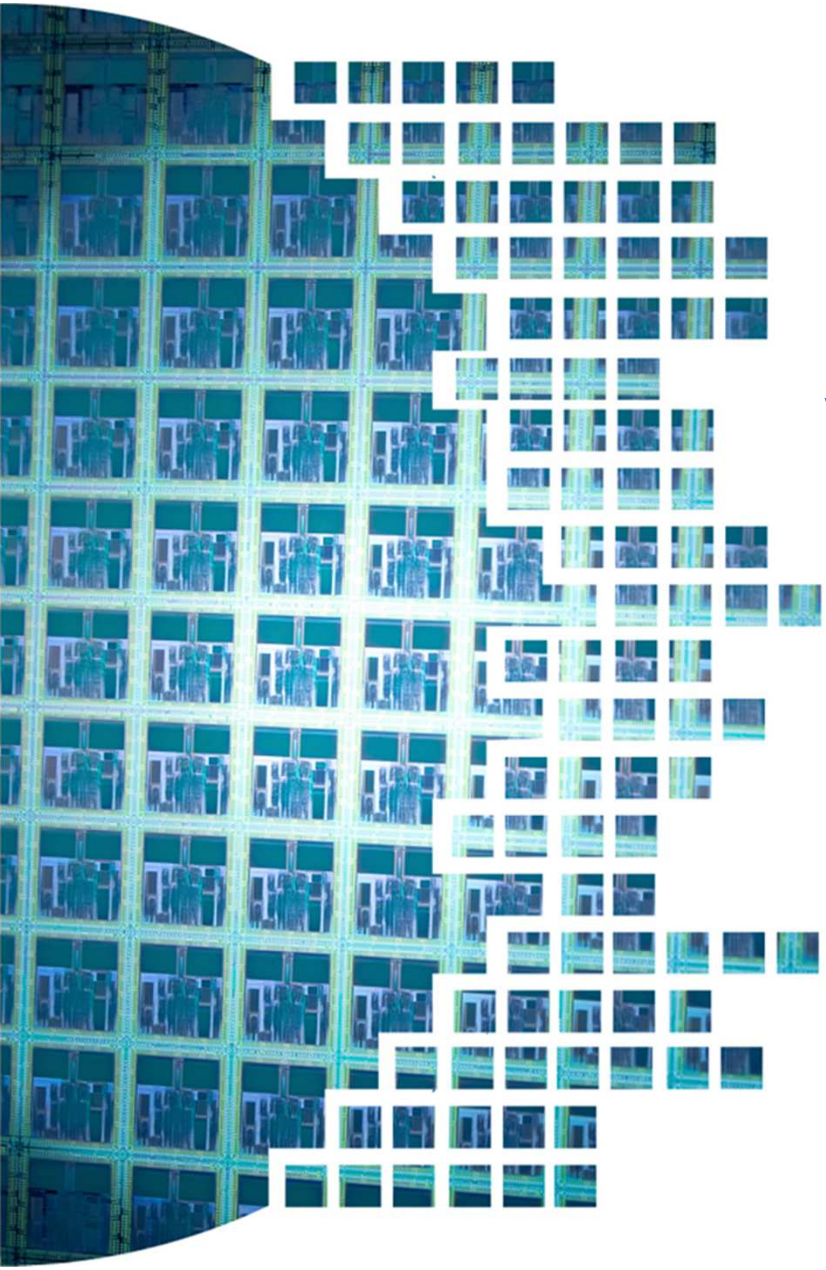

GIGAPHOTON

HIGH POWER HVM LPP-EUV SOURCE WITH LONG COLLECTOR MIRROR LIFETIME

Dr. Hakaru Mizoguchi
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Agenda

- **Introduction**
- **HVM Ready System Progress**
  - Configuration and Key Component Technology
    - EUV Chamber System
    - Driver Laser and PPL System
    - Pre-pulse Technology
  - Latest System Update
  - Higher Power EUV Source Development
- **Collector Mirror Lifetime Test and Simulation**
  - Dummy Mirror test result
  - Simulation of Tin Deposition
- **Study of 500W Power EUV Source**
- **Summary**

INTRODUCTION

GIGAPHOTON

EUV Lab. (Hiratsuka, Kanagawa)

New Head Office (2017/ 7 Open office)

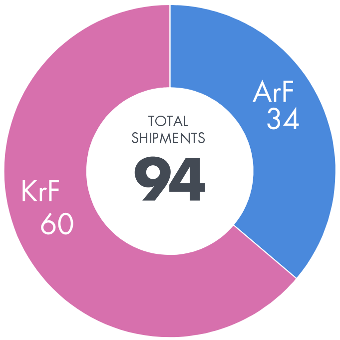
Product: **Light Source for Microlithography**

Established:	August 2000
Annual sales:	around $ 300 M
Market share:	more than 60% (2015,2016)
Employee:	around 700 persons
Head office:	Oyama -shi, Tochigi, Japan

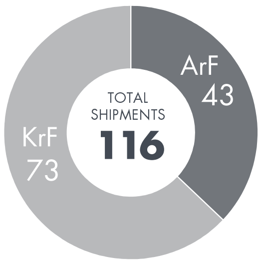
2016 Lithography Source Business Highlights

DUV Business

- In 2016, Gigaphoton achieved 60% share in DUV market
- Achieved 10,000 Kiloliter Ne Gas annual reduction
- Announced a new Green Innovation Roadmap with new environmentally friendly and economical technologies



2016



2015

EUV Business

- Began integration of Pilot system for scanner integration
- >100W average power with 5% CE on Pilot system
- Demonstrated 250W capabilities with 4% CE at 100KHz

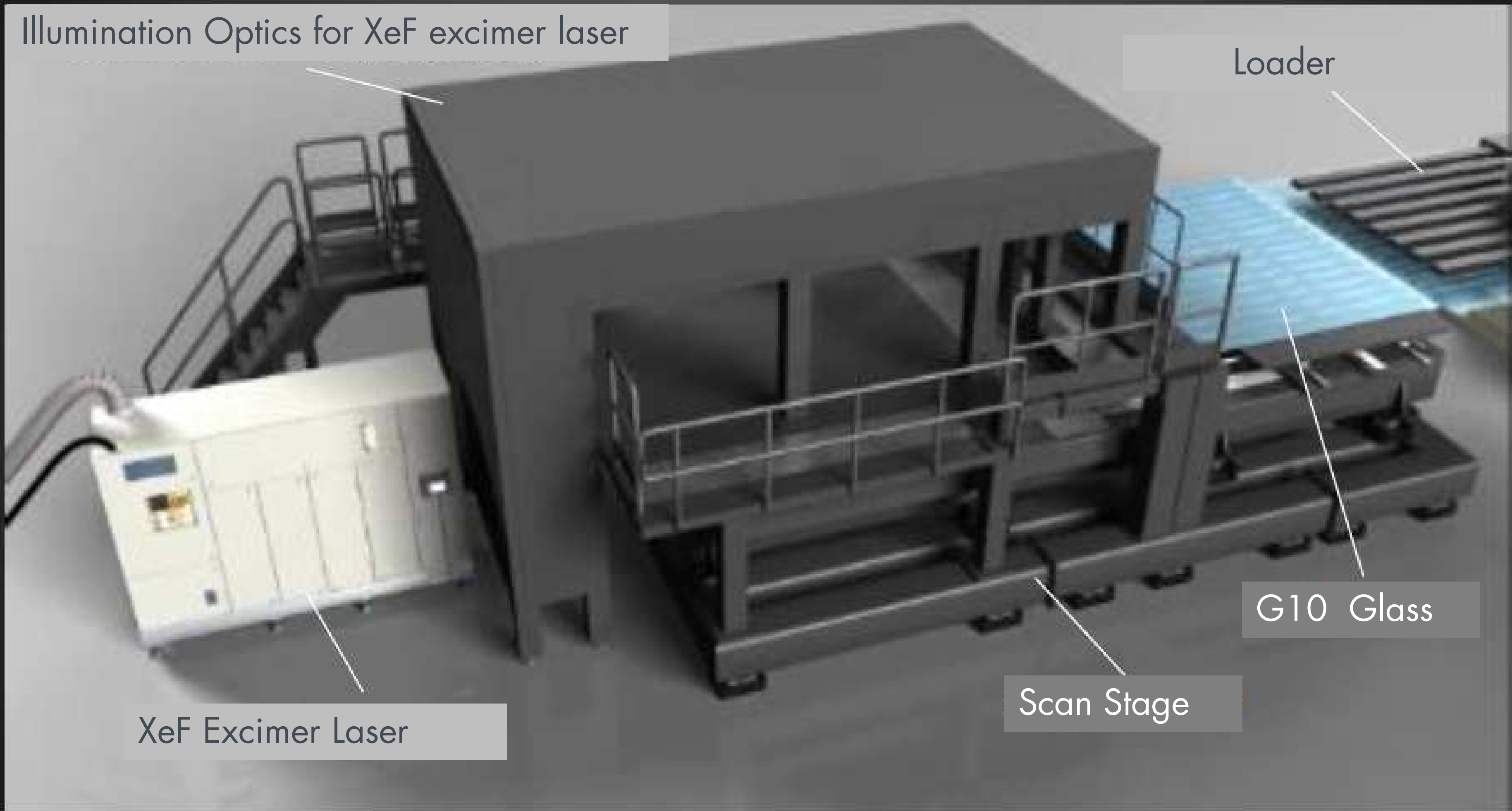
New Laser Brand for New Application

GIGANEX™

Lithography

Annealing for FPD

Material Processing


Illumination Optics for XeF excimer laser
Loader
G10 Glass
Scan Stage
XeF Excimer Laser

High power Excimer Laser for LCD Annealing

XeF GT480XZ
KrF GT600KZ

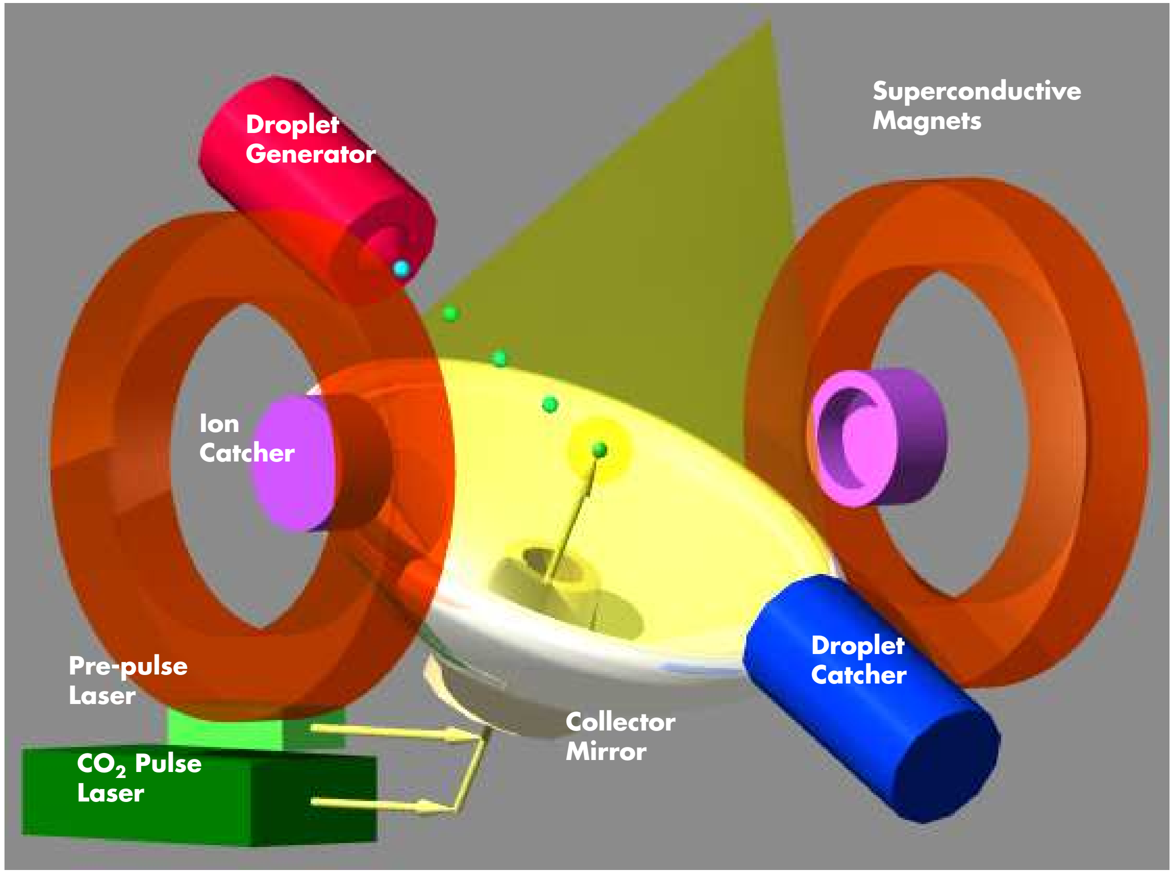
	GT480XZ	GT600KZ
Wavelength	351 nm	2 4 8 nm
Output Energy (Max.)	8 0 mJ	100 mJ
Output Power	480 W	6 0 0 W
Pulse Duration	40 – 50ns	40 – 50ns
Repetition Rate	6000Hz	6000Hz
Pulse Energy Deviation	Sigma < 2.0%	Sigma < 2.0%

Proto#1:GT480XZ 2016/3
Ploto#2:GT600KZ 2016/7

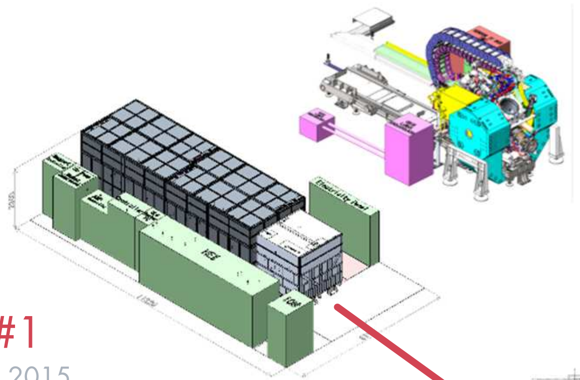
HVM READY SYSTEM PROGRESS

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



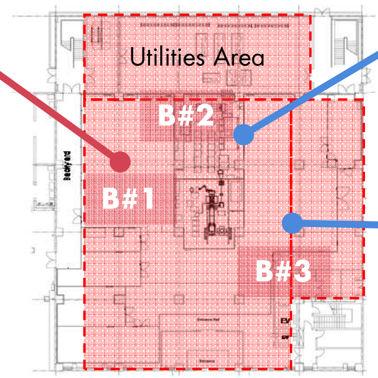
Current EUV Sources at Gigaphoton

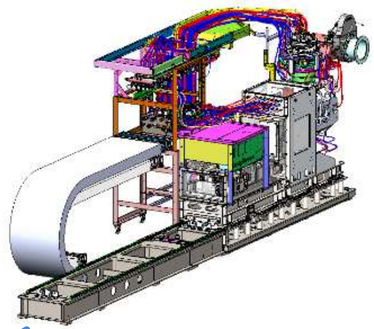


NEW Pilot#1

Operational since 2015

First pilot EUV system designed for ASML NXE integration and HVM operations

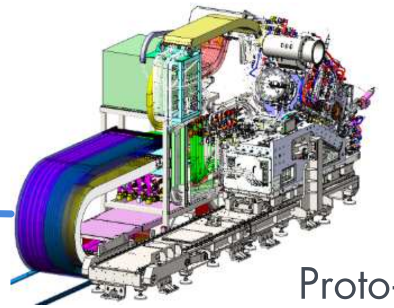




Proto#1

Operational since October 2012

Elemental technology research and proof of concept



Proto#2

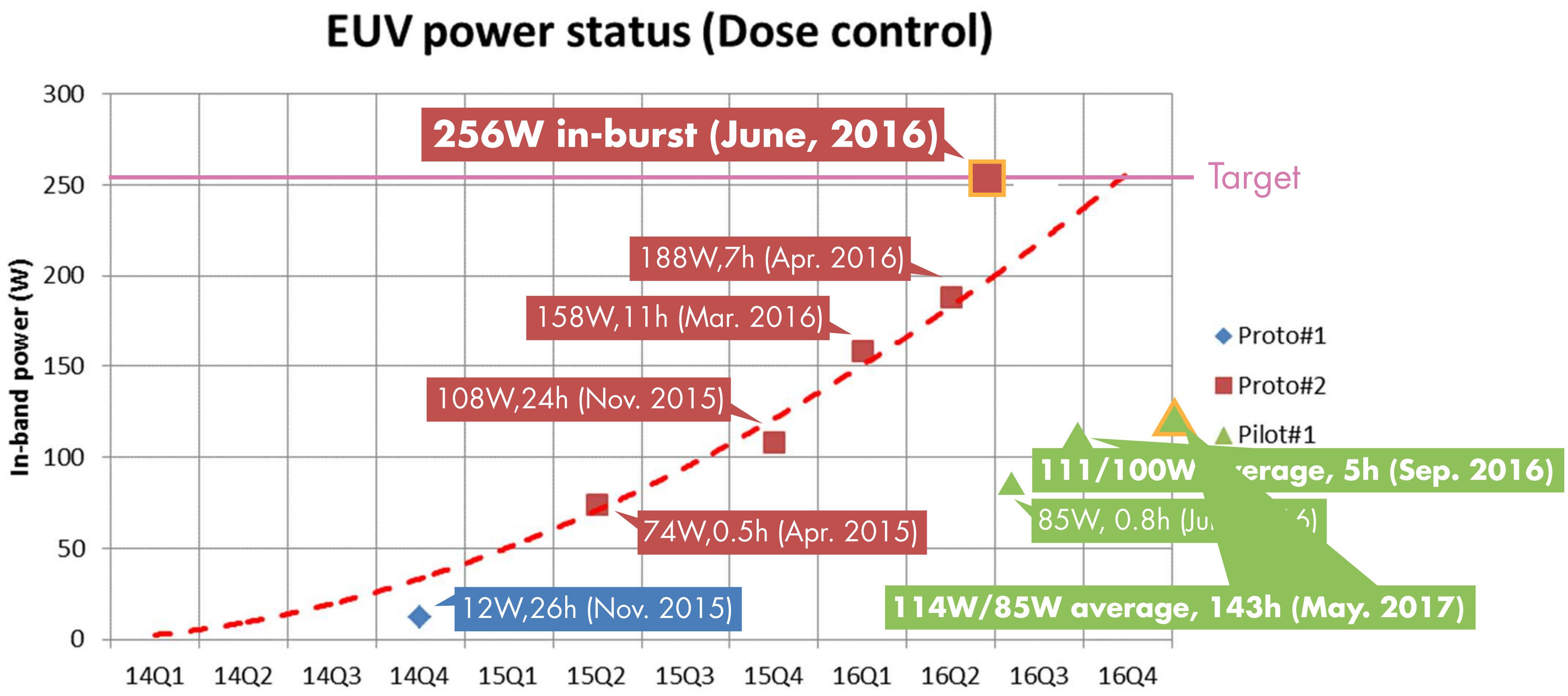
Operational since November 2013

Key technology development for HVM

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	>75%
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

Latest LPP Source Systems Experiment Update



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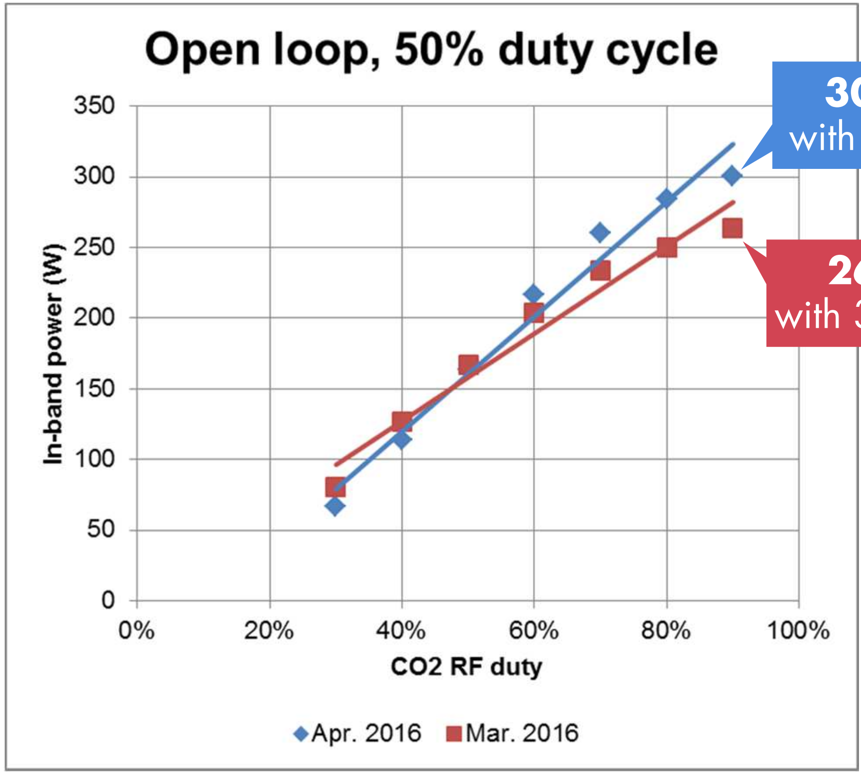
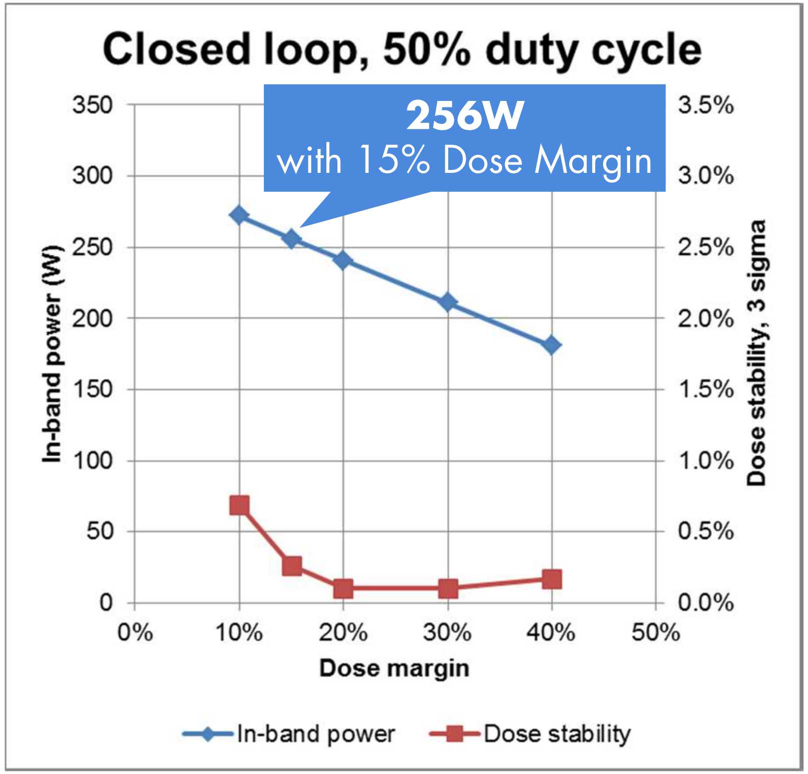
Latest LPP Source Systems Experiment Update

Proto#2: 250W with 4% CE at 100KHz



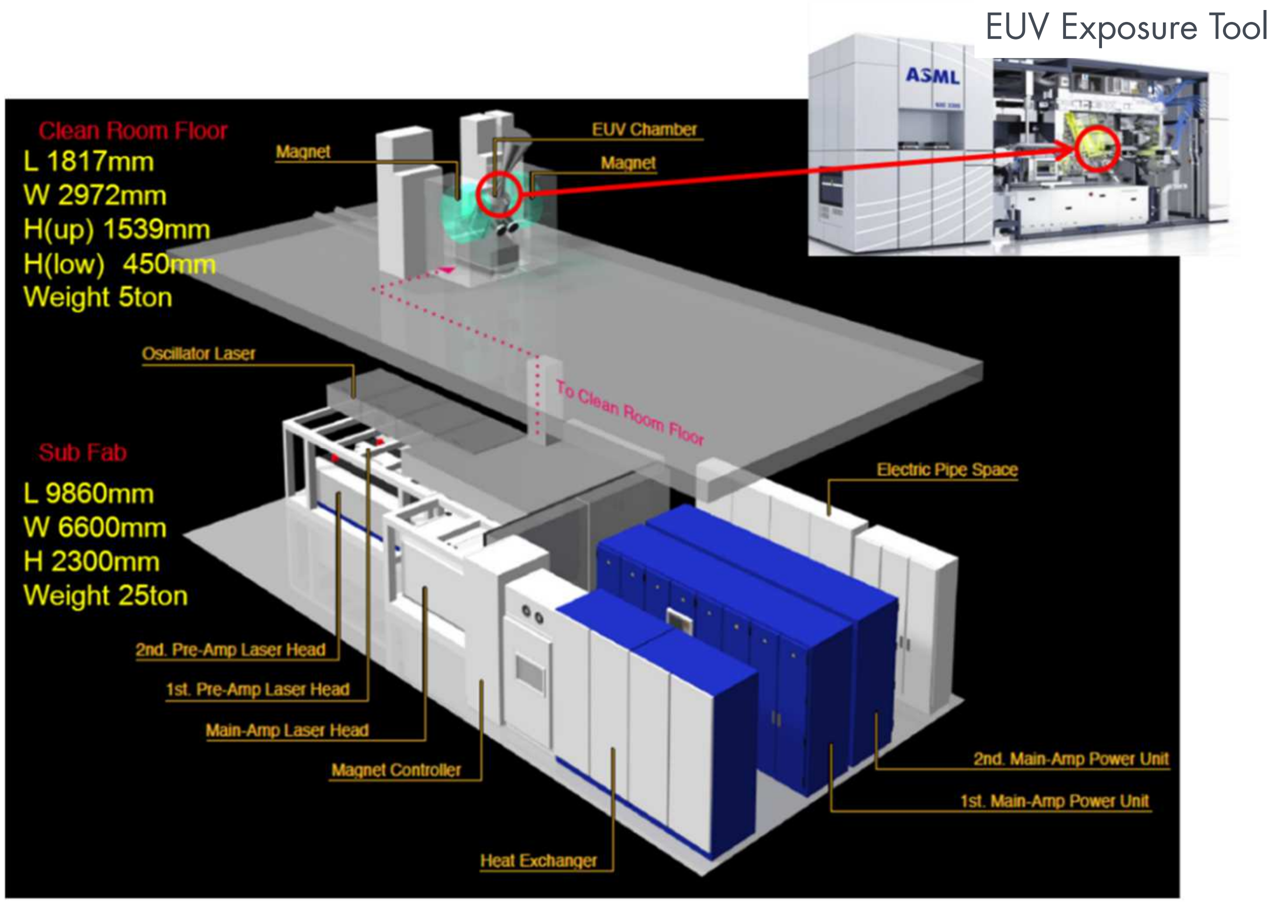


Layout of 250W EUV Light Source Pilot #1

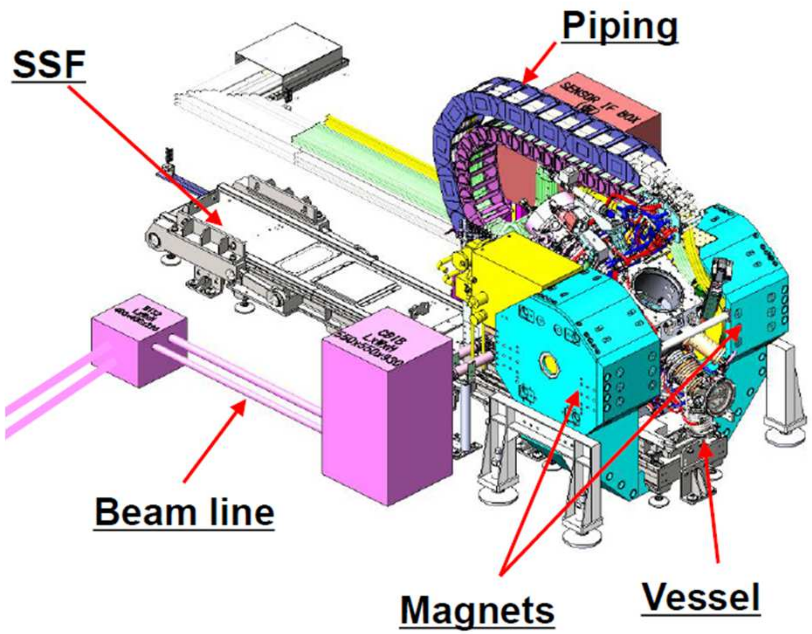
First HVM EUV Source

- 250W EUV source

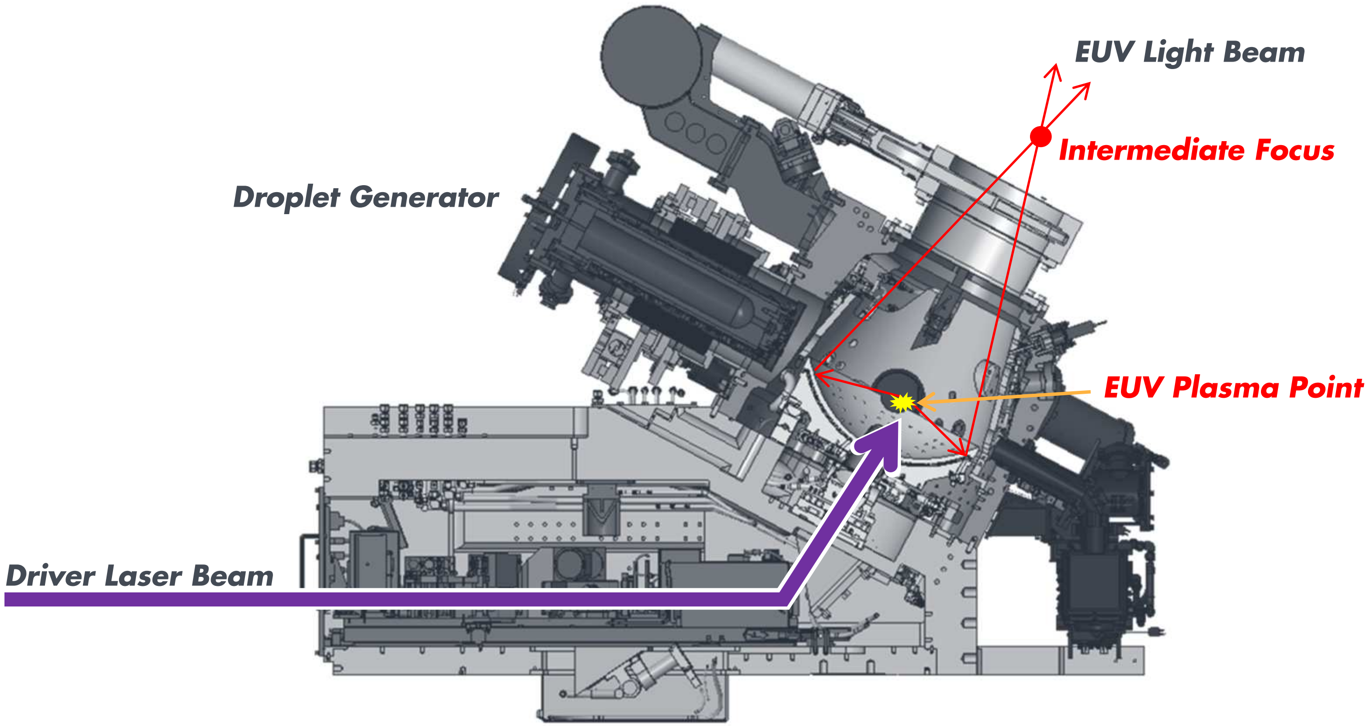
Operational specification (Target)			HVM Source
Performance	EUV Power		> 250W
	CE		> 4.0 %
	Pulse rate		100kHz
	Availability		> 75%
Technology	Droplet generator	Droplet size	< 20mm
	CO2 laser	Power	> 20kW
	Pre-pulse laser	Pulse duration	psec
	Debris mitigation	Magnet, Etching	> 15 days (>1500Mpls)



Pilot System EUV Chamber



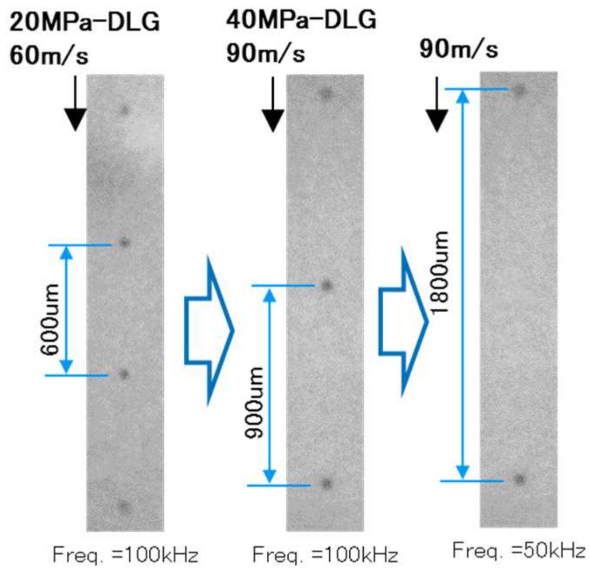
Pilot System EUV Chamber



Pilot System Droplet Generator Technology Transfer

High speed droplet generator technology was successfully transferred from Prototype to the Pilot system

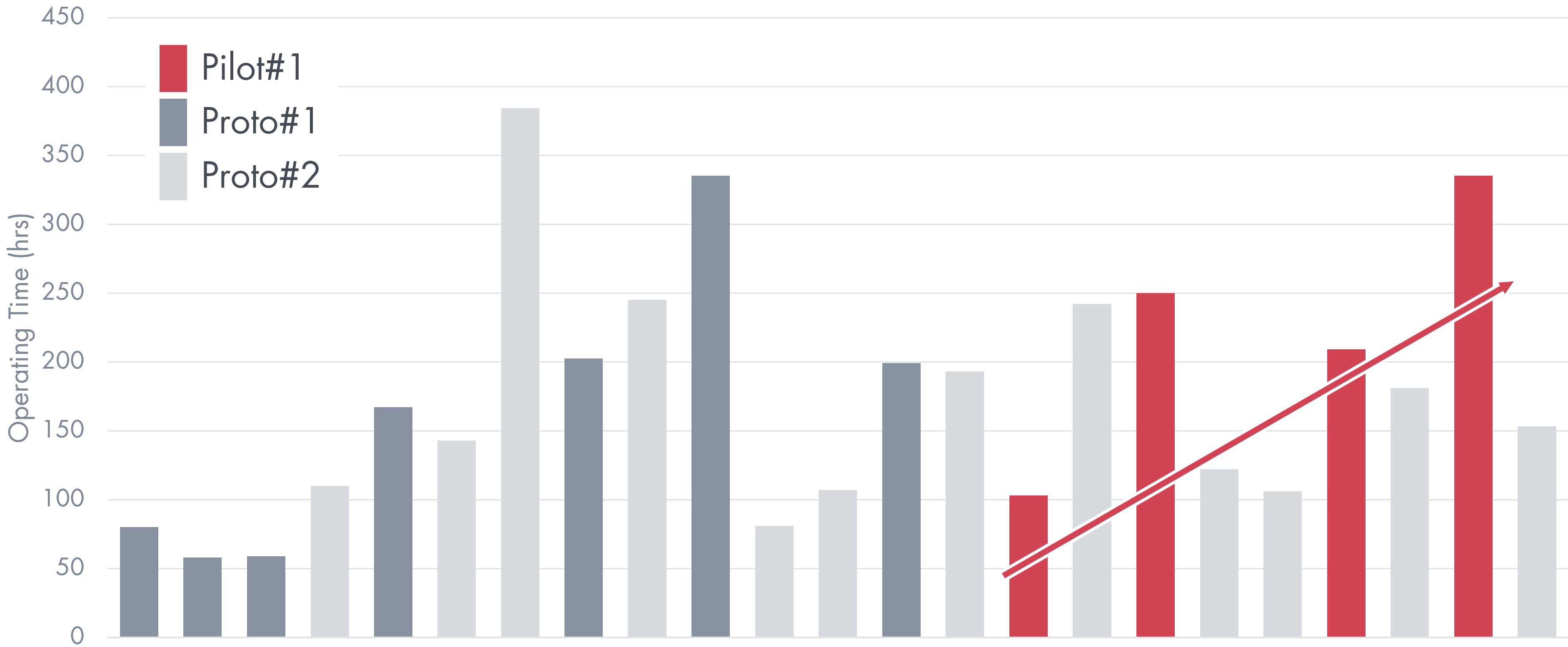
	Proto#1	Proto#2	Proto#2 ⇨	Pilot#1
Droplet Speed (m/s)	45	60	90	90
Back Pressure (MPa)	12	20	40	40
Max Repetition Rate (kHz)	50	80	100	100



Droplet Status

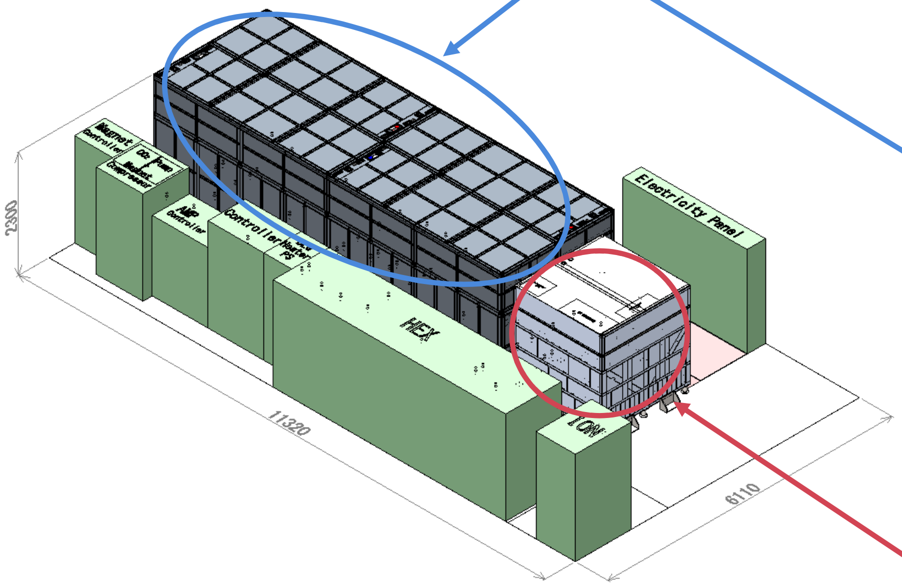
Pilot System Droplet Generator Lifetime Improvements

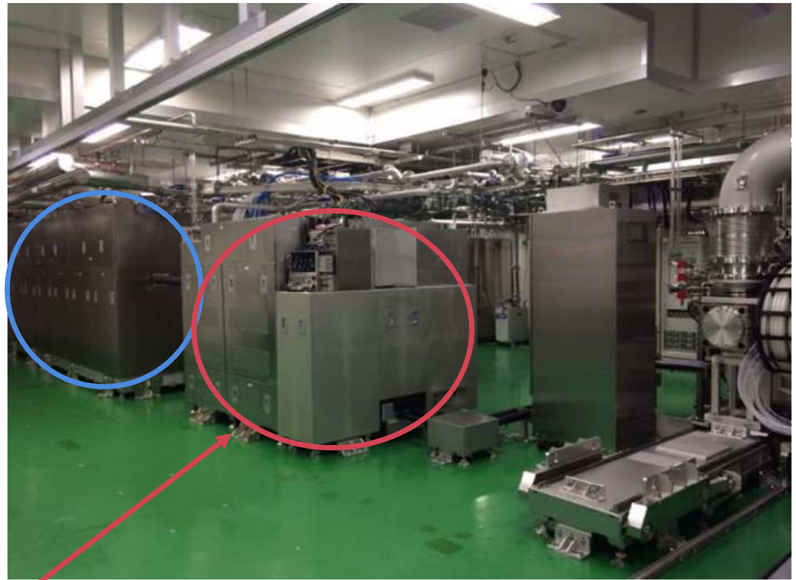
Lifetime of New Droplet Generator for Pilot#1 extended to more than 200 hours



Pilot System Driver Laser and PPL System

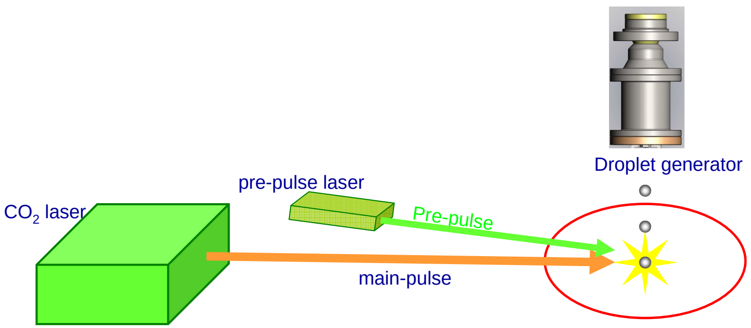
4 x CO_2 Laser Amplifier Modules

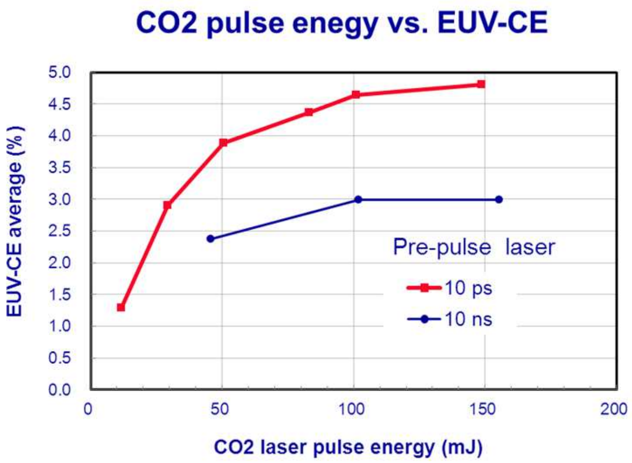




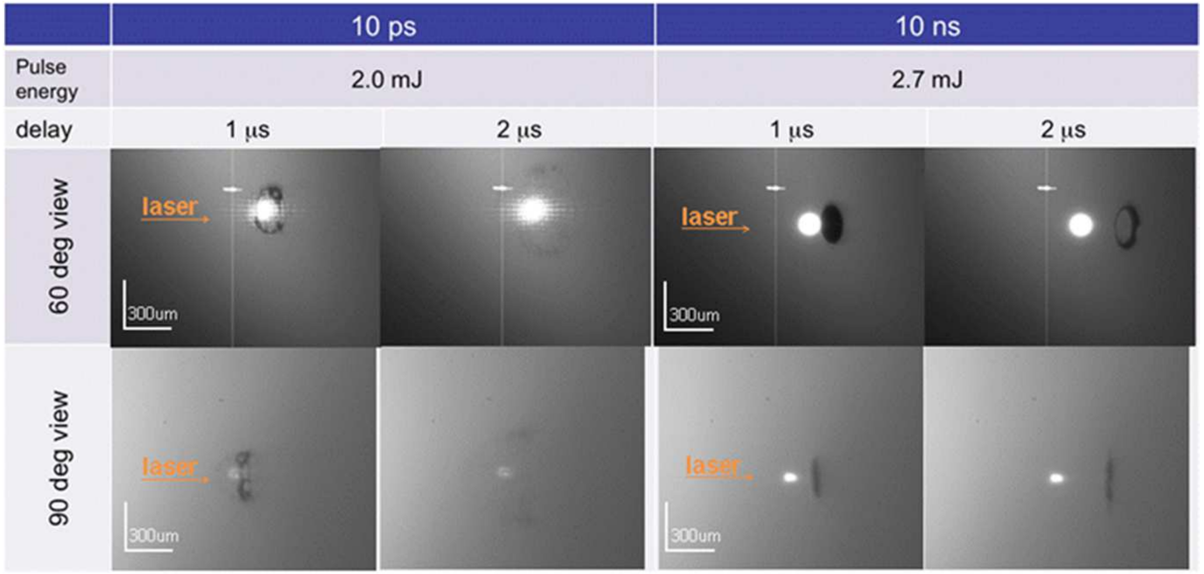
Oscillator/PPL Module

Pre-Pulse Technology





- The mist shape of a picosecond pre-pulse is different from that of a nanosecond
- Nano-cluster distribution could be a key factor for high CE



Pre-Pulse Technology

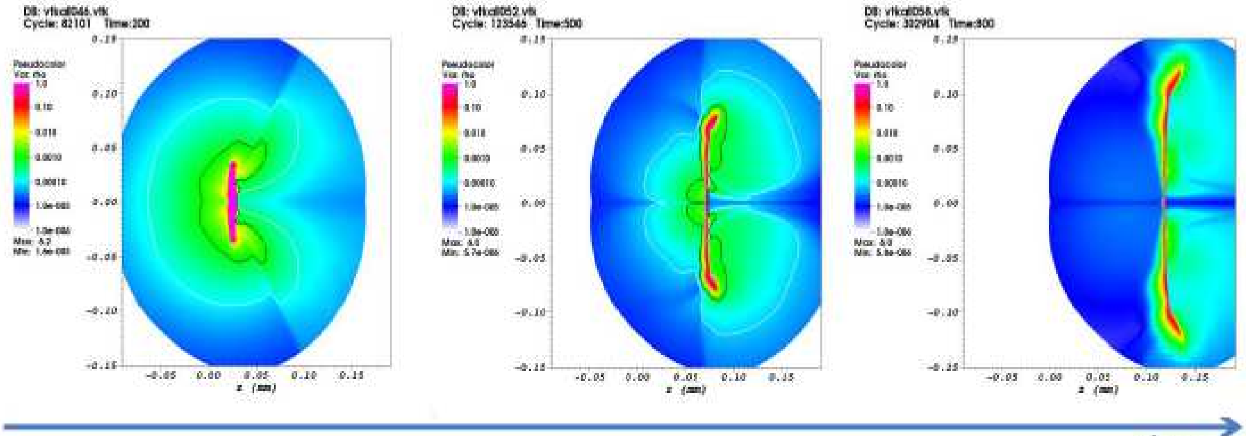
Modeling nanosecond pre-pulses

~ 10 ps pre-pulse
"Disk like target"

H. Mizoguchi, Dublin (2013)

RALEF simulations

Evolution of Sn density profile for 10 ns pre-pulse



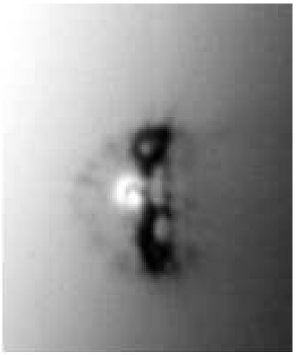
"Advances in computer simulation tools for plasma-based sources of EUV radiation"

V.V. Medvedev[1,2], V.G. Novikov[1,3], V.V. Ivanov[1,2], et.al.
[1] *RnD-ISAN/EUV Labs, Moscow, Troitsk, Russia*
[2] *Institute for Spectroscopy RAS, Moscow, Troitsk, Russia*
[3] *KeldyshInstitute of Applied Mathematics RAS, Moscow, Russia*

Pre-Pulse Technology

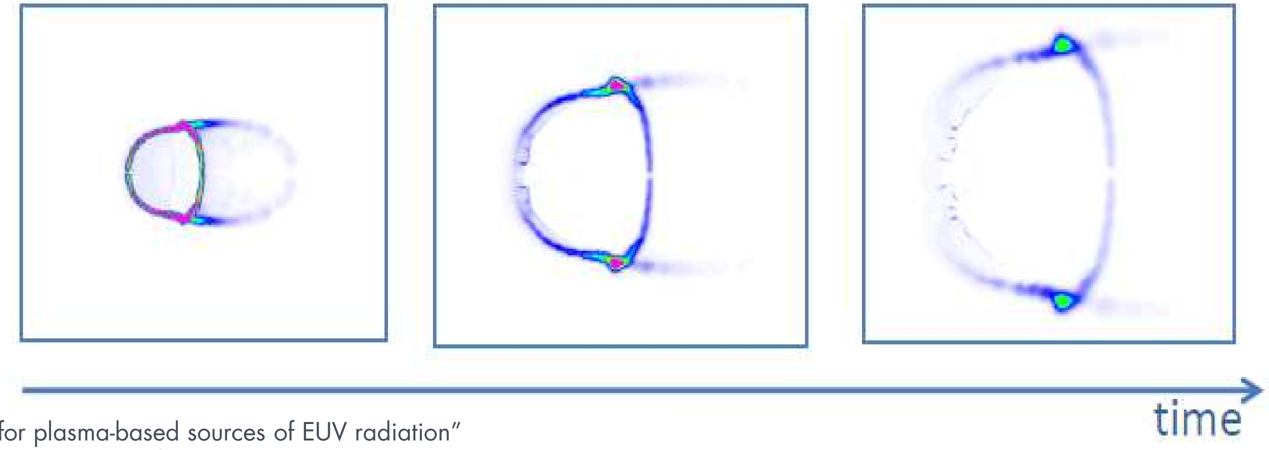
Modeling picosecond pre-pulses

~ 10 ps pre-pulse
"Dome like target"



H. Mizoguchi, Dublin (2013)

RALEF simulations
Evolution of Sn density profile for 10 ps pre-pulse



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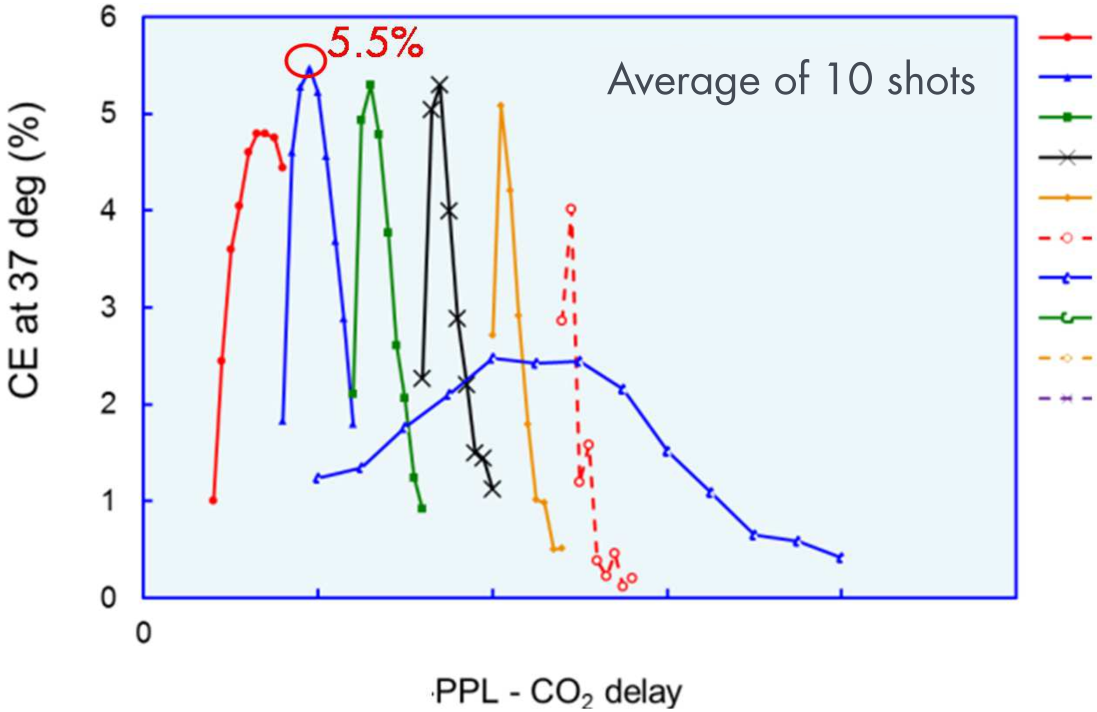
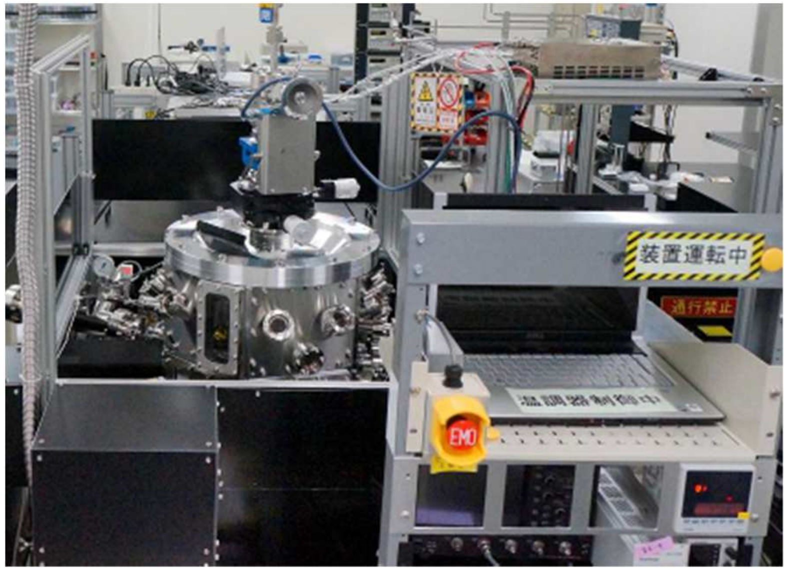
Pre-Pulse Technology

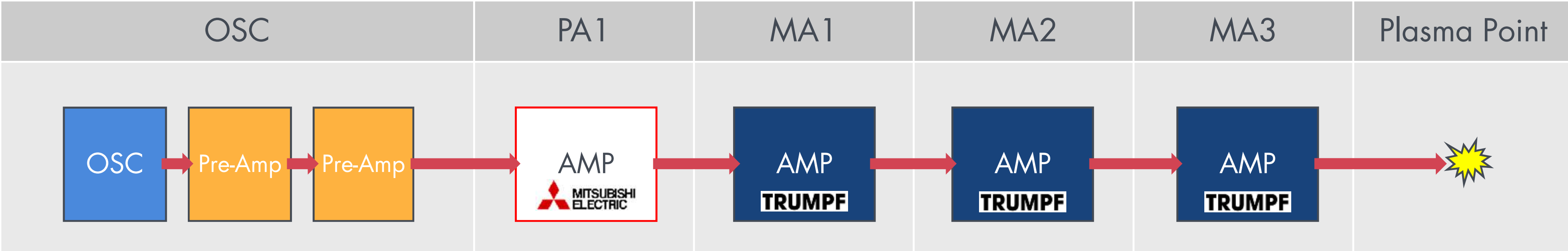
In an experiment device, we observed **5.5% CE** under optimized conditions.
This was a **17% increase** from our old champion data (CE = 4.7%).



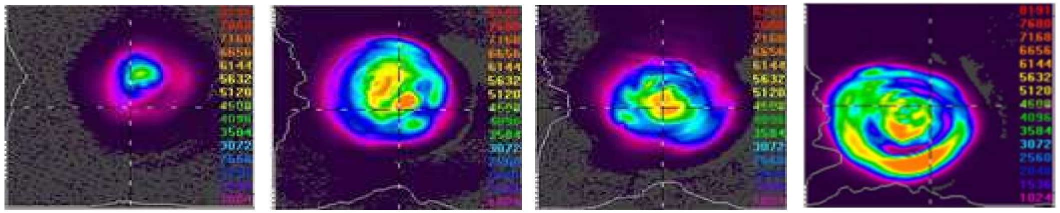


Experiment Device

Pilot System Driver Laser and PPL System Improvements

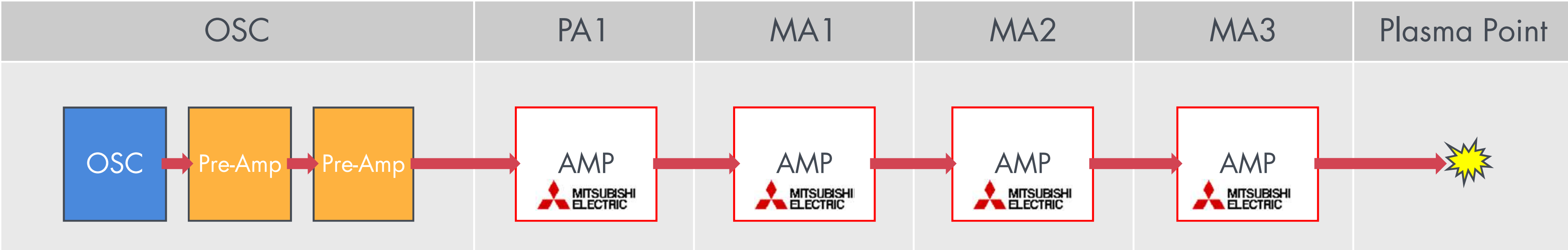


Proto#2 uses TRUMPF lasers for the three main amplifiers



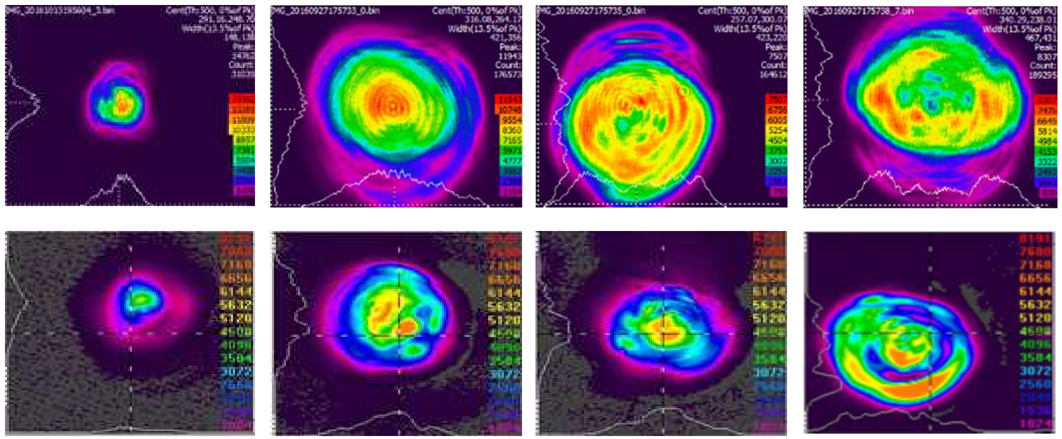
uneven and inefficient

Pilot System Driver Laser and PPL System Improvements



Pilot#1 uses Mitsubishi lasers for all amplifiers

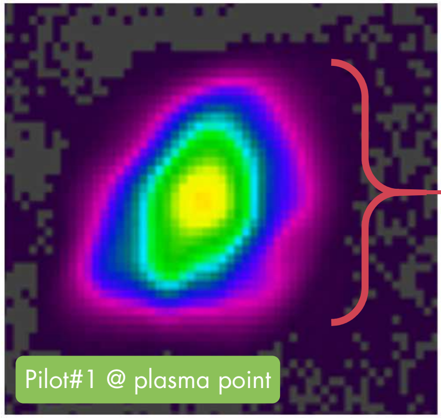
Proto#2 uses TRUMPF lasers for the three main amplifiers



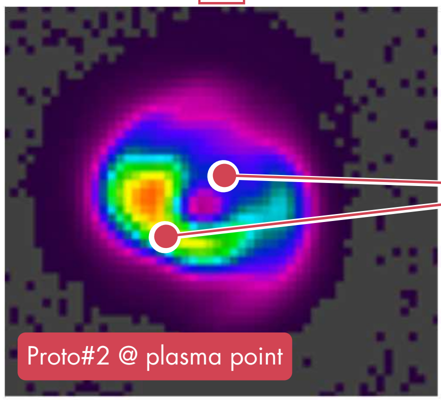
greatly improved uniformity

Pilot System Driver Laser and PPL System

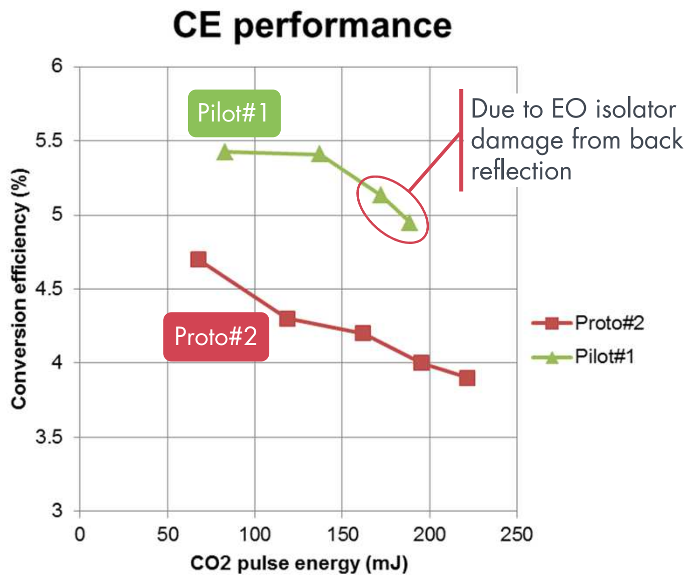
>5% CE was achieved due to the greatly improved CO_2 beam profile



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

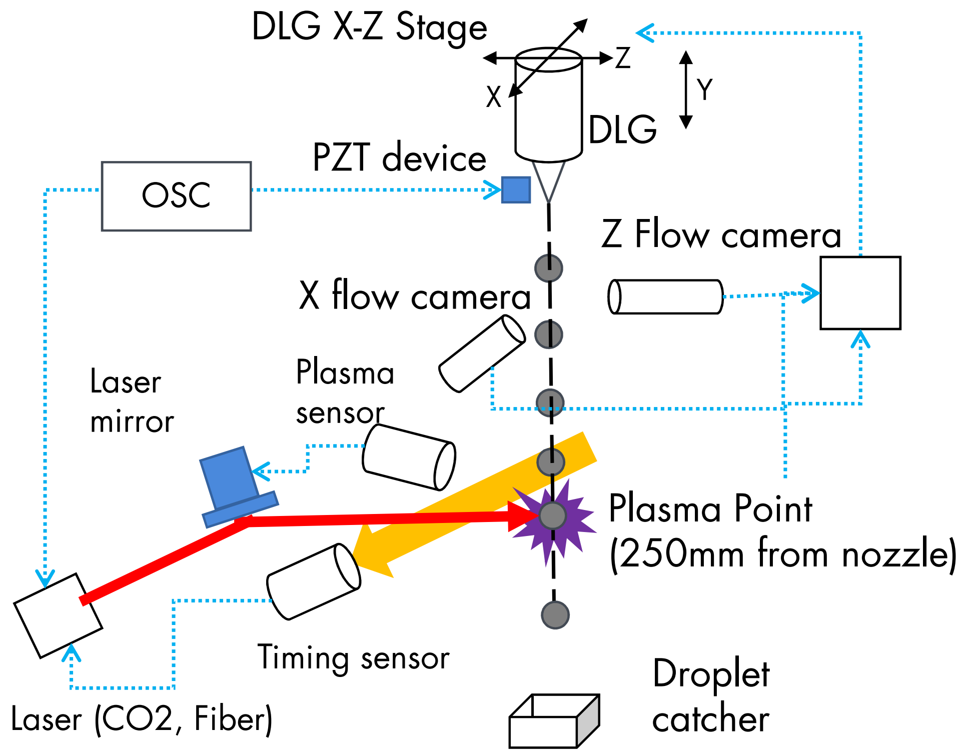


Previous CO_2 beam profile was very uneven and hence less efficient by comparison

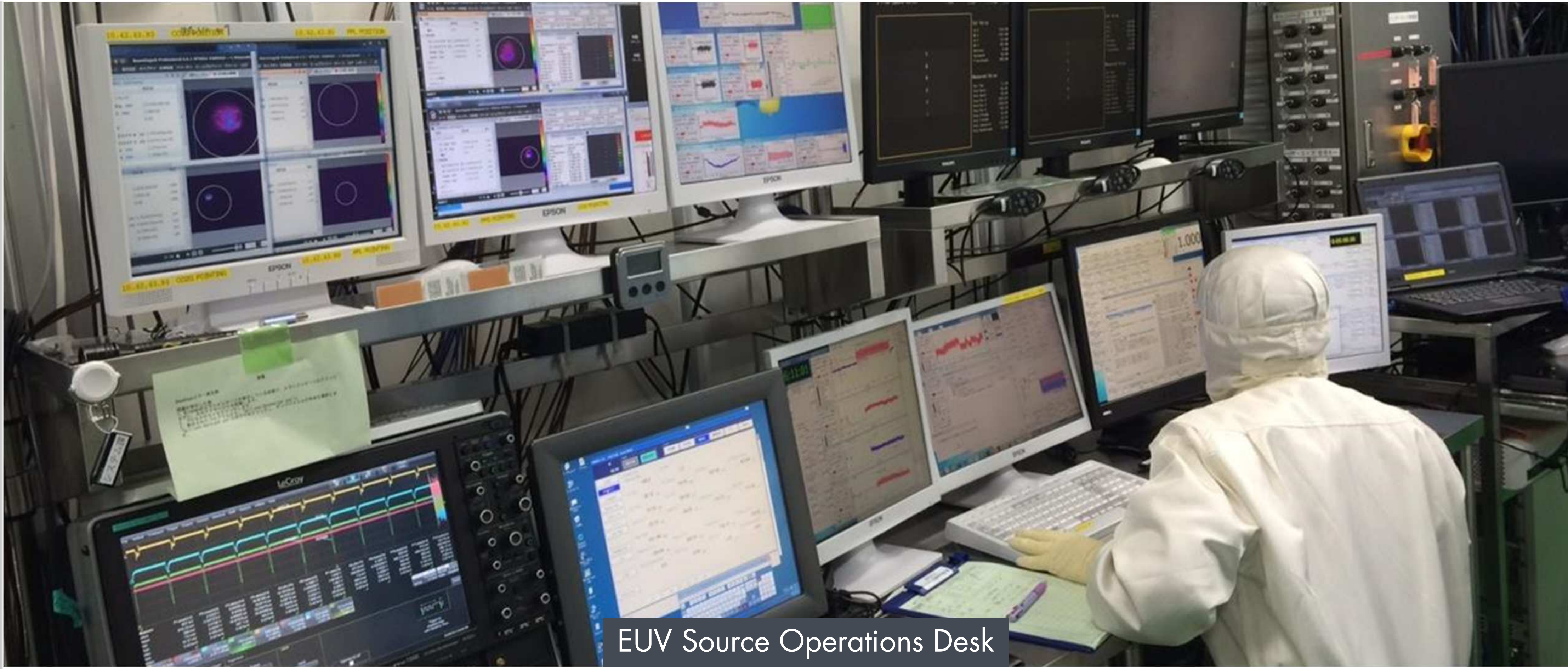


Pilot System Droplet Generator

LPP EUV Source Shooting Control System

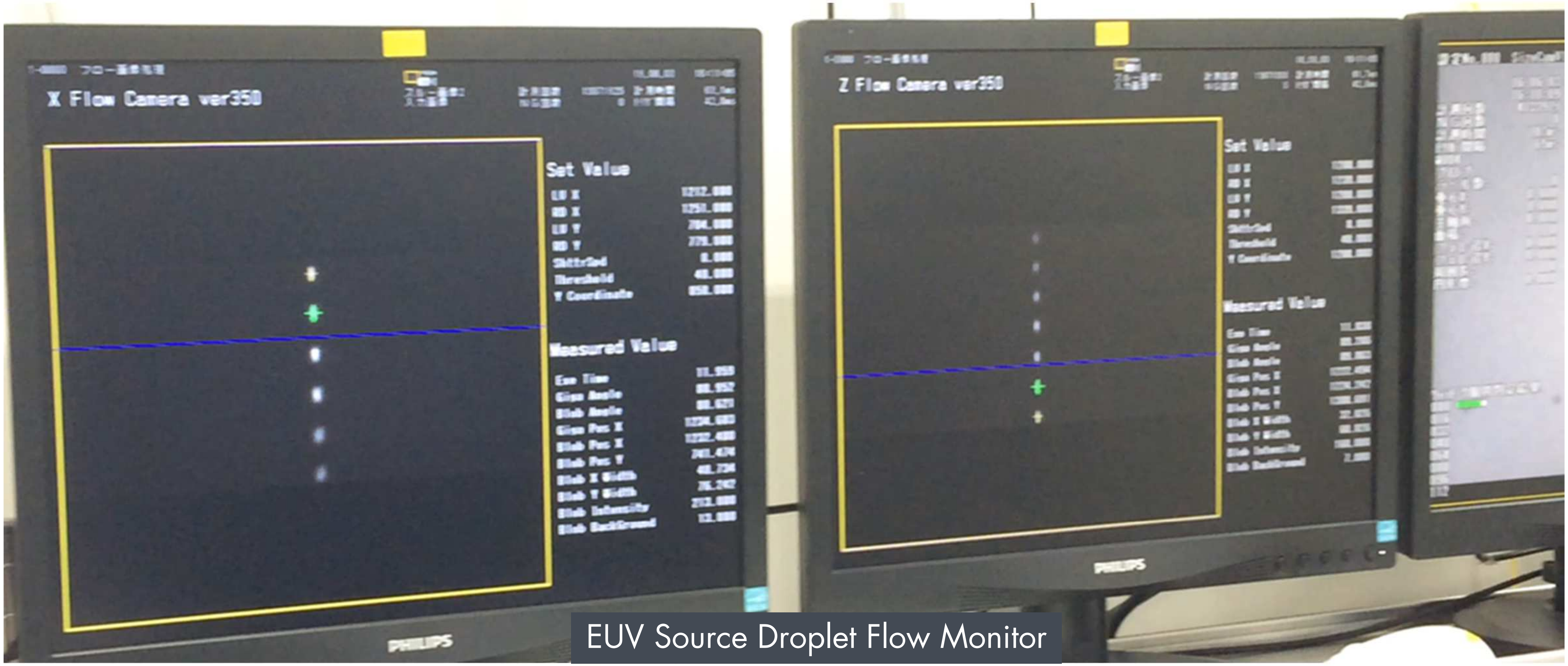


Pilot#1 System in Operation



EUV Source Operations Desk

Pilot#1 System in Operation



EUV Source Droplet Flow Monitor

System performance: Summary

Major achievements since last ERM(Executive review meeting)

- 99.4% die yield was achieved.
- 64% availability was confirmed in 2 week operation.
- Magnetic debris mitigation performance has been improved by heat management improvement.
- Collector lifetime test has been started.

Typical test data

	Sep-16	Oct-16	Mar-17	Apr-17
Average power at IF	100W	111W	80W	85W
Dose error (3 sigma)		**0.15%**	**0.08%**	**0.04%**
Die yield (< 0.16%)		**92.3%**	**97.7%**	**99.4%**
Operation time	5h	22h	204h	143h
Pulse Number	1Bpls	4Bpls	28Bpls	19Bpls
Duty cycle	95%	95%	75%	75%
In-band power	105W	117W	107W	113W
Dose margin	30%	25%	25%	35%
CE	5.0%	4.9%	4.5%	4.4%
Availability 4wk (2wk)	**13%**	**17%**	**40% (64%)**	**32%**
Collector lifetime	-	-	-	**-10%/Bpls**
Repetition rate	50kHz	50kHz	50kHz	50kHz
CO2 power	**9.1kW**	**9.5kW**	**9.8kW**	**12kW**

Last ERM | Availability potential test | Collector test

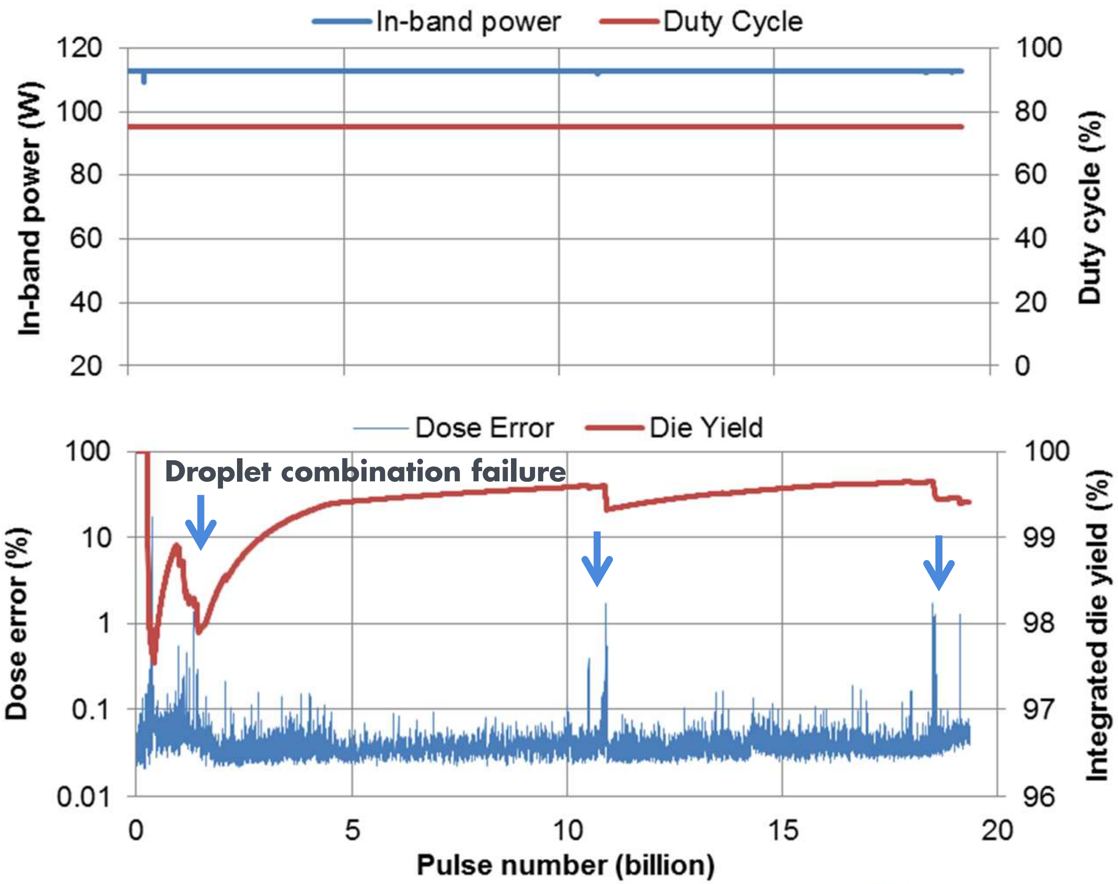
Dose stability performance (Apr.-17)

	Performance
Average power at IF	**85W**
Dose error (3 sigma)	**0.04%**
Die yield (< 0.16%)	**99.4%**
Operation time	**143h**
Pulse Number	**19Bpls**
Duty cycle	**75%**
In-band power	**113W**
Dose margin	35%
CE	4.4%
Availability 4wk	32%
Collector lifetime	-10%/Bpls
Repetition rate	50kHz
CO_2 power	12kW

Note

Dose error was mainly due to droplet combination failure and it was improved by droplet generator improvement(but not perfect).

Burst pattern: 1000ms ON, 333ms OFF
Dose error: including pre-exposure phase(10ms)
Die yield: defined by 0.16% dose error



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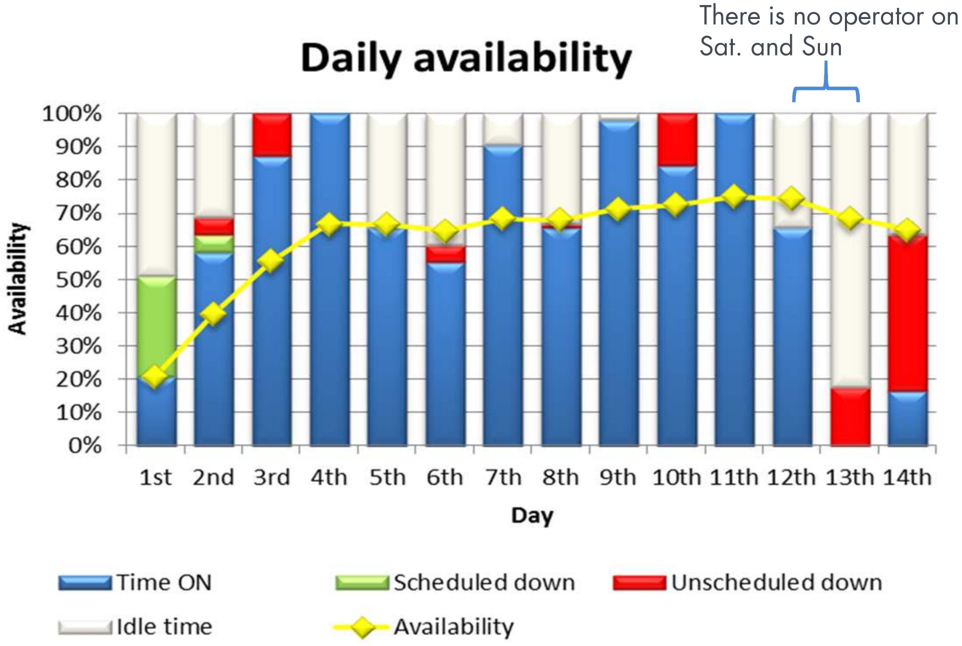
Availability potential test

- 2 week availability potential test was done. Availability was 64% and idle time was 25%. Availability is potentially achievable at 89%.



Dose error : System stopped at > 2% Dose error (3 sigma) /10kpls slit and error was not recovered by automatic function
Idle time: Time for waiting operator.

24 hour x 7 days definition
Unmanned operation between 9pm thru 8am

System stop event table

MTTR: 2.8h

Day	Event	Repair time	Root cause	Countermeasure
2	Dose Error	1.25h	25% dose margin is not sufficient	Dose margin 25% -> 28% New shooting control will be applied at Jun.
3	Sensor Error	3h	Sensor reliability	New sensor will be applied (TBD).
5	Dose Error	-	Droplet combination failure	Countermeasures will be applied at Jul.
6	Dose Error	1.25h	Shooting control algorism	Same as Day 2 countermeasure
8	Dose Error	0.25h	28% dose margin is not sufficient	Dose margin 28->35% . Same as Day 2 countermeasure.
10	Dose Error	3.75h	Droplet position instability due to particle issues.	Countermeasures are going on.
13	Dose Error	4.25h	Mirror damage in BTS(Beam transfer system) for new mirror evaluation.	Replacement to conventional mirror
14	Dose Error	11.25h		

COLLECTOR MIRROR LIFETIME TEST AND SIMULATION

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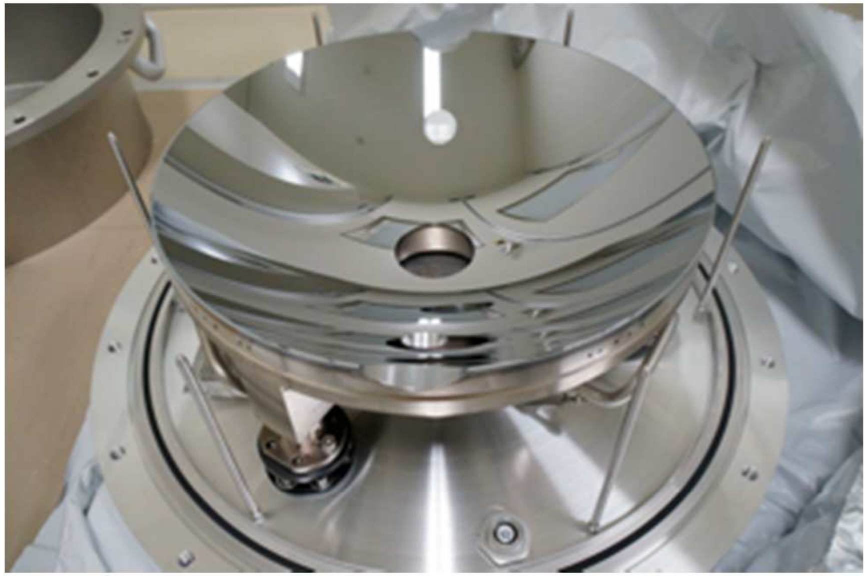
Latest LPP Source Systems Experiment Update

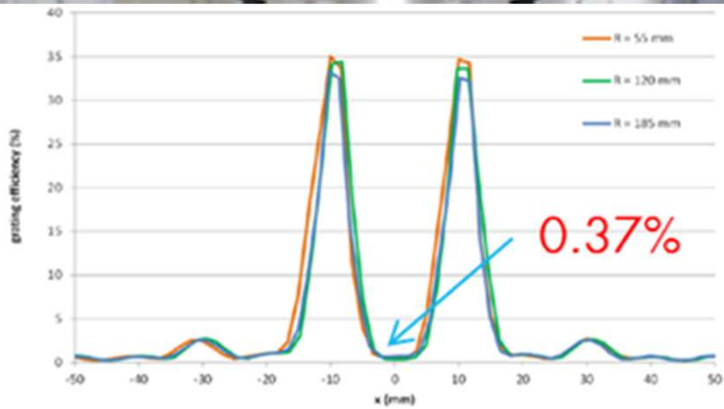
Currently 2 prototype high power EUV light sources are being used for experiments

Proto#1
POC in Power Scaling and Debris Mitigation

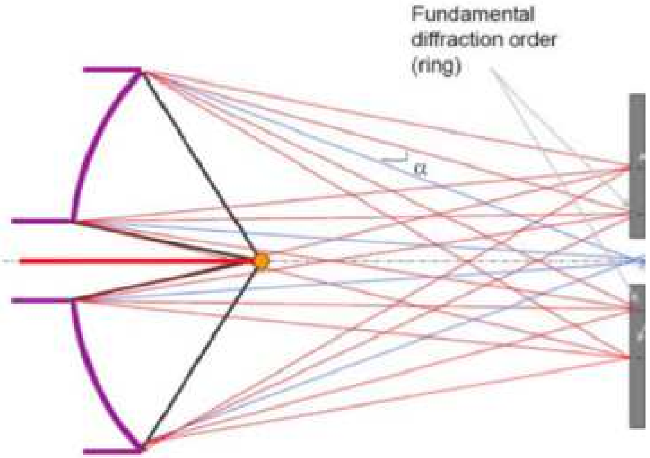
Proto#2
High Power Experiment

HVM Collector Mirror Specifications





- Size Φ412mm
- Weight 22kg
- Collector efficiency >74%
- Collector reflectivity >48%
- Grating structure



- Measured IR reflectivity: 0.37%

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Debris Mitigation

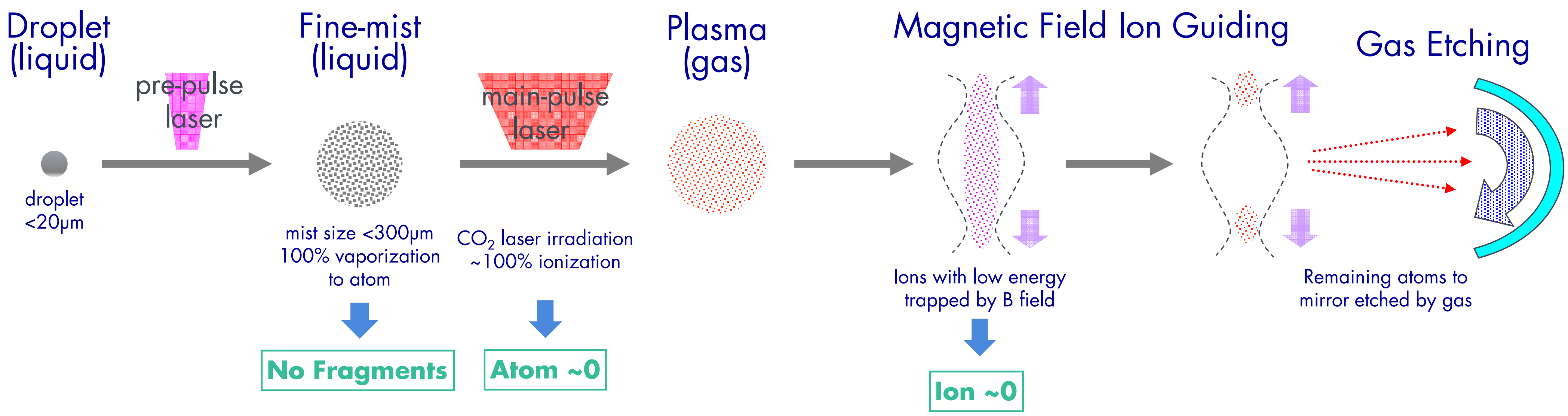
Gigaphoton's Magnetic Debris Mitigation concept

Higher CE and Power

- Optimum wavelength to transform droplets into fine mist
- Higher CE achievement with ideal expansion of the fine mist

Long Life Chamber

- Debris mitigation by magnetic field
- Ionized tin atoms are guided to tin catcher by magnetic field



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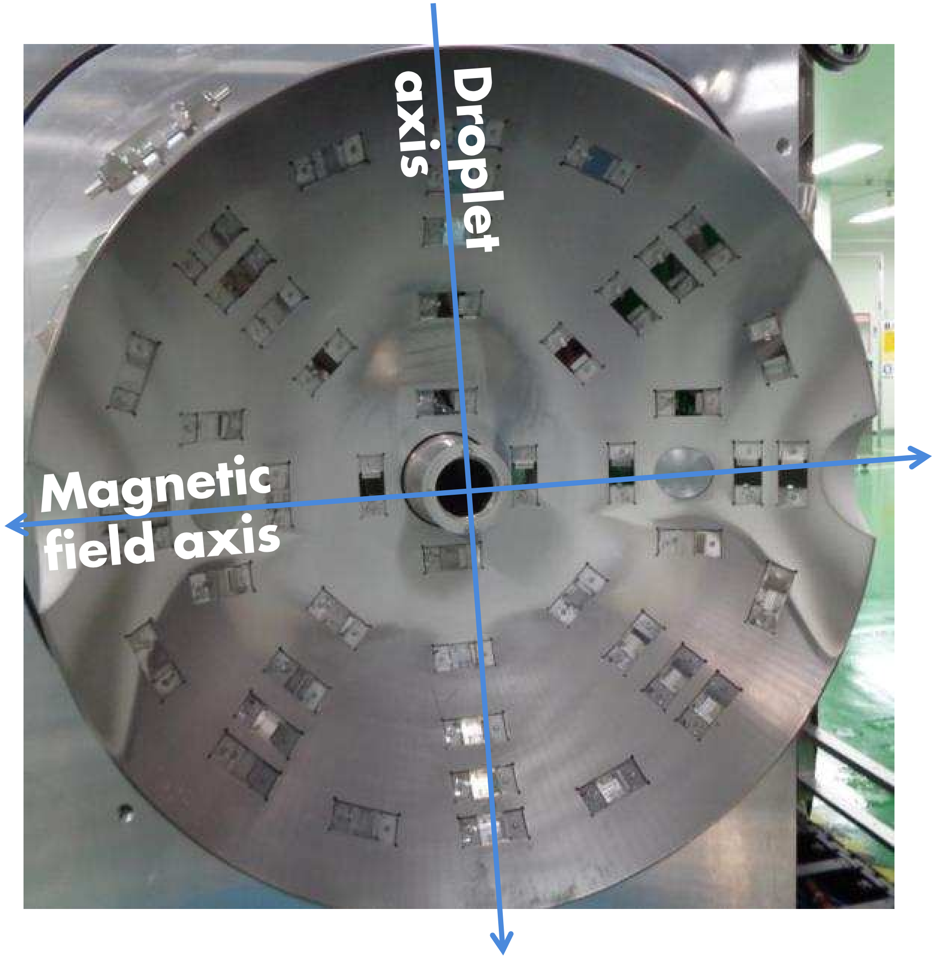
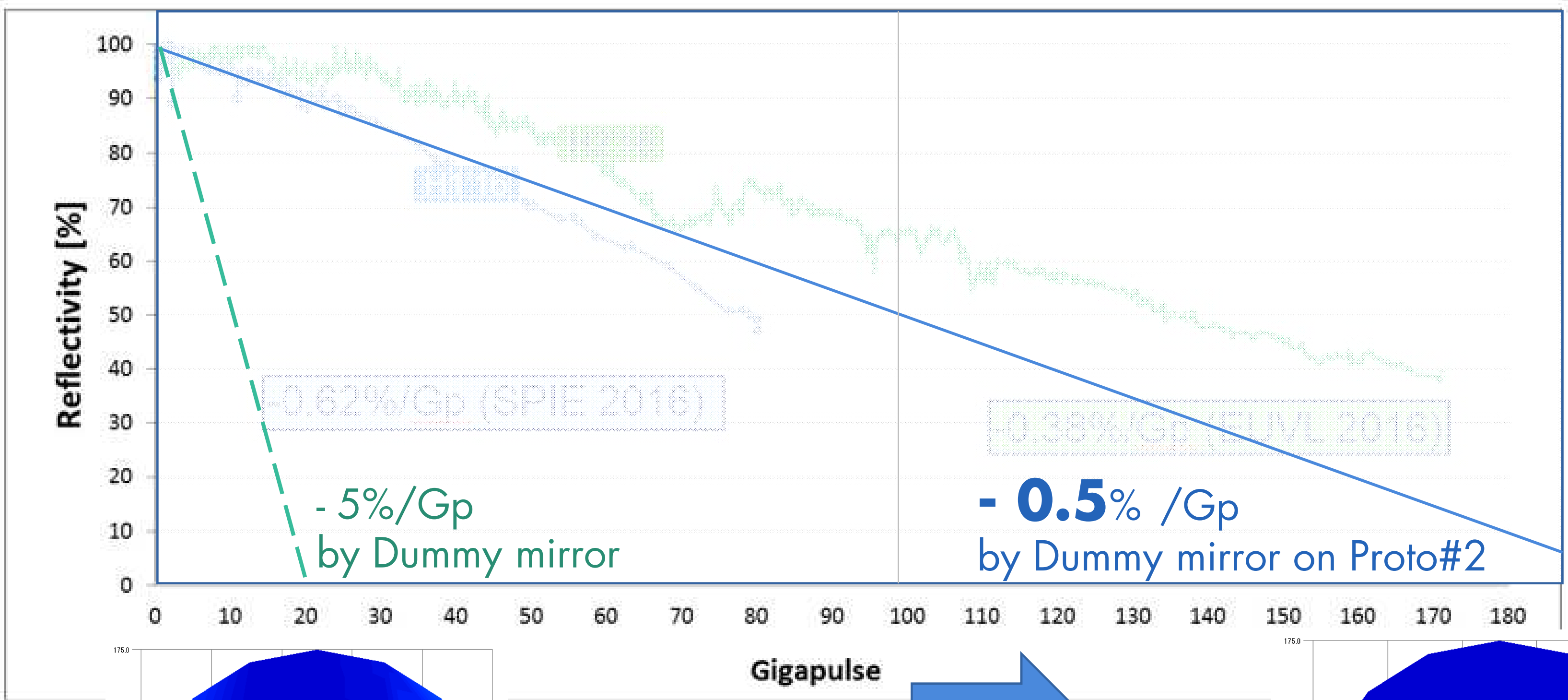
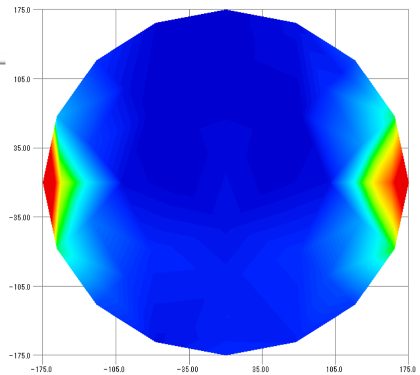
Debris Mitigation and Capping Layer Evaluations by Dummy Mirror



- Purpose
  - Evaluation of tin deposition distribution on the collector mirror
- Method
  - Dummy collector mirror (no coating)
  - Sampling plate (sample coupon)
    size: 15mmx15mmx0.7mmt
    material : Si plate (46 pieces)
    +multi layer (Si/Mo) + Capping layer
- Analysis after test
  - Surface condition : SEM
  - Deposited tin thickness : XRF
  - Capping layer thickness: TEM

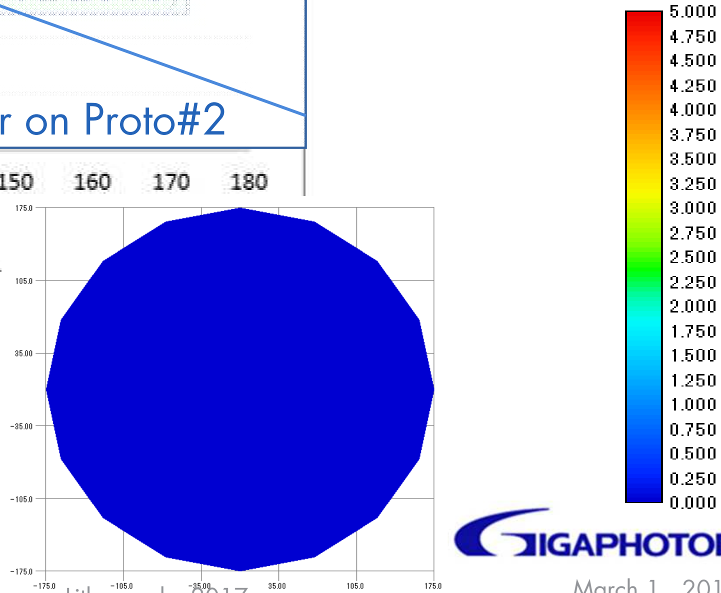
Collector Lifetime Status through Dummy Mirror Test





10 times improvement made by

- ✓ Capping Layer Optimization
- ✓ Temperature Control
- ✓ H_2 Condition optimization



Difference of Deposition on the Sample Coupon of Dummy Mirror

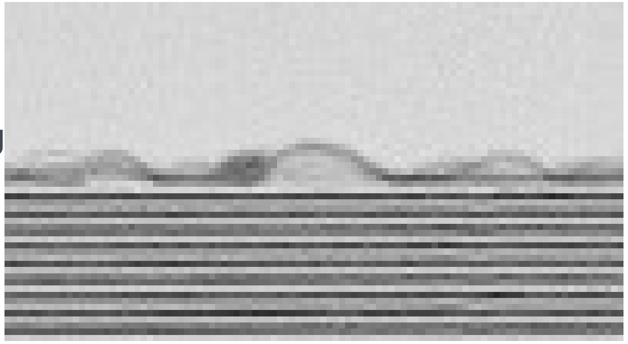
Capping layer disappearance
Blister generation

Capping layer deformation
Blister generation

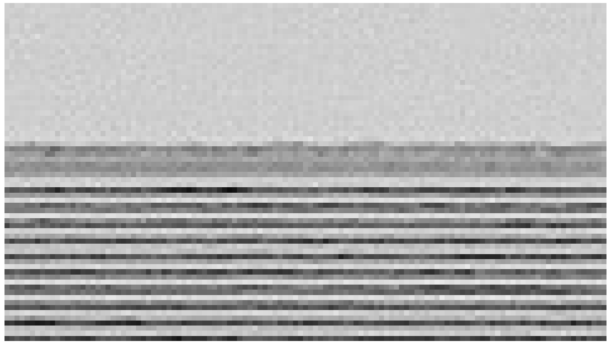
Capping layer survived
No blister generation

Capping

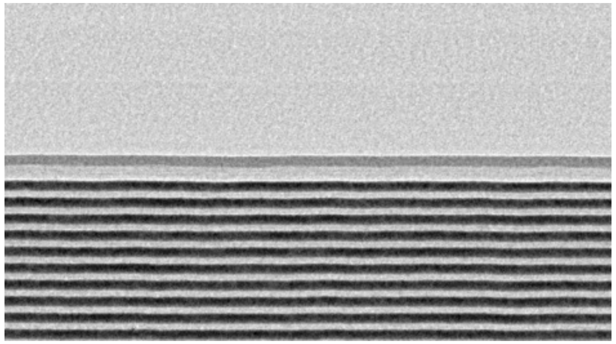
Mo/Si



A
124W, 7.3Bpls



B
124W, 6.1Bpls

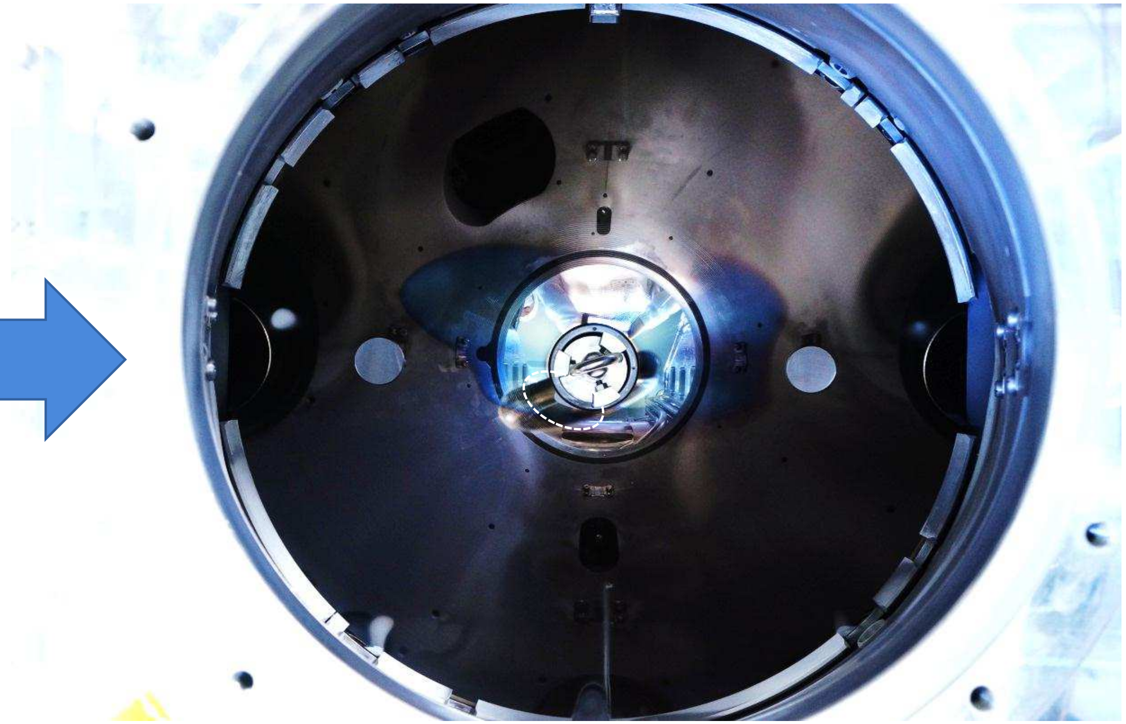


C
124W, 7.3Bpls

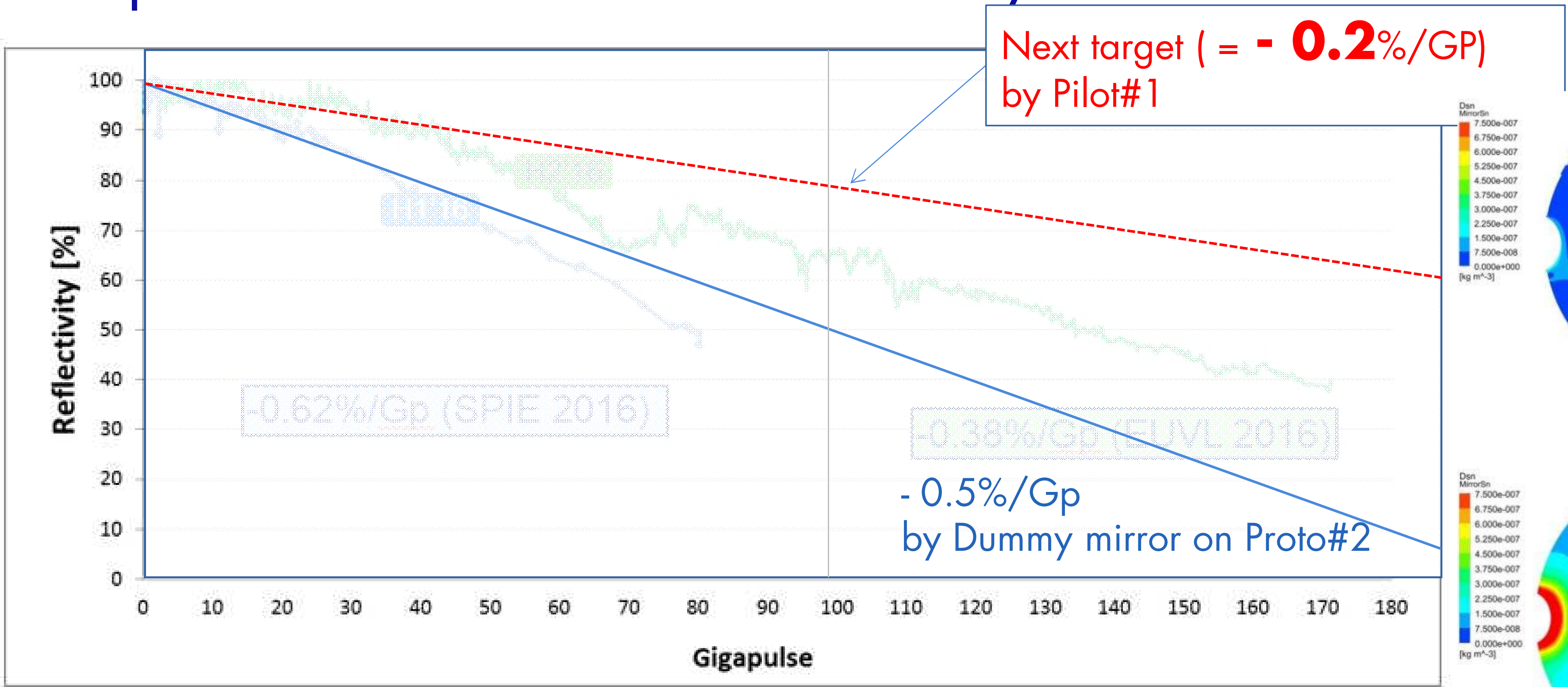
Preliminary Result of Real Collector Mirror on Proto#2

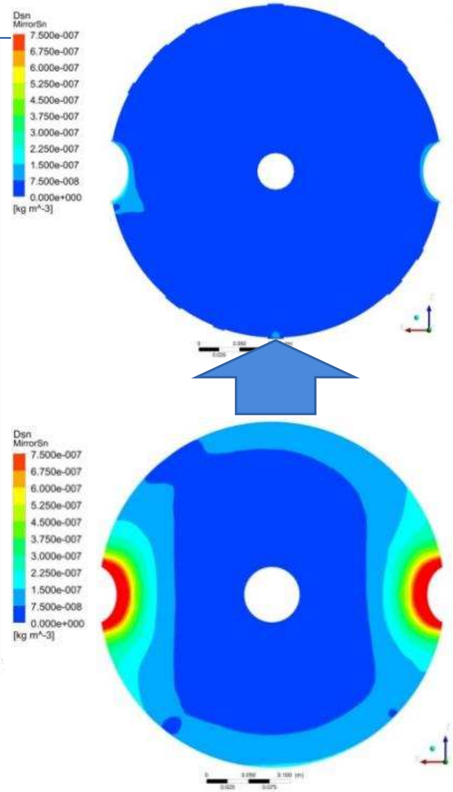
15. Feb.2017 : 325 Mpls,

100W in burst, Duty 26%, 26W (ave)



Improvement of Collector Lifetime by Simulation





1. Back Diffusion Mitigation
   - H_2 Gas Flow Design
   - Cooling System
2. Shooting Accuracy Improvement
   - Reduction of Target Misses

STUDY OF 500W POWER EUV SOURCE

SPIE Advance Lithography 2017

GIGAPHOTON

March 1 , 2017

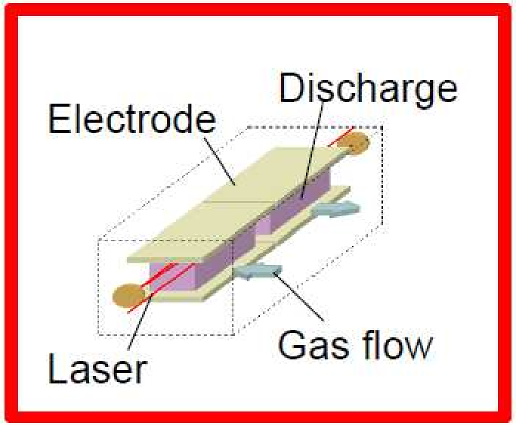
High Power EUV Source for High NA EUV exposure tool

EUV ave.Power[W] @100kHz		Conversion Efficiency [%]						
CO2 laser Energy [mJ]	CO2 laser ave. Power [kW]	2%	3%	4%	5%	6%	7%	8%
15	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	5	19.1	28.7	38.2	47.8	57.3	66.9	76.4
100	10	46.4	69.6	92.8	[illegible]	139.2	162.4	185.6
150	15	73.7	110.6	147.4	[illegible]	221.1	258.0	294.8
200	20	101.0	[illegible]	202.0	[illegible]	303.0	353.5	404.0
250	25	128.3	192.5	256.6	320.8	384.9	449.1	513.2
300	30	155.6	233.4	[illegible]	389.0	466.8	544.6	622.4
350	35	182.9	274.4	365.8	457.3	548.7	640.2	731.6
400	40	210.2	315.3	420.4	525.5	630.6	735.7	840.8
450	45	237.5	356.3	475.0	593.8	712.5	831.3	950.0
500	50	264.8	397.2	529.6	662.0	794.4	926.8	1059.2
550	55	292.1	438.2	584.2	730.3	876.3	1022.4	1168.4
600	60	319.4	479.1	638.8	798.5	958.2	1117.9	1277.6
650	65	346.7	520.1	693.4	866.8	1040.1	1213.5	1386.8
700	70	374.0	561.0	748.0	935.0	1122.0	1309.0	1496.0
750	75	401.3	602.0	802.6	1003.3	1203.9	1404.6	1605.2
800	80	428.6	642.9	857.2	1071.5	1285.8	1500.1	1714.4
850	85	455.9	683.9	911.8	1139.8	1367.7	1595.7	1823.6
900	90	483.2	724.8	966.4	1208.0	1449.6	1691.2	1932.8
950	95	510.5	765.8	1021.0	1276.3	1531.5	1786.8	2042.0
1000	100	537.8	806.7	1075.6	1344.5	1613.4	1882.3	2151.2

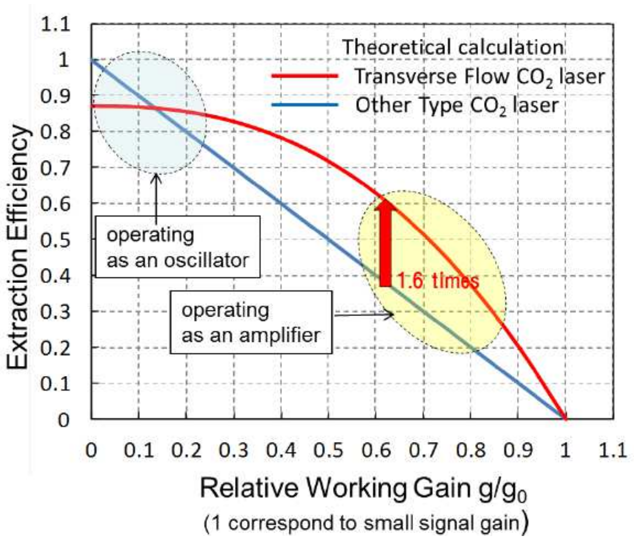
Lithography	R(nm)*	NA	λ/n (nm)	Power (W)
KrF dry	102	0.85	248	40
ArF dry	73	0.93	193	45
F_2 dry	69	0.80	157	-
ArF immersion	50	1.35	134	90
EUV	14	0.33	13.5	>250
EUV (High NA)	7	0.6	13.5	>500

	HVM1	HVM2	HVM3
EUV Power	250W	300W	500W
Pulse Rate	100kHz	100kHz	100kHz
CE	4.5%	5%	5%
CO_2 Laser Power	25kW	25kW	40kW

Study of 50kW CO2 Laser Design



1. Transverse-gas-flow



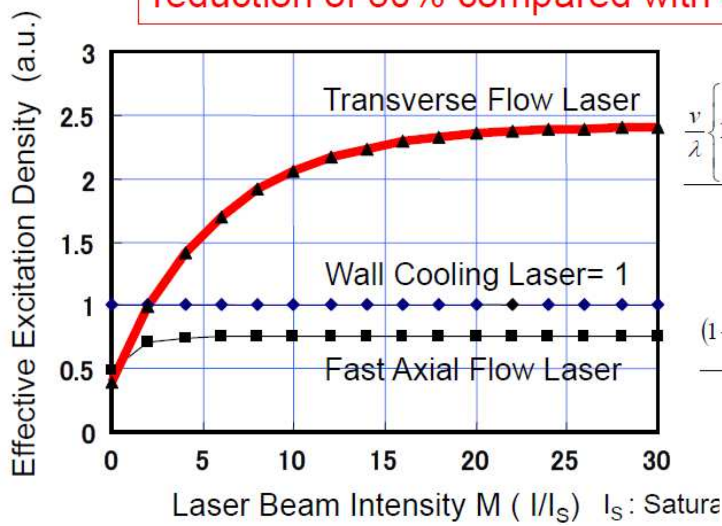
MITSUBISHI ELECTRIC Changes for the Better

2. Advantages of our CO_2 laser source

Today

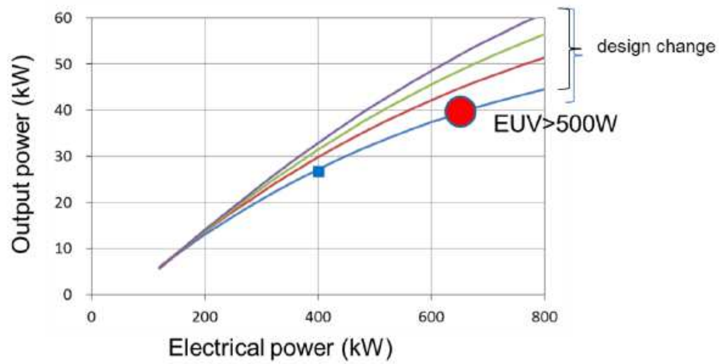
User Advantages (1)High power >25kW with better efficiency

Theoretical calculation to explain electrical input power reduction of 50% compared with other CO_2 lasers



$$\frac{\frac{v}{\lambda}\left\{1+\frac{\lambda}{v}(W-l)-e^{-\frac{l\lambda}{v}}\left(1-e^{-\frac{(1+M)(r-l)\lambda}{v}}\right)-\frac{e^{-\frac{(1+M)(r-l)\lambda}{v}}}{1+M}\left(M+e^{-\frac{(1+M)(W-l)\lambda}{v}}\right)\right\}}{(r-l)}$$

$$\frac{(1+M)W+\frac{v}{\lambda}e^{-\frac{(1+M)L\lambda}{v}}\left(1-e^{-\frac{(1+M)W\lambda}{v}}\right)}{(1+M)L}$$



Next Generation High Power EUV Source Development

in cooperation with MITSUBISHI ELECTRIC

OSC		PA1	MA1	MA2	MA3	Plasma Point
OSC → Pre-Amp → Pre-Amp →		AMP MITSUBISHI ELECTRIC →	AMP MITSUBISHI ELECTRIC →	AMP MITSUBISHI ELECTRIC →	AMP MITSUBISHI ELECTRIC →	
For 250W EUV	100W	5kW	10kW	20kW	30kW	25kW
For 500W EUV	100W	**10kW**	**20kW**	**30kW**	**50kW**	**40kW**

Basic Experiment in 2013

1st Amplifier installation in 2015

Amplifier system installation in 2016

Next Generation Pre-pulse Laser

- ✓ Pre-pulse laser technology is one of the most important component of HVM EUV Source.
- ✓ Recently we achieved 250W operation with 4% CE on Prot#2. Also Pilot#1 system is on operation around 100W with 5% CE.
- ✓ Hilase laser is one of the candidate on pre-pulse laser.

Requirement of Next Generation Pre-pulse Laser

Item	Current Specification	Target
Pulse width	12ps+/-4ps	<12ps +/-4ps
Wavelength	1064nm+/-0.5nm	**1064nm or 1030um**
Pulse energy	>1mJ at 100kHz	**>2mJ at 100kHz**
Pulse energy stability	<3% at sigma	**<1% at sigma**
Repetition rate	Single to 120kHz	Single to 120kHz
Timing jitter	<50ns at P-P	**<20ns at P-P**
Beam profile	10mm+/-1mm at 1/e^2	10mm+/-1mm at 1/e^2
Pointing stability	<50urad at 3 sigma	<50urad at 3 sigma
Beam divergence	<210urad	<210urad
Mechanical/Electrical Interface	-	TBD
Service ability	-	TBD
Delivery / Price	-	TBD

hilase
Power of light

HiLASE Centre, Institute of Physics, CAS
Za Radnicí 828, 252 41 Dolní Břežany
The Czech Republic

www.hilase.cz www.fzu.cz

0.5 kW Compact Picosecond Laser

Solution for high-tech material processing

High-tech industrial and biological laser applications such as precise cutting and drilling of metals, plastics, semiconductors and glasses, and microstructuring of surfaces, etc., require the development of high average power picosecond laser systems. State-of-the-art ultrashort pulse OPA systems also need a high beam quality picosecond pump source for reliable operation.

We offer small-footprint, thin-disk-based, regenerative amplifiers including a fiber-based front-end and pulse compressor producing train of < 2 ps long pulses (1030 nm) in fundamental spatial mode (M^2< 1.3).

Average power and pulse repetition rate can be modified according to the customer's needs up to 0.5 kW and 800 kHz, respectively. Optionally, the output can be converted to the 2nd, 3rd or 4th harmonic.

Technical data:

- Default wavelength 1030 nm
- Average power up to 0.5 kW
- Pulse energy up to 5 mJ
- Repetition rate up to 800 kHz
- M^2 < 1.3
- Pulse duration < 2 ps
- Energy stability < 1.5% RMS

Benefits:

- Small footprint
- High-beam quality
- Fiber front-end
- Stable bulk grating compressor
- Optional wavelength: 515 nm; 343.3nm; 257.5 nm

For more information please contact
Mr. Oskar Lazansky
(technology transfer office) lazansky@fzu.cz

Fig. 1 3D model

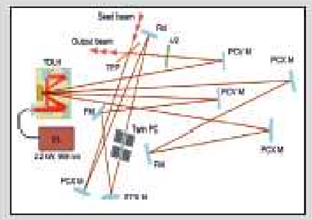


Fig. 2 0.5 kW ring cavity regenerative amplifier

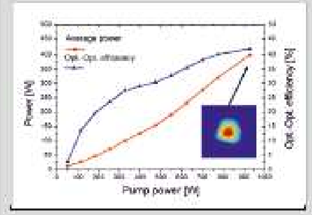


Fig. 3 Output power and beam profile up to 0.4 kW

FZU citt

Corroboration with Mitsubishi Electric / HiLASE Project

- *Gigaphoton appreciate corroboration with Mitsubishi Electric / Hilase project !*

SUMMARY

Summary

- Pilot#1 is up running and its demonstrates HVM capability;
  - EUV power recorded at113W average (85W in burst stabilized, 75% duty) with 5% conversion efficiency for 143hours operation in May 2017.
  - High conversion efficiency (5% level) is realized with several key engineering efforts.
  - Pilot#1 system recorded Availability was 64% and idle time was 25%. Availability is potentially achievable at 89% (2weeks average).
- Long-life Collector Mirror mitigation test is in progress;
  - Superior magnetic mitigation (= 0.5%/Gp) has been demonstrated above 100W level operation with dummy mirror test.
  - Full scale C1 mirror life test is on going.
  - Next target is >100W average power with high duty cycle operation with C1 full-scale mirror lifetime demonstration (Expectation from simulation: < 0.2%/Gp) .
- Further scalability scenario toward 300/500W EUV source power is under investigation

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Thank you for co-operation:

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Dr. Kentaro Tomita, Prof. Kiichiro Uchino and others in Kyushu University

Dr. Jun Sunahara, Dr. Katsunori Nishihara, Prof. Hiroaki Nishimura, and others in Osaka University

** The authors would like to express their deepest condolences to the family of Dr. Yoichi Tanino who suddenly passed away on February 1st, 2014. We are all indebted to his incredible achievements in CO_2 amplifier development. He will be missed very much*

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THANK YOU

