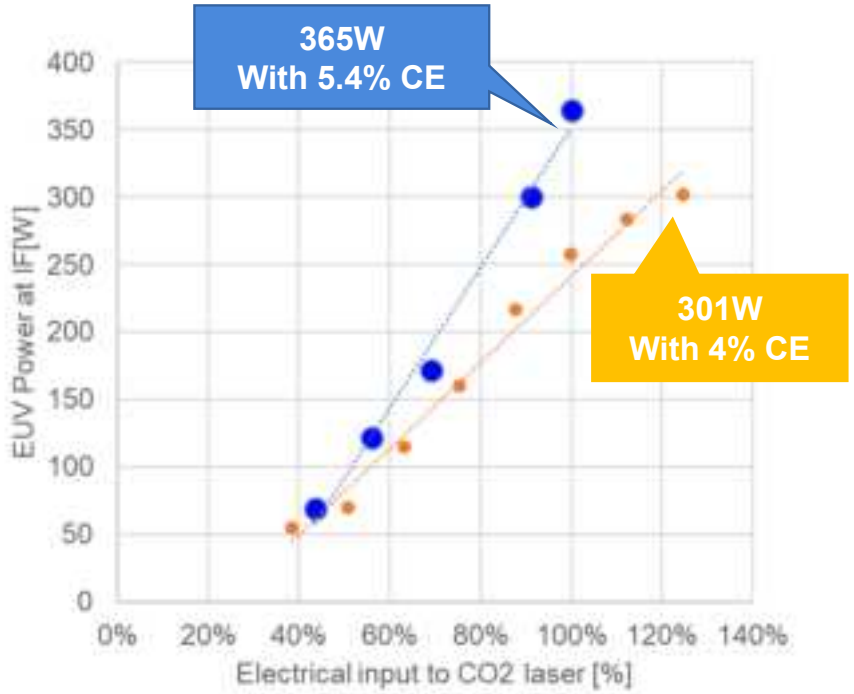



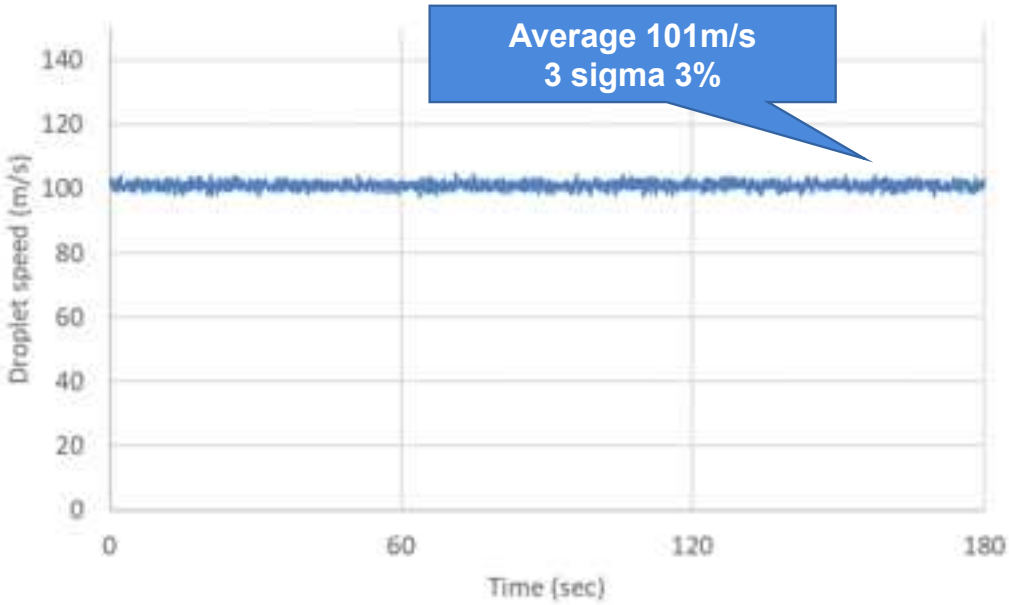

CO2 spot profile

# Data for Higher Power

- **>360W** with **>5% CE at 100kHz** operation is demonstrated at Pilot#1 (short term)




- **Higher Droplet speed(>100m/s)** realized 1mm spacing and demonstrated more stable EUV generation

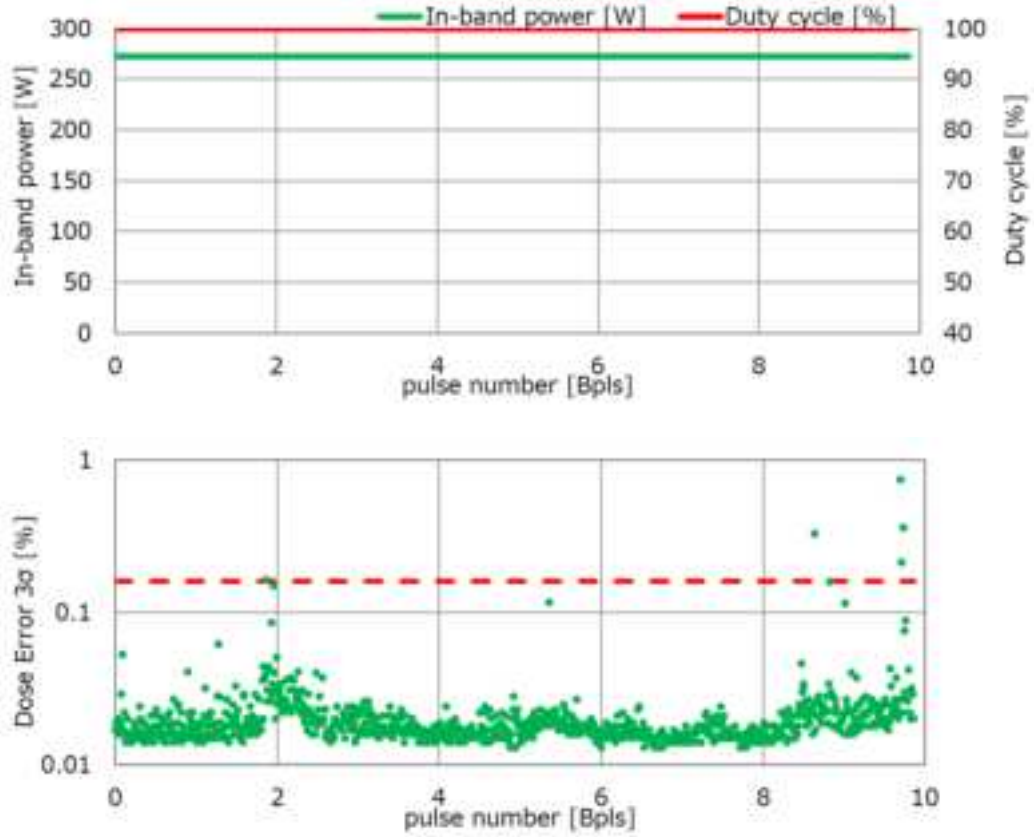


# Long-term High Power Operation Data > 270W

- 270W stable operation was achieved.

| | Performance |
|---|---|
| Average power at IF | 270W |
| CO2 Power | 17kW |
| CE | 5.4% |
| Dose error average (3 sigma) | 0.03% |
| Pulse Number | 10 Bpls |
| Dose margin | 20% |
| Repetition rate | 100kHz |

Plasma to IF: 30%



# Agenda

## Introduction

- New Trend of Semiconductor Manufacturing Technology
- New DUV laser processing for Middle End Semiconductor Packaging

## EUV Source development for Lithography

- Concept and key technologies
- 250W EUV Source System
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## Summary & Acknowledgement

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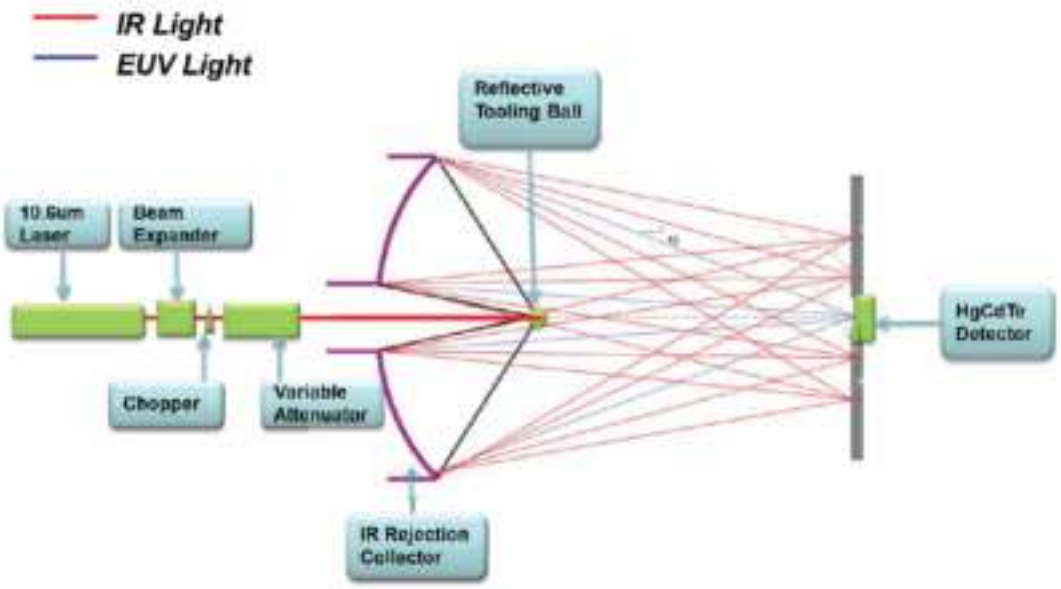
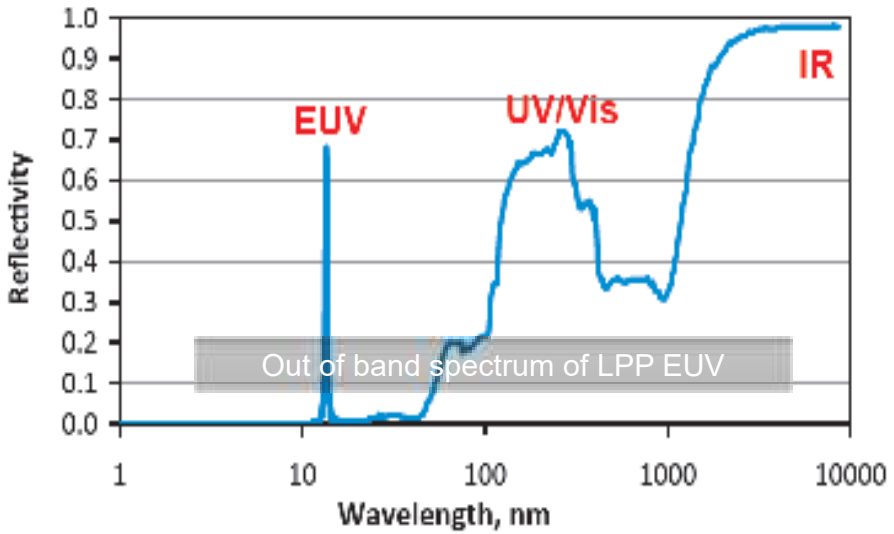
# Collector Mirror Technology

## IR Reduction Technology is applied

Gigaphoton is developing IR reduction mirror in co-operation with multiple mirror suppliers.

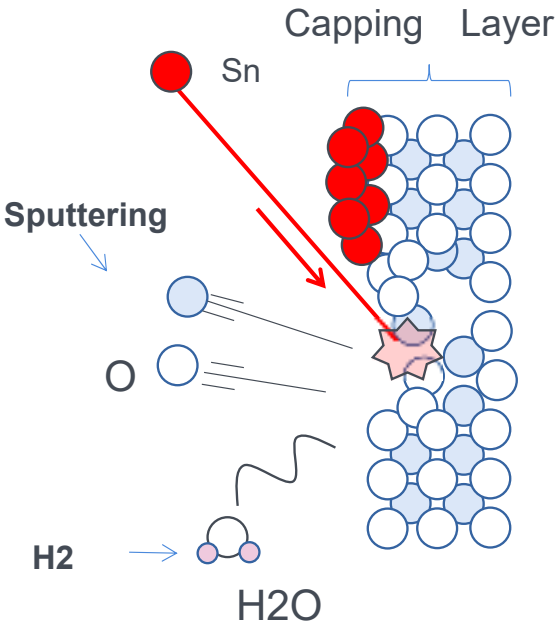


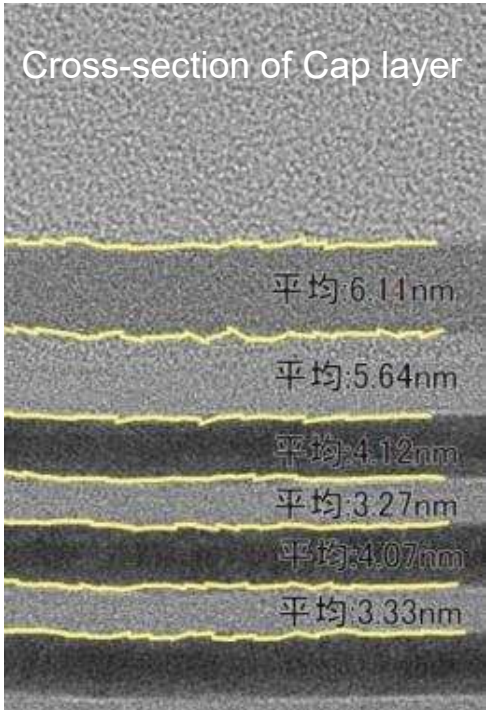

Gigaphoton's Patent Pending IR Reduction Technology

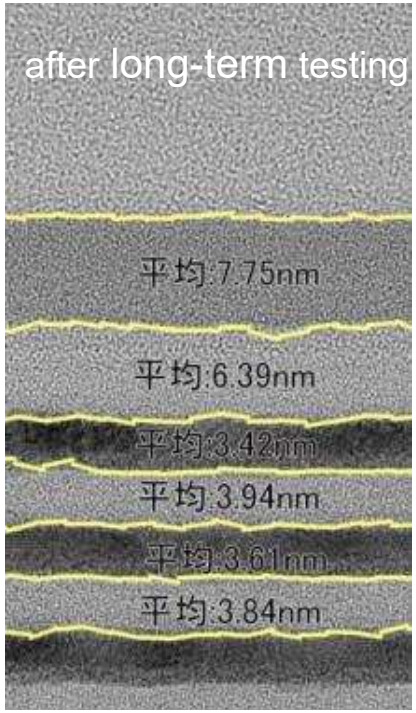


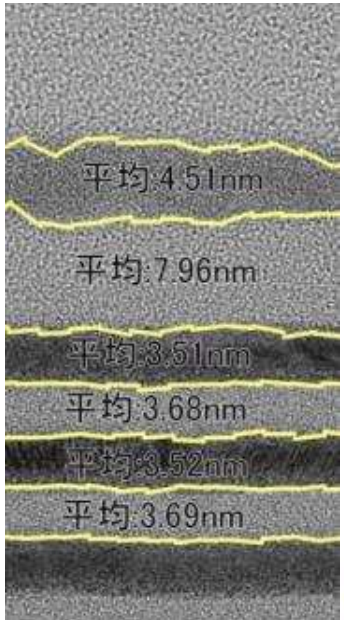
# Change of Capping Layer and Multi-Layer under Tin Plasma Sputtering

- Thickness changes at capping layer due to sputtering.
- First Si layer become thicker and reflectance down around 30% due to oxidization.




Capping Layer

1st Si Layer

2nd Mo Layer

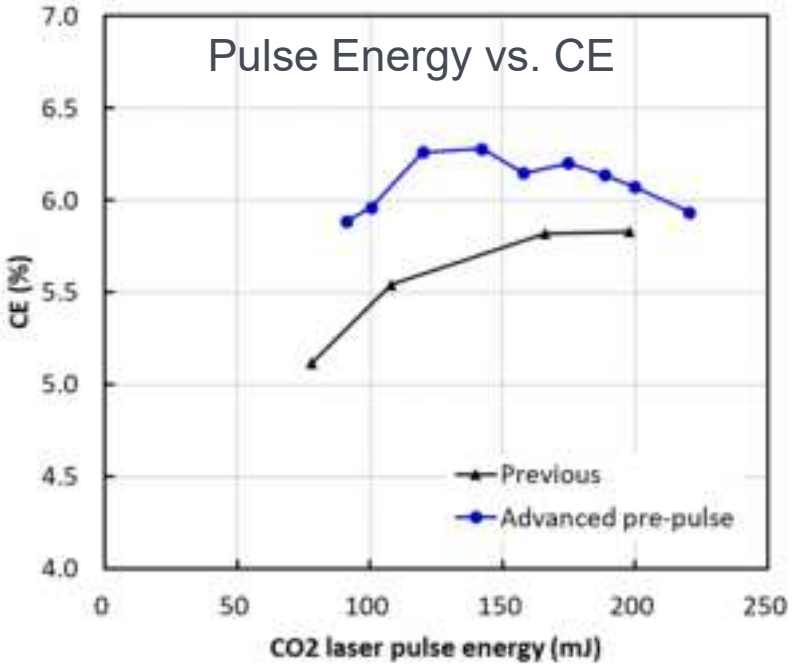
3rd Si Layer

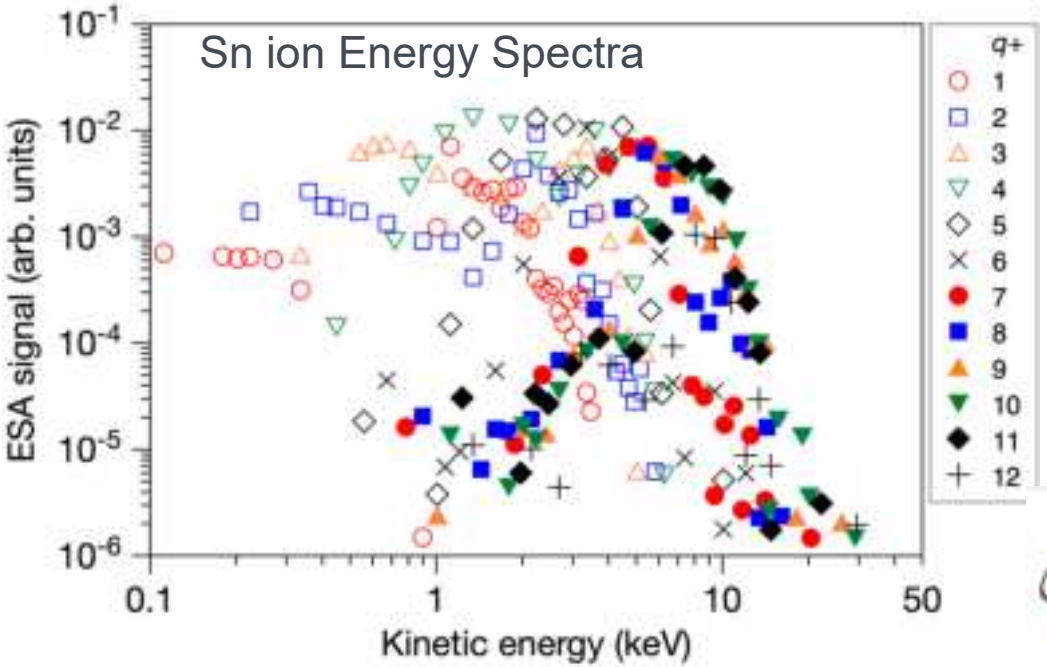
.
.
.

# CE Improvement & Energy distribution of Sn ionic charge states

- CE reaches >6% by optimization of pre-pulse parameter
- Effective suppression of high energy ion
- Further suppression of ion energy is on going

Target: Sn planer target
Laser wavelength: 1064 nm
Pulse duration: 6 ns (FWHM)
Laser Intensity: $2.1 \times 10^{11}$/W/cm$^2$



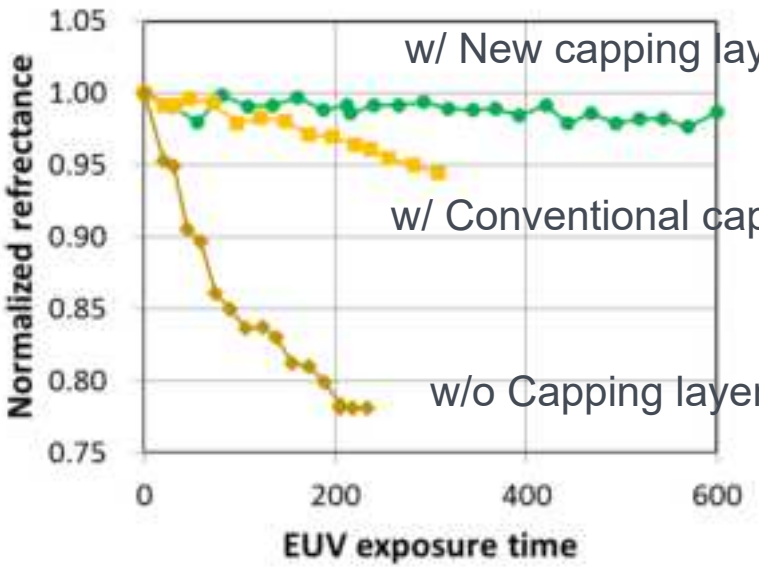




Prof.Takeshi Higashiguchi

*Takeshi Higashiguchi, "Features of High charged Ions from LPP EUV sources" P43-EUV Source Workshop (2020)*

# Durability test of collector capping layer at New SUBARU

- Screening of oxidation of reflection layer with synchrotron radiation (λ=13.5nm) source ( Name of SOR in Hyogo Univ.= “New SUBARU”)
- Improvement of collector lifetime is on going



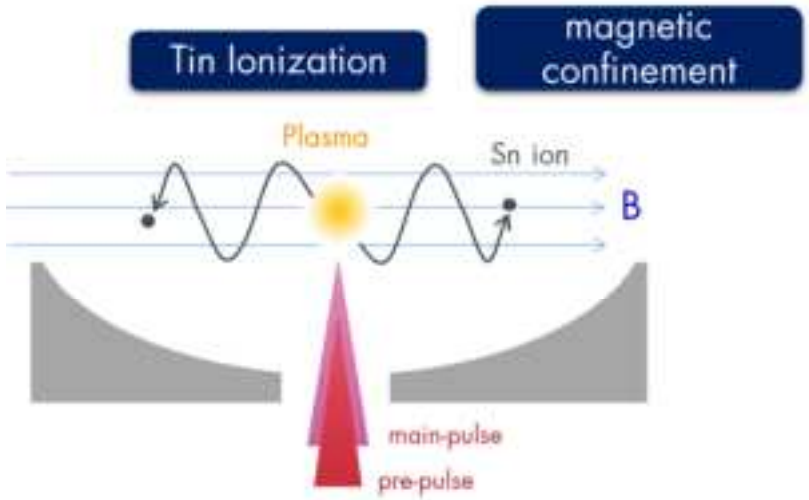

Capping layer evaluation results by New SUBARU


Prof. Takeo Watanabe
Director of LASTI

Two beam lines for EUV test in “New SUBARU”

# Etching and Dissociation Sn balance on the Mirror Surface

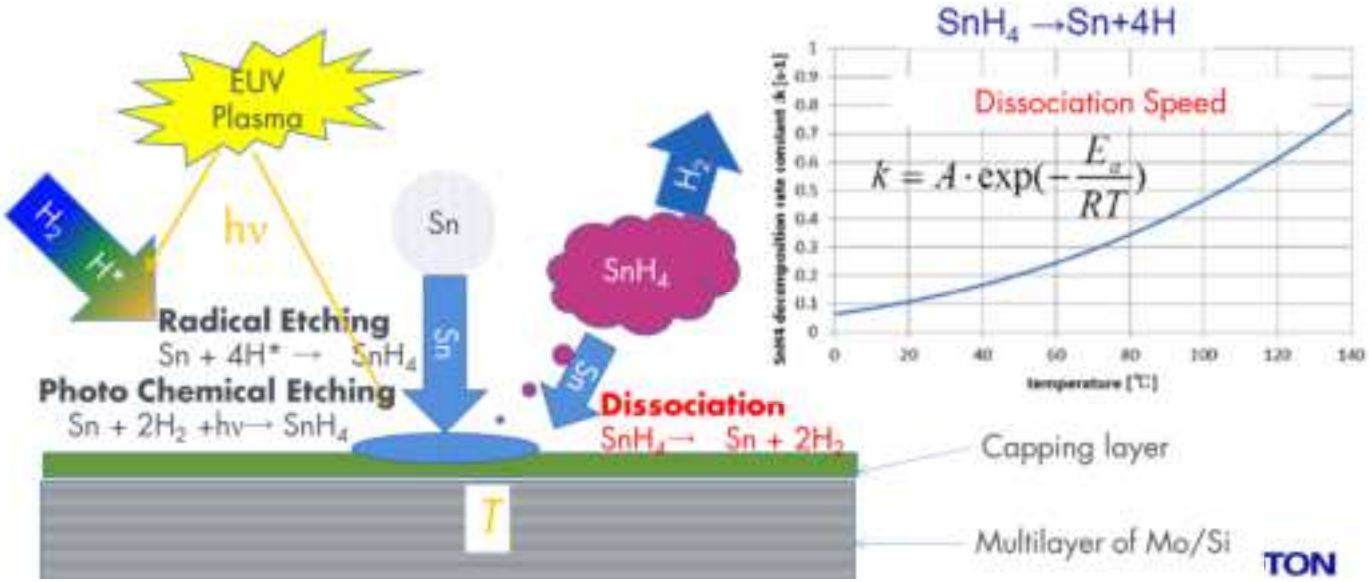
## Chemical Aquarium on the Mirror Surface




- Tin ionization & magnetic guiding
  - Tin is ionized effectively by double pulse irradiation
  - Tin ions are confined with magnetic field
  - Confined tin ions are guided and discharged from exhaust ports

- Protection & cleaning of collector with $H_2$ gas
  - High energy tin neutrals are decelerated by $H_2$ gas in order to prevent the sputtering of the coating of collector.
  - Deposited tin on the collector is etched by H radical gas*.
  - Gas flow and cooling systems for preventing decomposition of etched tin ($SnH_4$)

*$H_2$ molecules are dissociated to H radical by EUV-UV radiation from plasma.



# Further analysis of Collector Mirror Deposition.

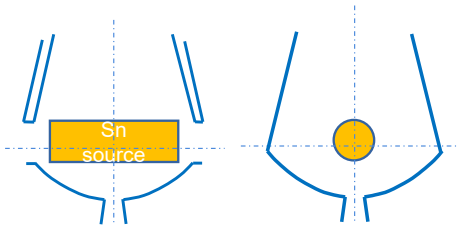
- Accuracy of the simulation has been improved by modifying initial Sn distribution

**Initial Sn distribution**

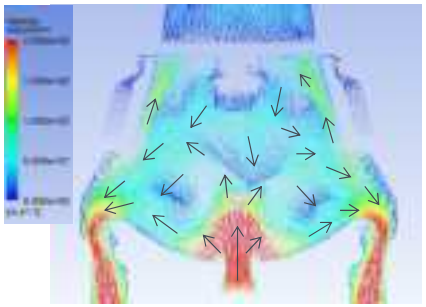
**Calculation of steady gas flow**

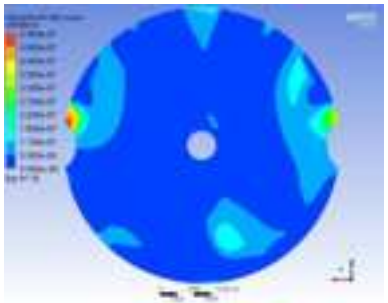
**Sn density distribution on collector**

**Previous method**




Simple distribution

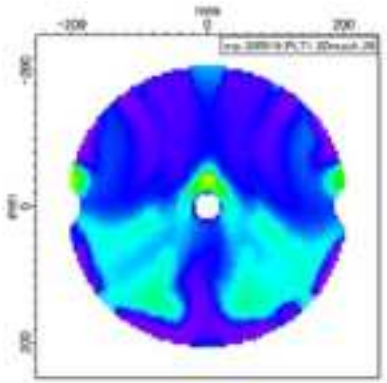




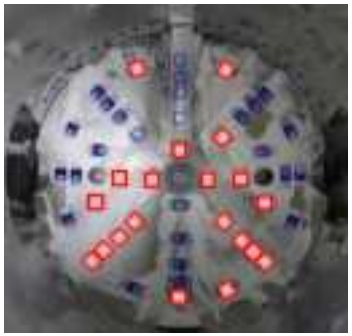
**Improved method**

Calculated 3D distribution considering plasma gas interaction in B-filed

Gas velocity distribution



**Test result**

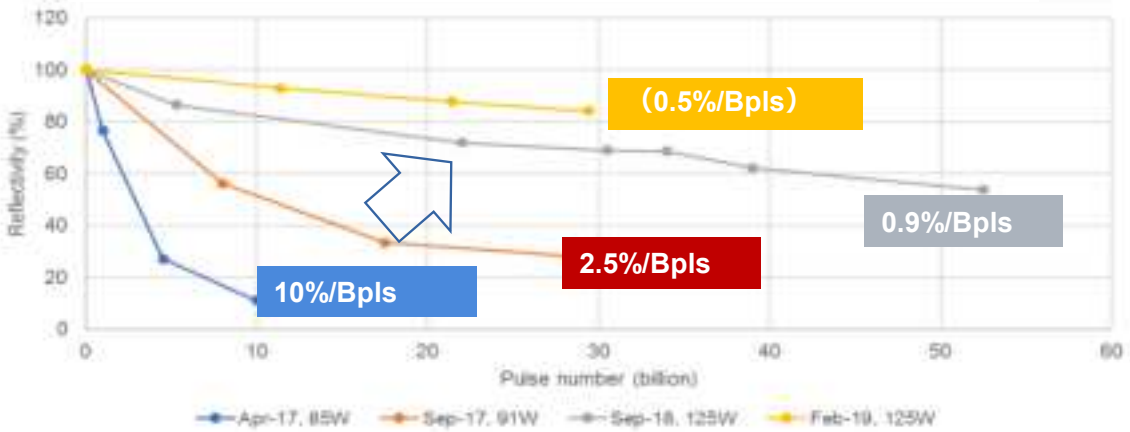


Red: Sn deposition
Blue: No deposition

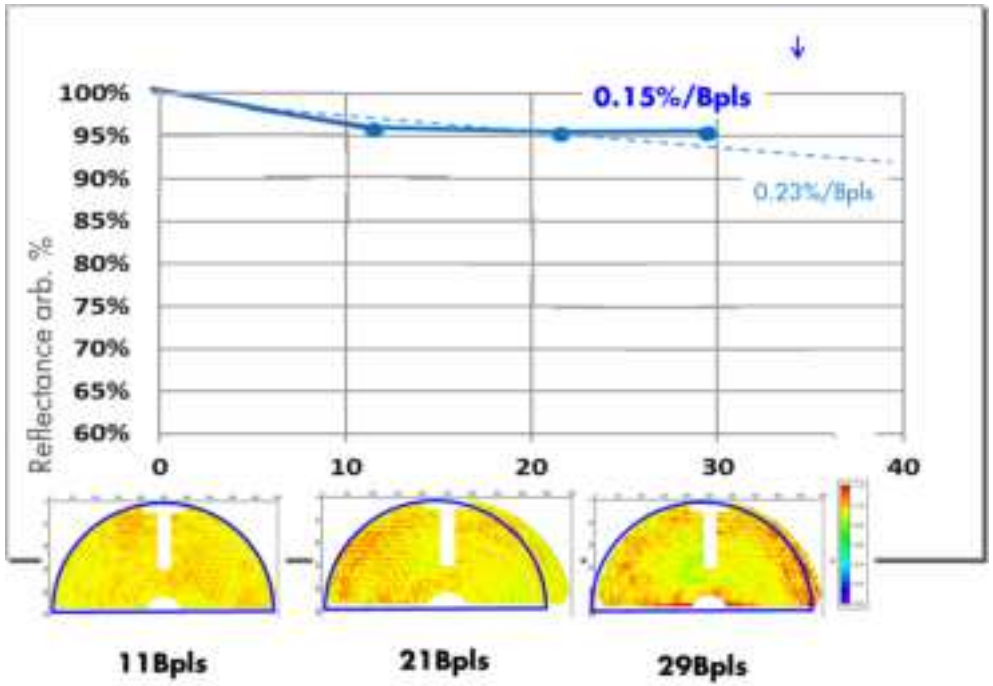
# Collector Mirror: Lifetime Status

- Capping layer and Tin contained Gas flow Improvement are effective.
- Collector reflectivity degradation is certainly improving.

## Data at SPIE AL-2019 (Feb.2019)




## At present (125W level operation)



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- **Introduction**
  - New Trend of Semiconductor Manufacturing Technology
  - New DUV laser processing for Middle End Semiconductor Packaging
- **EUV Source development for Lithography**
  - Concept and key technologies
  - 250W EUV Source System
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  - Extendibility toward >800W of EUV power
- **Summary & Acknowledgement**

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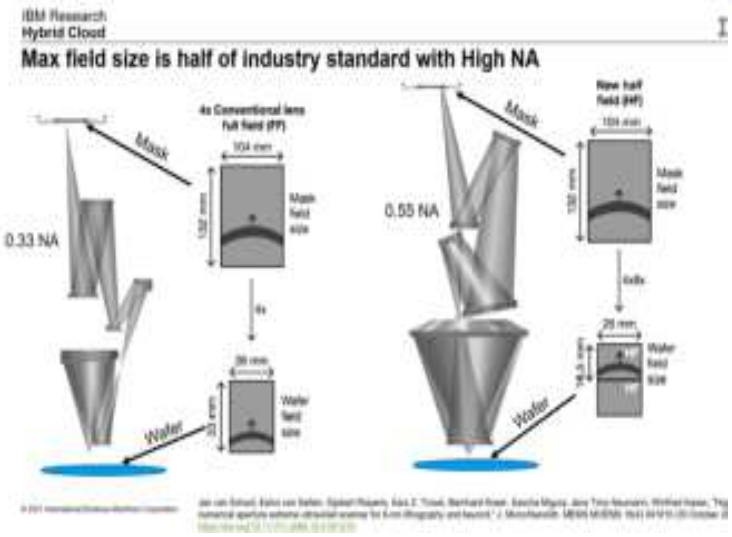
# Next Requirement EUV Power scaling toward >800W (1)




## High-NA system architecture finalized

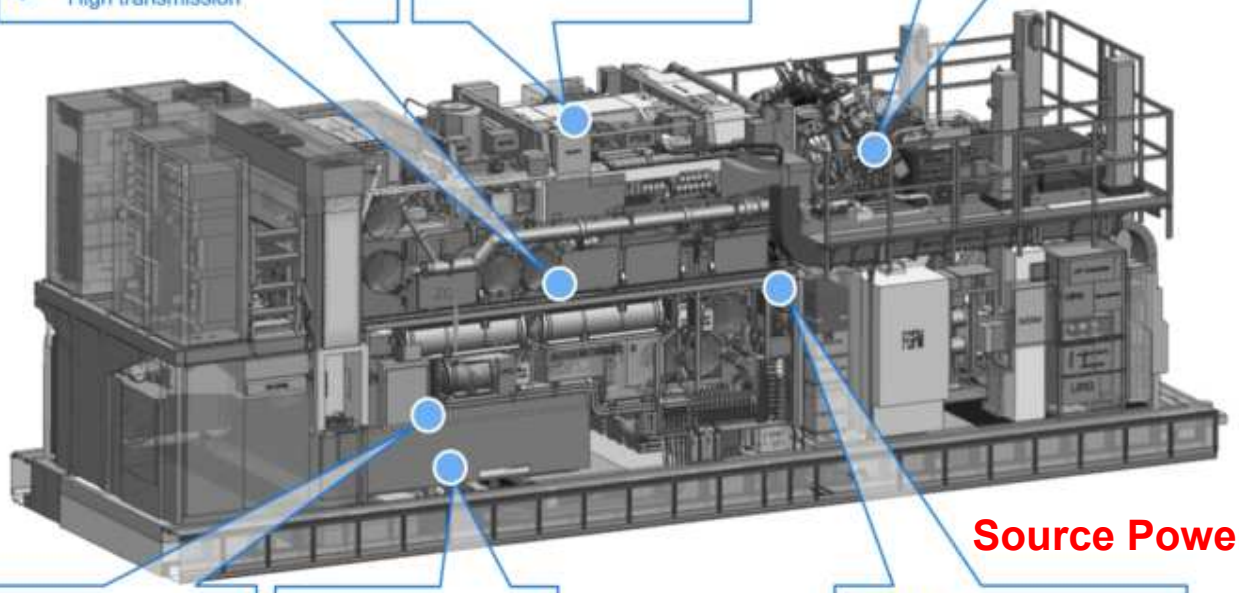
ASML

Slide 21
SPIE FEB21

**Lens & illuminator**
- NA 0.55 for high contrast
- High transmission

**Mask Stage**
4x increase in acceleration

**Improved Source position**
Allows for larger transmission, compatible with 0.33 NA



**Source Power 800W**

**Improved metrology**
2~3x improvement in overlay/focus

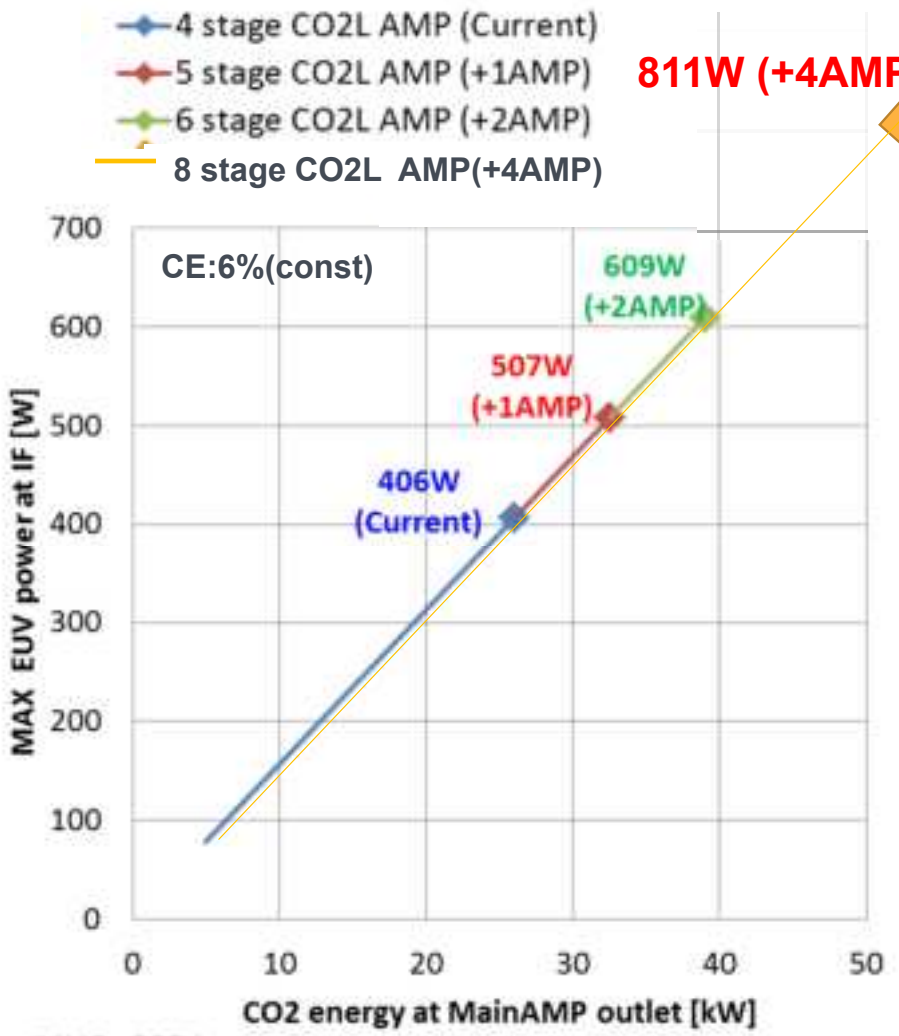
**Wafer Stage**
2x increase in acceleration

**New Frames**
Improved thermal and dynamic control with larger optics

Public

Ref. from SPIE AL-2021,ASML

# Next Requirement EUV Power scaling toward >800W (2)




- EUV power scaling with CO2 laser power is discussed
- Scaling of CO2 laser power is feasible toward >800W.

| | 4stage CO2L Amp System (current) | 6stage CO2L Amp System (+2AMP) | 8stage CO2L Amp System (+4AMP) |
|---|---|---|---|
| Max CO2L output | 26 kW | 39.0 kW | **52.0 kW** |
| Max EUV power | 406 W | 609 W | **811 W** |
| Operation EUV Power * | 360W | 550W | **740W** |
| Foot print | 9.9 x 2.5 m | + 3.6 x 2.4m | **+ 7.2 x 2.4m** |
| Input Electricity (full load) | 880 kVA | +300 kVA | **+600 kVA** |

＊Minimum dose margin requirement is at least10%.

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# Summary

- ***Trend of Semiconductor Manufacturing***
  - *3D structure, Minimization by EUV lithography and Packaging are three key direction of Semiconductor manufacturing.*
  - *Packaging technology is very important to enhance chip performance which is dominated physical size. Gigaphoton has started the business development of Middle edge process.*
  - *EUV lithography is now rump up. Huge investment are on going all over the would.*

- ***EUV Source***
  - *CO2 laser power upgrade >27kW and  Beam uniformity  upgrade is successfully done.*
  - *>350W operation is successfully demonstrated at Pilot#1 system (short term) .*
  - *250W had been achieved with only 18 kW of CO2 power during one week operation.*
  - *-0.15%/Gpls with 125Wave. was demonstrated during 30Mpls with life test (125Wav.).*
  - *Long-term Test and Challenge for Long-life Mirror and Availability. Engineering effort to fit thin deposition simulation and experiment is continuously doing under 270W condition.*
  - *Next Requirement for High-NA exposure tool is >800W. Feasibility of CO2 laser driver is discussed.*

# Acknowledgements

**Thank you for co-operation:**

- Mitsubishi electric $CO_2$ laser amp. develop. team: *Dr. Junichi Nishimae, Dr. Shuichi Fujikawa, Dr. Yoichi Tanino* and others*
- *Dr. Kentaro Tomita, Prof. Kiichiro Uchino and others in Kyushu University*
- *Prof. Takeshi Higashiguchi in Utsunomiya Univ.*
- *Prof. Takeo Watanabe in New Subaru Institute*
- *Dr. Akira Endo :HiLase Project (Prague) and Prof. Masakazu Washio and others in Waseda University*

**Thank you for funding:**

EUV source development funding is partially support by *(New Energy and Industrial Technology Development Organization) in JAPAN*

**Thank you to my colleagues:**

EUV development team of Gigaphoton: *Hiroaki Nakarai, Tamotsu Abe, Takeshi Ohta, Krzysztof M Nowak, Yasufumi Kawasuji, Hiroshi Tanaka, Yukio Watanabe, Tsukasa Hori, Takeshi Kodama, Yutaka Shiraishi, Tatsuya Yanagida, Tsuyoshi Yamada, Taku Yamazaki, Takashi Saitou and other engineers*


# *Thank you for your Attention.*

**Any question and Comment is appreciated;**

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*The Future is Today*