
2019 Source Workshop Nov. 4-6, 2019
Amsterdam ▪ The Netherlands

CHALLENGE OF HIGH POWER LPP-EUV SOURCE WITH LONG COLLECTOR MIRROR LIFETIME FOR SEMICONDUCTOR HVM

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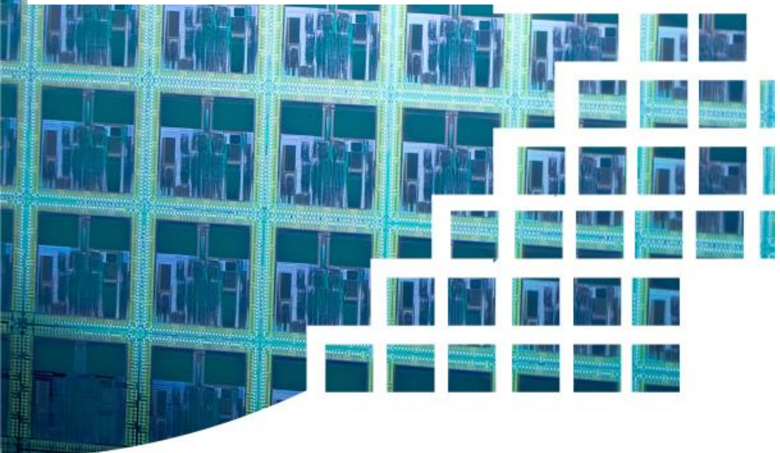
Gigaphoton Inc. Hiratsuka facility: 3-25-1 Shinomiya Hiratsuka Kanagawa,254-8567, JAPAN



Agenda

- **Introduction**
  - Gigaphoton Business update
- **EUV Research & Development History**
- **Experiment A: >330W Power Challenge of EUV Source**
  - ① CO2 Laser Power Upgrade
  - ② Beam Uniformity Upgrade at Plasma Point
  - ③ Optimization of Plasma Parameters
- **Experiment B:**
  Long-term Test and Challenge for Long-life Mirror and Availability
  - ④ Lifetime Extension of Collector Mirror
- **Summary & Acknowledgement**

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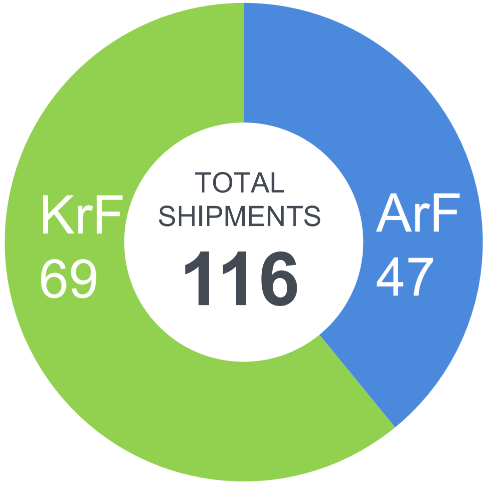
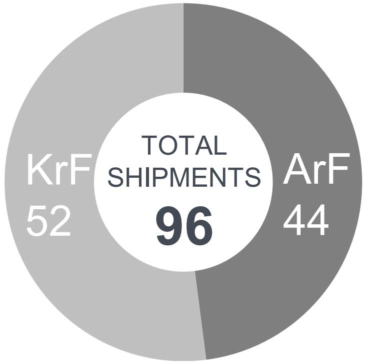
2Q2019 Business Highlights - DUV

DUV Business

- GPI recorded to ship **116 unit shipment** as **51% M/S** in FY2018 (Apr., 2018 – Mar., 2019)
- Stronger KrF demand driven by 3D NAND device transitioning
- Released G45K as higher power model to the market in 1Q2019



FY2018



FY2017

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Products Lineup for Tomorrow

DUV Lithography

NEW
2019

KrF

G45K

248nm wavelength

4 kHz max repetition

40-50W output

20% module life* improvement

NEW
2020

ArF

GT45A

193nm wavelength

4~6kHz repetition

45W-90W output

Utilizing same platform with ArFi

ArFi

GT65A

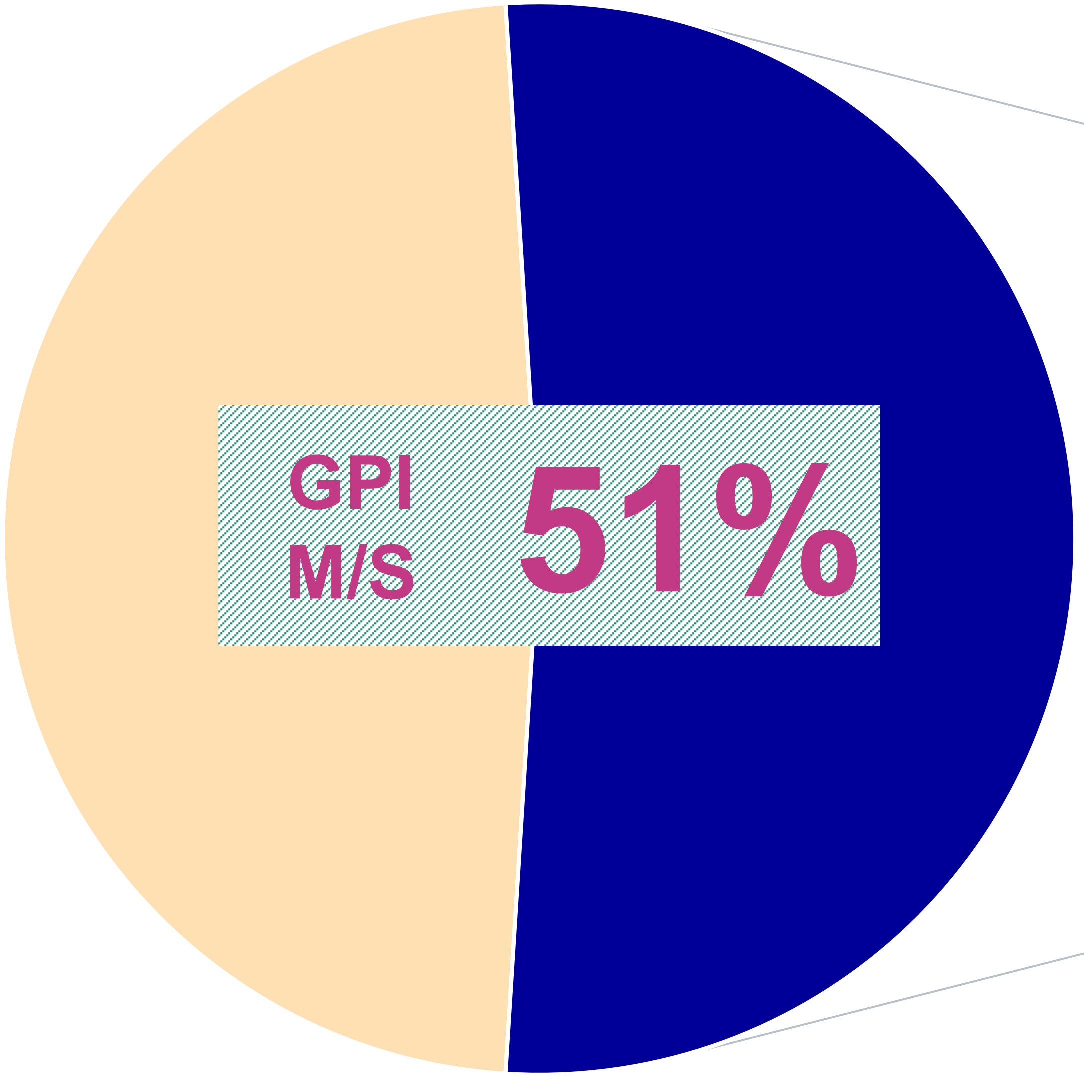
193nm wavelength

6kHz max repetition

60-120W output

30% module life* improvement

CY2018 Light Source Projected Install Share Analysis

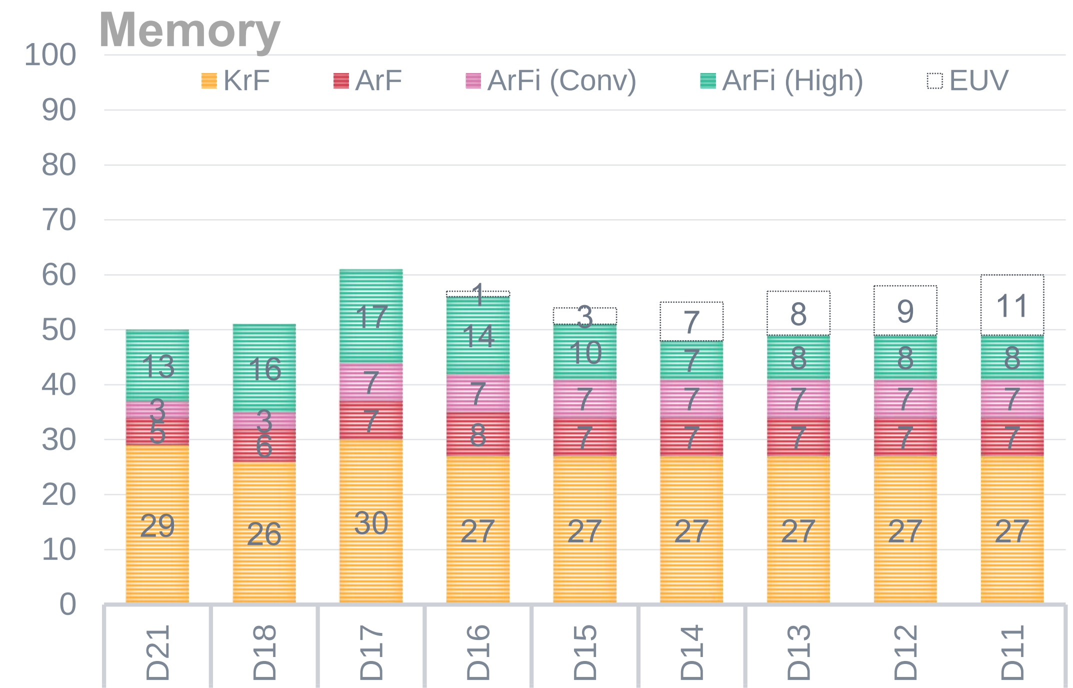


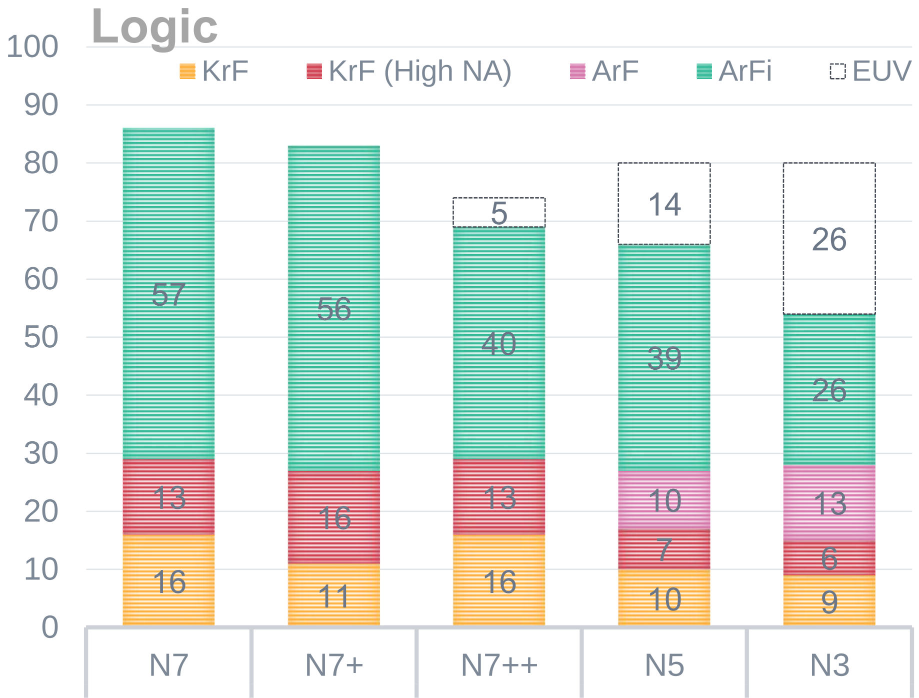
TOTAL UNITS 209	GPI INSTALL UNITS	GPI INSTALL SHARE
Japan (21)	12	57%
Korea (85)	50	59%
Taiwan (17)	8	47%
Mainland China (47)	31	66%
US (18)	4	22%
S'pore+EU (21)	3	14%

source: GPI analysis with internal source Oct. 2018,
New machine only

DUV Layers would be decreased after EUV HVM

- CY2018 is the peak of DUV adoption in HVM.
- **CY2020-21 will be the Drastic Rump up of EUV at real HVM line.**





	2015	2016	2018	2020	2021	2022	Future				2017	2018	2019	2021	2023
EUV				1	3	7	8	9	11				5	14	26
KrF	29	26	30	27	27	27	27	27	27		16	11	16	10	9
KrF H/N	5	6	7	8	7	7	7	7	7		13	16	13	7	6
ArFD	3	3	7	7	7	7	7	7	7					10	13
ArFi	13	16	17	14	10	7	8	8	8		57	56	40	39	26
DUV TTL	**50**	**51**	**61**	**56**	**51**	**48**	**49**	**49**	**49**		**86**	**83**	**69**	**66**	**54**

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EUV Research & Development History

Study Apparatus EUV & Photo Material by EIDEC

year 2002-2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

EUVA

NEDO (Matching Fund)

KOMATSU (LPP)

GIGAPHOTON (LPP)

USHIO (DPP)

~~Join Venture Finished~~

KOMATSU (TIC, MTC)

ETS-1

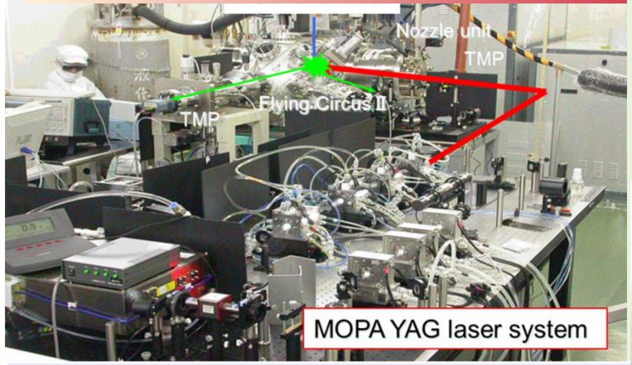
ETS-2

Proto#2

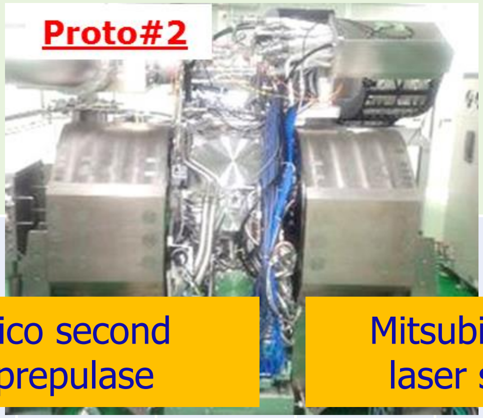
Magnetic Mitigation

Proto#1

Pilot#1



MOPA YAG laser system



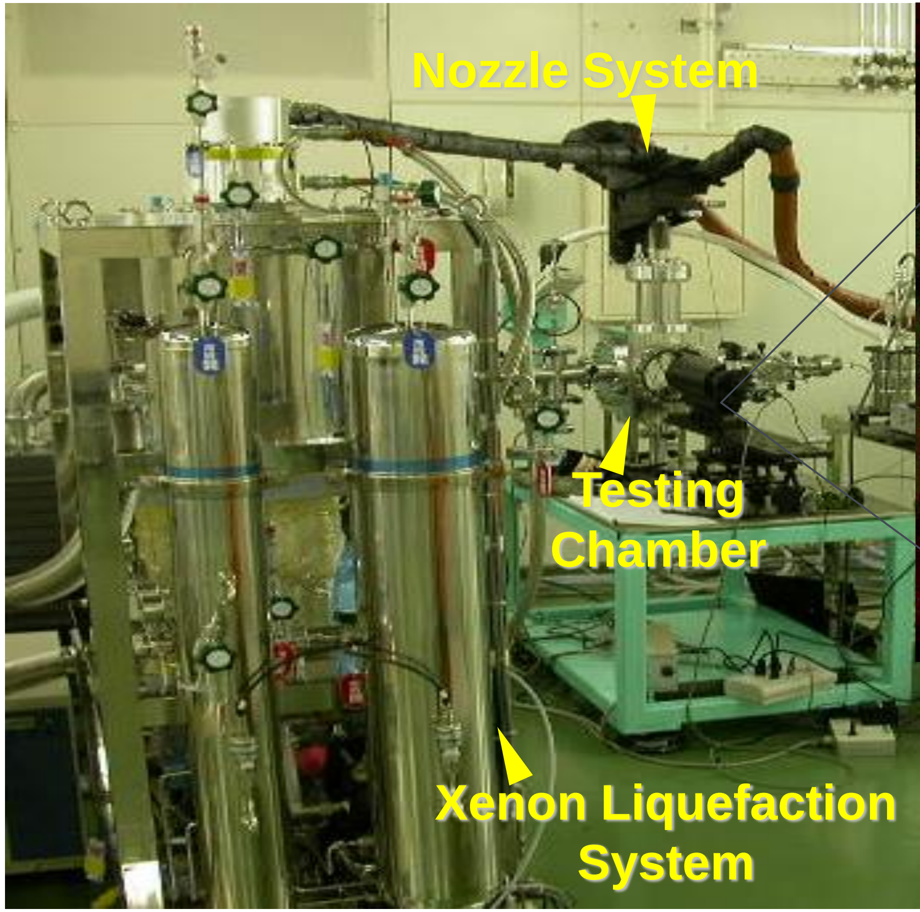
Xe +YAG Laser
↓
Sn +CO2 Laser

Pico second prepulase

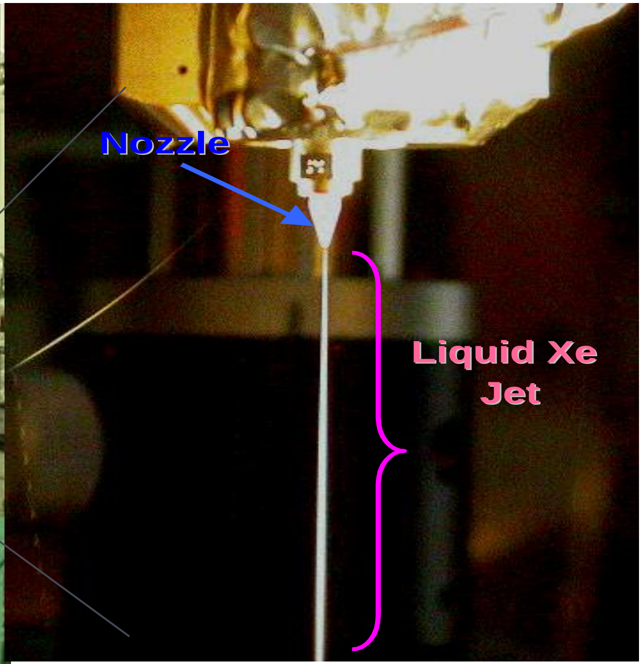
Mitsubishi CO2 laser system

History of LPP source development 2004

- **Start with Liquid Xe Jet target** experiment with **YAG laser driver**

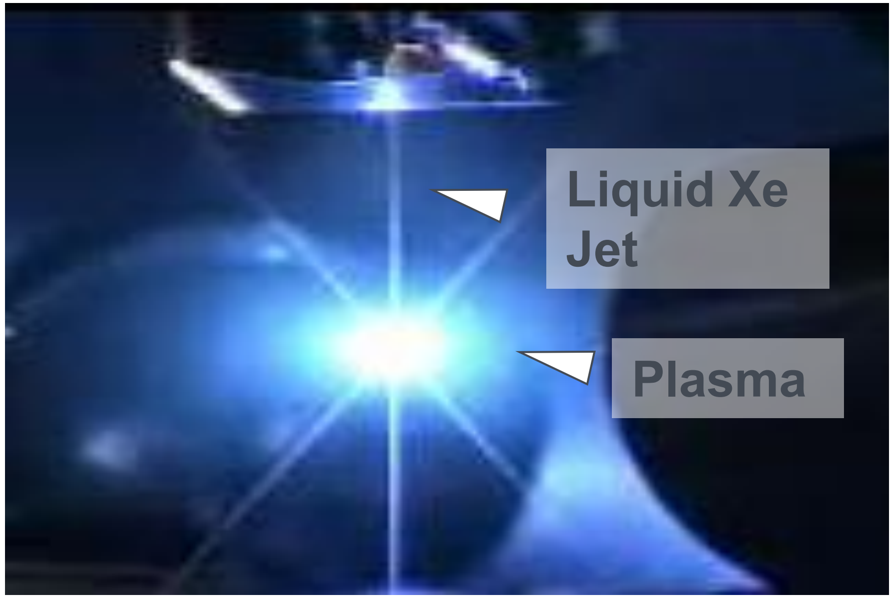


Liquid Xenon Jet System



Xe Jet

Velocity :30m/s
Stability σ : 10μm @10mm

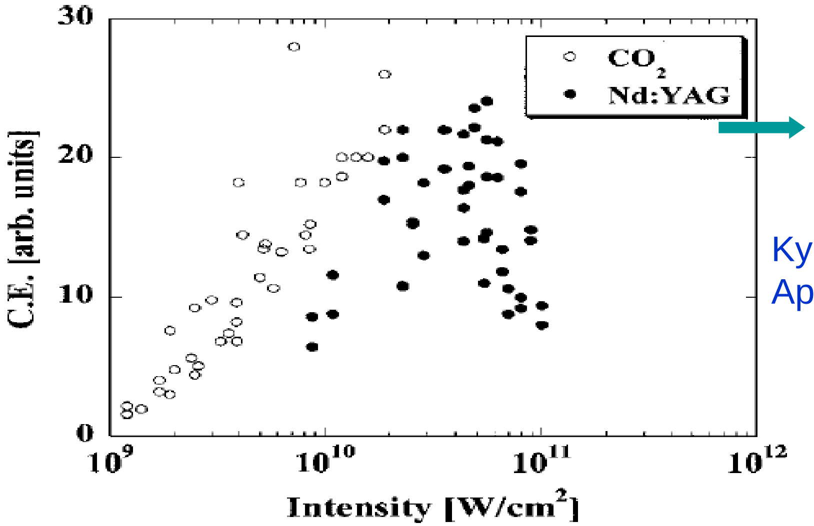


Xe Jet and Plasma

Xe Temperature: 160K - 190K
Xe Pressure: <5MPa

History of LPP source development 2006

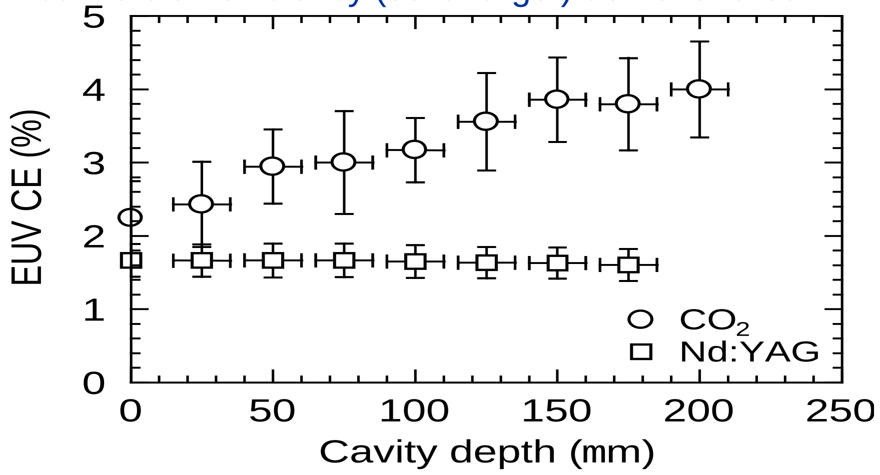
- **We found out Tin + CO2 laser could be around 8% efficiency** through Leading project & EUVA.

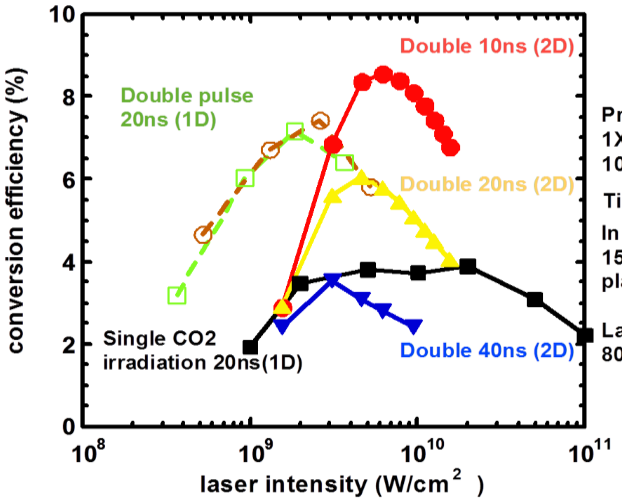


estimated
to be 2%

Kyusyu Univ., H. Tanaka et al.
Appl. Phys. Lett. 87,041503(2005)

EUV conversion efficiency (solid target) demonstrated in EUVA (2005)

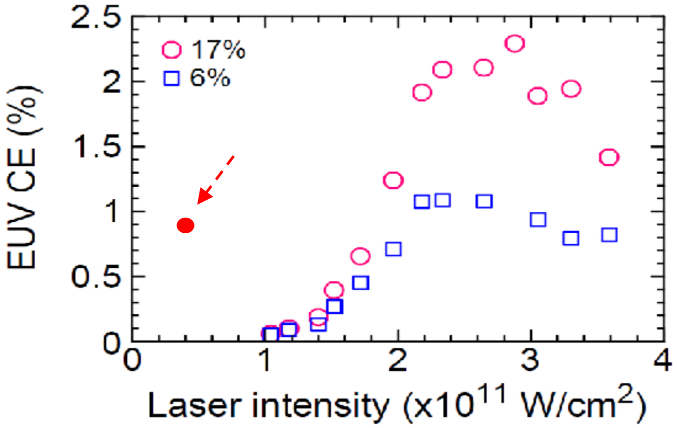




Pre-pulse
$1X10^8W/cm^2$
10ns(0.53μm)
Time delay :180ns
In 2D simulation,
150μm pre-formed
plasma is initially set.
Laser spot diameter:
800 μm.

Dr.Sunahara

EUV conversion efficiency simulation by Osaka Univ. team (20

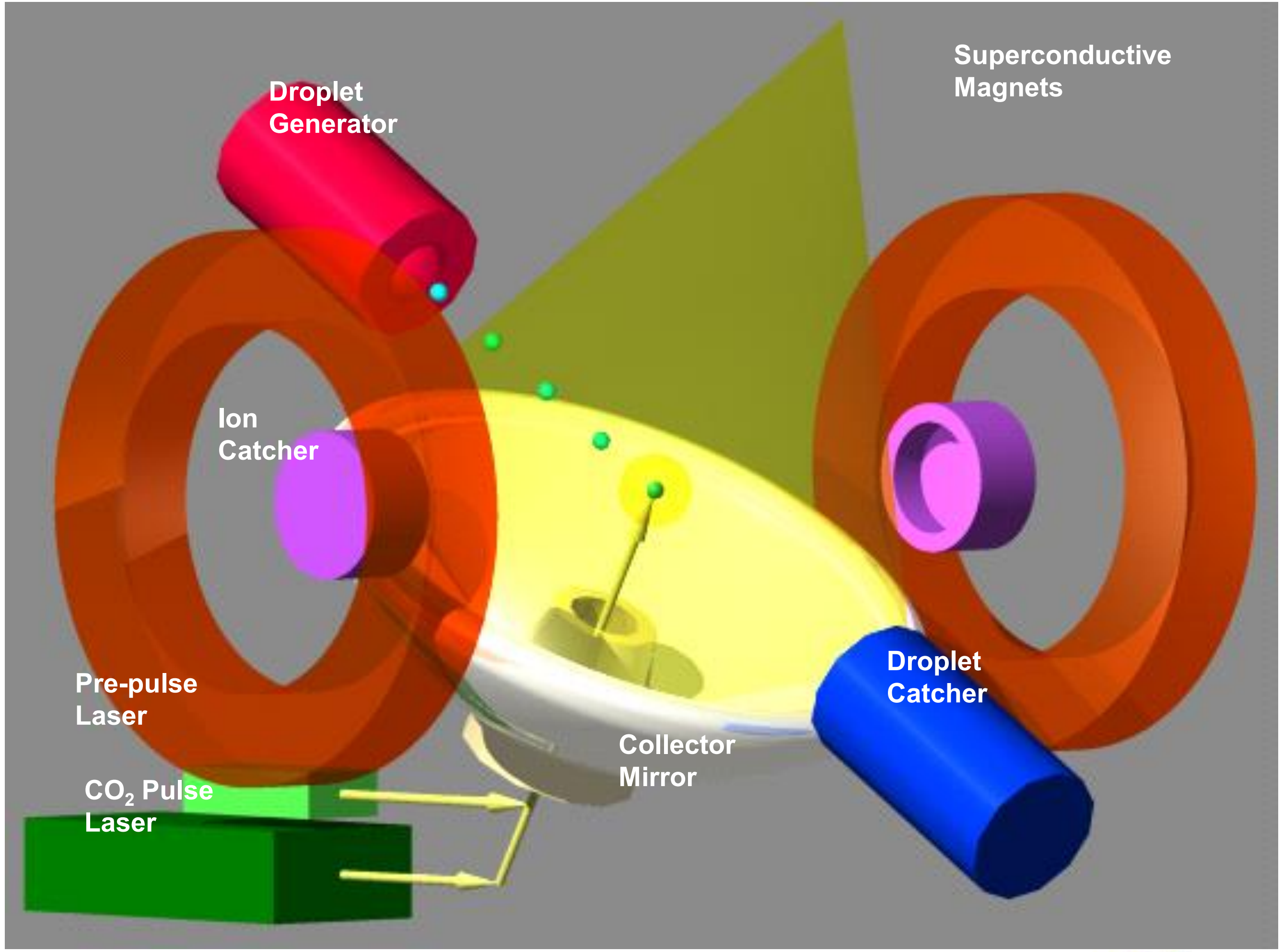


Miyazaki Univ., T.
Higashiguchi et al.
SPIE Microlithography
2006, 6151-146(2006)

History of LPP source development 2007

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

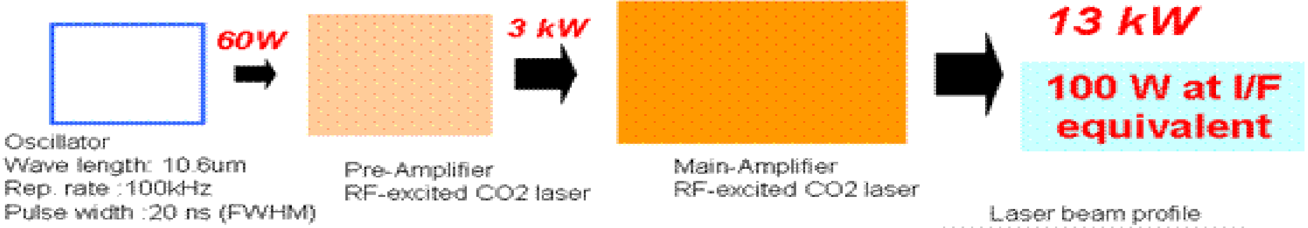


KOMATSU GIGAPHOTON

History of LPP source development 2010

- **ETS-2 demonstrated at 10W avg. power and 50W power** with Magnetic Mitigation.

- Laser System



60W

3 kW

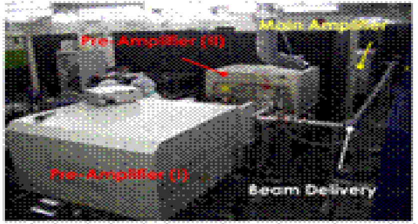
13 kW

100 W at I/F equivalent

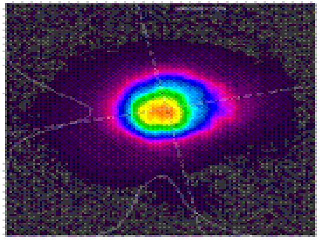
Oscillator
Wave length: 10.6um
Rep. rate :100kHz
Pulse width :20 ns (FWHM)

Pre-Amplifier
RF-excited CO2 laser

Main-Amplifier
RF-excited CO2 laser

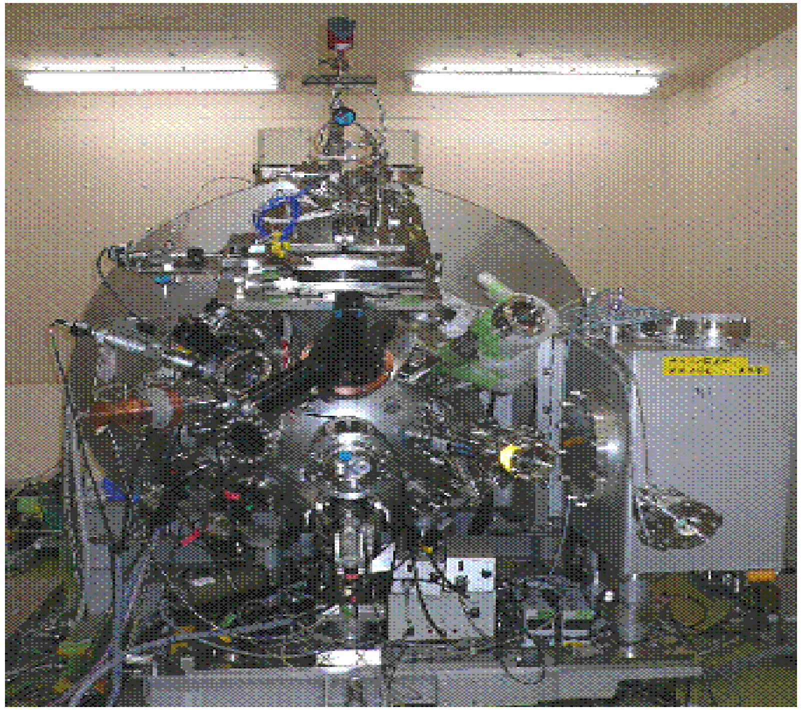


Laser beam profile



	SPIE 2010 (Feb.2010)	EUV Symposium (Oct.2010)	SPIE2011 (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

- EUV chamber

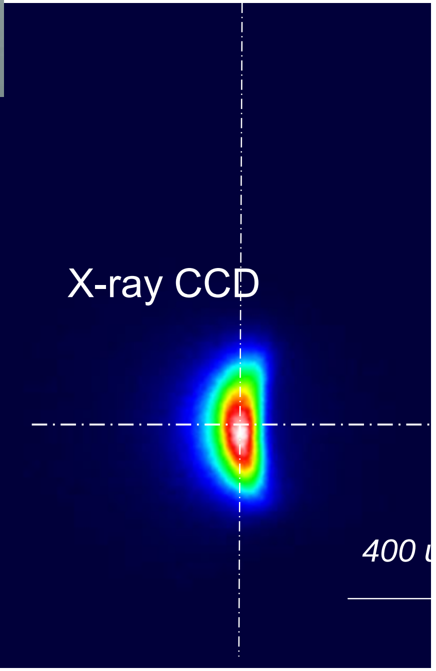


History of LPP source development 2012

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

Pre-pulse (nano-second)

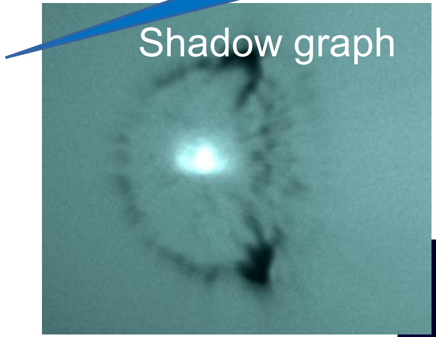
'Disk' like target



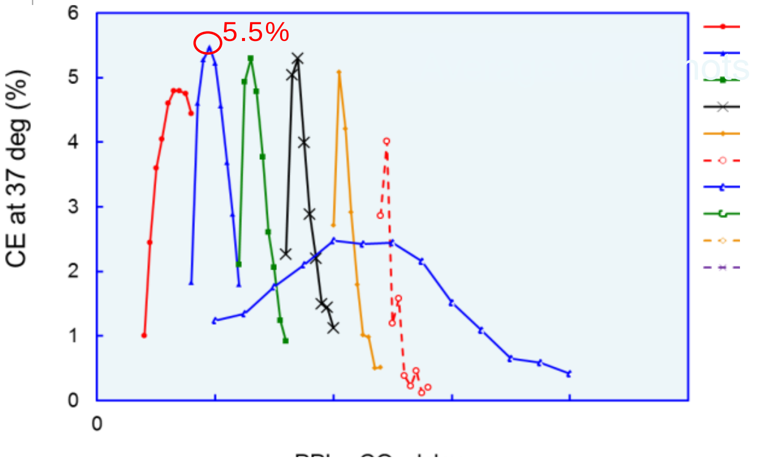
Pre-pulse(pico-second)

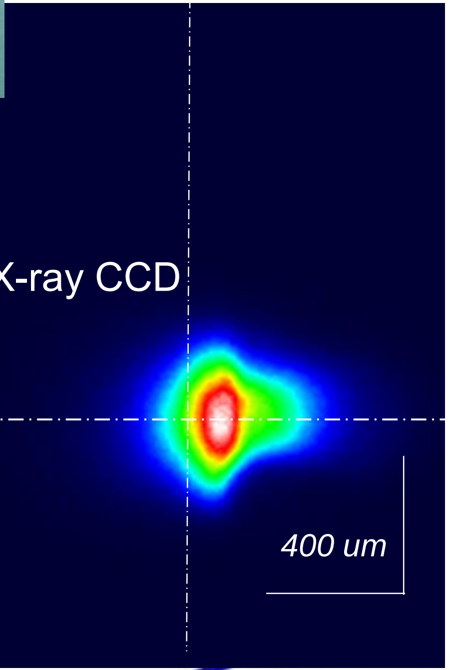
Very short pulse duration with 1um wavelength laser

Same optical path between pre-pulse and main



Ideal
'Dome' like target





History of LPP source development 2013

- *High power amplifier ETS achieved 20kW peak power.*

➢ CO$_2$ AMP system experiment is on going in Mitsubishi electric co.

Osc. Unit

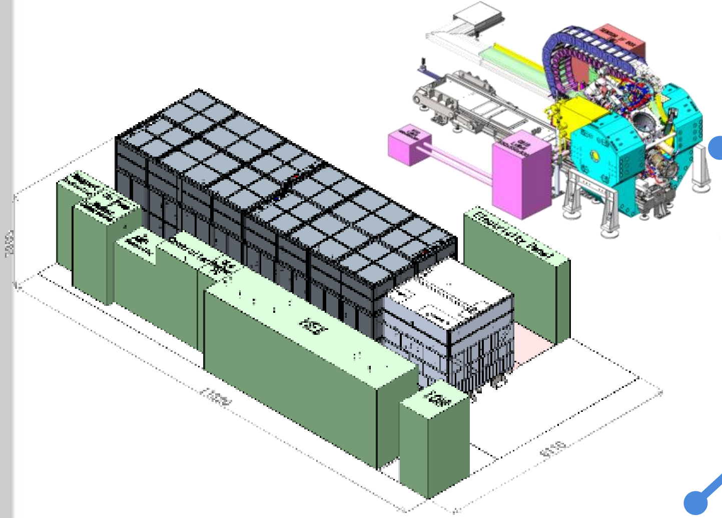
Amp. Unit

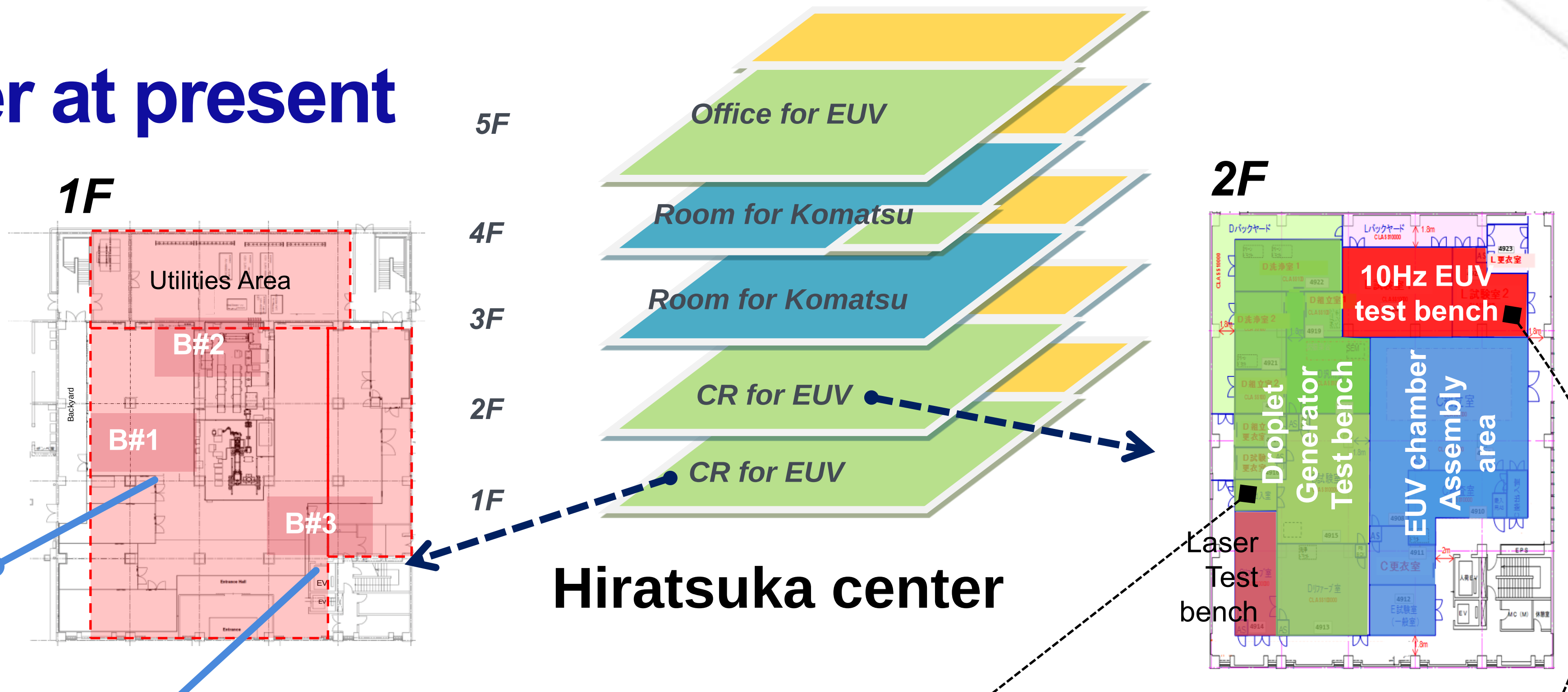
Hiratsuka Center at present

Pilot#1

Operational since July 2016

First pilot system designed for NXE integration



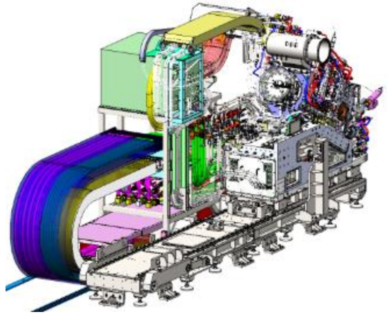


Hiratsuka center

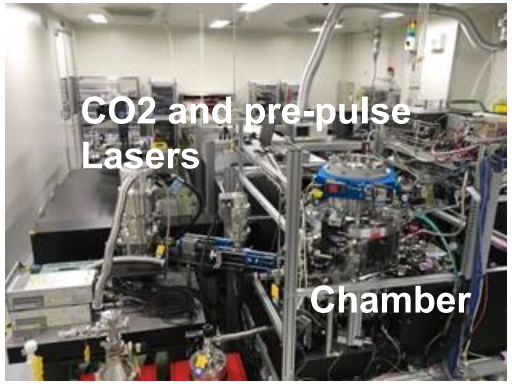
Proto#2

Operational since November 2013

System for key technology development in >100W power level



- Droplet test bench
  Reliability, Stability etc.



- EUV plasma study (<10Hz)
  CE, ions energy etc.

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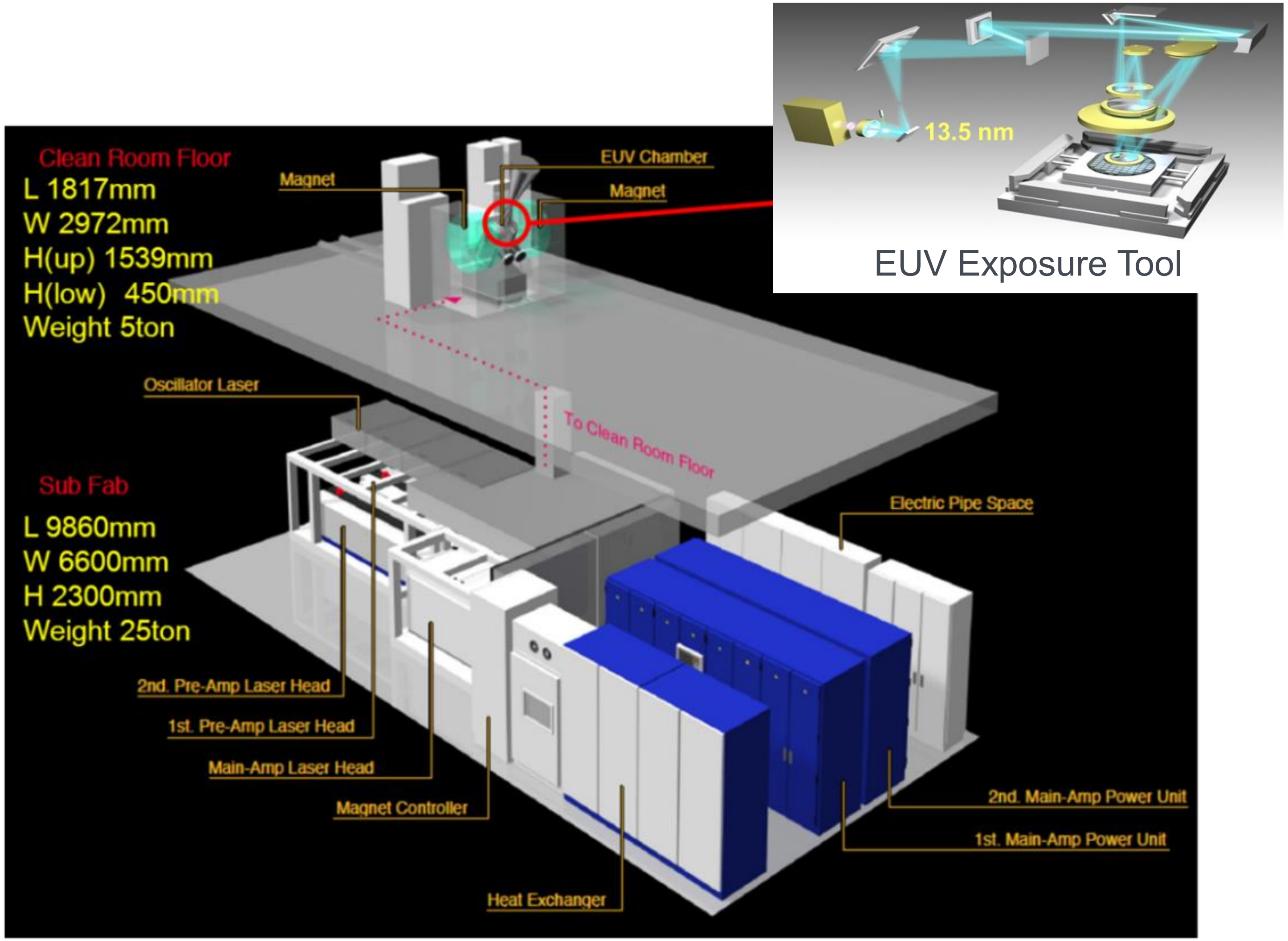
Layout of >330W EUV Light Source Pilot #1

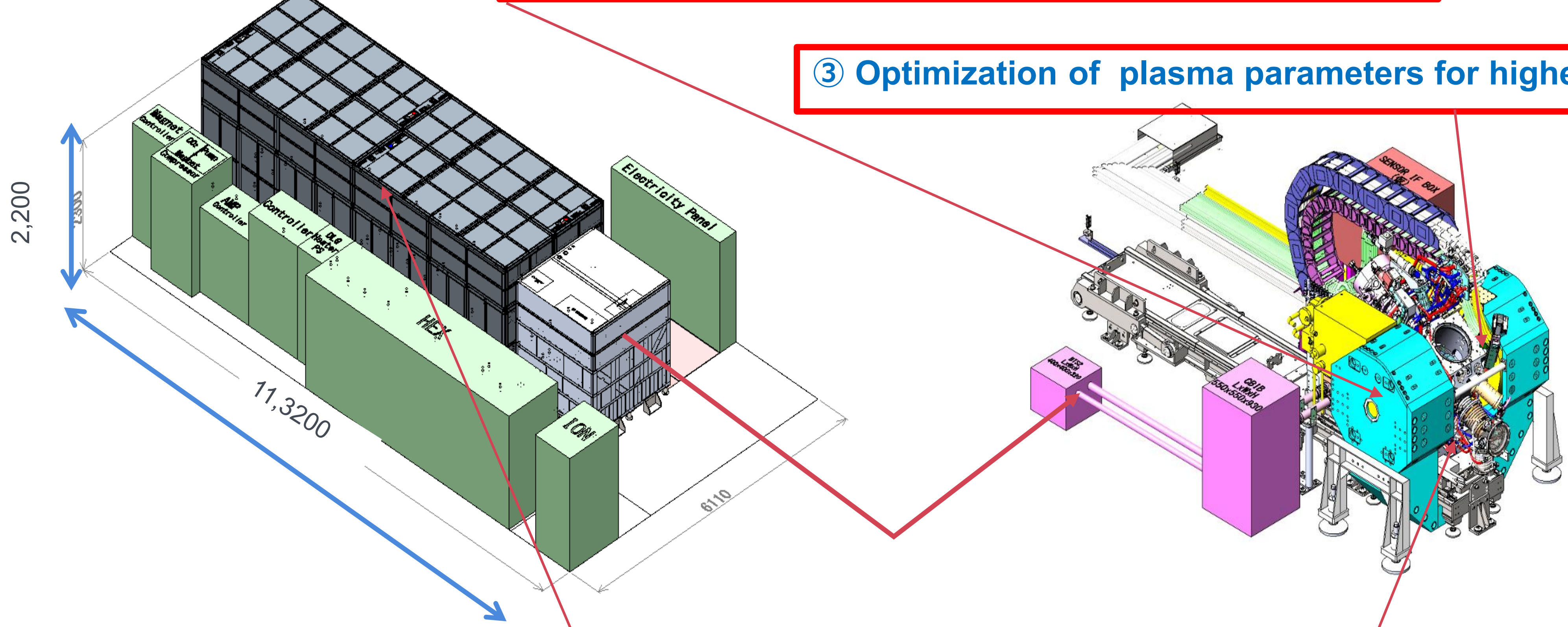
First HVM EUV Source

- 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**



>330W Power Challenge with Upgraded Hardware



② Beam Uniformity Upgrade at Plasma Point ✓ Done

③ Optimization of plasma parameters for higher CE ✓ On going

① CO2 Laser Power Upgrade ✓ Done

④ Lifetime Extension of Collector Mirror -0.05%/B pls ✓ On going

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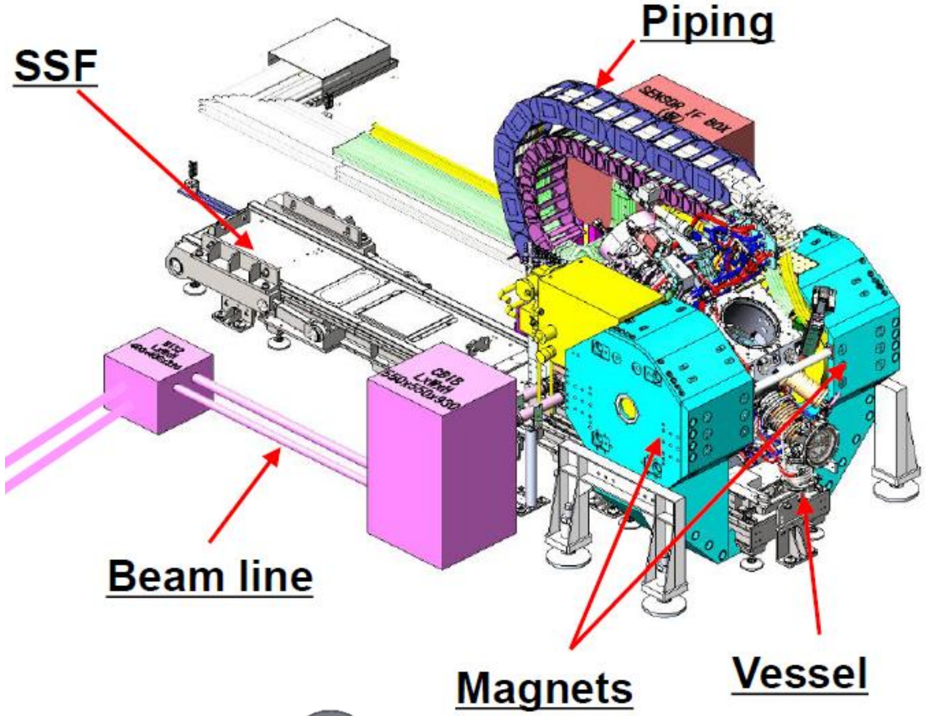
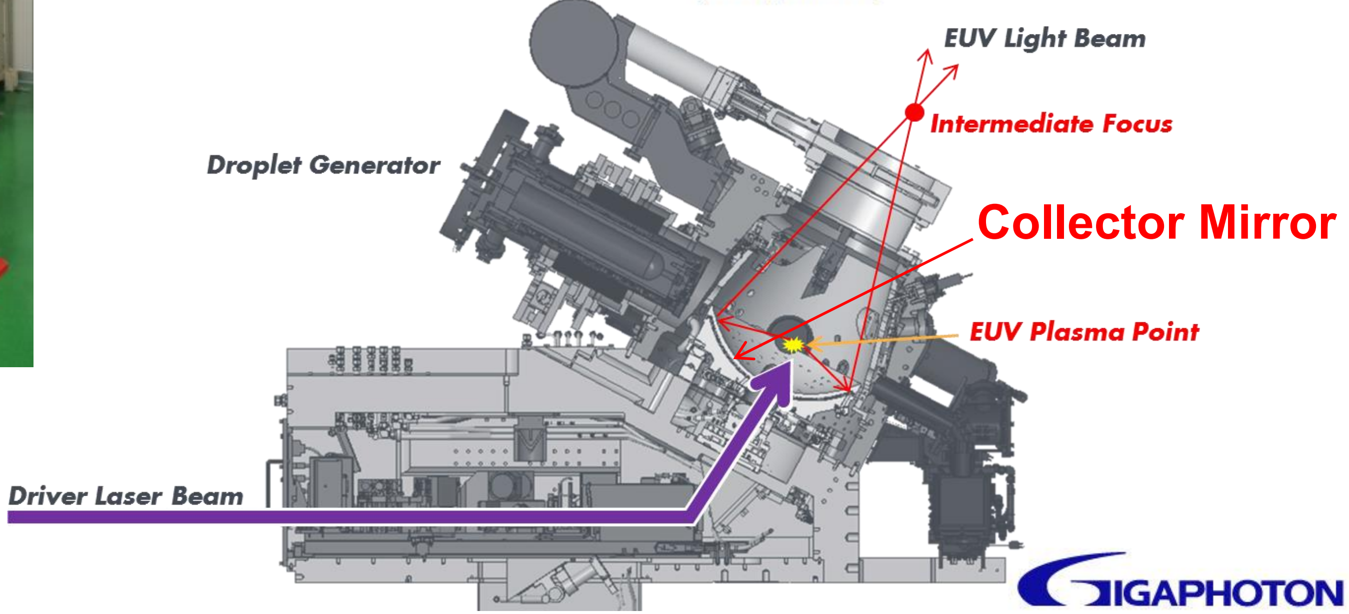
Pilot System EUV Chamber





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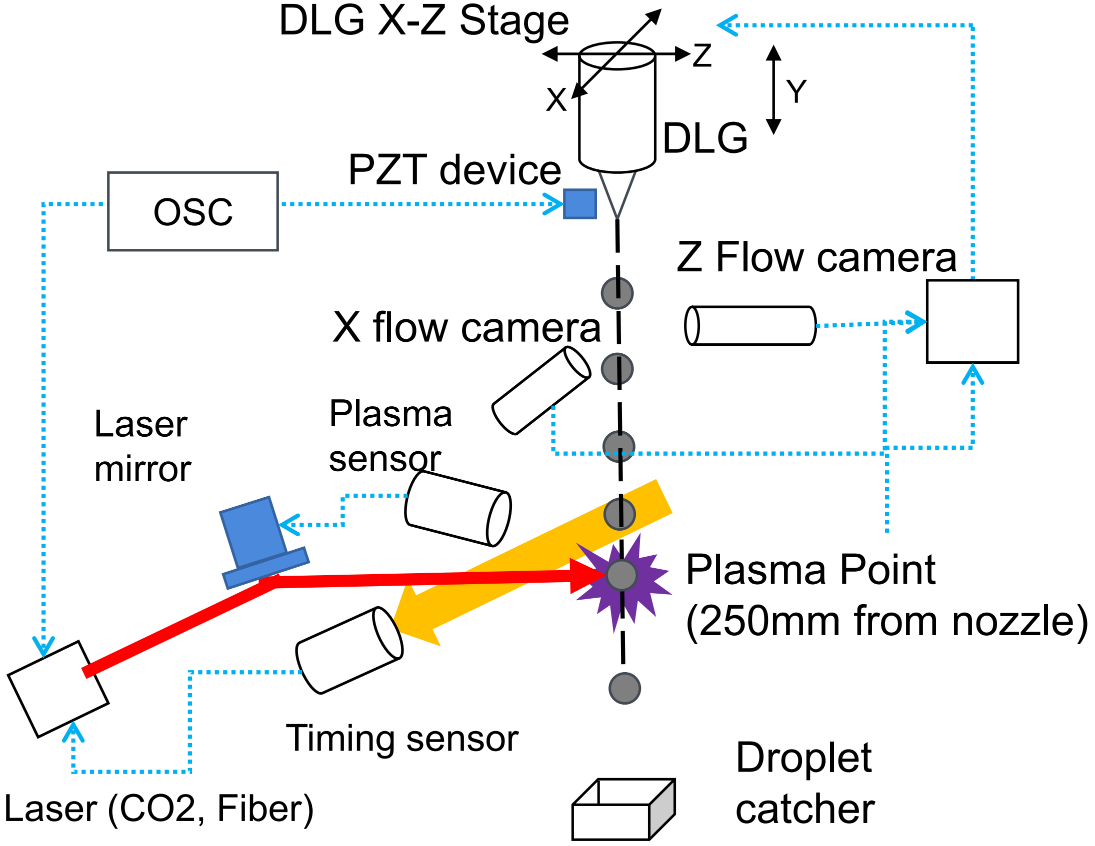
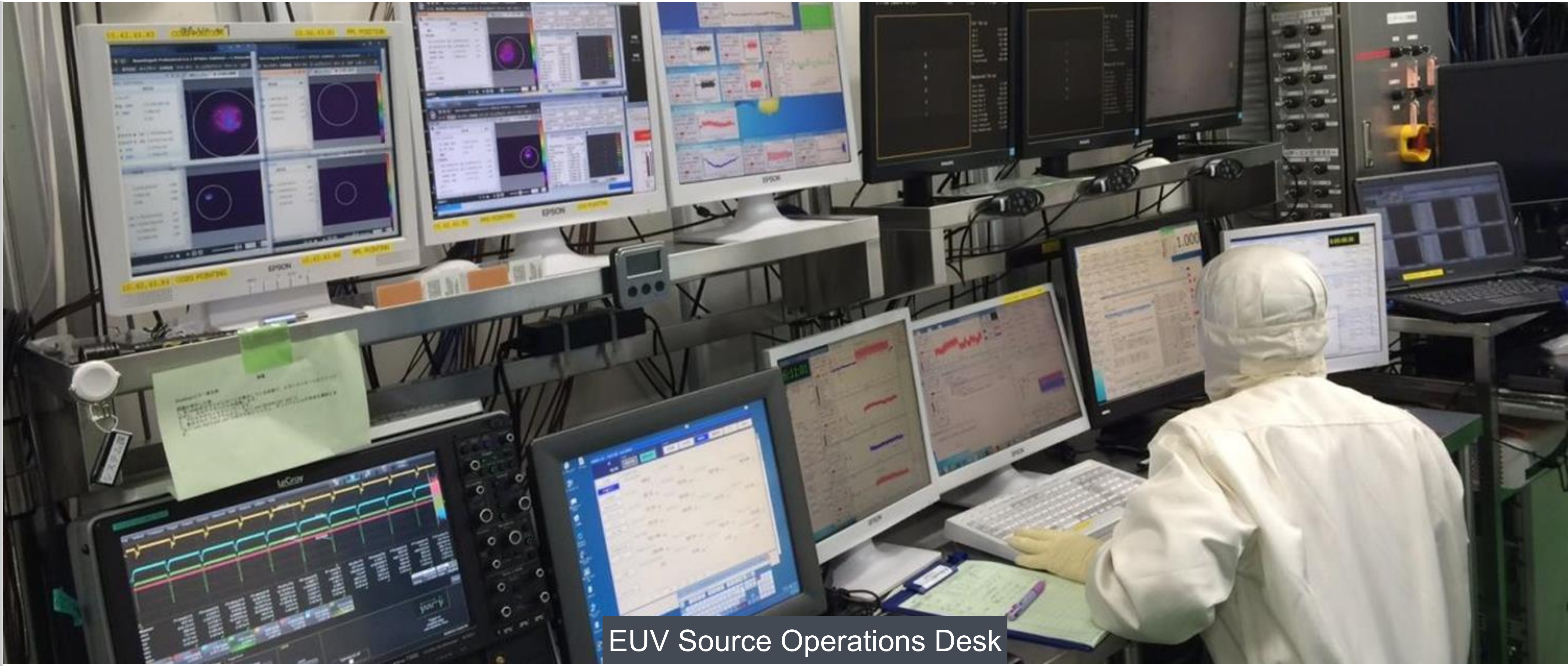
Pilot System Droplet Generator

LPP EUV Source Shooting Control System



Pilot#1 System in Operation



EUV Source Operations Desk

>330W Power Challenge with Upgraded Hardware

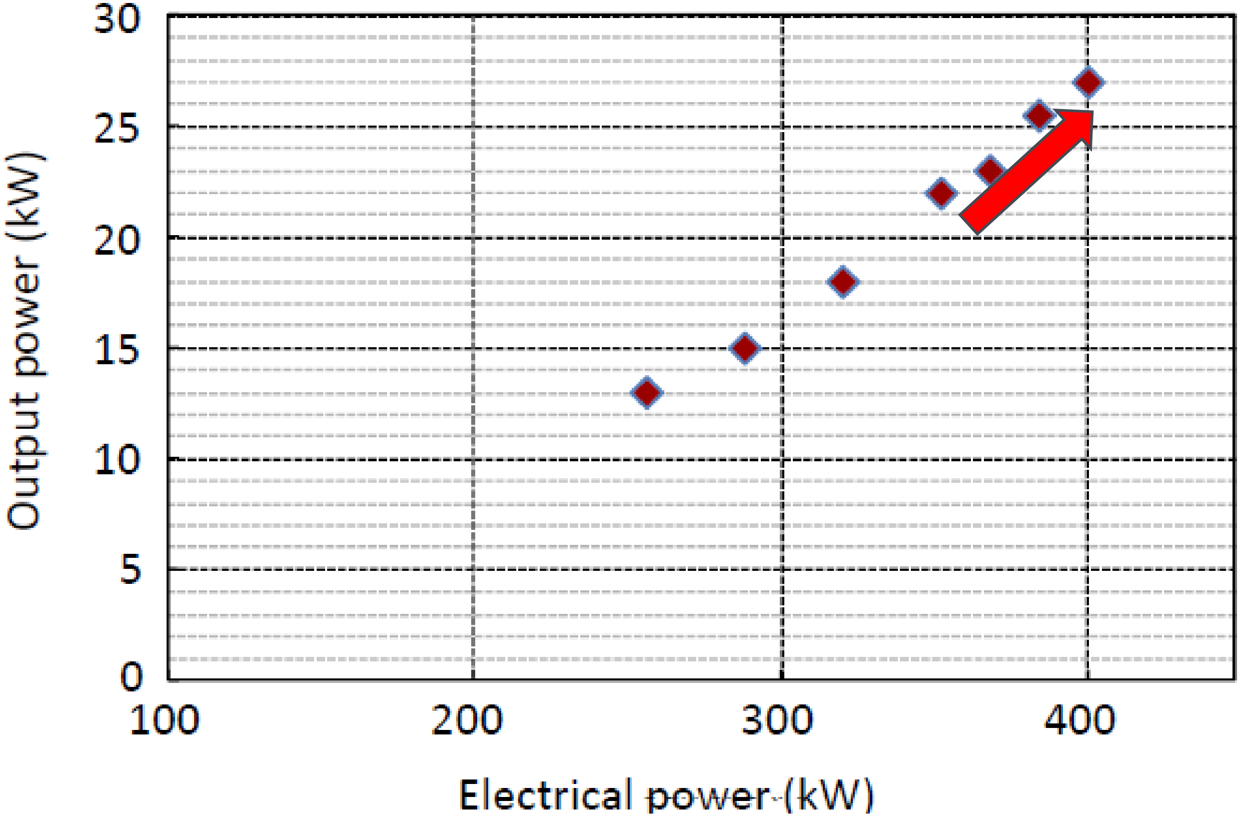
Target	Q4 2018	**On Going**	Q4 2019
Average Power	125W	**250W-330W**	**≧330W**
Repetition rate	100kHz	**100kHz**	100kHz
CO2 power (energy) at plasma operation with dose ctrl./maximum	10kW/16kW (100mJ/160mJ)	**18kW/25kW (180mJ/250mJ)**	18kW/25kW (180mJ/250mJ)
CE	4.0%	**4.5~5.0%**	**5.5～6%**
Technology for high power			
① CO2 Laser power Upgrade		✓	✓
② Beam Uniformity Upgrade at Plasma Point		✓	✓
③ Optimization of Plasma Parameters			✓
④ Lifetime Extension of Collector Mirror <0.05%/Bpls			✓

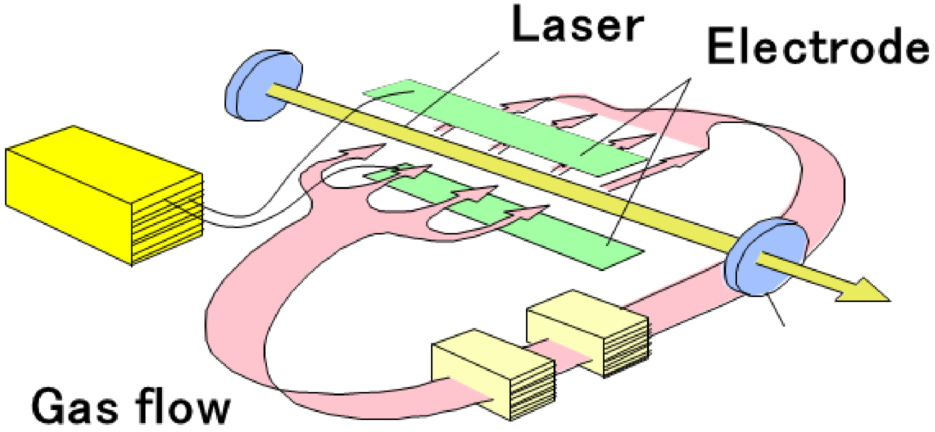
① CO_2 LASER POWER UPGRADE

Improvement of Higher-power CO_2 laser

- High-efficient laser amplifier with transvers flow concept (Mitsubishi electric).
- Recent improvement achieved **27 kW** laser power operation.

Output laser power





Transverse flow type amplifier

MITSUBISHI ELECTRIC

GIGAPHOTON

Transverse flow type CO_2 Laser

Benefits

- **Excellent beam uniformity** enables efficient EUV creation
- Short maintenance down time
  - Separated optical binding module design
  - Auto beam adjustment
- Efficient CO2 Laser and eco-friendly

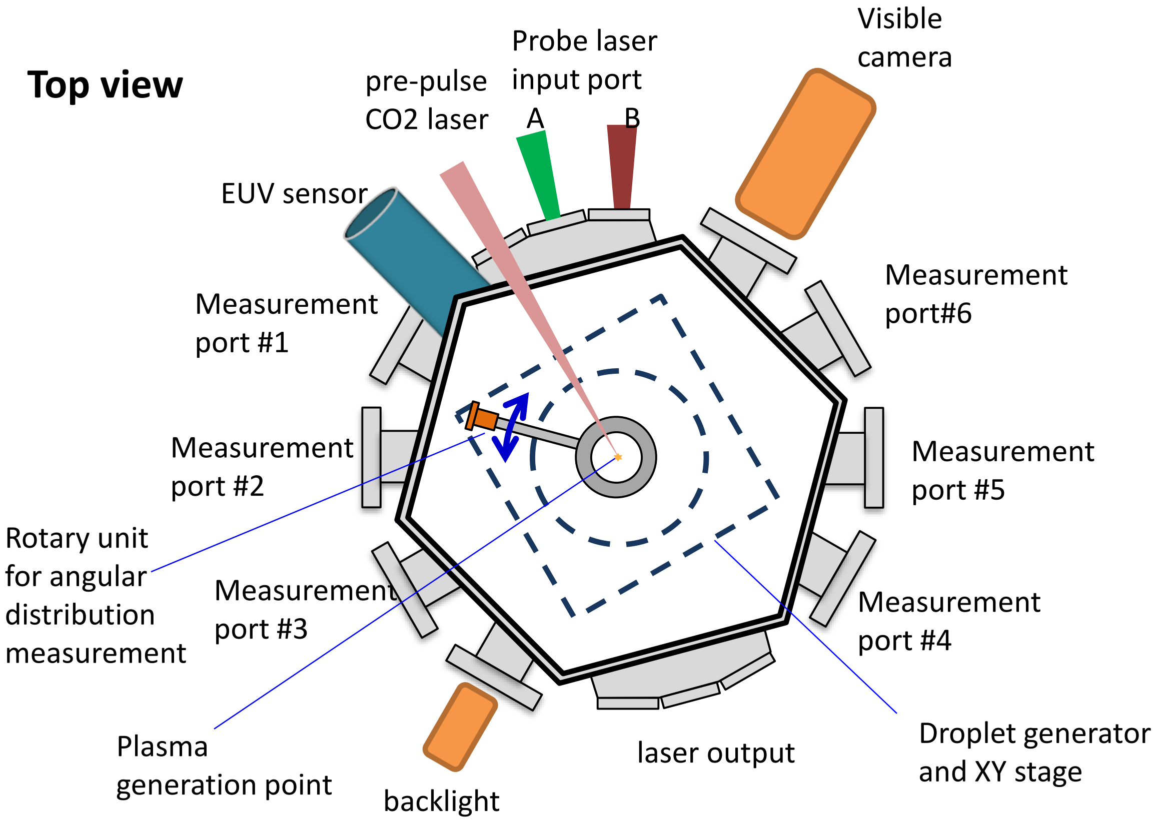
Utility	Spec.		Pilot#1
Input Electricity (full load)	1690 kVA	>	880 kVA
Cooling Water Flow Rate	2221 L/min.	>	1608 L/min.
Hydrogen Flow Rate	600 L/min.	>	360 L/min.
Laser Gas	*TBD*		351 kL/year

	Conventional	GPI	Remark
Beam profile uniformity	Not uniform	**Uniform**	Uniform beam profile leads higher CE.
Separate Optical Binding module	N/A	**Yes**	Minimize chamber replace time
Auto Beam adjustment	N/A	**Yes**	Keep uniform beam profile without interruption for adjustment
Utility requirement	▲	◎	30% less electricity and other utilities

② BEAM UNIFORMITY UPGRADE AT PLASMA POINT

Test apparatus for pre-pulse study

- EUV generation at 10Hz
- Studies on CE improvement and debris mitigation
- Measurement tools for EUV radiation and tin particles and plasma characterization



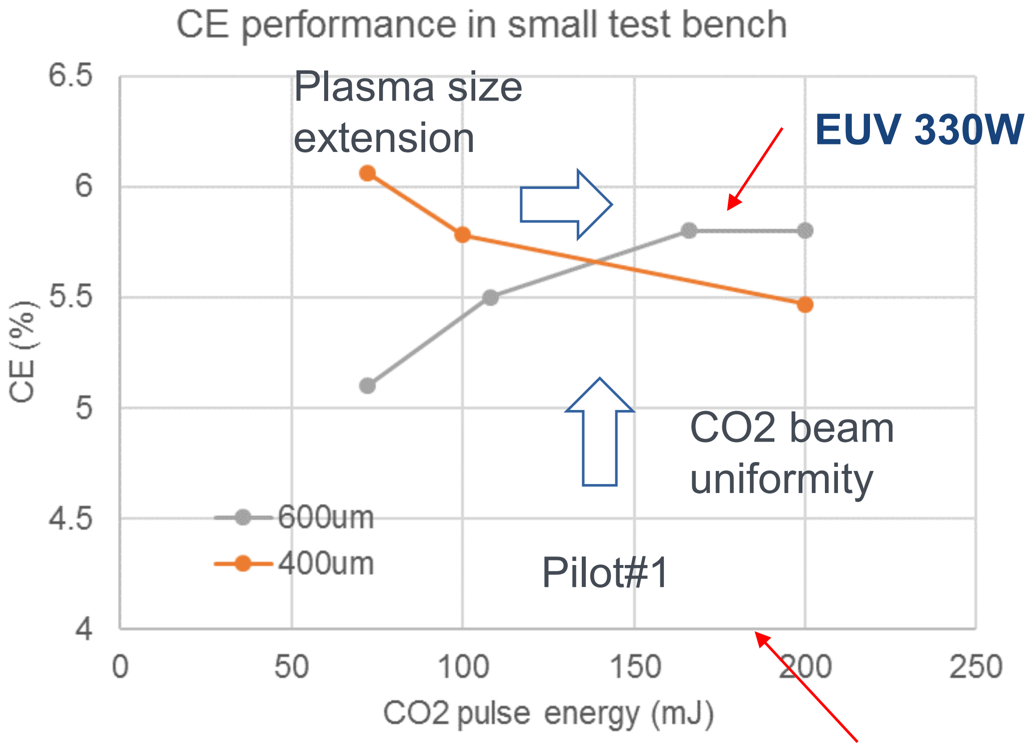
Overview of test apparatus

Measurement tools

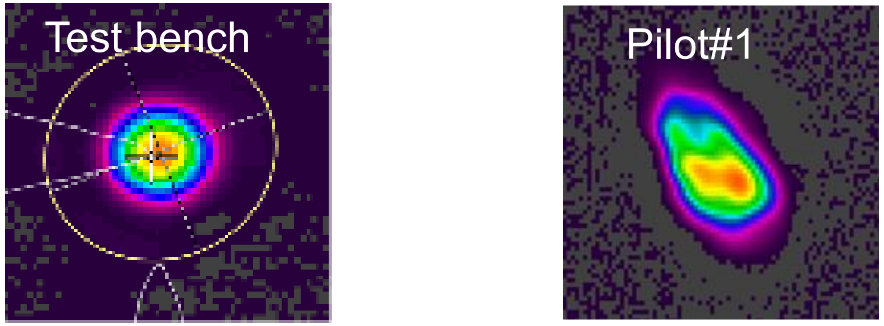
- EUV radiation
  - spectrometer
  - imaging camera
- Sn ions
  - Faraday cup
  - Electro static analyzer
- Sn atoms
  - Laser induced fluorescence
- Sn fragments
  - Mie scattering
- Plasma
  - Thomson scattering

Key Technology 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 18kW at 100kHz

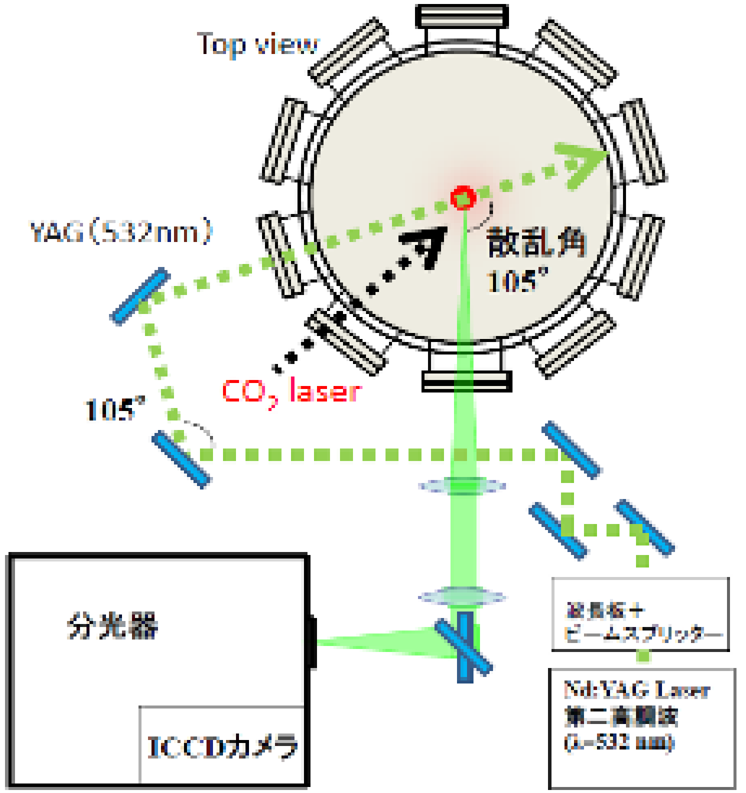


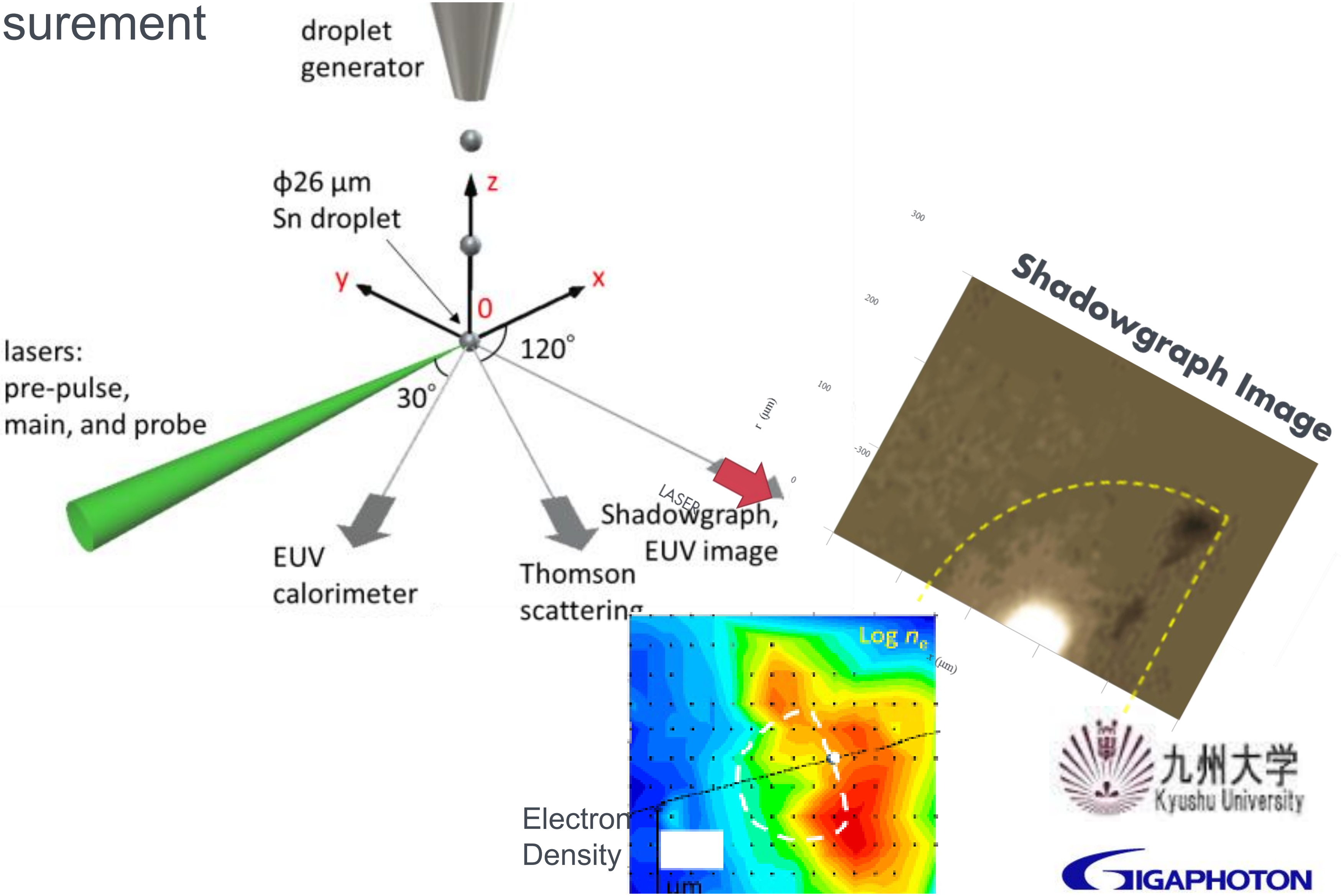
CO2 spot profile

③ OPTIMIZATION OF PLASMA PARAMETERS

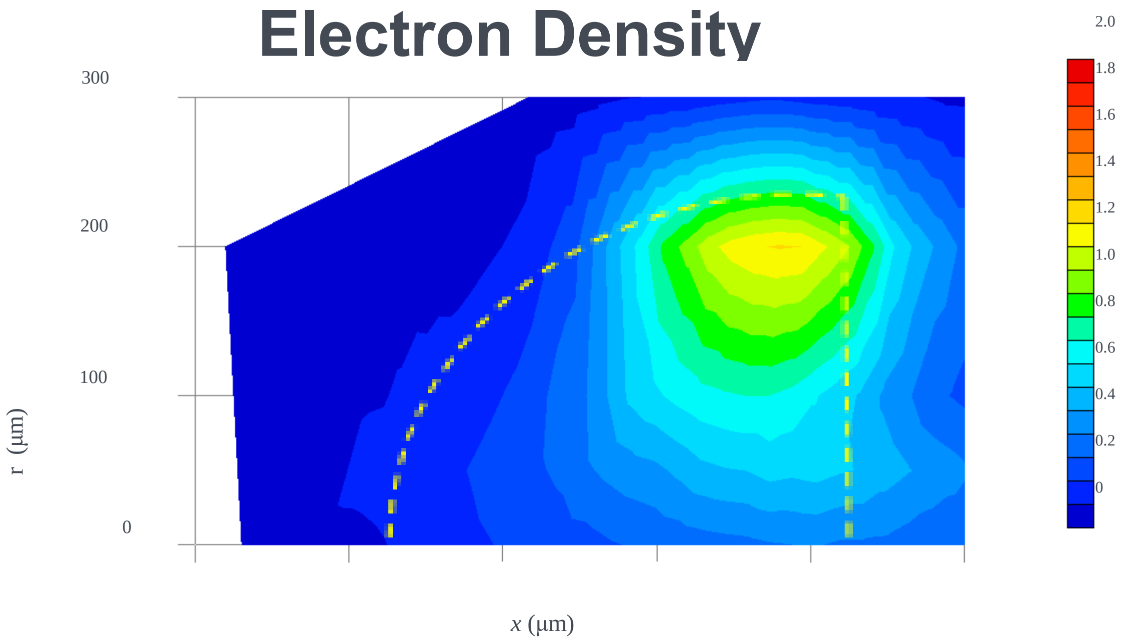
Plasma Parameter Measurement (1/2)

Thomson Scattering Measurement

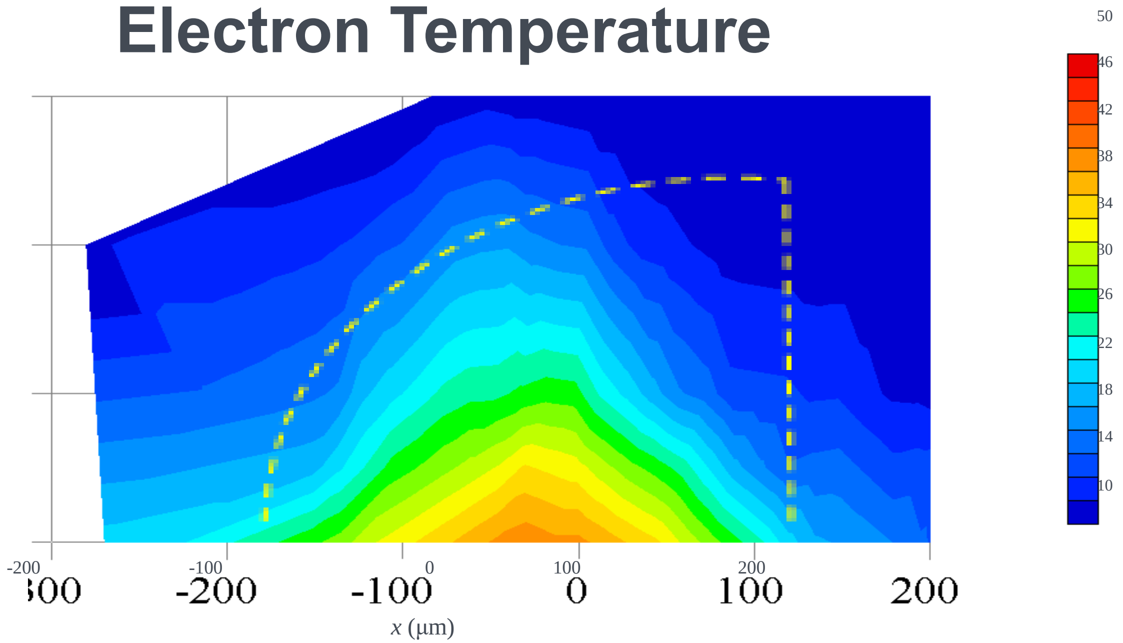




Plasma Parameter Measurement (2/2)



Electron Density



Electron Temperature

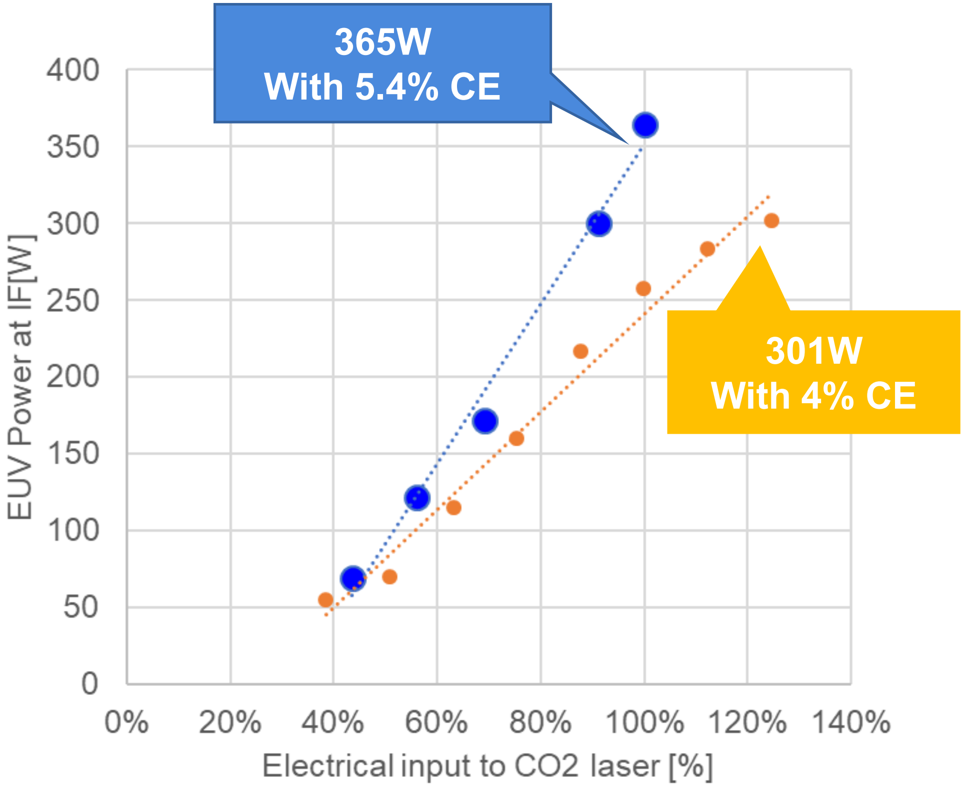
Tomson Scattering measurement characterize pre-pulse plasma in detail !

Next step: CE enhancement by plasma optimization.

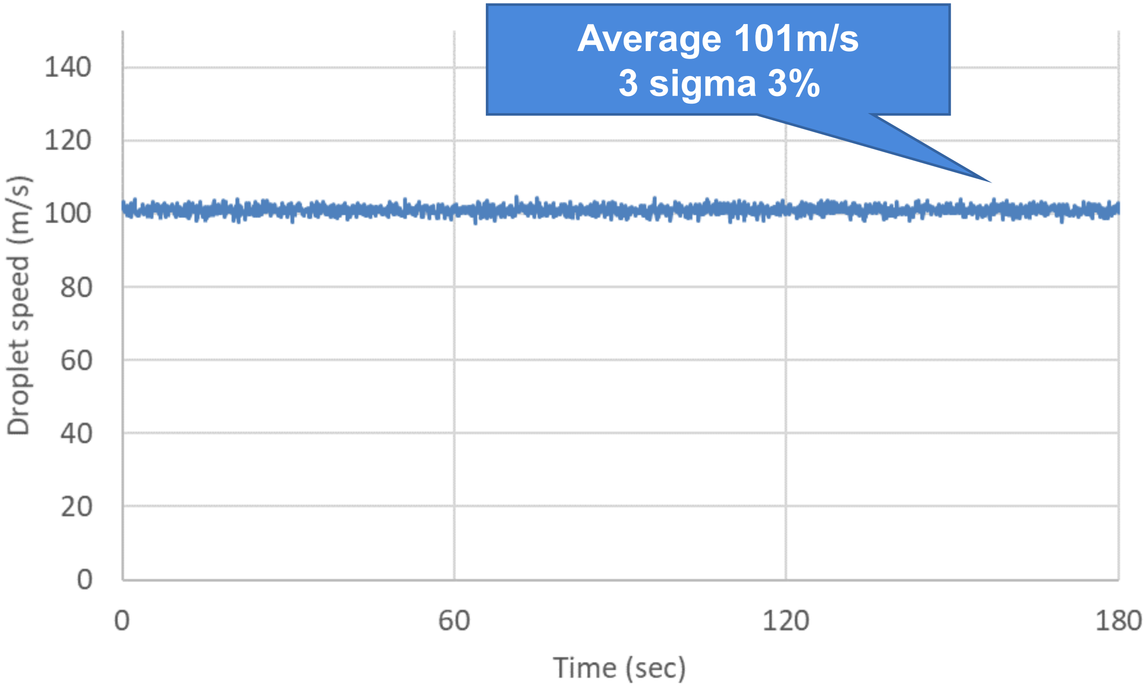
LATEST SYSTEM OPERATION DATA OF PILOT#1

Latest data for higher power

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



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



Agenda

- **Introduction**
  - Gigaphoton Business update
- **EUV Research & Development History**
- **Experiment A: >330W Power Challenge of EUV Source**
  - ① CO2 Laser Power Upgrade
  - ② Beam Uniformity Upgrade at Plasma Point
  - ③ Optimization of Plasma Parameters
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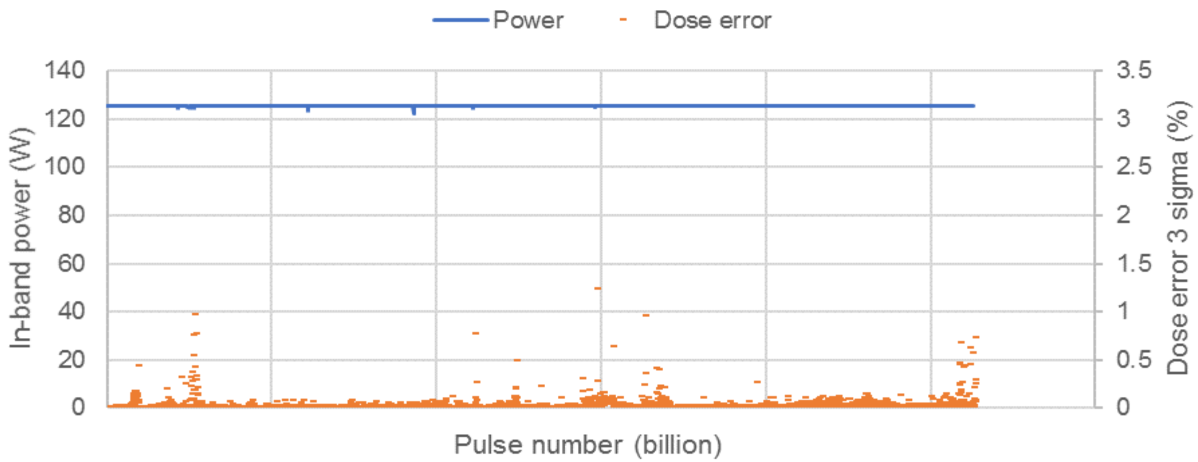
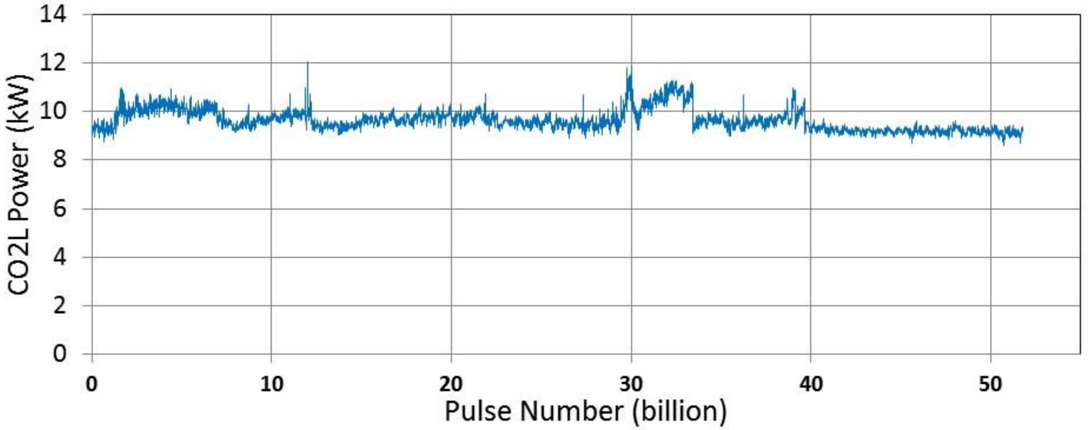
  - ④ Lifetime Extension of Collector Mirror
- **Summary & Acknowledgement**

System Performance: 125W Operation Data

- 125W had been achieved with only 10 kW of CO_2 power for 53Bpls operation.

	Performance
Average power at IF	125W
Dose error average (3 sigma)	0.04%
Die yield (<0.16%)	98.5%
Pulse Number	53Bpls
Duty cycle	100%
In-band power	125W
Dose margin	40%
Collector lifetime	0.9%/Bpls
Repetition rate	100kHz





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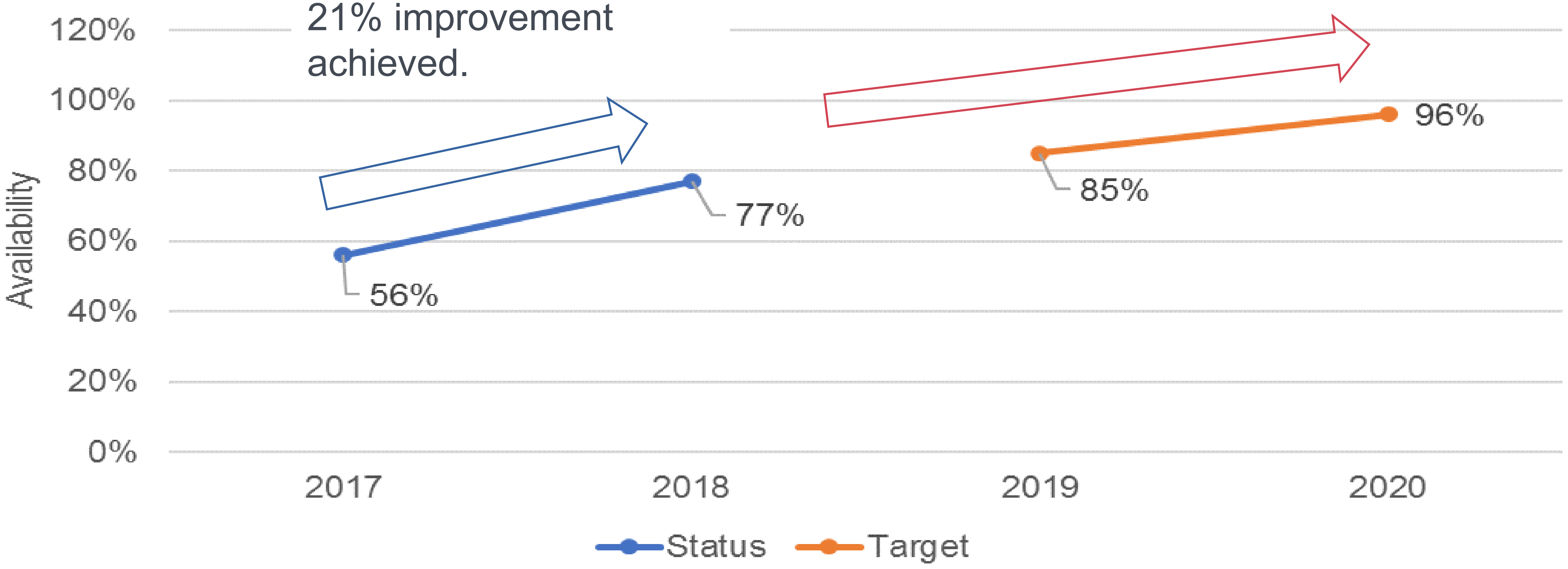
Availability: Status and Targets

* Potential availability is calculated, based on module lifetime and maintenance time.

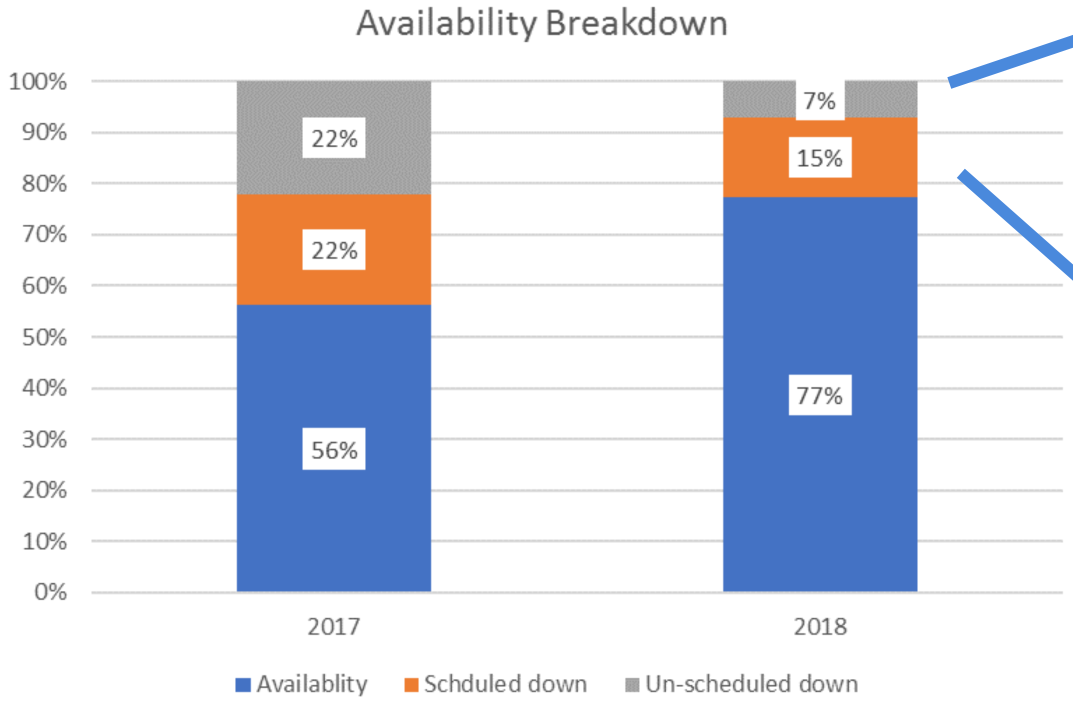


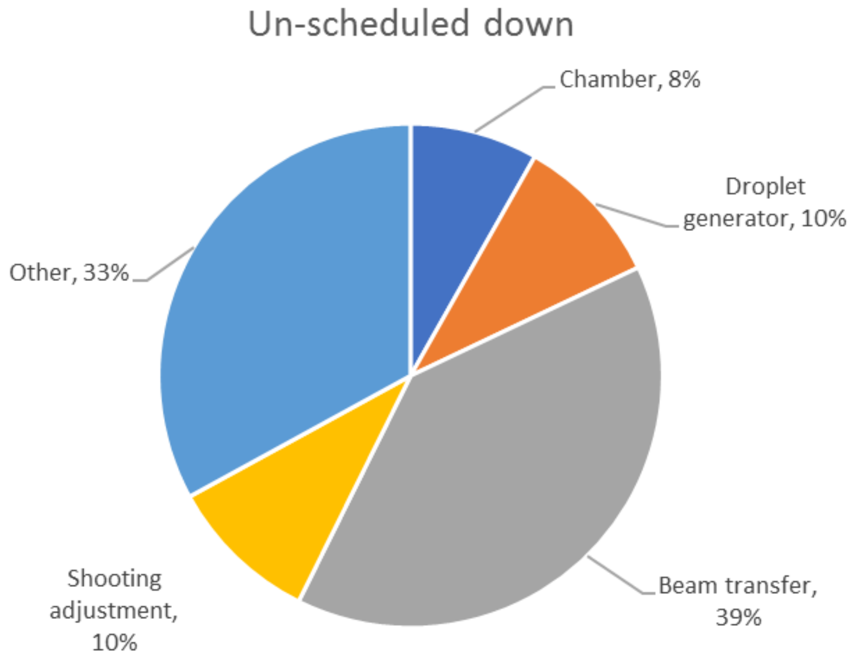
21% improvement achieved.

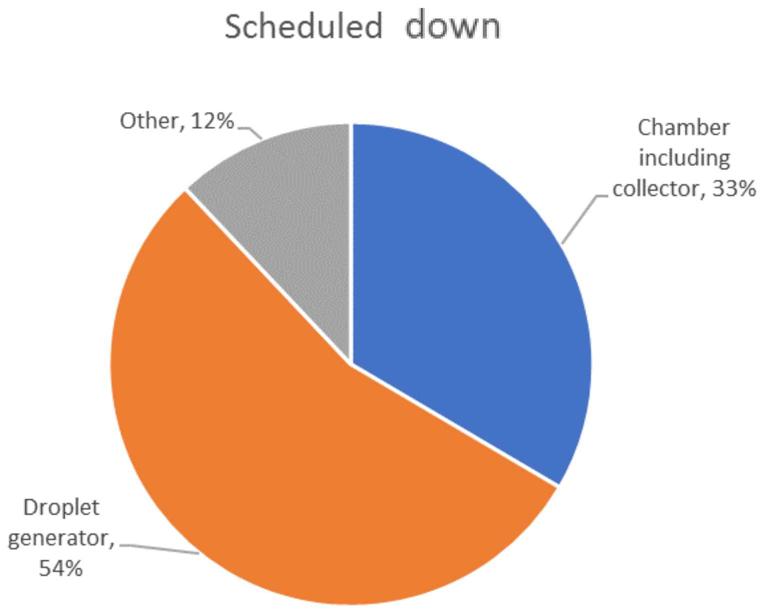
19% improvement planned.

DLG lifetime	15 days	15 days	15 days	60 days
DLG swap time	26 hrs	18 hrs	16 hrs	11 hrs
Collector lifetime	< 1 mo.	3 mo.	6 mo.	12 mo.
Chamber maintenance	58 hrs.	45 hrs.	38 hrs.	28 hrs.

Availability: Breakdown





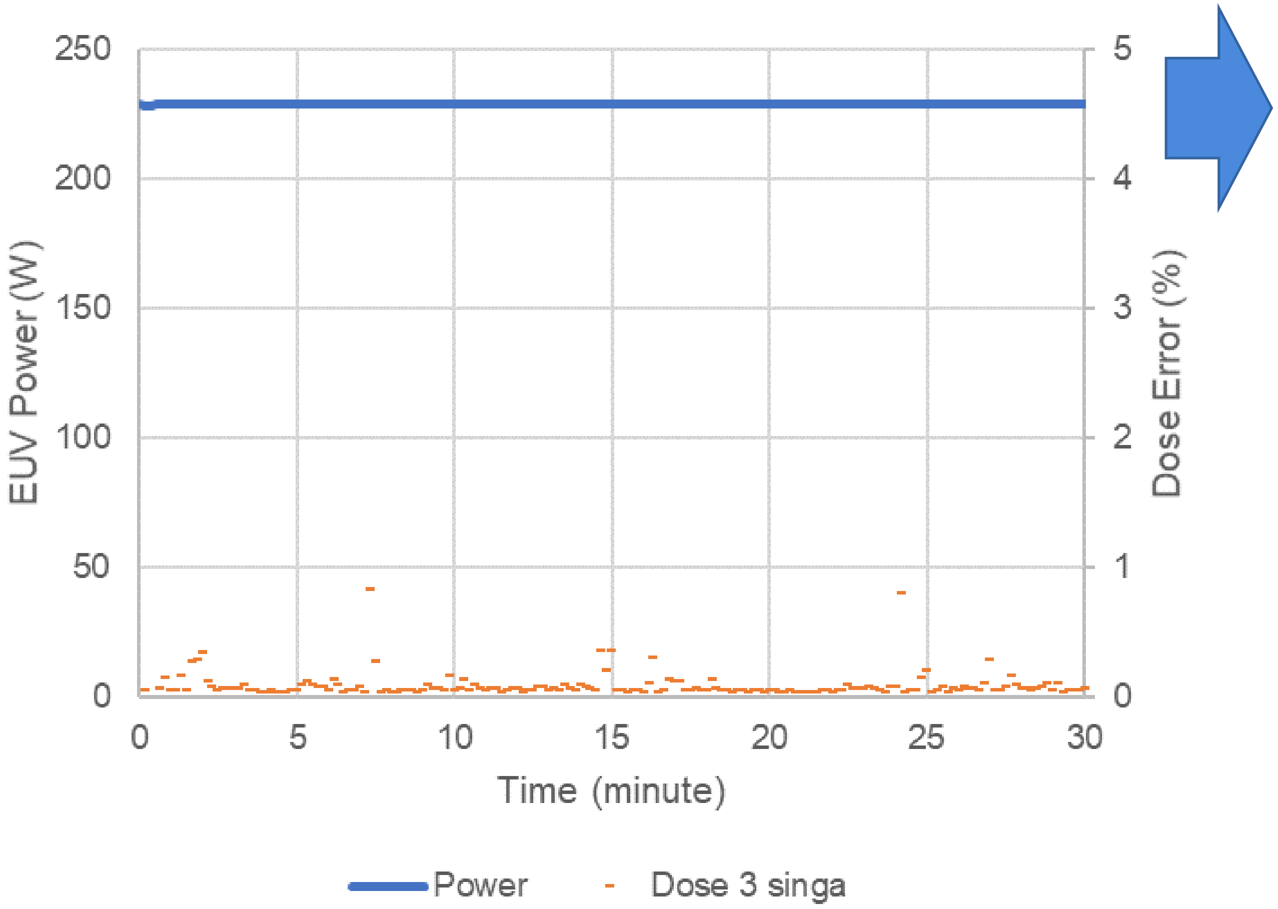


Presentation Only

Latest 230W Middle-term Operation Data

- Closed loop performance of 230W has been just started. (shown data is only 30min however experiment is still continuing).

	Performance
Average power at IF	230W
Dose error average (3 sigma)	0.09%
Dose margin	20%
Repetition rate	100kHz



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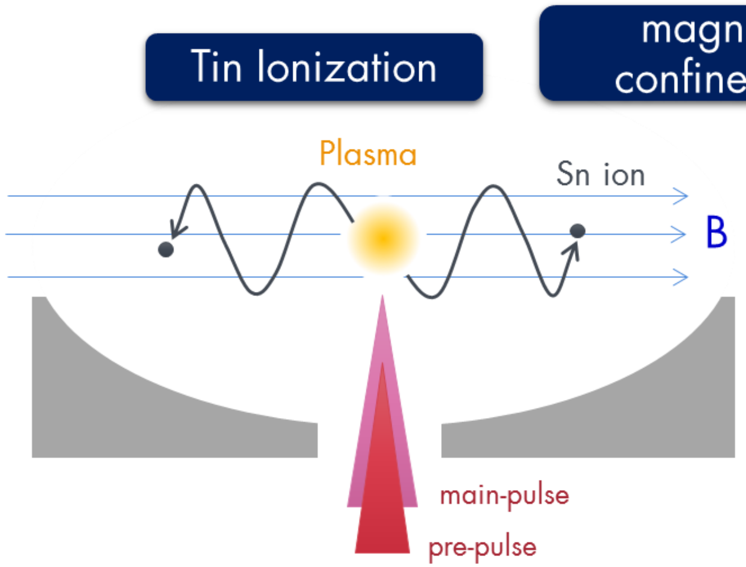
④ LIFETIME EXTENSION OF COLLECTOR MIRROR

Etching and Dissociation Sn balance on the Mirror Surface

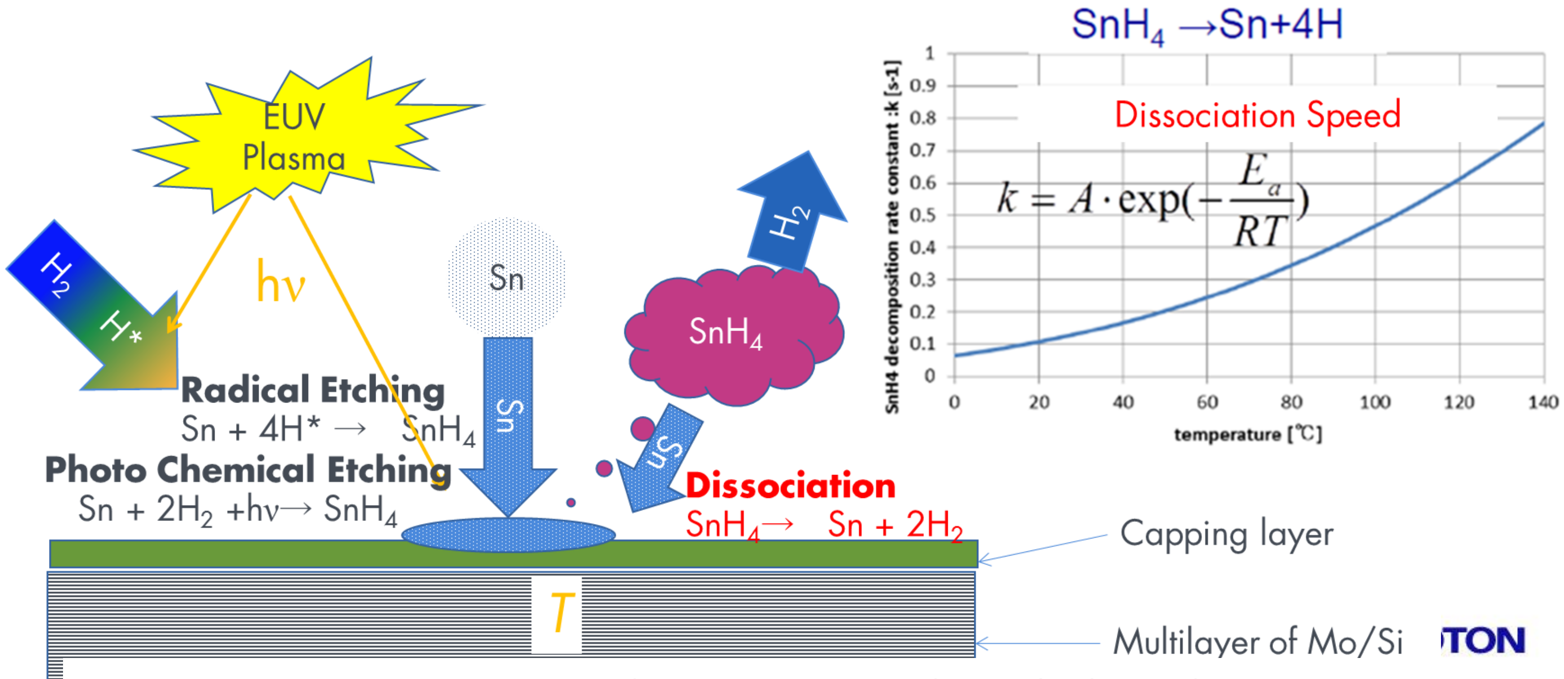
Chemical Aquarium on the Mirror Surface



- 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

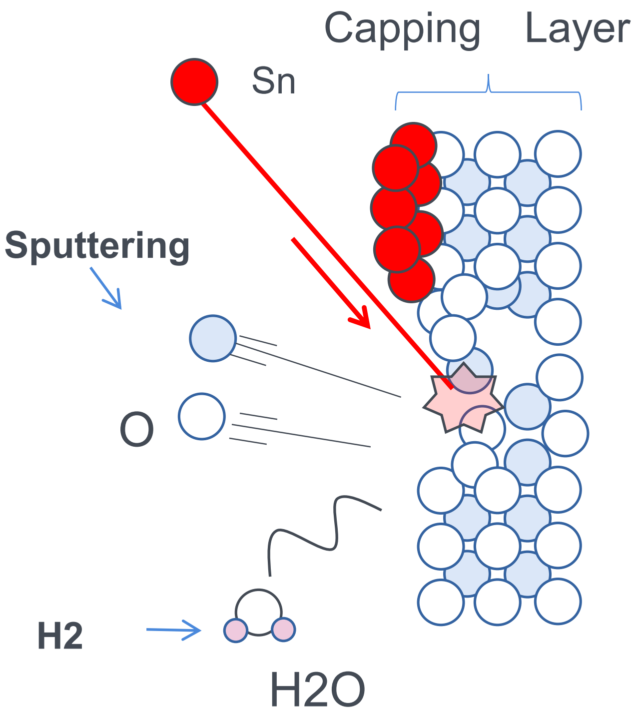
- Protection & cleaning of collector with H_2 gas
  - High energy tin neutrals are decelerated by H_2 gas in order to prevent the sputtering of the coating of collector.
  - Deposited tin on the collector is etched by H radical gas*.
  - Gas flow and cooling systems for preventing decomposition of etched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

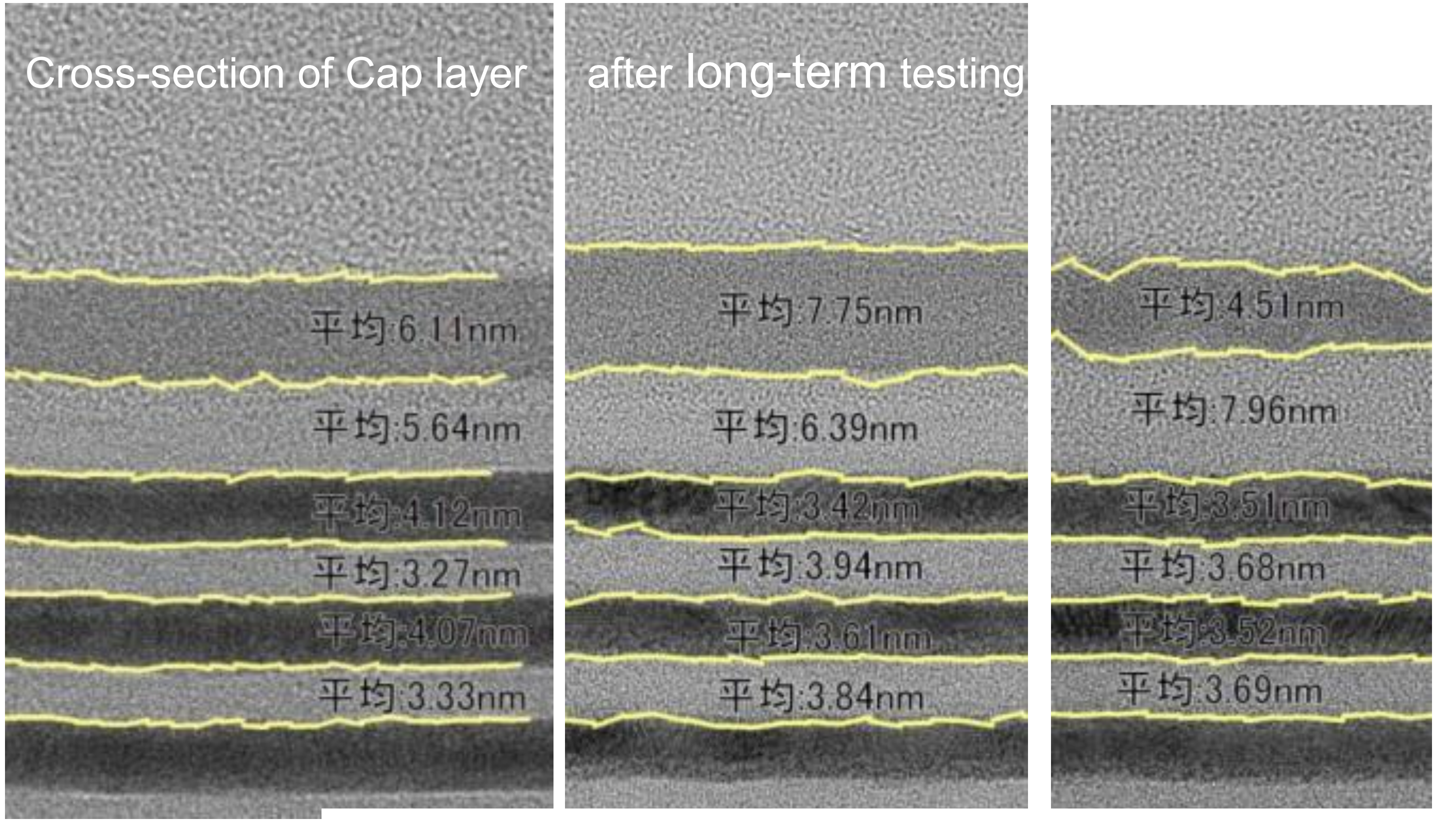
*H_2 molecules are dissociated to H radical by EUV-UV radiation from plasma.



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

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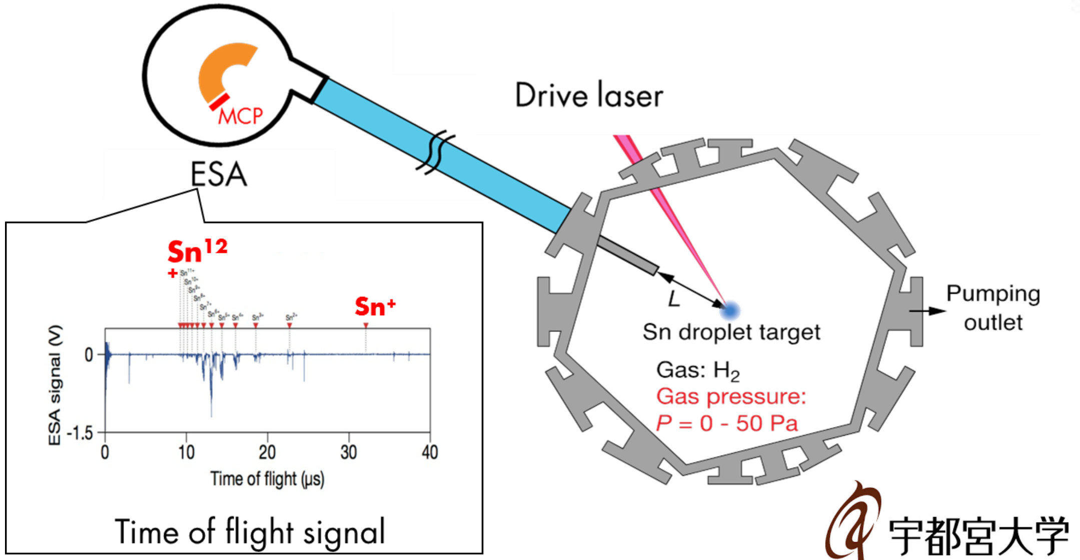
Suppression of Fast Tin Ion

- Ion energy and charge-state measurement with electro-static analyzer(ESA)
- Improvement of Ion energy distribution is essentially effective.



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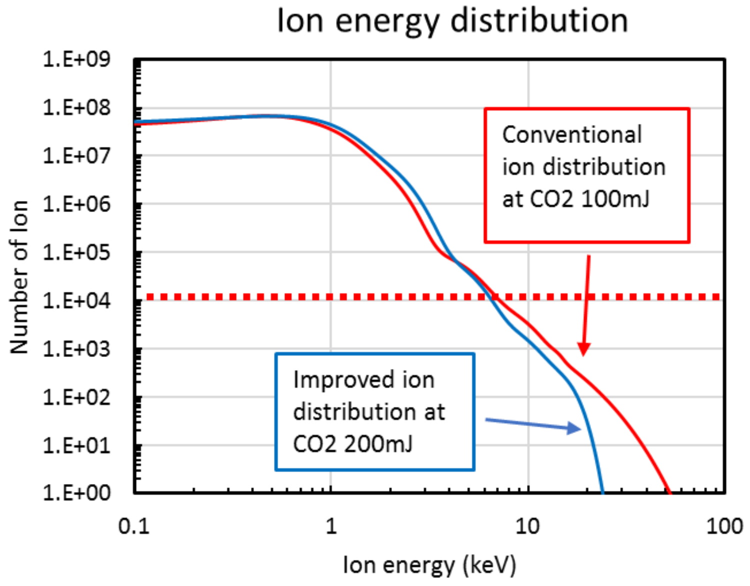
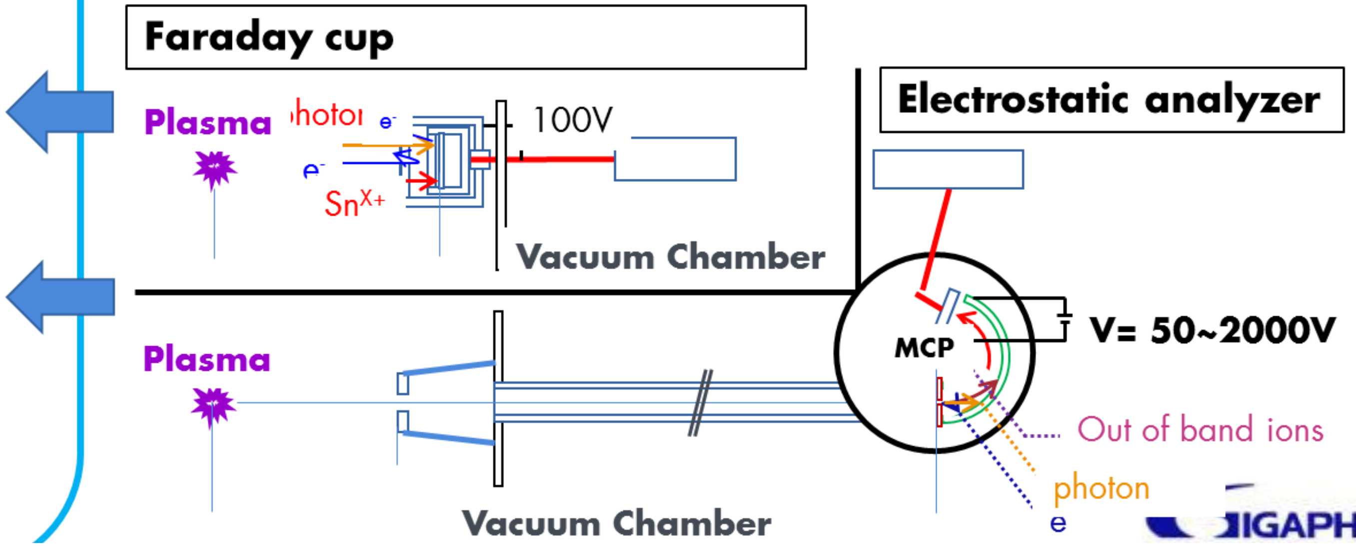




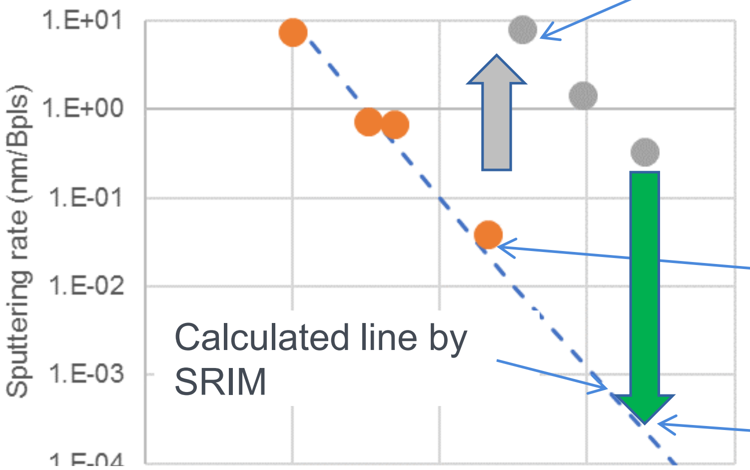
EUV Plasma Cooling

- Sputtering rate enhancement occurred by gas heating at higher output power.
- **EUV plasma cooling** is key of mirror lifetime extension at higher power operation.

<Mechanism>

Higher power → **Gas heating** → **Gas density decrease** → **Gas stopping decrease**

Sputtering rate in current set-up



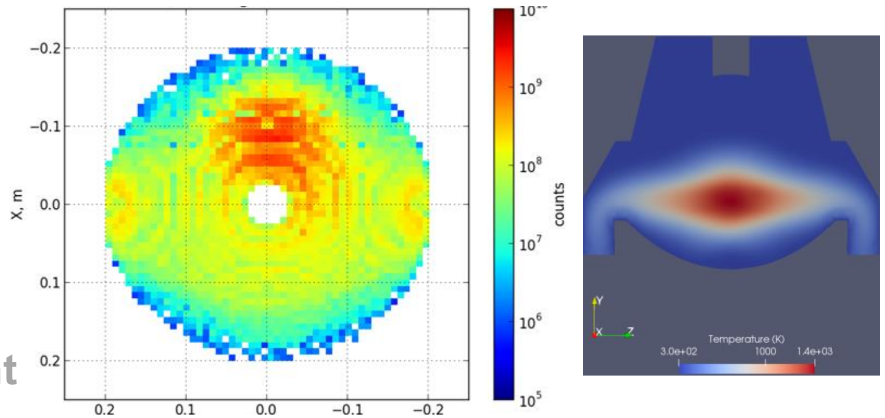
Higher plasma Temp. at Old 125W experiment

38W

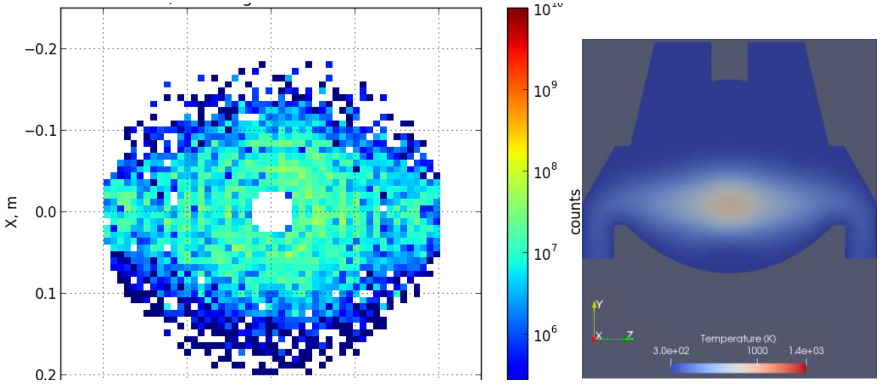
Cooled plasma temp.

New125W experiment

Higher plasma Temp.

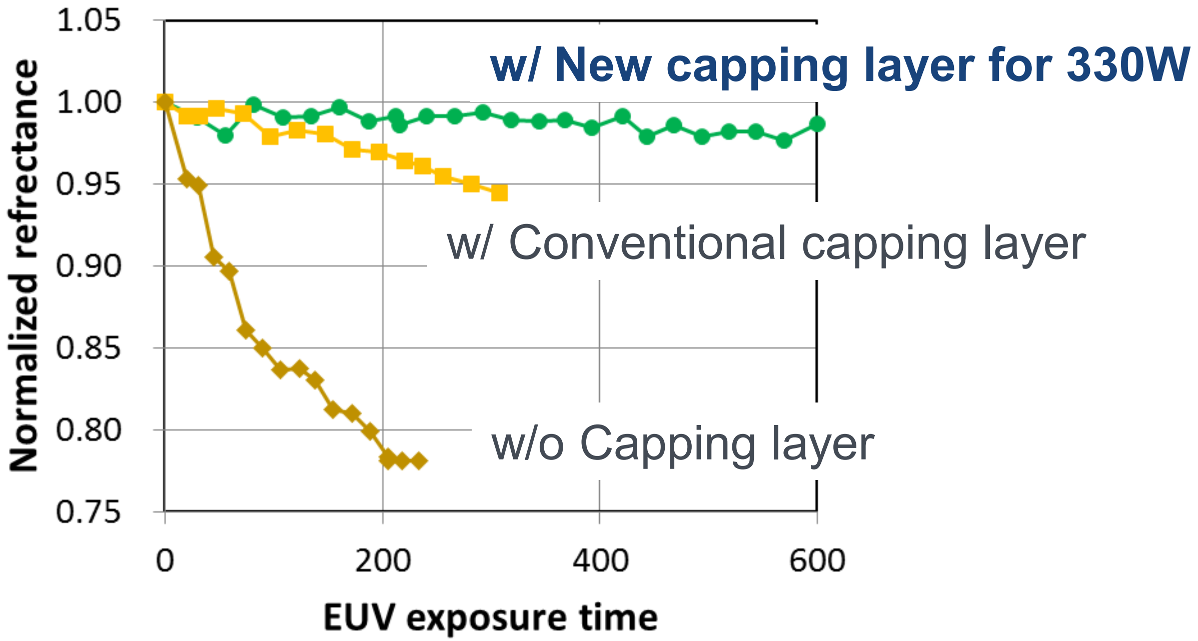


Cooled plasma temp.

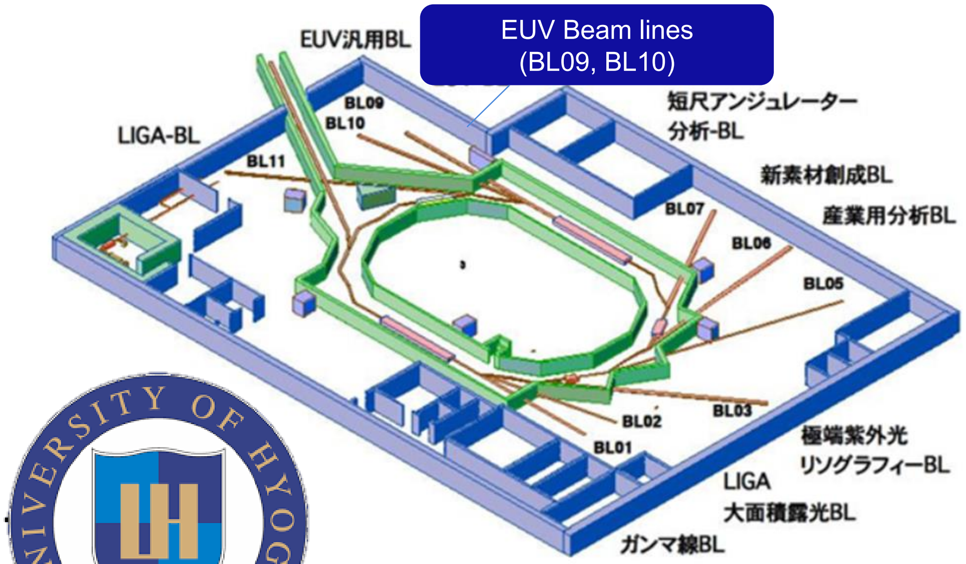


New Capping Layer Search at New SUBARU Japan

- 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

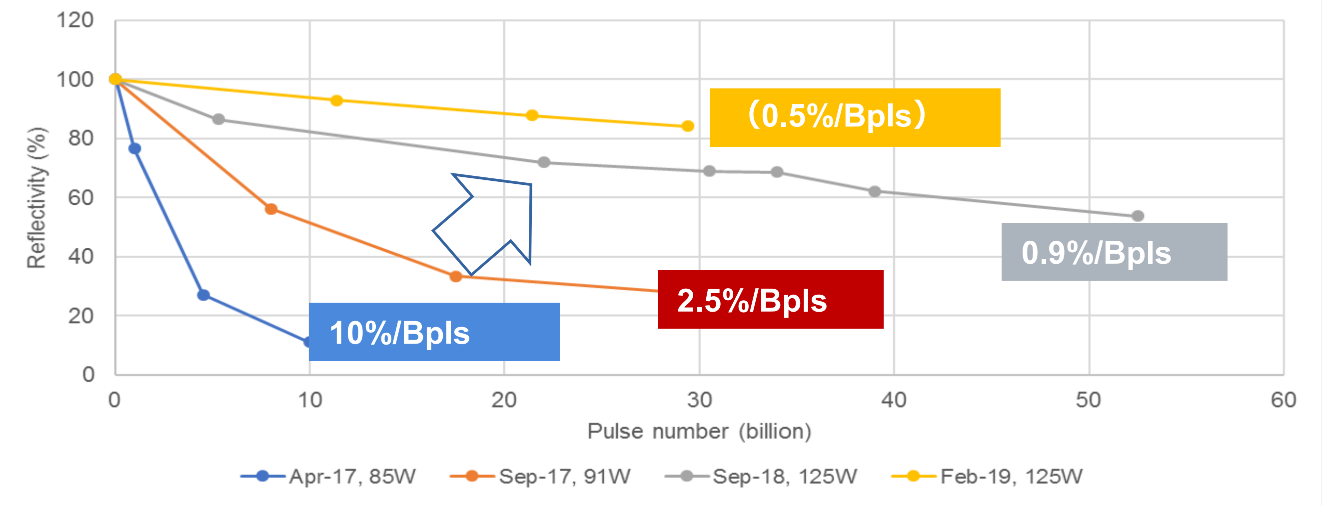


Two beam lines for EUV test in “New SUBARU”

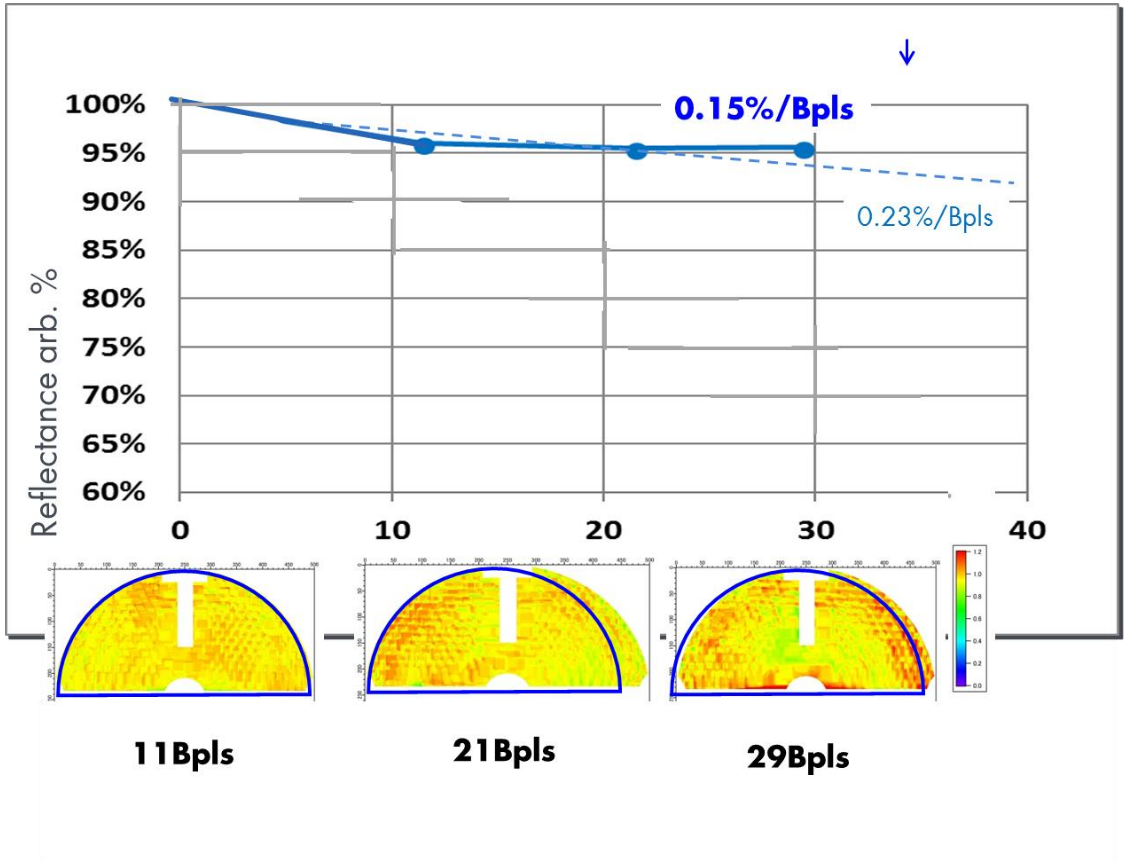
Collector Mirror: Lifetime Status

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

Data at SPIE AL-2019 (Feb.2019)



Latest Data (125W level operation; June 2019)



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Summary

EXPERIMENT-A: >330W Power Challenge of EUV Source

- *Gigaphoton redefined power target to ≧330W ave. with -0.05%/Gpls, >90% availability*
- *High conversion efficiency 5.0% is realized with improved driver laser technology.*
- *High speed (>100m/s) & small (20micron) droplet successfully stabilize EUV emission..*
- *CE enhancement >6% by plasma parameter optimization is clarified through small experimental device by Tomson scattering measurement.*
- ***CO2 laser power upgrade >27kW and Beam uniformity upgrade** is successfully done.*
- ***>350W operation is successfully demonstrated at Pilot#1 system (short term) .***

EXPERIMENT-B: Long-term Test and Challenge for Long-life Mirror and Availability

- *125W had been achieved with only 10 kW of CO2 power for around 50Bpls operation.*
- *Pilot#1 system achieved potential of >85% Availability (2weeks average).*
- ***-0.15%/Gpls with 125W ave.** was demonstrated during 30Mpls with mirror test.*
- ***230W operation is just started to prove durability of high power EUV source.***

Demonstration of Full Spec. >330W operation will be by Q4 2019

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*
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- *Prof. Takeshi Higashiguchi in Utsunomiya Univ.*
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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

GIGAPHOTON

The Future is Today