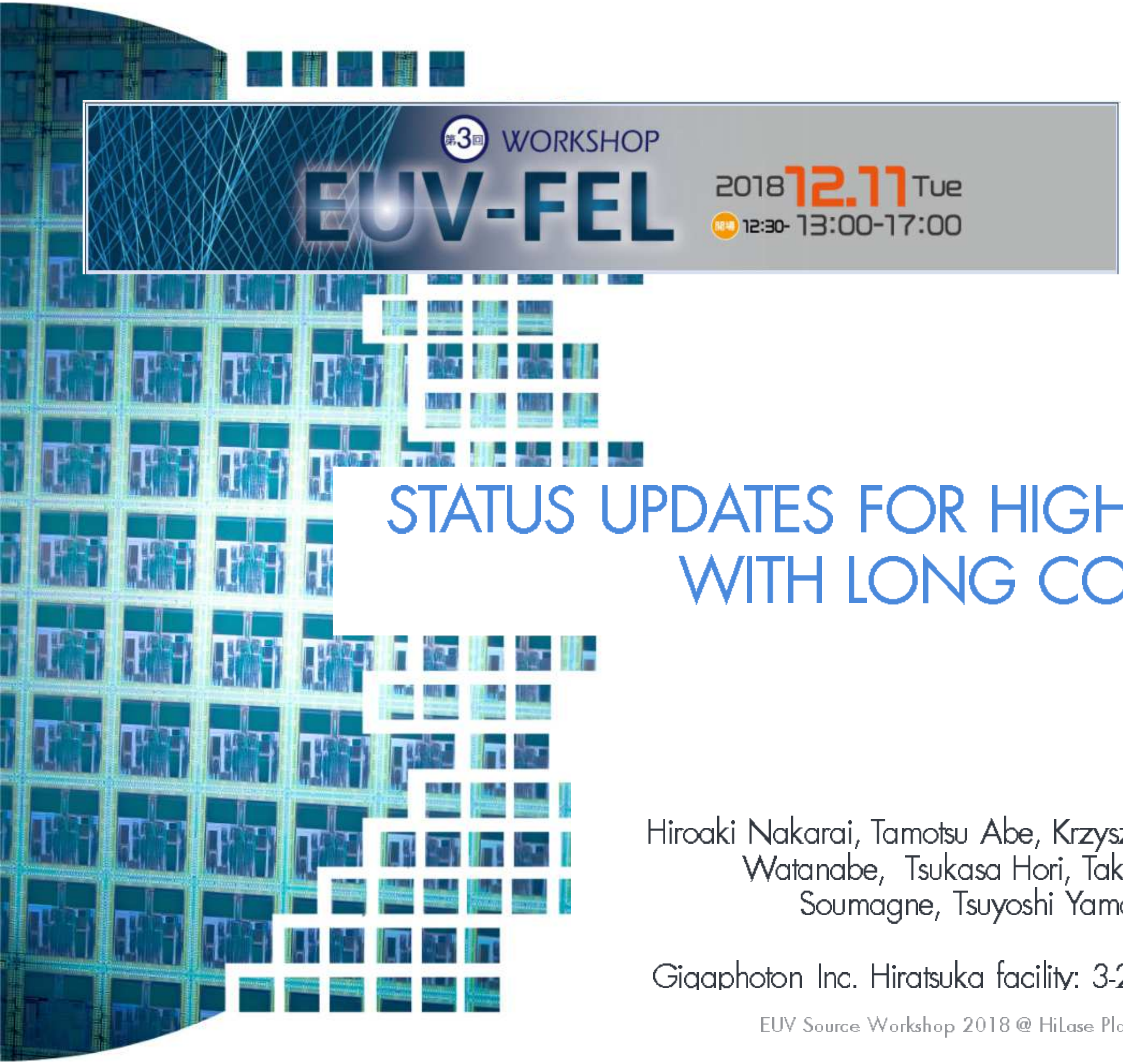
GIGAPHOTON



STATUS UPDATES FOR HIGH POWER LPP-EUV SOURCE WITH LONG COLLECTOR MIRROR LIFETIME

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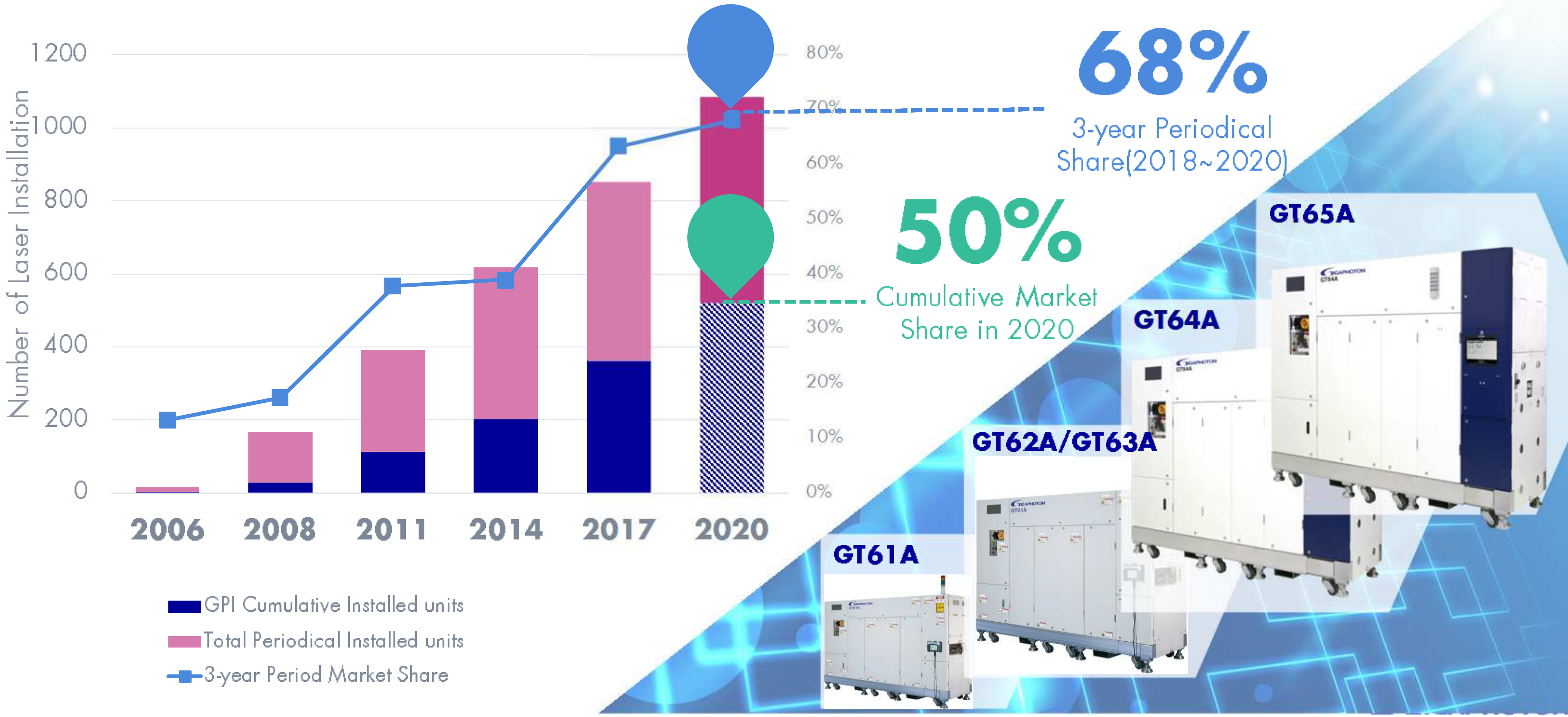
Agenda

- Introduction
- HVM Ready System Performance
    - EUV Source System
- Key Component Technology Update
    - Pre-pulse technology
    - Droplet generator
    - CO2 laser
    - Collector Mirror Life Extension
- Summary

INTRODUCTION

- EUVL-SYMPOSIUMから -

Predicted Market Share for Cutting Edge ArFi through 2020



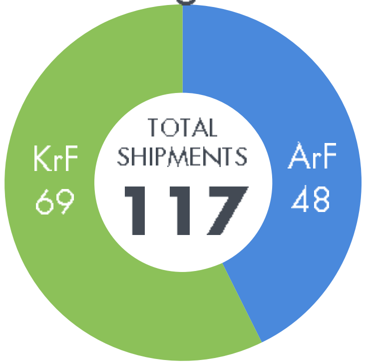
68%
3-year Periodical Share(2018~2020)

50%
Cumulative Market Share in 2020

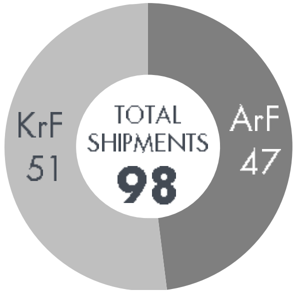
1H2018 Business Highlights

DUV Business

- In 1H2018, GPI recorded to ship 53 unit, foresee **117 unit shipment** as the projection for 2018
- Obtains high market share in China as accumulated **70%** or more.
- GPI starts to roll out Data Product : **FABSCAPE™** as open platform for big data management and analysis.



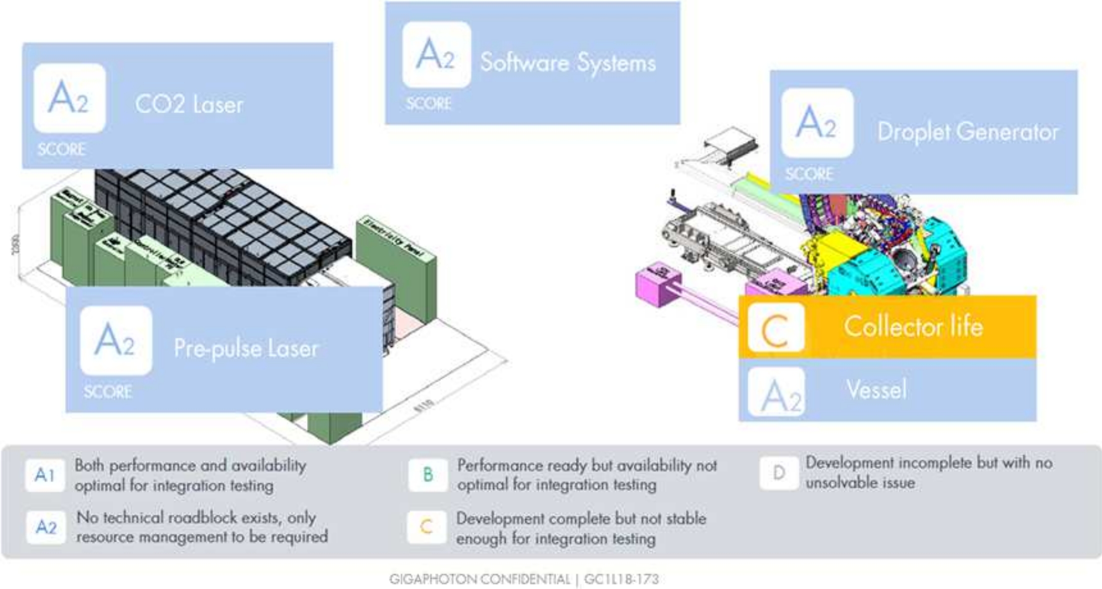
2018



2

EUV Business

EUV development has steadily progressed



A1 Both performance and availability optimal for integration testing

A2 No technical roadblock exists, only resource management to be required

B Performance ready but availability not optimal for integration testing

C Development complete but not stable enough for integration testing

D Development incomplete but with no unsolvable issue

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EUVLシンポ前後にユーザ状況がダイナミックに変化

一般情報

Date	News	出展
2018.5.15	Chinese Chipmaker SMIC Orders $120m EUV System	Nikkei Asian Review
2018.8.28	ファウンドリ大手のGLOBALFOUNDRIES、7nm開発を無期限に延期	マイナビニュース
2018.9.07	EUVプロセス開発、けん引役をTSMCに譲ったIntel	EE Times Japan
2018.10.18	Samsung、EUV 7nm LPPの開発が完了。ArF液浸露光から大幅コストダウン Low Power Plus Samsung Electronicsは10月18日(韓国時間)、EUV(Extreme Ultra-Violet：極端紫外線)露光を採用した7nm LPP(Low Power Plus)の製造技術の開発が完了し、同技術による半導体の生産を開始したと発表。さらに、3nmプロセスへのロードマップも確定させた。	PC Watch
2018.10.23	中国半導体のイノトロン、装置調達 欧州に活路 貿易戦争回避、蘭社と交渉	日本経済新聞

TSMC/Samsungの2強体制へ。Intel 日程延期、GF撤退の一方、中国が新規参戦

ASMLの状況

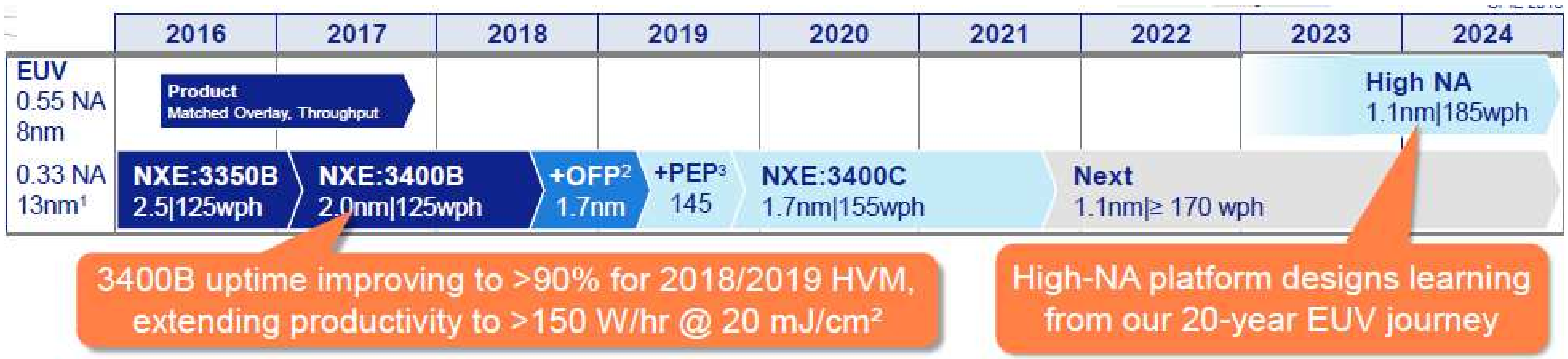
■ASMLのroadmapは変化なく、2022年まで現機種のversion upで対応。

像性能はNAに見合う13nm解像仕様を達成し、残項目はスループット向上のみ。
装置開発の主力はペリクルなどのsub-system開発/ 高NA装置にシフトか。

■高NA装置開発は着実に進行。WWで製造設備の大規模な建設が進む。

■光源はASMLがユーザ先で250W operation実施。

250W量産光源を実現と宣言、ただし市場データの詳細発表なし。瞬時450W出力確認。
GPIもcollector寿命の改善を報告。



3400B uptime improving to >90% for 2018/2019 HVM, extending productivity to >150 W/hr @ 20 mJ/cm²

High-NA platform designs learning from our 20-year EUV journey

OFP: Overlay and Focus (improvement) Package
PEP: Productivity Enhancement Package

NXE-3400

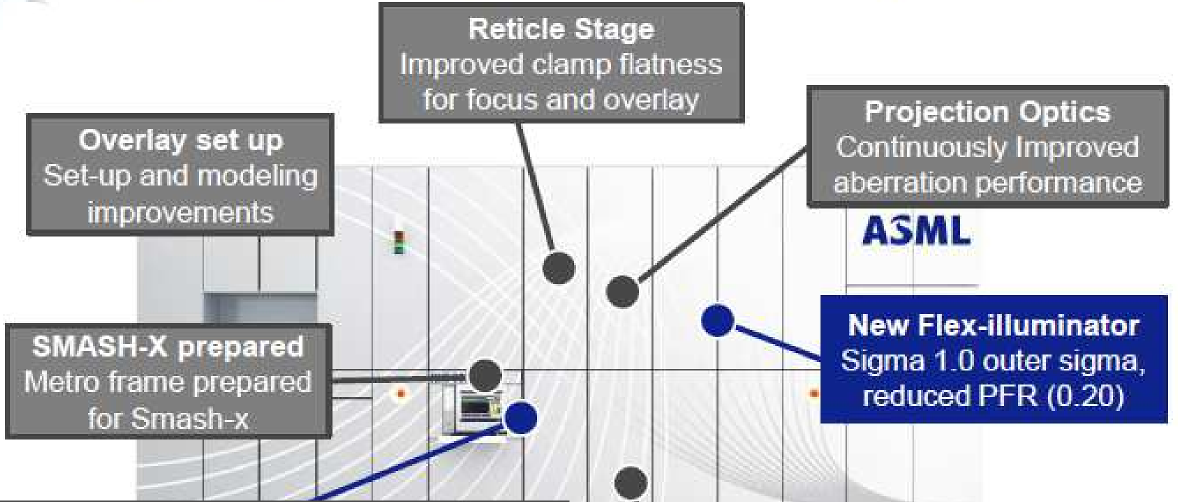
Shipment in 2017

NXE:3400B: 13 nm resolution at full productivity

Supporting 5 nm logic, <15nm DRAM requirements

ASML

Public
Slide 10
EUVL 2017



Reticle Stage
Improved clamp flatness for focus and overlay

Projection Optics
Continuously Improved aberration performance

Overlay set up
Set-up and modeling improvements

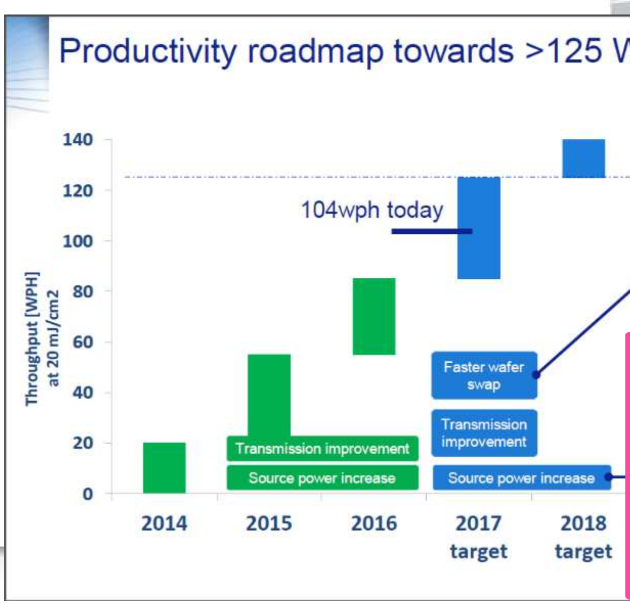
New Flex-illuminator
Sigma 1.0 outer sigma, reduced PFR (0.20)

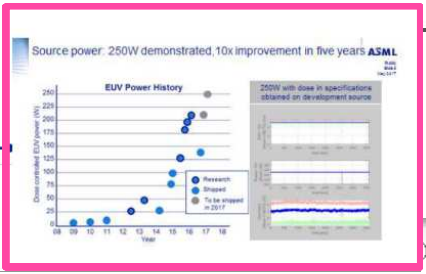
SMASH-X prepared
Metro frame prepared for Smash-x

Wafer Stage
Flatter clamps, improved dynamics and stability

Resolution	13 nm
Full wafer CDU	≤ 1.1 nm
DCO	≤ 1.4 nm
MMO	≤ 2.0 nm
Focus control	≤ 60 nm
Productivity	≥ 125 WPH

▬ Overlay
▬ Imaging/Focus
▬ Productivity



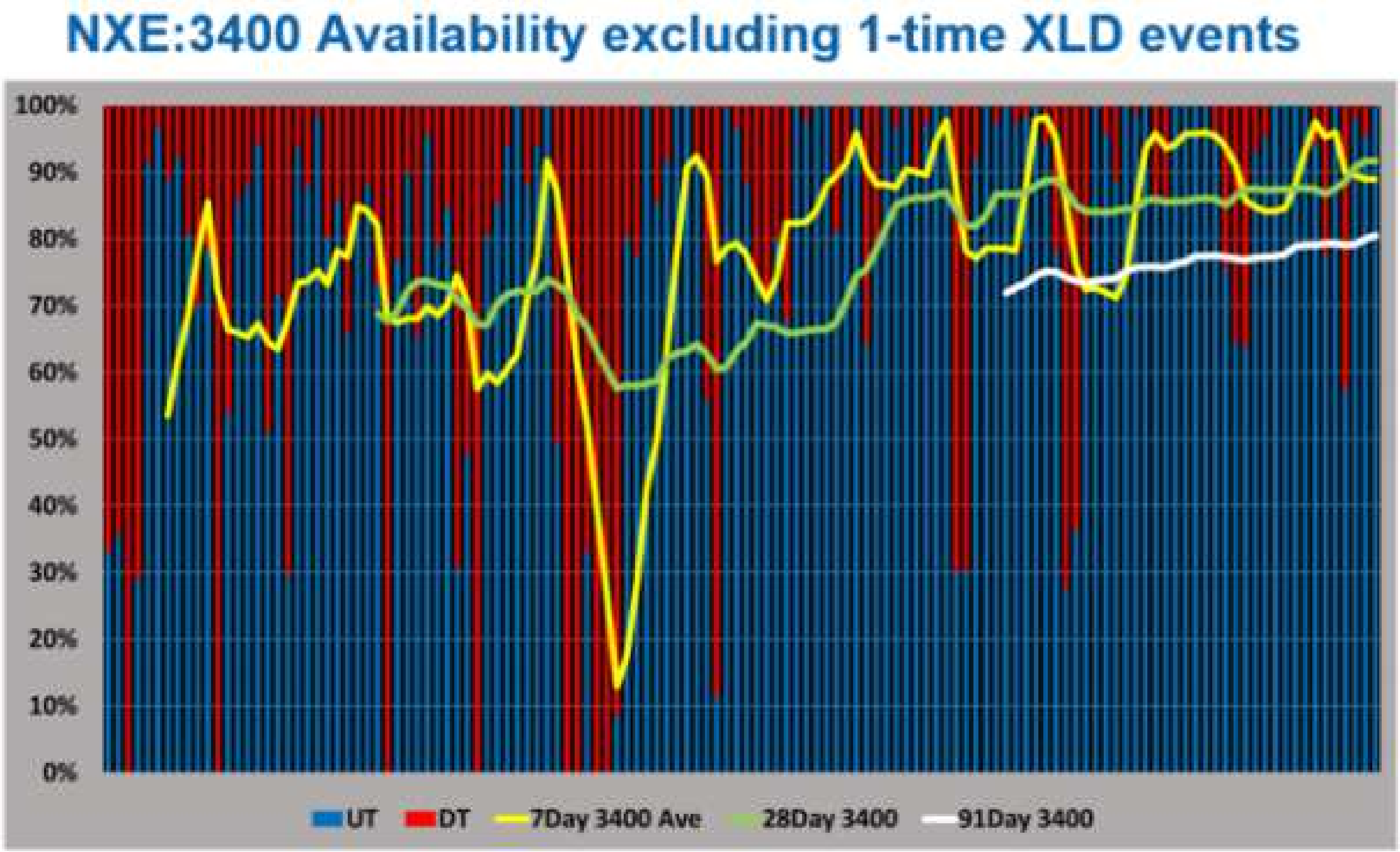


Igor Fomenkov (ASML); "EUV Lithography: Progress in LPP Source Power Scaling and Availability", EUVL workshop 2017, 2017/6/12-15 Berkeley, USA

←*Still Source Power is large issue.*

125W at present (Target 250W)

Availabilityの向上



"EUV industrialization high volume manufacturing with NXE3400B" by Marcel Mastenbroek
or
"NXE:3400B EUV source performance in the field, readiness for HVM and power scaling beyond 250W" by Igor V. Fomenkov, Michael A. Purvis, Alexander A.Schafgans, Yezheng Tao, Slava Rokitski, et al.

EUVL workshop 2018, 2018/6/12-15 Berkeley, USA

量産導入を控えWWデータ4週間平均が70～80%まで向上した。

250W光源は量産機モジュールを開発

"EUV industrialization high volume manufacturing with NXE3400B" by Marcel Mastenbroek
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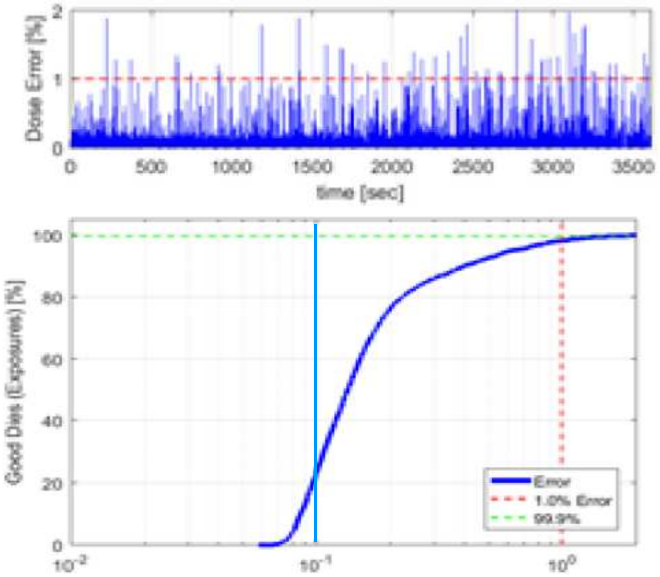
/6/12-15 Berkeley, USA

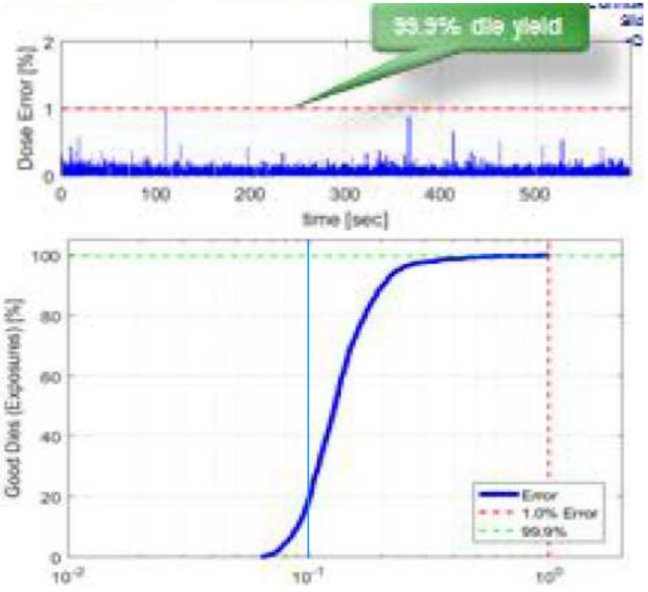
Proto 1

May 2017
@ 250W



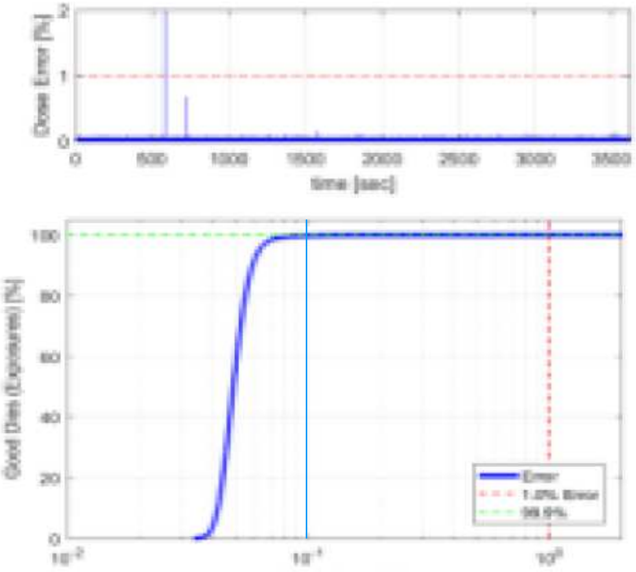
Pre-Pilot

July 2017
@ 250W / 125wph



Industrialized module

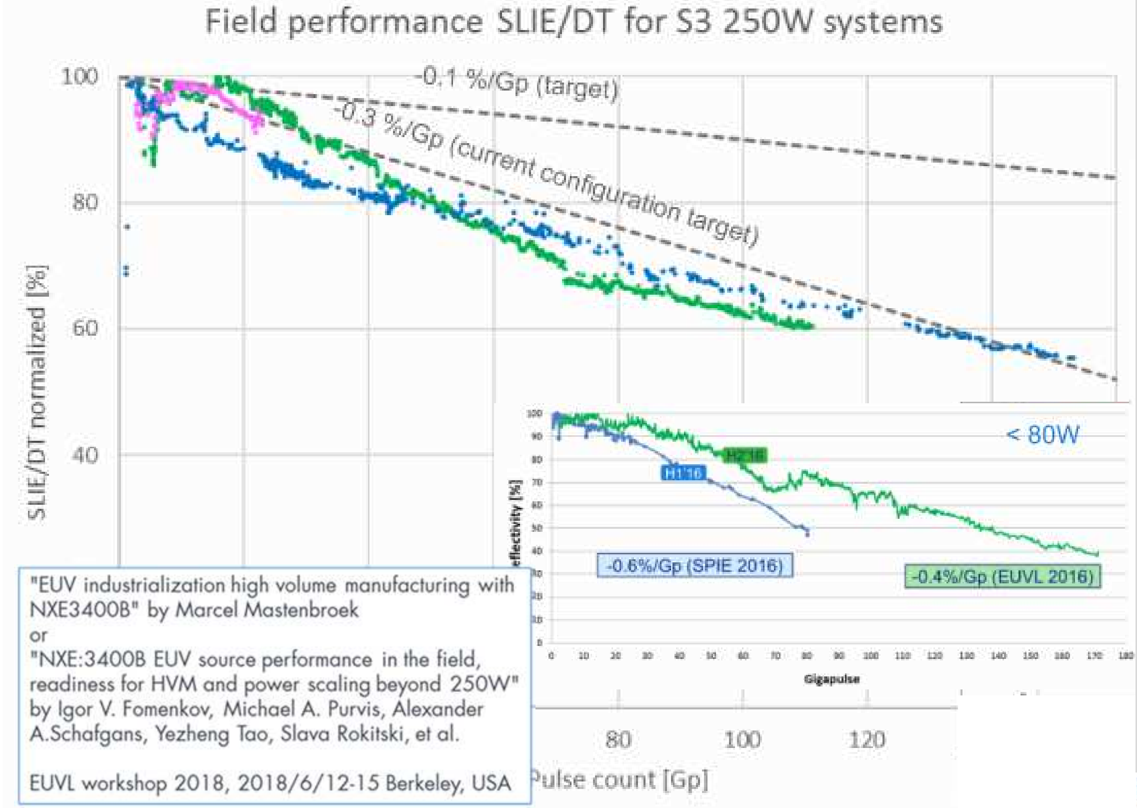
December 2017
@ 250W



2017年5月のプロトから12月量産機まで制御性を大幅に改善

課題のCollector寿命の状況

ASML



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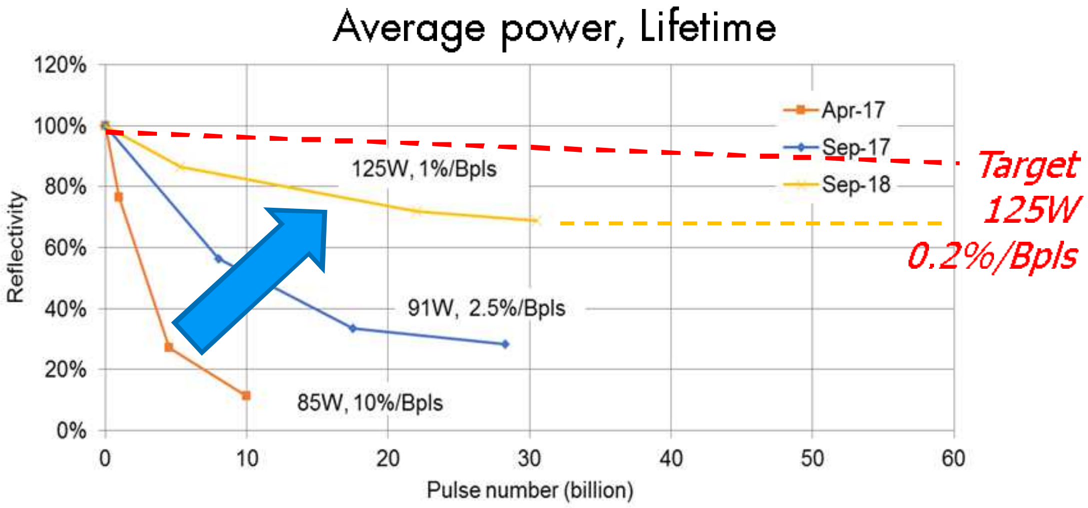
EUVL workshop 2018, 2018/6/12-15 Berkeley, USA

GPI



ASMLは250Wで▲0.3%/BPを達成、GPIは125Wで▲0.2%/BPの目途。

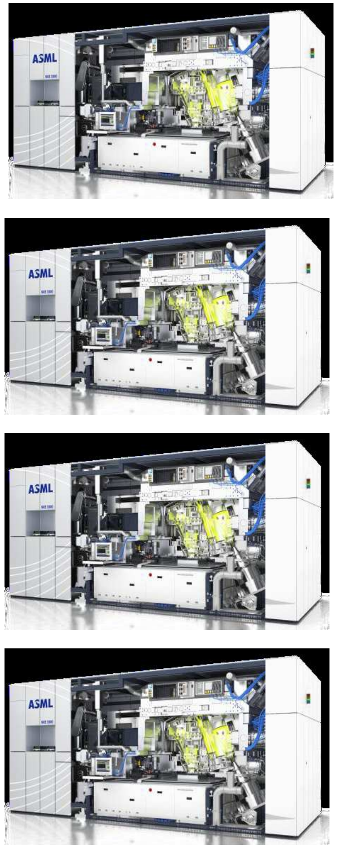
EUV露光装置の処理能力実績

（ギガフォトン鈴木章義氏試算）

液浸露光装置

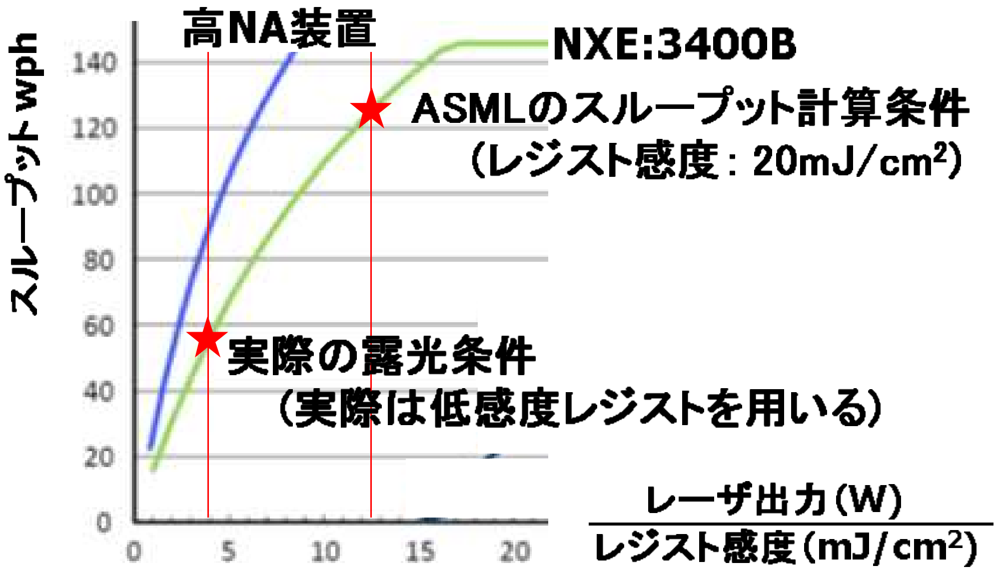
4,000～5,000wpd
(市場実績)

EUV露光装置



Imbalance

実績：1,000～1,200wpd

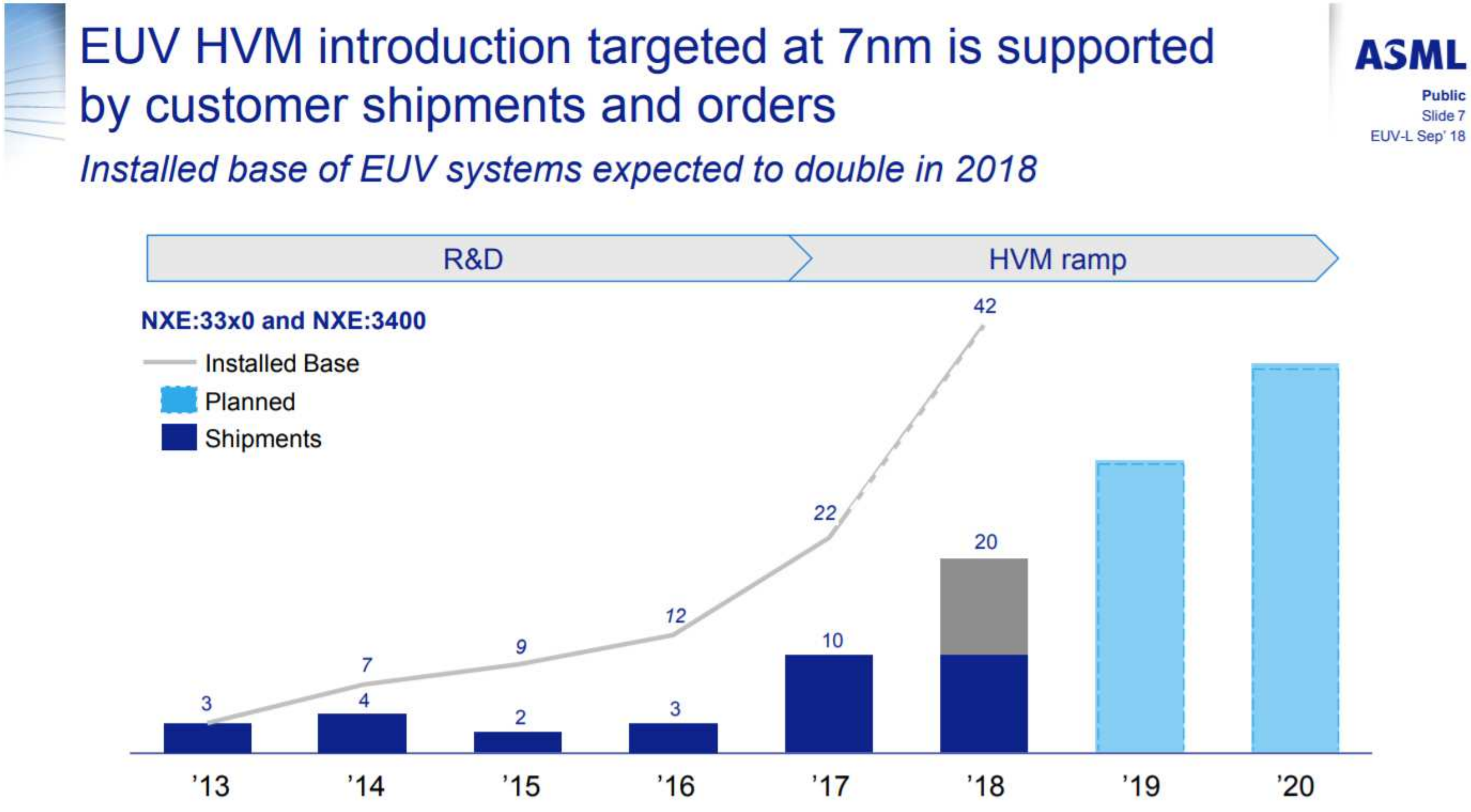


実際の素子の露光条件でのEUV装置の処理能力は1000～1200 wafers/dayと液浸装置の1/4

複数のEUV装置間の互換性検討の報告は未だない

EUVは液浸に比べ処理能力が低い状況でも対応できる製品で生産開始予定。

Logic: Demand of EUV is increasing



EUV HVM introduction targeted at 7nm is supported by customer shipments and orders

Installed base of EUV systems expected to double in 2018

ASML

Public
Slide 7
EUV-L Sep' 18

"EUV industrialization high volume manufacturing with NXE3400B" by Marcel Mastenbroek
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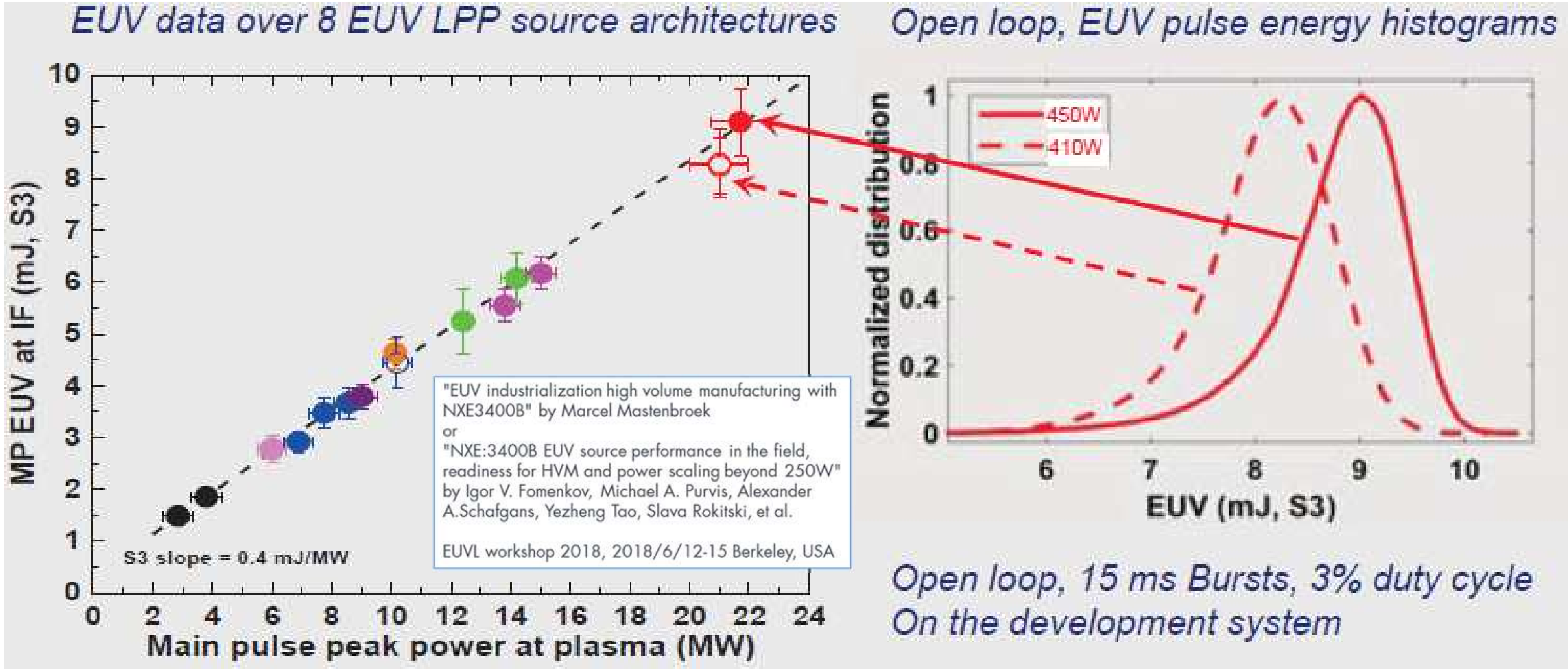
EUVL workshop 2018, 2018/6/12-15 Berkeley, USA

ASML光源　瞬時（0.015秒間）動作で450Wを確認



EUV data over 8 EUV LPP source architectures

Open loop, EUV pulse energy histograms

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EUVL workshop 2018, 2018/6/12-15 Berkeley, USA

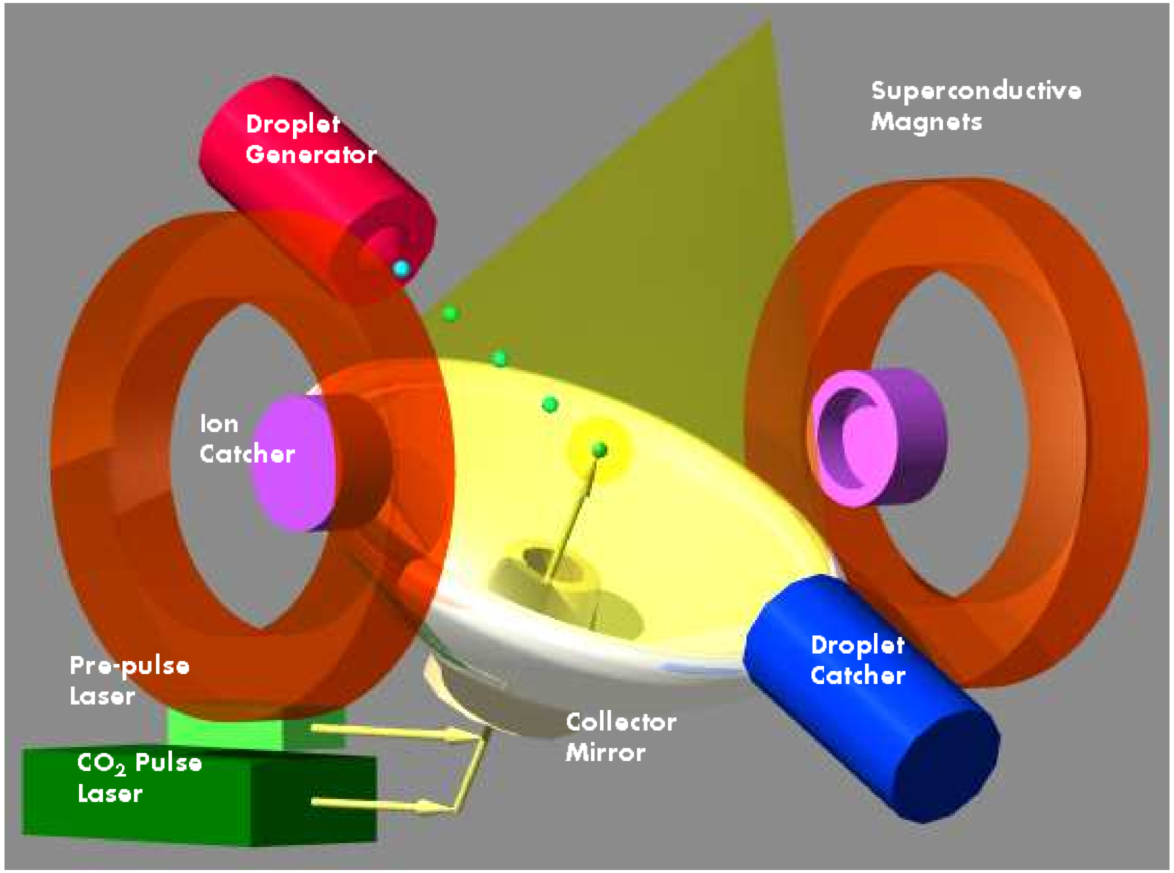
Open loop, 15 ms Bursts, 3% duty cycle
On the development system

瞬時動作で450W出力（In burst、3%duty、オープンループ、平均出力13W）を確認
Control マージンを約25%と考えると換算：330W程度の定格出力に相当か

HVM READY SYSTEM PERFORMANCE

Gigaphoton LPP Source Concept

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



Target System Specification

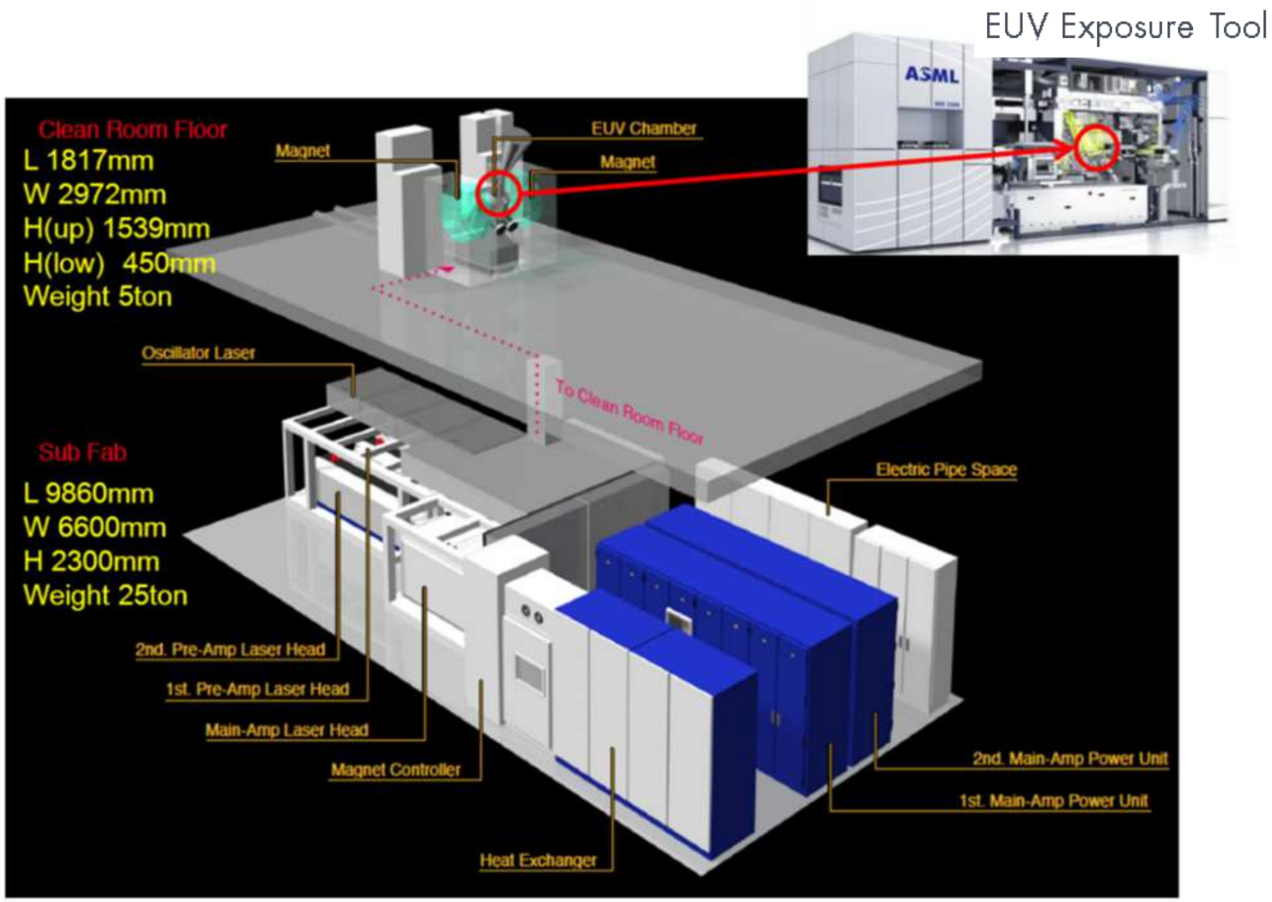
		Proto#1 Proof of Concept	**Proto#2** Key Technology	**Pilot#1** **HVM Ready**
Target Performance	EUV Power	25W	>100W	**250W**
	CE	3%	> 4%	**> 5%**
	Pulse Rate	100kHz	100kHz	**100kHz**
	Output Angle	Horizontal	62°upper	**62°upper**
	Availability	~1 week	~1 week	**>80%**
Technology	Droplet Generator	20 - 25μm	< 20μm	**< 20μm**
	CO_2 Laser	5kW	20kW	**27kW**
	Pre-pulse Laser	picosecond	picosecond	**picosecond**
	Collector Mirror Lifetime	Used as development platform	10 days	**> 3 months**

Layout of 250W EUV Light Source Pilot #1

First HVM EUV Source

- 250W EUV source

Operational specification (Target)			HVM Source
Performance	EUV Power		> 250W
	CE		> 4.0 %
	Pulse rate		100kHz
	Availability		> 80 %
Technology	Droplet generator	Droplet size	< 20mm
	CO2 laser	Power	> 20kW
	Pre-pulse laser	Pulse duration	psec
	Debris mitigation	Magnet, Etching	> 15 days (>1500Mpls)



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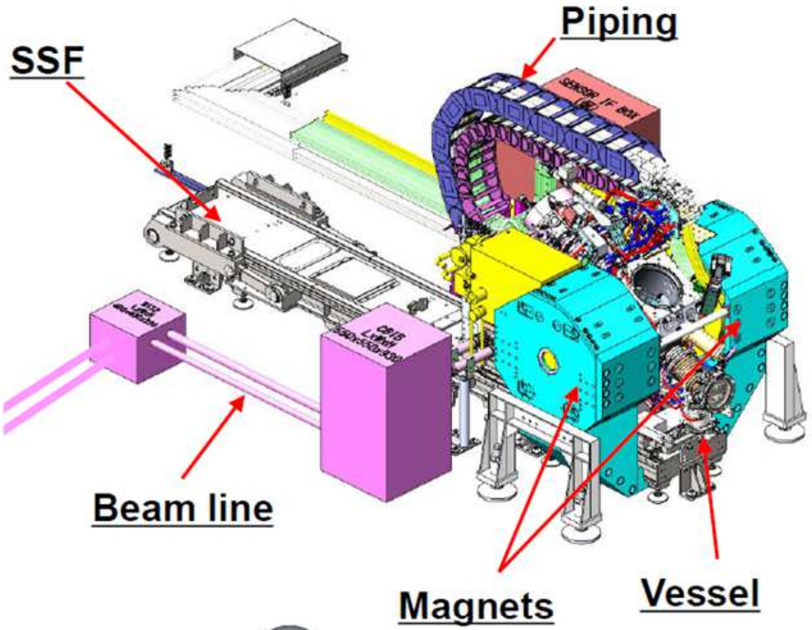
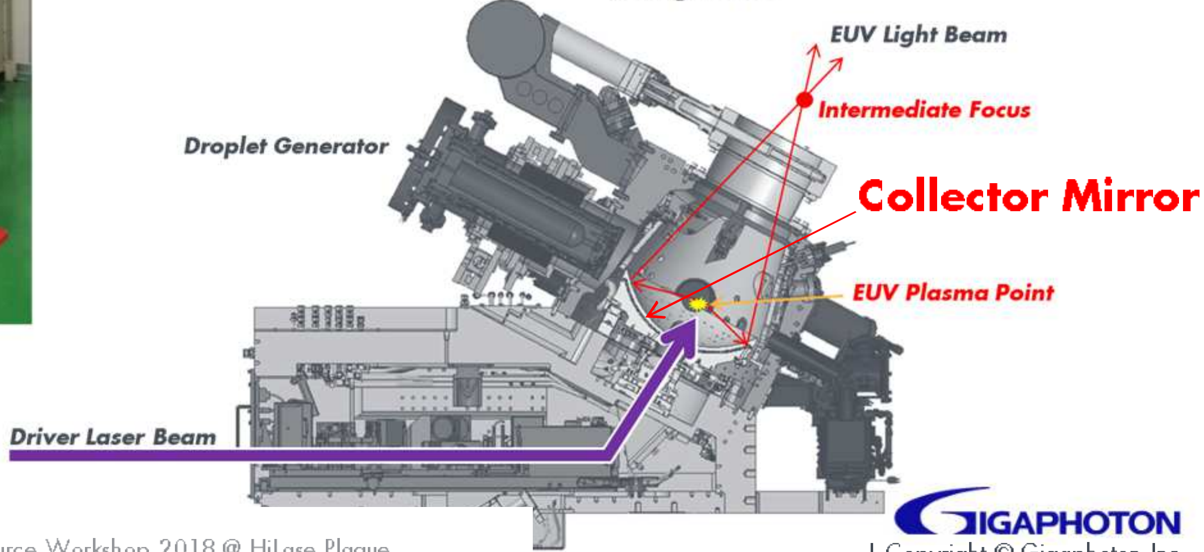
Pilot System EUV Chamber



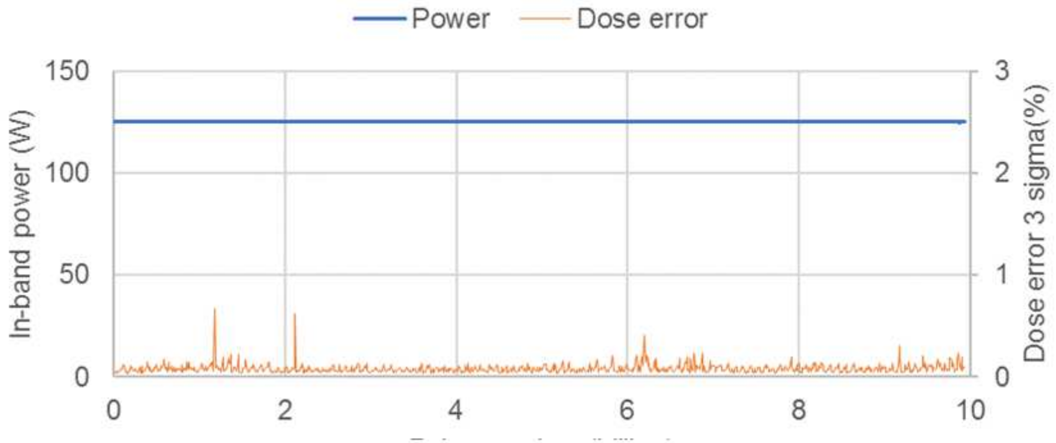


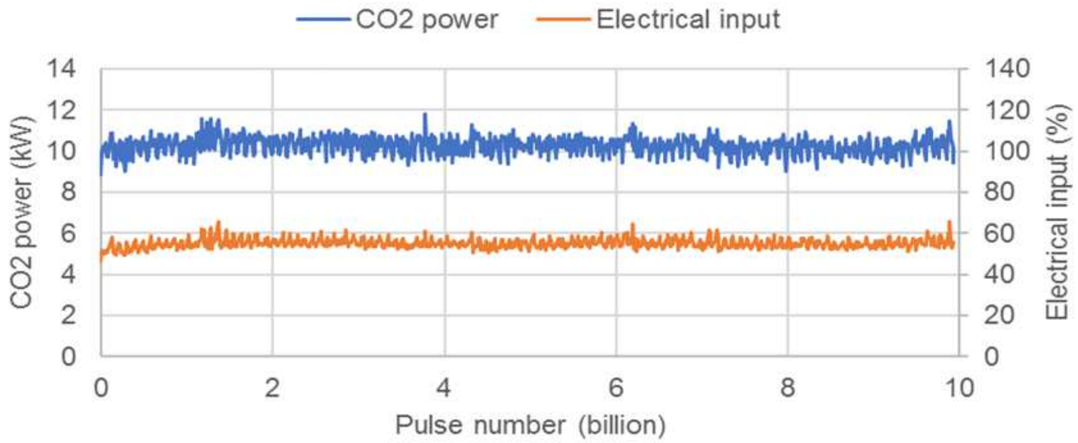
4-7. System Performance: 125W Operation Data

	Performance
Average power at IF	**125W**
Dose error (3 sigma) *1	**0.09%**
Die yield (<0.16%)*2	**96.9%**
Operation time	**28h**
Pulse Number	**10Bpls**
Duty cycle	**100%**
In-band power	**125W**
Dose margin	**30%**
Collector lifetime *3	**--**
Repetition rate	**100kHz**

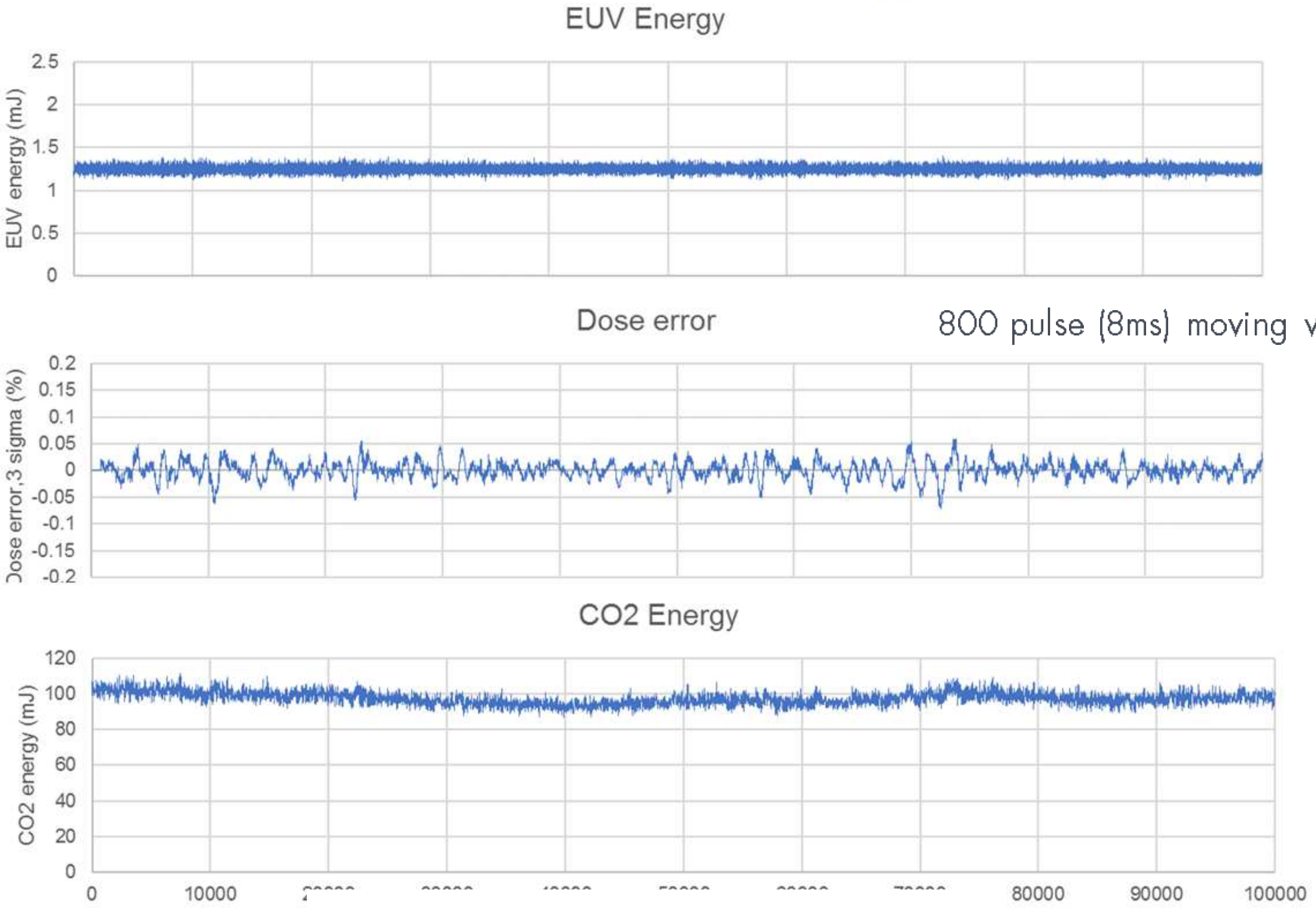
Note

*1: Dose error is defined by 800 pulse (8 ms) moving window
*2 Dose performance failure is mainly due to droplet combination failure
*3: Dummy mirror was used for investigation.





4-8. System Performance: Pulse to Pulse Operation Data

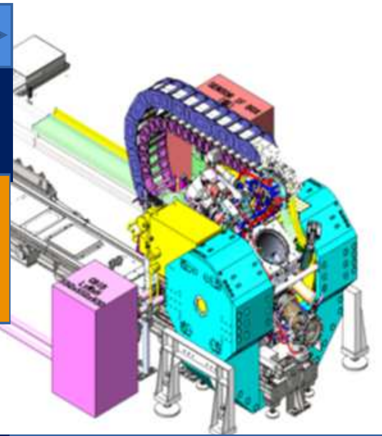


800 pulse (8ms) moving window

KEY COMPONENT TECHNOLOGY UPDATE

Gigaphoton EUV Technology for Lower CoO

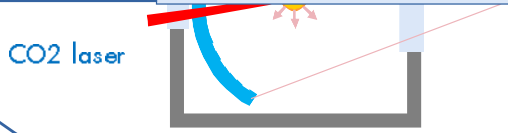
4. Debris Mitigation by Magnet



2. Pre-pulse laser

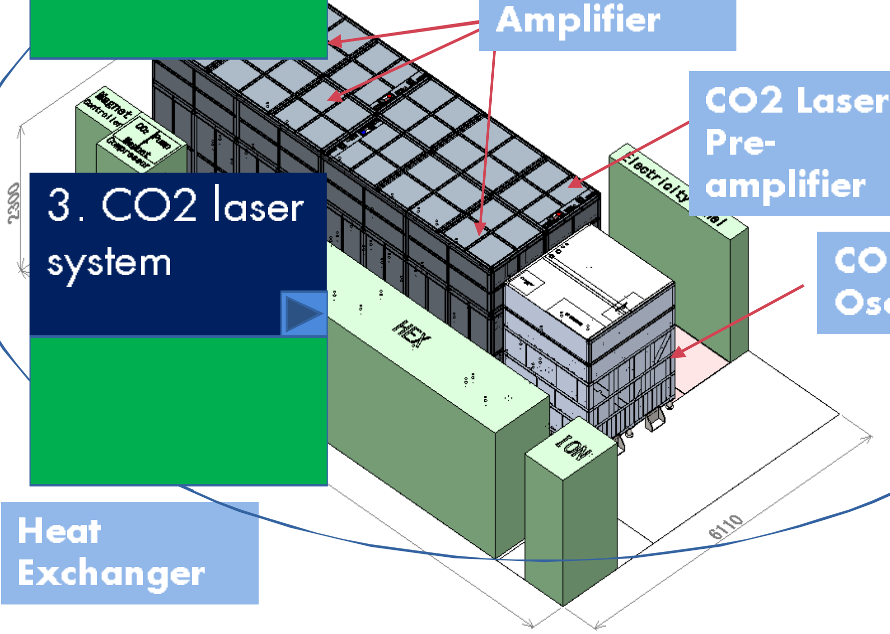
1.Droplet Generator

- ✓ 100kHz (2x) rep rate
- ✓ 90m/sec DL speed
- ✓ 900um droplet distance
- ✓ 20um small droplet
  - =>less contamination
  - =>longer DLG life



Chamber

3. CO2 laser system



CO2 Laser Amplifier

CO2 Laser Pre-amplifier

CO2 Laser Oscilator

Heat Exchanger

1-1. Gigaphoton EUV Technology : Droplet Generator

- Benefit: Small sized high speed droplets
  - **Less debris and 3x tin reservoir lifetime** due to 1/3 volume against conventional droplets
  - High speed droplets to support up to 100kHz operation, **doubling the today's source**

	Conventional	**GPI**	**Remark**
Droplet speed	(60m/s)	**90m/sec**	Influence from plasma is ½ vs conventional technology because the distance of 2 droplet is 1.5x
Frequency	50kHz	**100kHz**	High frequency enables to reduce one plasma energy by half to reduce Sn contamination
Droplet size	30 micron	**20 micron**	1/3 in Sn volume. Less contamination on the corrector mirror

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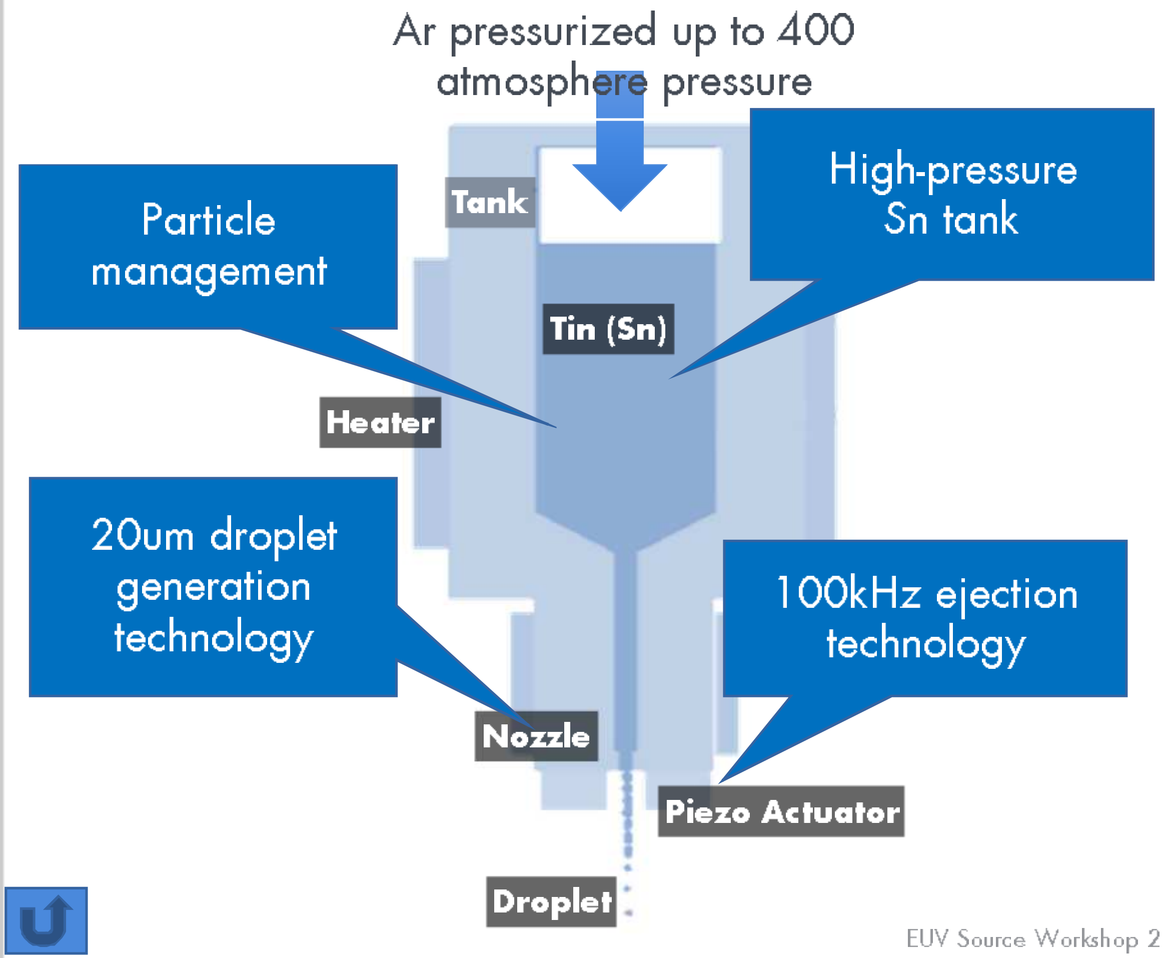
1-2. Droplet Generator



Ar pressurized up to 400 atmosphere pressure

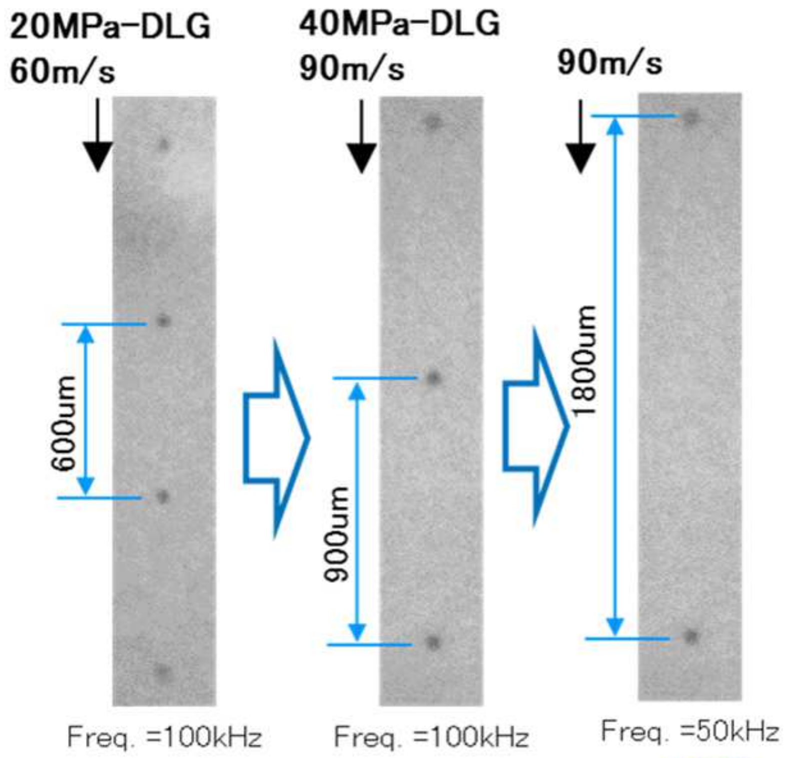
Particle management

High-pressure Sn tank

20um droplet generation technology

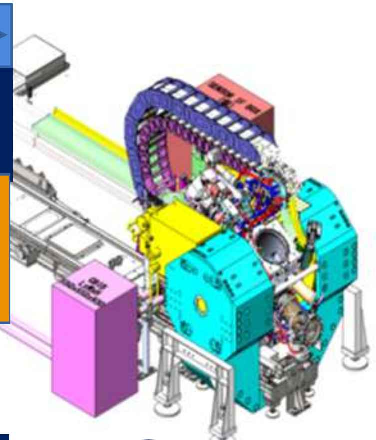
100kHz ejection technology

Diameter 20um position stability <+/- 5um

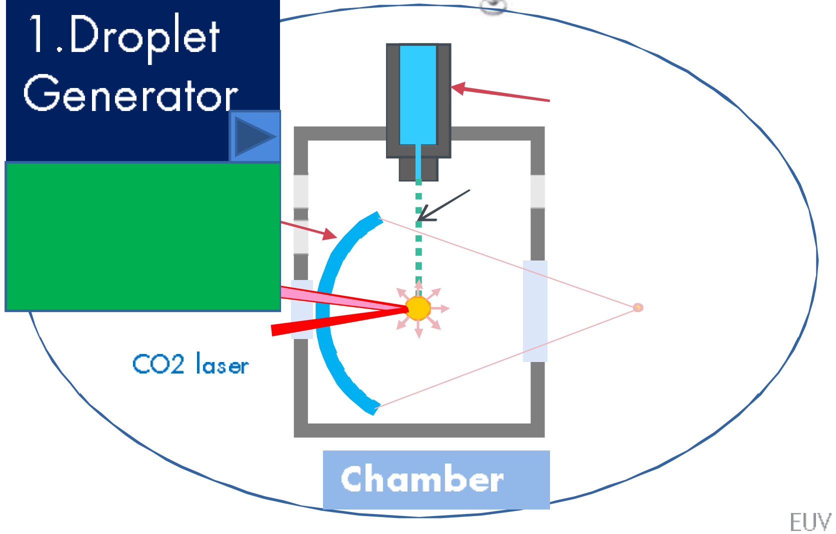


Gigaphoton EUV Technology for Lower CoO

4. Debris Mitigation by Magnet



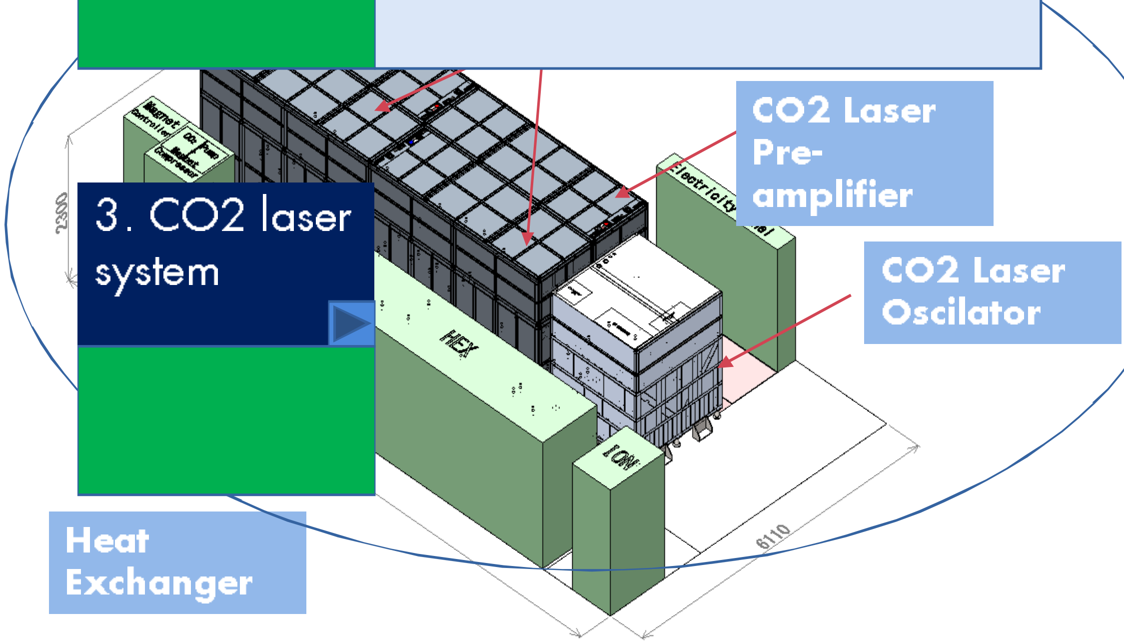
1.Droplet Generator



2. Pre-pulse laser

- ✓ Pico sec 1um pre-pulse
- ✓ Ideal dome mist
- ✓ >5% EUV CE

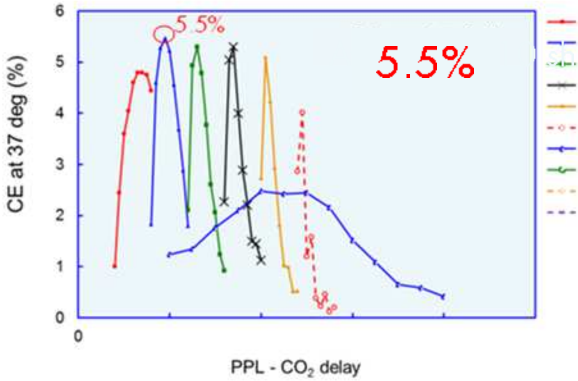
3. CO2 laser system



2-1. Gigaphoton EUV Technology : Pre-pulse technology

Benefit

- Highest **CE (Conversion Efficiency) at 5%** demonstrated
- Supports growing demand for **high power >500W**
- Run with less resources such as electricity/water/gas

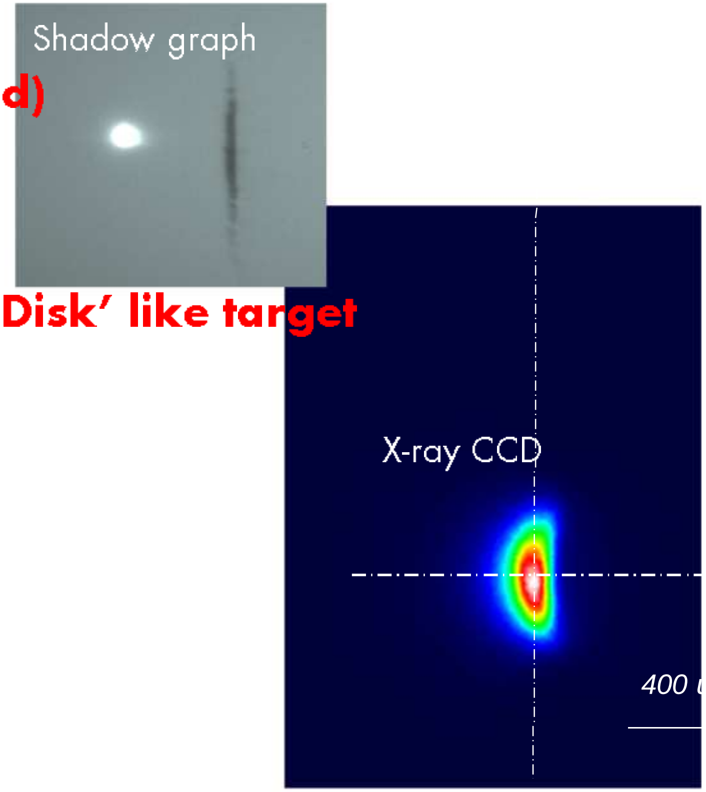


	Conventional	**GPI**	**Remark**
Pulse duration	(Nano sec)	**Pico sec**	High EUV CE >5%
WL of pre-pulse	10.6um	**1um**	Separate pre-pulse unit provide flexibility for the optimization for long term operation
Optical path	2 optical path	**Coaxial**	Pre-pulse beam with the same optical path as main CO2 beam. Shorter beam axis alignment time.

2-2. Pre-pulse technology

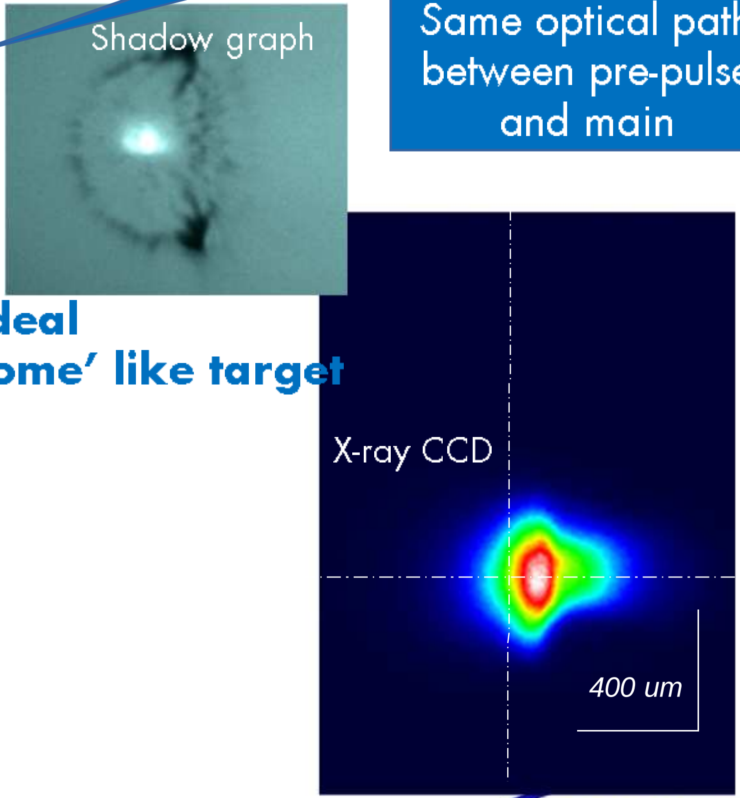
- Advantage of pico-second pre-pulse over nano-second

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



'Disk' like target

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



**Ideal
'Dome' like target**

Very short pulse duration with 1um wavelength laser

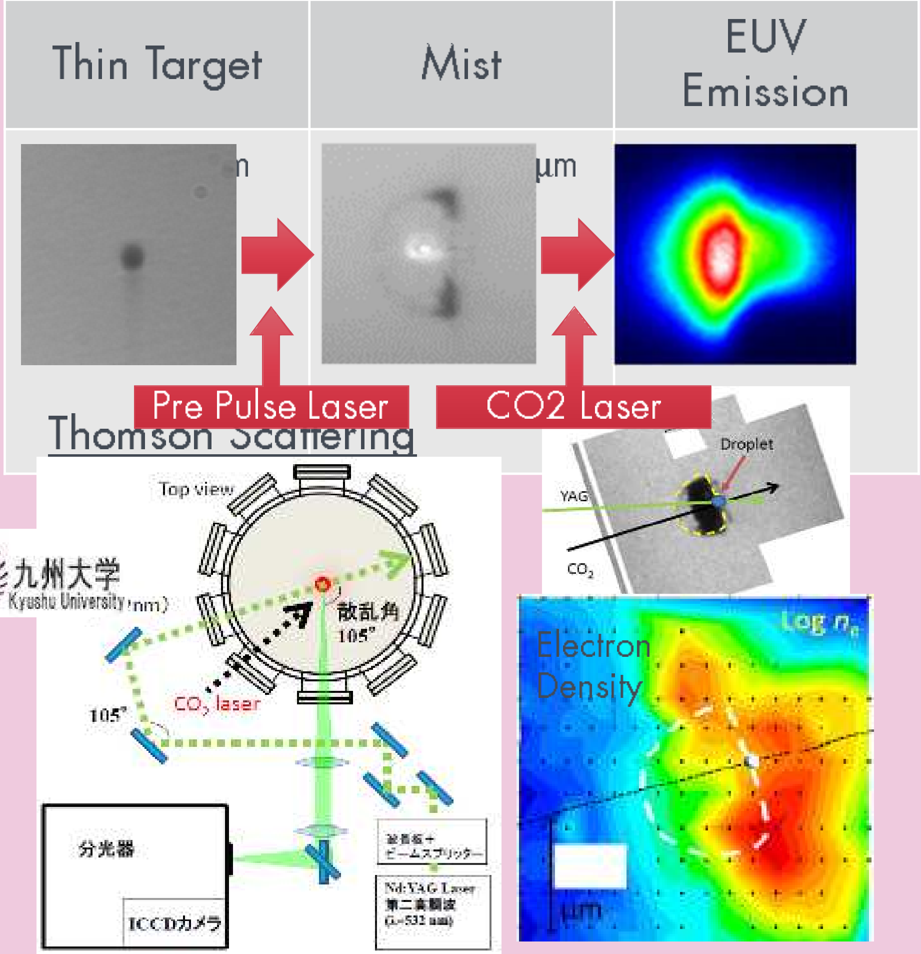
Same optical path between pre-pulse and main

2-3. Pre-Pulse Technology

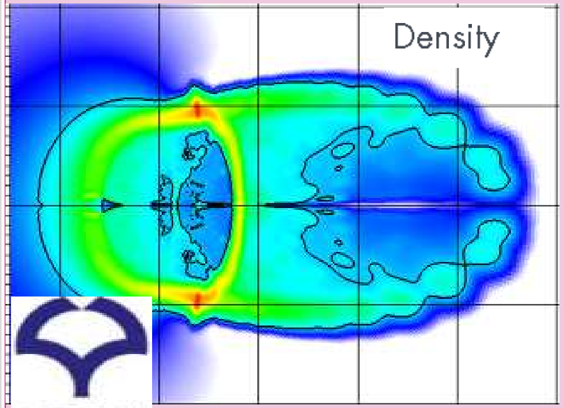
Collaborated with

- ***Comparison between Thomson scattering Measurements and plasma simulation results for a EUV lithography source plasma (Gigaphoton)***

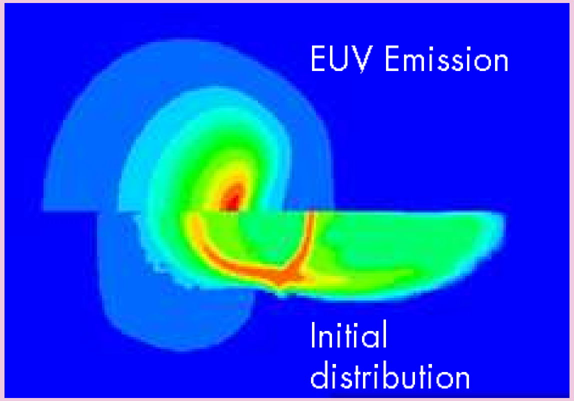
  -> Poster P-ET-05 by Dr. George Soumagne



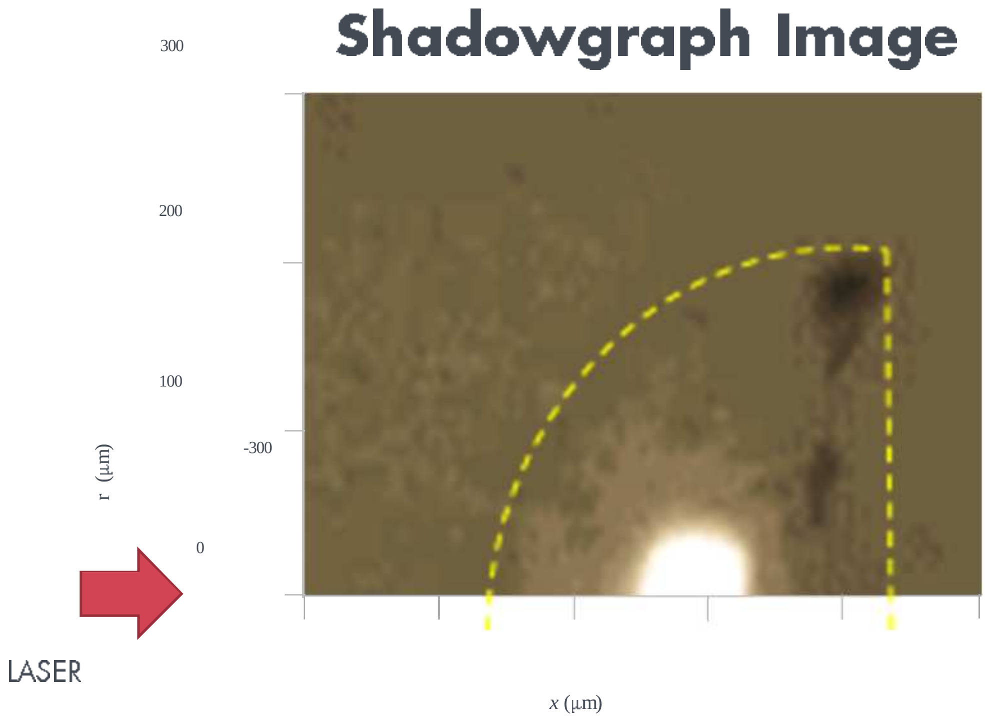
Target Simulation



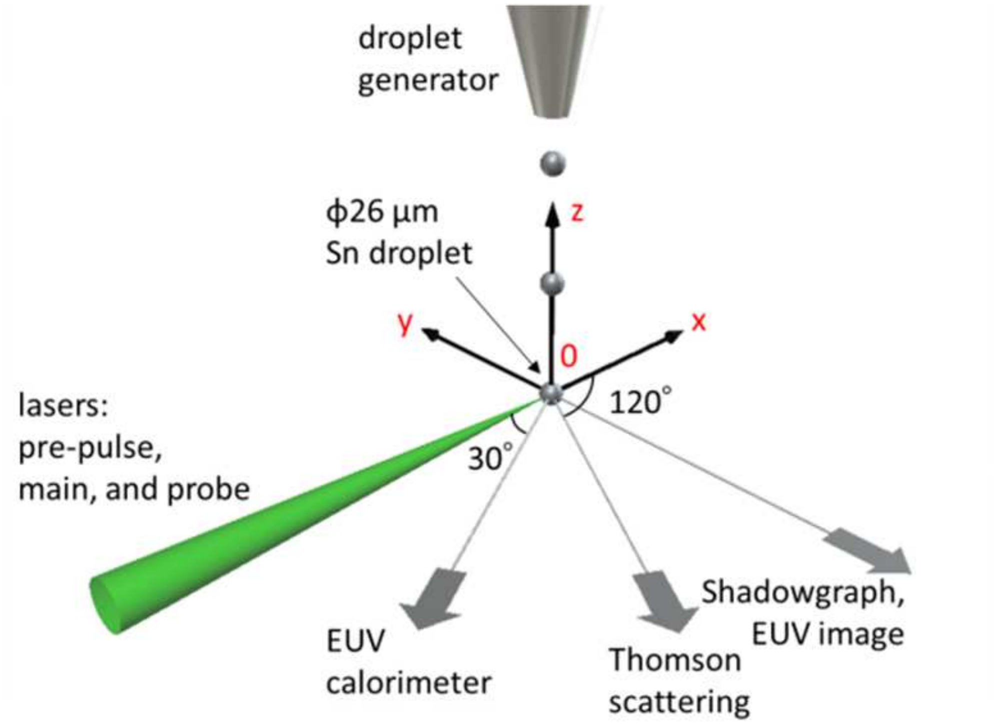
Simulation of EUV Emission



Tomson Scattering Measurement (1)



Shadowgraph Image



九州大学
Kyushu University

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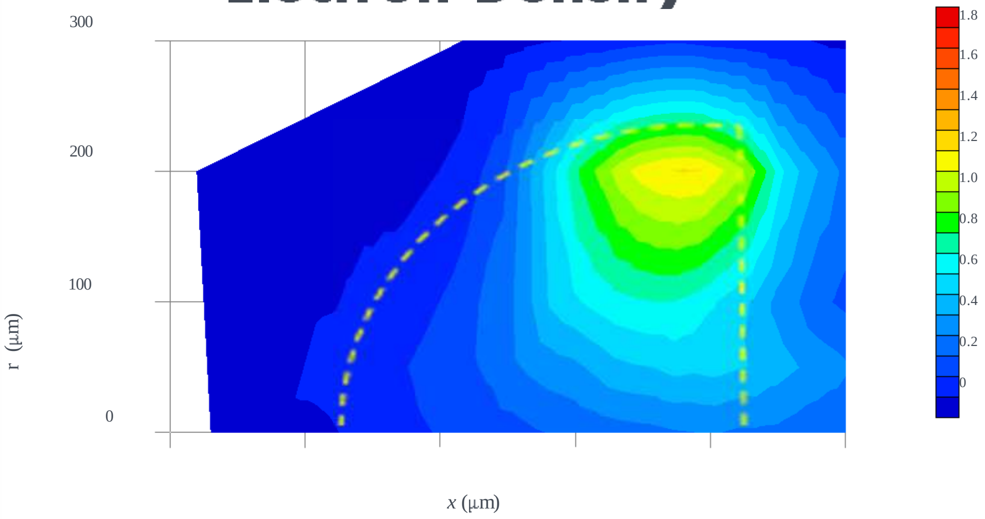
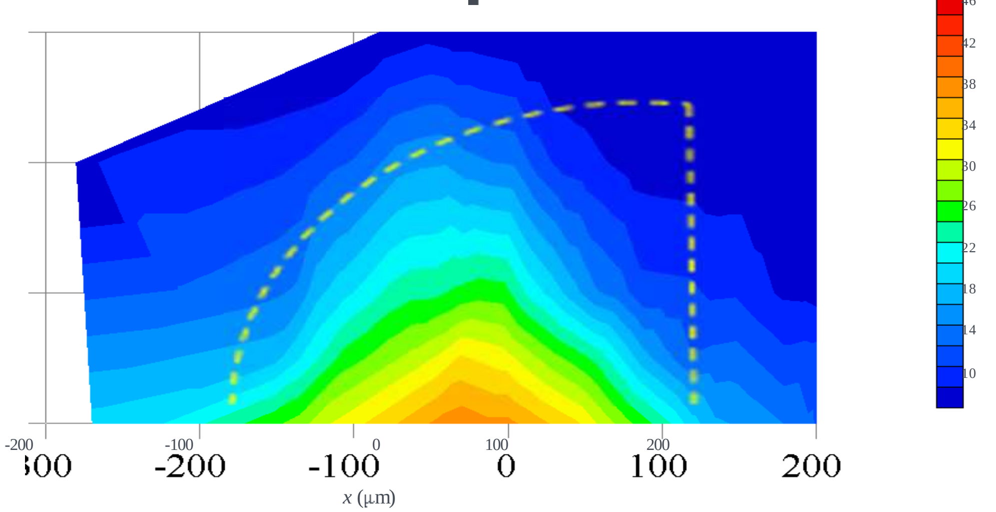
Tomson Scattering Measurement (2)

Electron Density



Electron Temperature

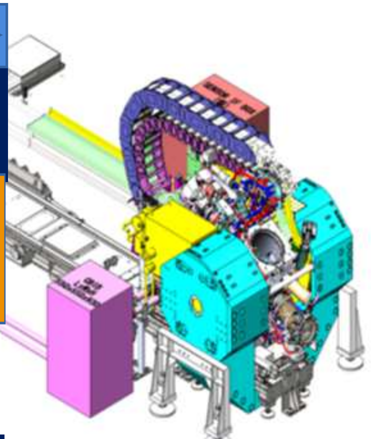


Tomson Scattering measurement characterize pre-pulse plasma in detail !

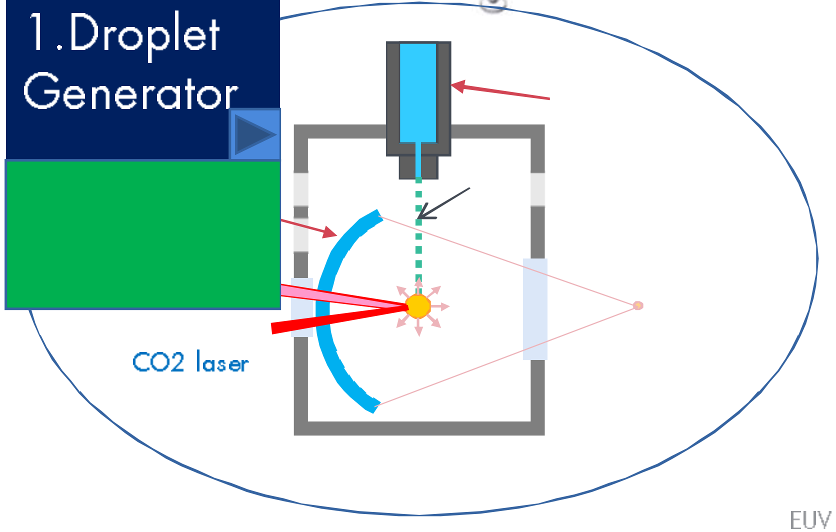
Next step: Optimization of Ce enhancement by plasma measurement.

Gigaphoton EUV Technology for Lower CoO

4. Debris Mitigation by Magnet



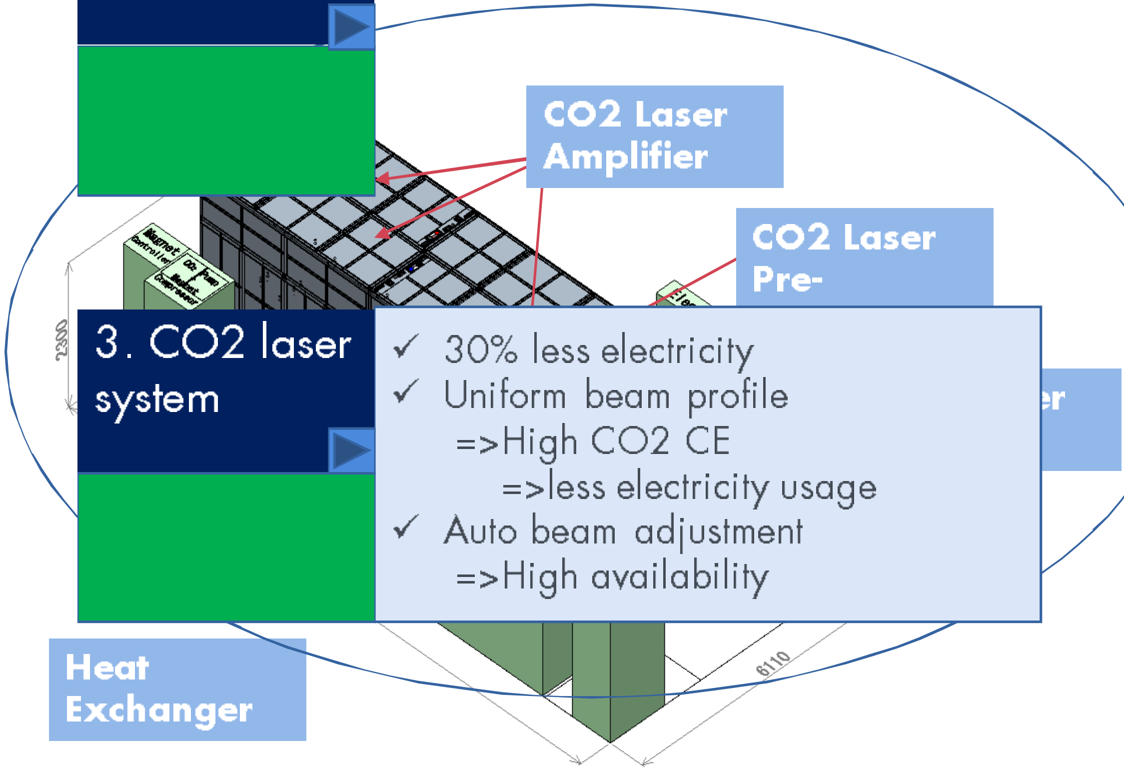
1.Droplet Generator



2. Pre-pulse laser

3. CO2 laser system

- ✓ 30% less electricity
- ✓ Uniform beam profile
  - =>High CO2 CE
    - =>less electricity usage
- ✓ Auto beam adjustment
  - =>High availability



3-1. Gigaphoton EUV Technology : CO_2 Lasers

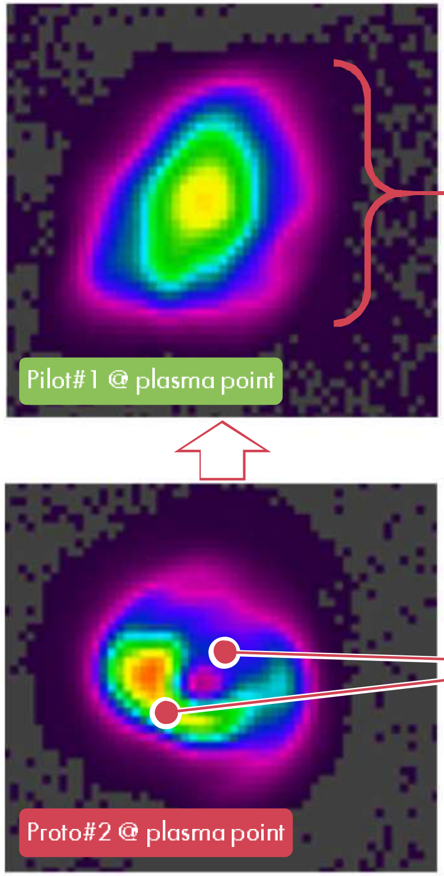
Benefit

- **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**

	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
Power requirement	>1,200kVA	**880kVA**	30% less electricity

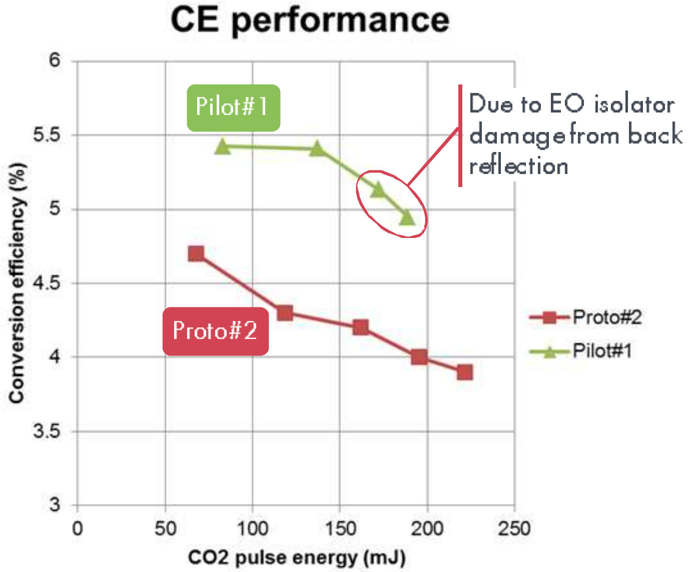
3-2. CO$_2$ Lasers : Higher EUV CE with Uniform Beam Profile

- >5% CE was achieved due to the greatly improved CO2 beam profile



Greatly improved evenness in beam profile allows for more uniform and efficient ionization of droplets – thus resulting in higher CE

Previous CO$_2$ beam profile was very uneven and hence less efficient by comparison

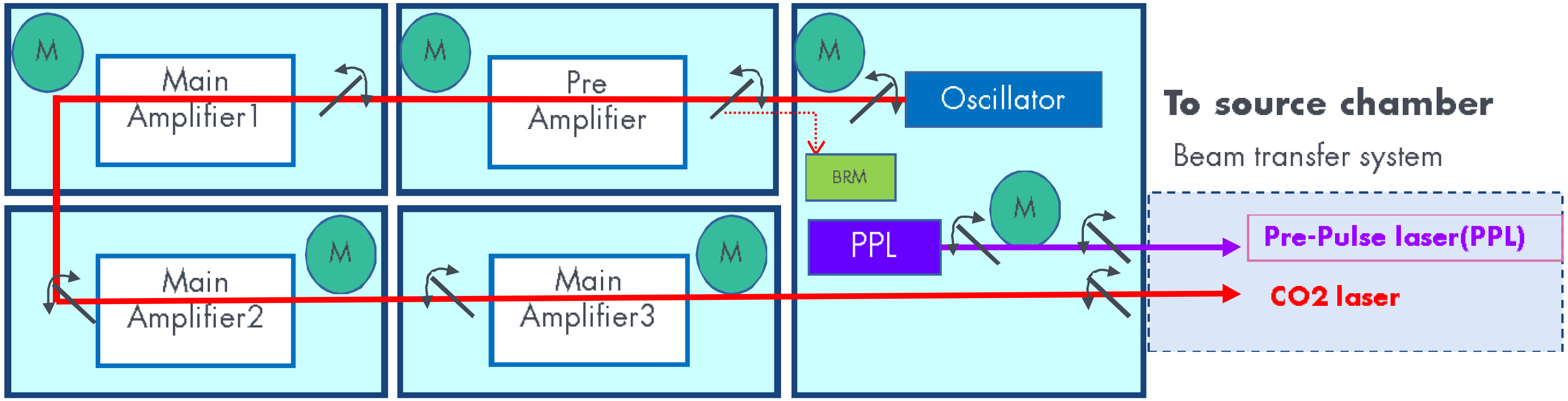


Due to EO isolator damage from back reflection

3-4. CO$_2$ Lasers : Auto Beam Adjustment

- Monitor modules and beam steering modules support easy maintenance.

Easy & Stable beam axis adjustment

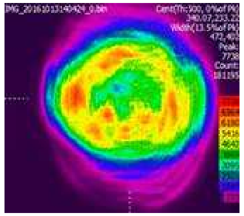


M <u>Monitor module</u>
- ✓ Beam profile camera
- ✓ Beam divergence camera
- ✓ Pulse energy sensor
- ✓ Pulse timing sensor (Oscillator only)

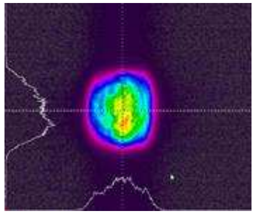
<u>Beam steering module</u>
- ✓ XY steering mirror
- ✓ Z beam expander

BRM <u>Back reflection monitor</u>
- ✓ Power meter

CO2 laser
Profile camera



PrePulse laser
Profile camera

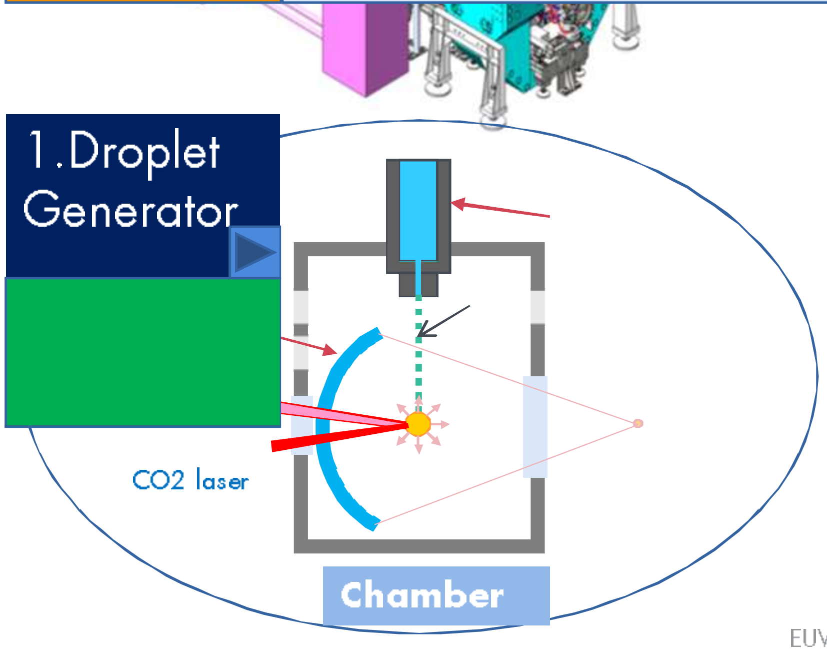


Gigaphoton EUV Technology for Lower CoO

4. Debris Mitigation by Magnet

- ✓ Magnetic field,20um small droplet, 98% Sn ionization lead less contamination
- ✓ 0.4%/G pulse @30W was achieved
- ✓ 125W mitigation test is ongoing

1.Droplet Generator

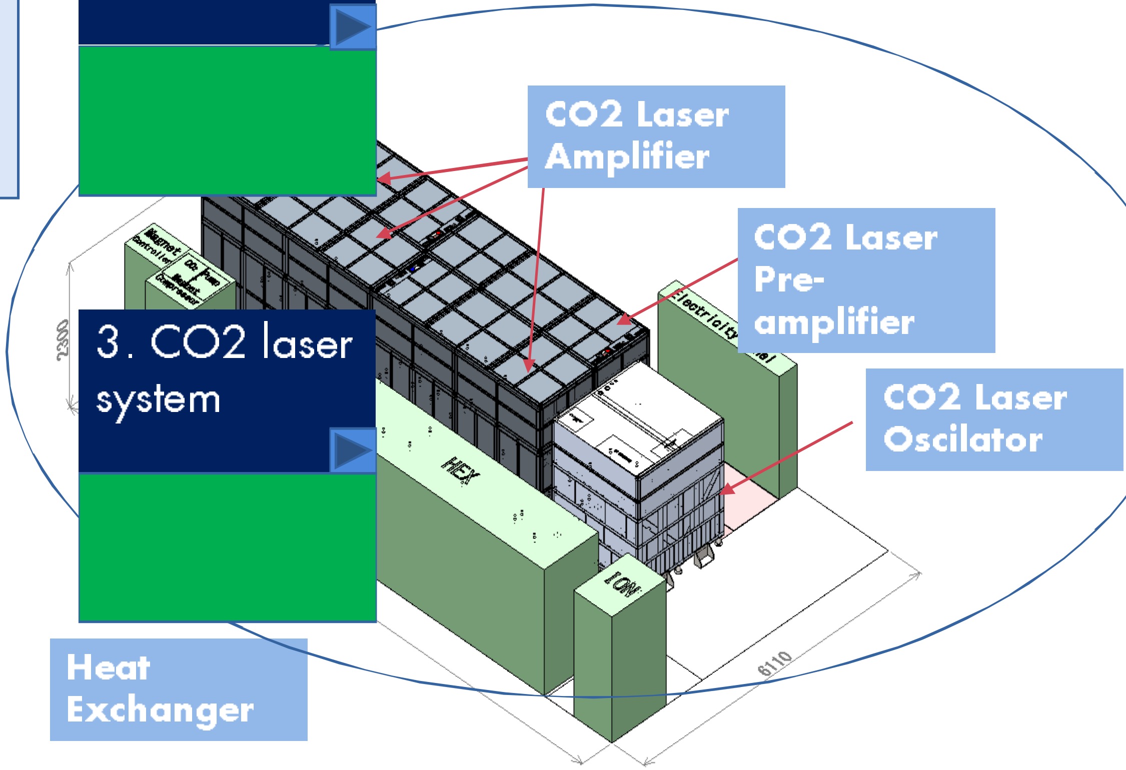


CO2 laser

Chamber

2. Pre-pulse laser

3. CO2 laser system



CO2 Laser Amplifier

CO2 Laser Pre-amplifier

CO2 Laser Oscilator

Heat Exchanger

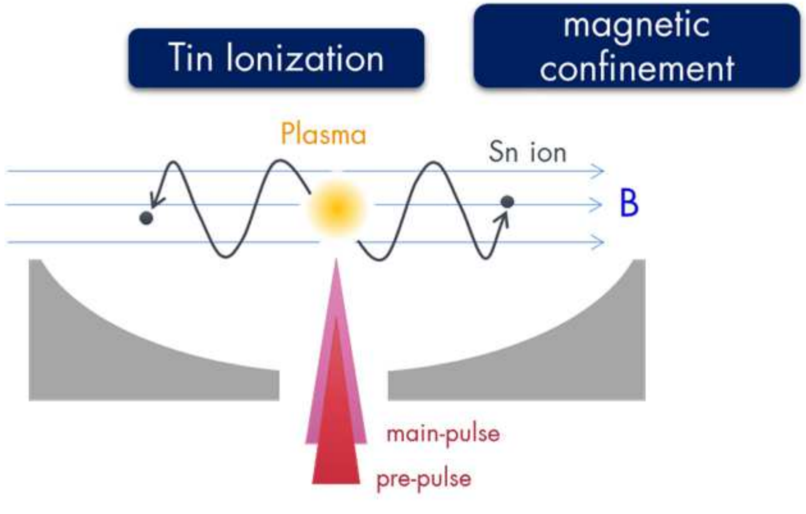
4-1. Gigaphoton EUV Technology : Debris Mitigation

- Benefit:
  - High uptime and low CoO by long collector mirror lifetime
  - **Magnetic mitigation** to protect the collector mirror surface from tin
  - Long lifetime to minimized downtime for collector swap

	Conventional	GPI	Remark
Magnetic field mitigation technology	N/A	**1/100 # of Tin atom**	Reduces # of Sn ion which reaches collector mirror.
Smaller Sn droplet	30 micron dia.	**20 micron dia. 1/3 in volume**	Less unusable Sn for EUV emission to reduce contamination.
Hi ionization ratio of Sn 20um droplet	60%	**98%**	Less contamination on collector mirror and also less contamination inside chamber.
>125W Mitigation	Practical performance at customer site	**GPI internal test is on going**	0.4% / G pulse at 30w average power was confirmed. Mitigation test with more than 125W is ongoing.

4-2. Short-term: Etching and Dissociation Sn balance on the Mirror Surface

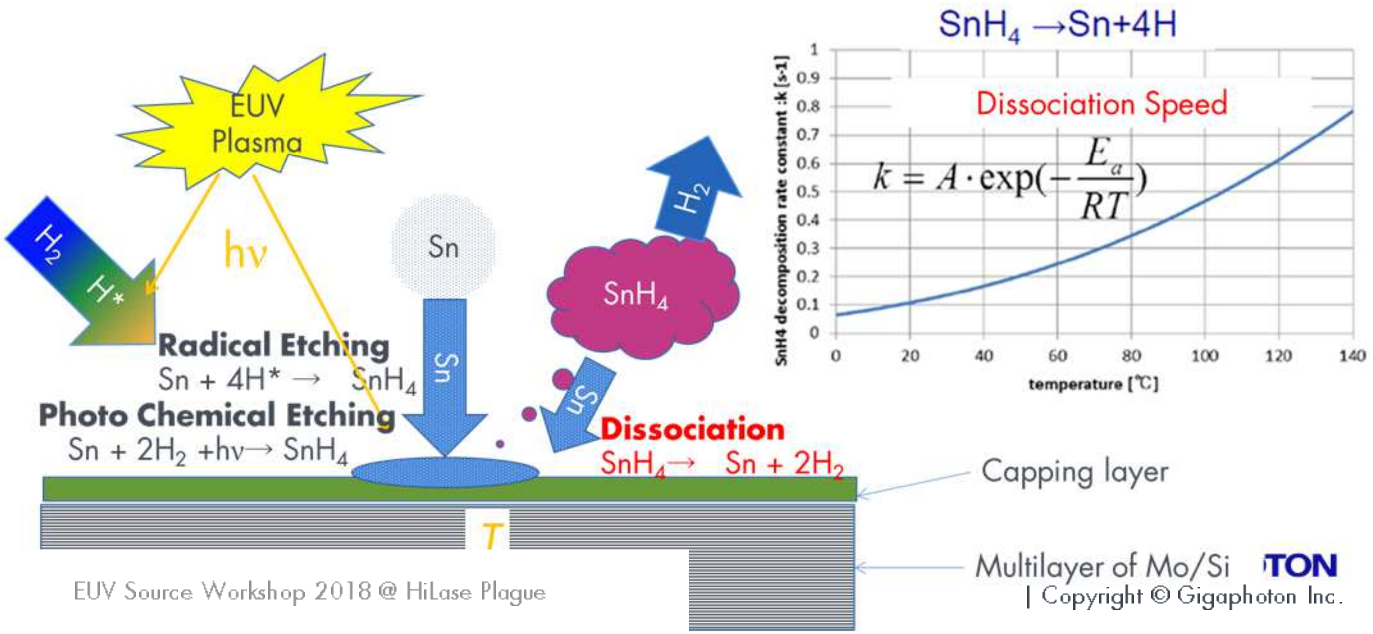
Chemical Equibrium on the Mirror Surface



- 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

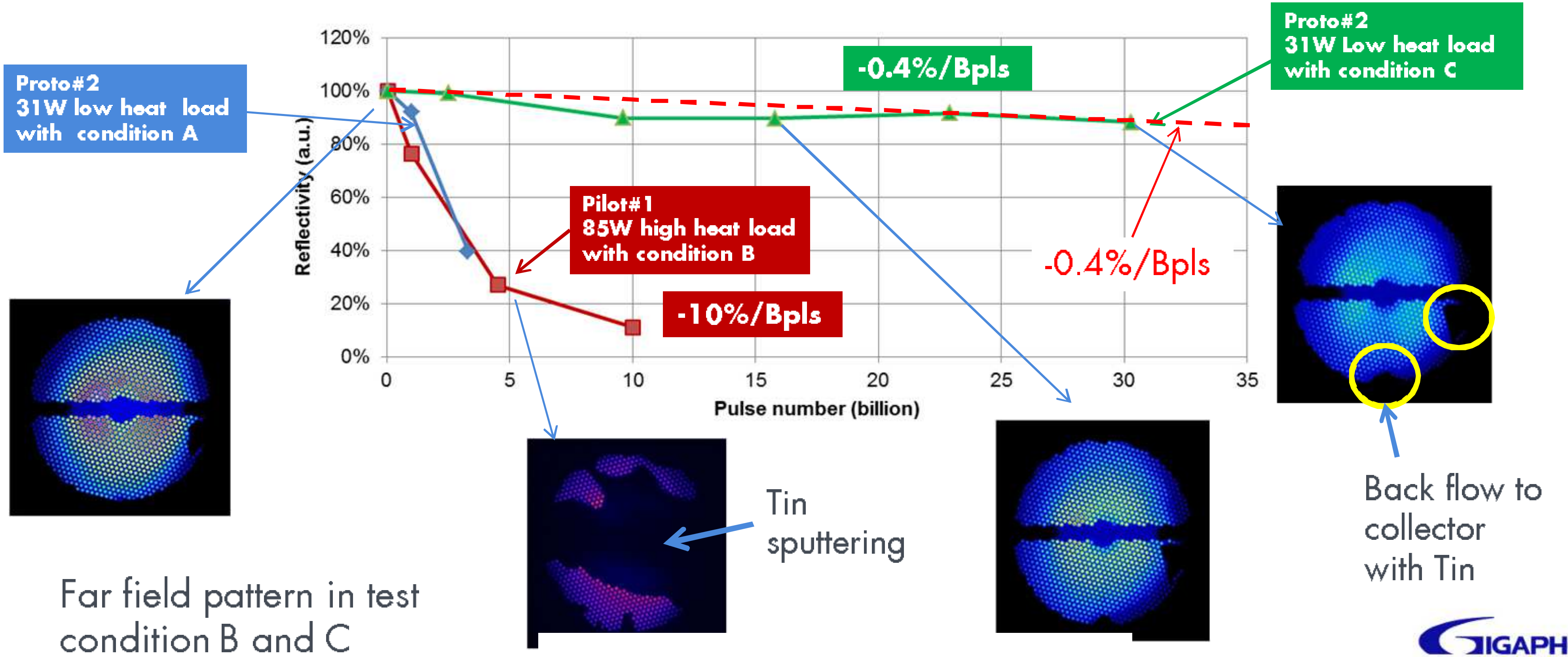
- Protection & cleaning of collector with H_2 gas
  - High energy tin neutrals are decelerated by H_2 gas in order to prevent the sputtering of the coating of collector.
  - Deposited tin on the collector is etched by H radical gas*.
  - Gas flow and cooling systems for preventing decomposition of etched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

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



4-3. Collector Mirror: Lifetime Status

- Power level of EUV: 95W in Burst, (= 1.9mJ x 50kHz), 33% duty cycle, 31W in average.
- Collector lifetime was improved to -0.4%/Bpls by magnetic debris mitigation technology optimization.



Proto#2
31W low heat load
with condition A

Proto#2
31W Low heat load
with condition C

-0.4%/Bpls

Pilot#1
85W high heat load
with condition B

-10%/Bpls

-0.4%/Bpls

Tin sputtering

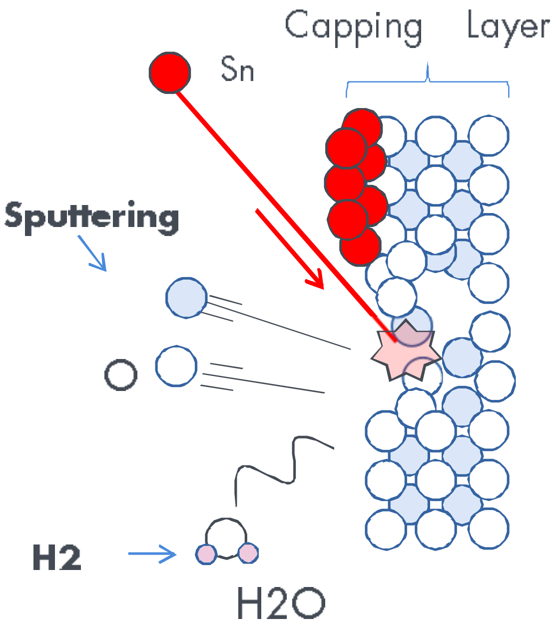
Back flow to collector with Tin

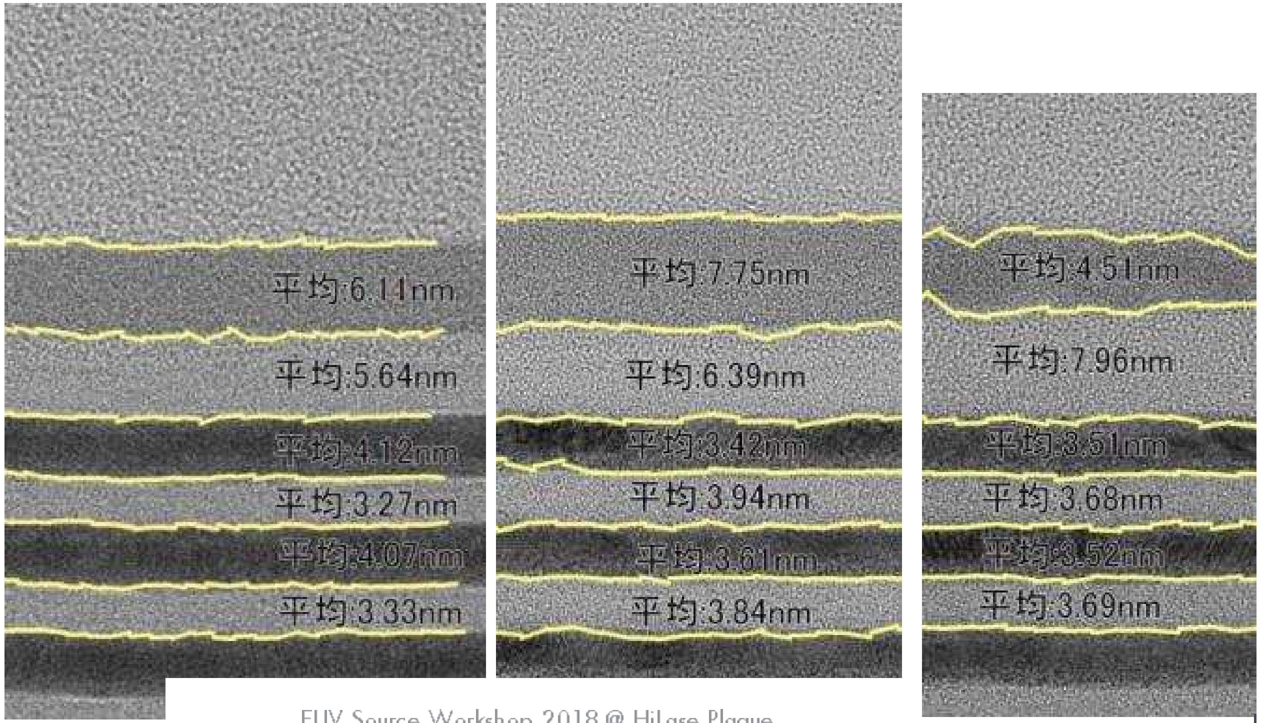
Far field pattern in test condition B and C

4-4. Long-term: Capping Layer and Multi-Layer Durability

■ Cross-section of Cap layer after long-term testing

- ➢ 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

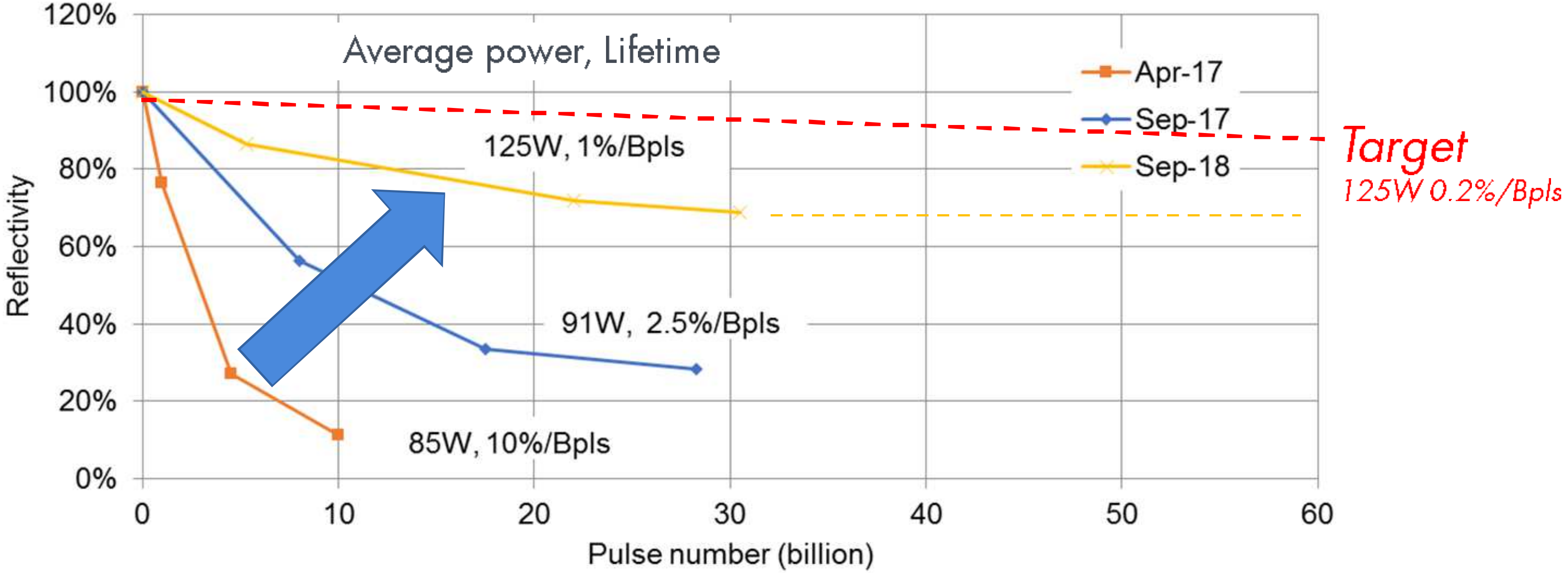
2nd Mo Layer
3rd Si Layer

⋮

Preliminary Result

4-7.Collector Lifetime Extension at High Power Operation

- Collector lifetime at high power operation was drastically improved.



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Key Performance Status and its target of Gigaphoton

	2015	2018 Current	2018 End	2019
In-band power (Average Power)	87W (83W)	125W (125W)	250W	>330W
Collector lifetime*1	No data	-0.2%/Bpls	-0.1%/Bpls	<-0.05%/Bpls
Availability*2	15%	(53%)	> 80%	> 90%

Proto #2

Pilot #1

*1, Collector lifetime estimation has been started from 2017
*2, Max availability in 4 week operation.
*3, Main issue was capping layer performance.

SUMMARY

Summary

- **Pilot#1 is up running and its demonstrates HVM capability;**
  - *High conversion efficiency 5% is realized with Pre-pulse technology.*
  - *High speed (>90m/s) & small (20micron) droplet is realized.*
  - *High power CO2 laser technology is one of the important technology for HVM.*
  - *Output power 250W in-burst power @50% duty (125W ave.) several min.*
  - *Output power 113W in-burst power @75% duty (85W ave.) 143hrs.*
  - *Pilot#1 system achieved potential of 89% Availability (2weeks average).*

- ***Recent achievement for most critical challenges mirror life***
  - *–0.2%/Gpls with 125W ave. was demonstrated at short term dummy mirror test*
  - *-1.0%/Gpls with 125W ave. was demonstrated during 30Mpls with mirror test (preliminary)*

- ***Next Step***
  - *-0.2%/Gpls with 125W ave. more than 50Bpls with full size mirror.*
  - *Ce enhancement based on Tomson scattering measurement.*
  - *>90% availability challenge with operation software enhancement.*
  - ***>300W ave. with -0.2%/Gpls, >90% availability proof test in 2020 target***

Acknowledgements

Thank you for co-operation:

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