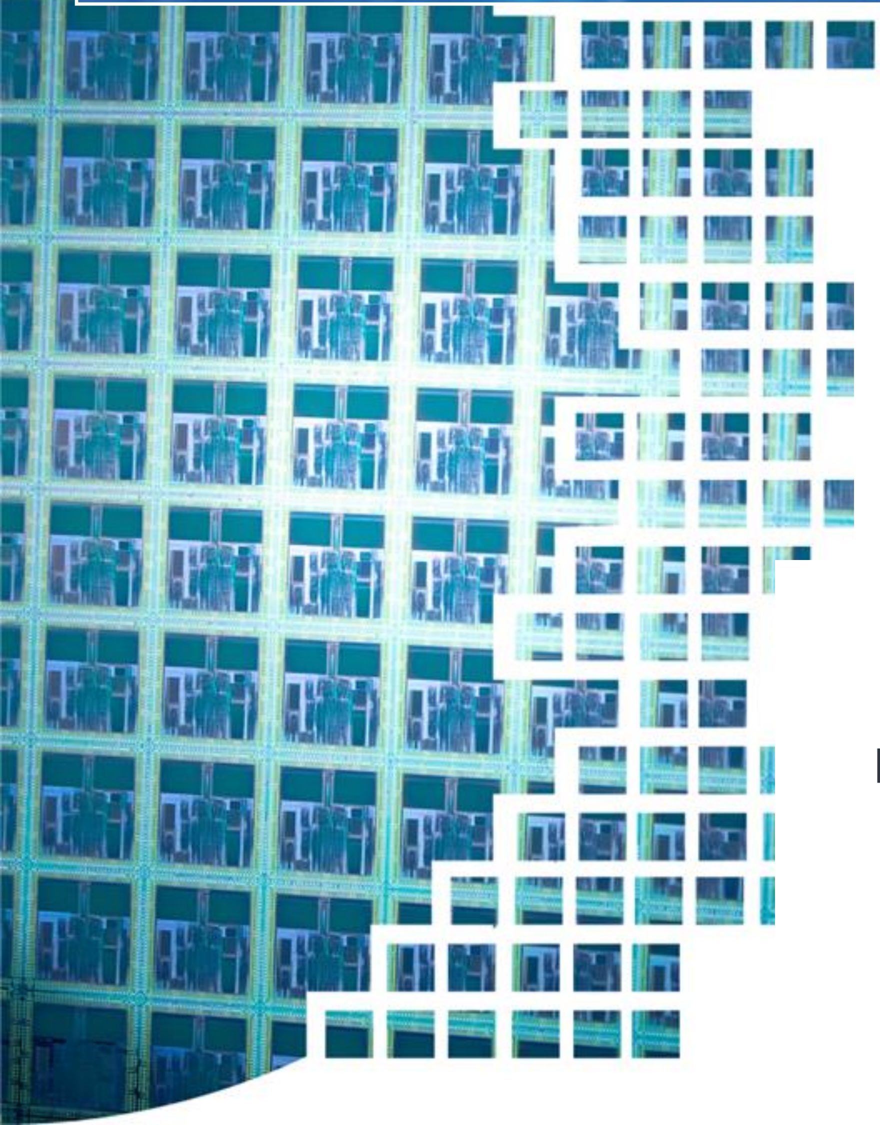
第2回 EUV-FEL ワークショップ WORKSHOP
開催 2017 12.12 Tue 10:00-17:00



HIGH POWER LPP-EUV SOURCE WITH LONG COLLECTOR MIRROR LIFETIME FOR HIGH VOLUME SEMICONDUCTOR MANUFACTURING

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Agenda

- Motivation
- HVM Ready System Performance Progress and Target
- HVM Ready Long-lifetime Collector Mirror
- Summary

MOTIVATION

Requirement for a Light Source in EUV Lithography

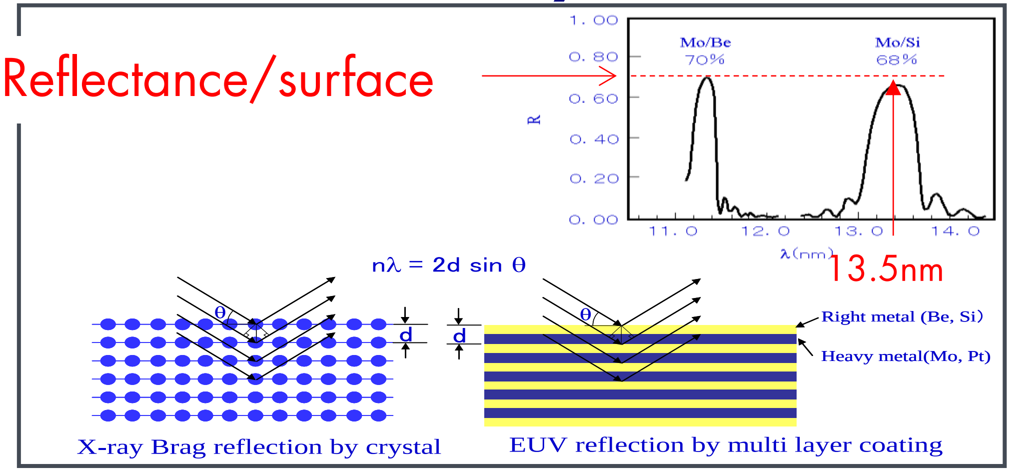
EUV light transmittance is less than 2% at 11-refection mirror system

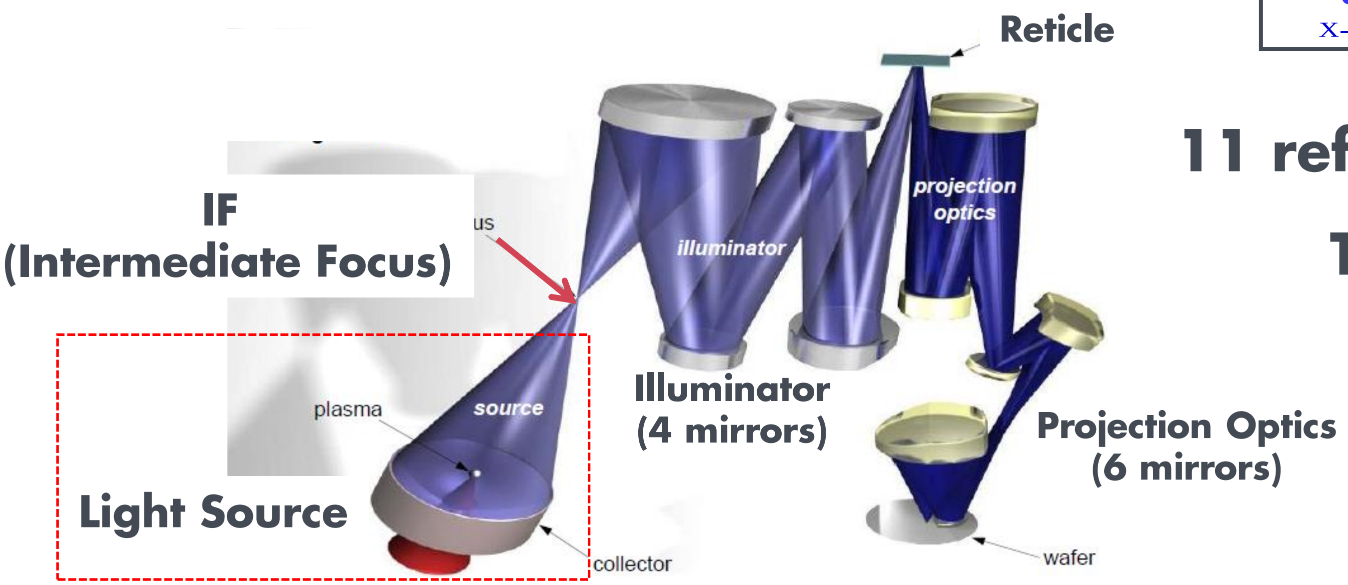
The development of a high power EUV light source for HVM exposure tools is the **KEY** Issue.

Requirement: >**250W** at IF (1st stage HVM)

Mo-Si multi-layer for EUV

70% Reflectance/surface





11 reflections (Maximum)

Transmittance: $0.70^{11}=0.02$

EUV extension roadmap

ASML
Public
Slide 3
EUVL 2017

introduction	55 WPH	125 WPH	145 WPH	185 WPH	Overlay [nm]
2013	NXE:3300B				7
2015		NXE:3350B			3.5
2017		NXE:3400B			3
			NXE:next		<3
				High NA	<2

products under study

2017-2019

Source : 250W

Source : 500W

Jan van Scoot (ASML);"The future of EUV lithography :enabling Moor's Low in the next decade", EUVL symposium 2017, 2017/9/11-14, Monterey, USA

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Motivation

- According to ASML roadmap*, EUV lithography will be released with 145wph throughput by 2019 for HVM.
  - EUV source power is increasing, but has not yet reached sufficient power levels, required **250W is Ready? Q1**
  - In order to reach 145wph, it requires high **Availability**, and also one key element such as **Collector Life are Ready ? Q2**
- Gigaphoton has been integrating an architecture of LPP with CO_2 laser plus Pre-pulse since 2002, and has the longest development history in EUV.
  - Will **Gigaphoton's** source be in time to meet145wph HVM **by 2019 ? Q3**

* *Reference: Christophe Smeets (ASML)@ EUVL Symposium- 2016*

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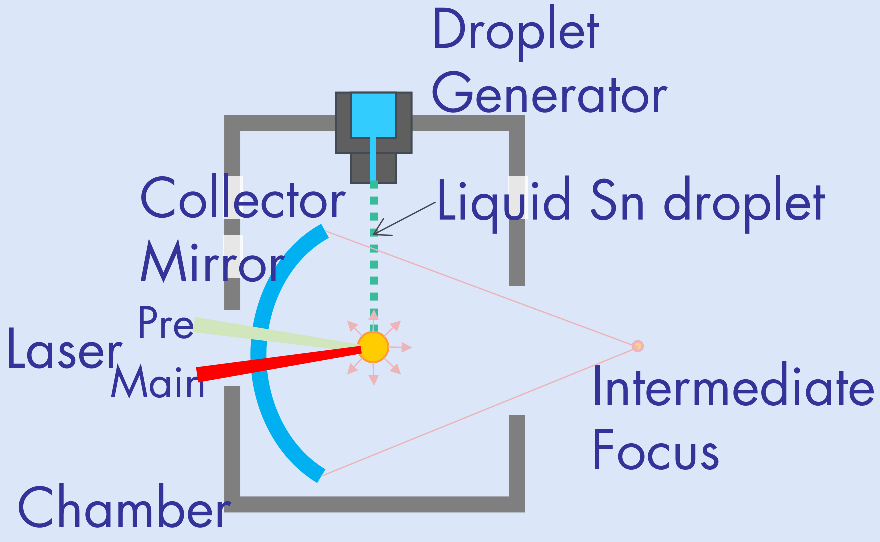
HVM READY PERFORMANCE PROGRESS AND TARGETS

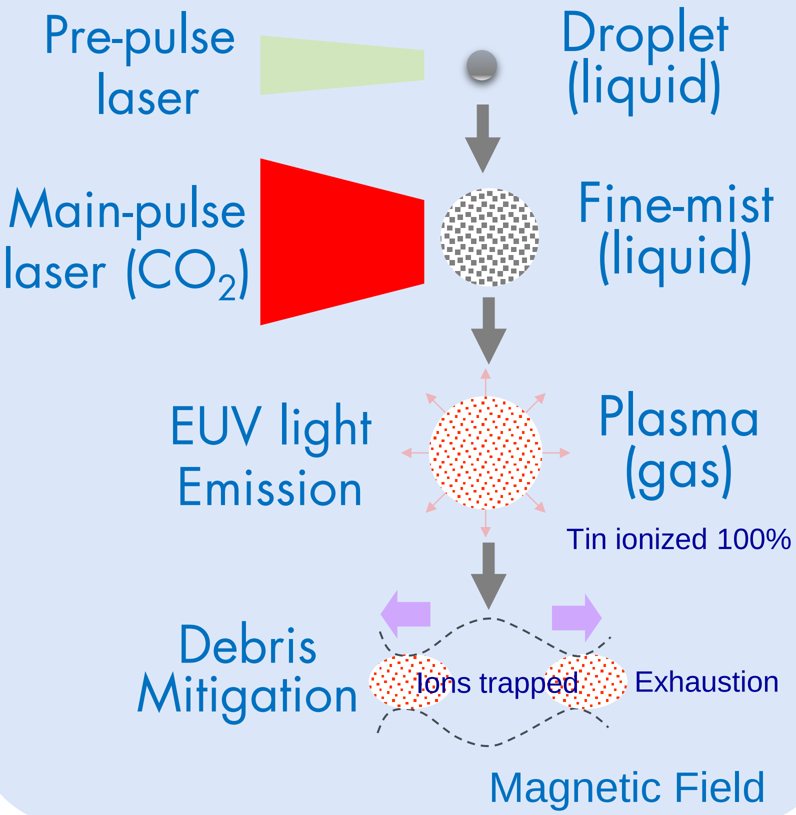
How to generate EUV light

Structure



- Sn droplet 20um Dia.100kHz ejection with 300km/h
- Pre and main lasers shoot every single droplets.
- Collector transfer EUV light to the IF point.

Sn life cycle



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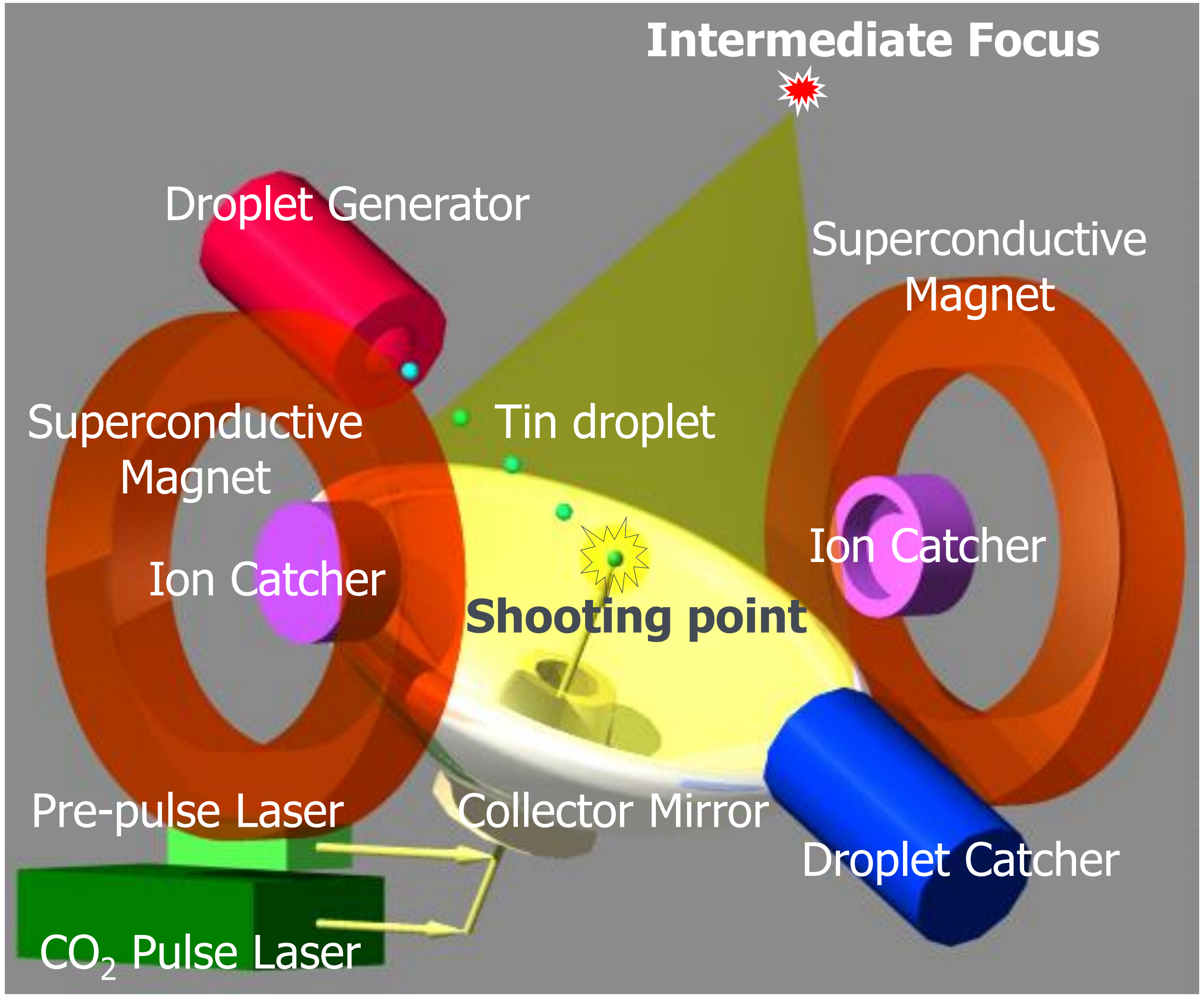
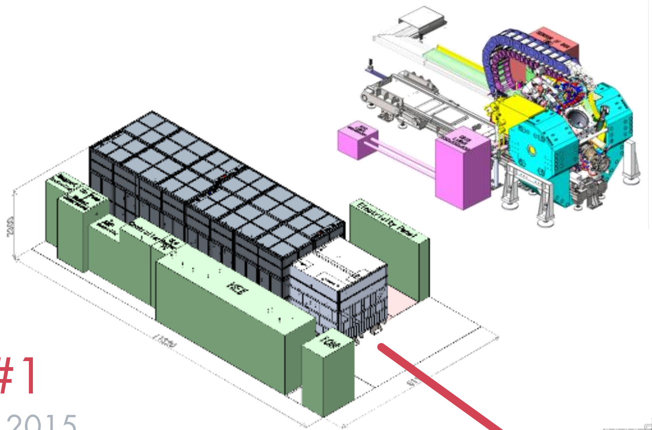
Gigaphoton's LPP Source Concept

1. **Dual-wavelength shooting concept**
   High CE attained with CO_2 and pre-pulse solid-state lasers
2. **EUV specific Hybrid CO_2 laser system**
   Short pulse/High repetition rate oscillator
   combined with commercial cw-amplifiers
3. **Debris mitigation with Super conductive magnets (SM3)**
4. **Accurate shooting system**
   Stable droplet generation and shooting beam control
5. **Out-of-band light reduction**
   Grating structured collector mirror



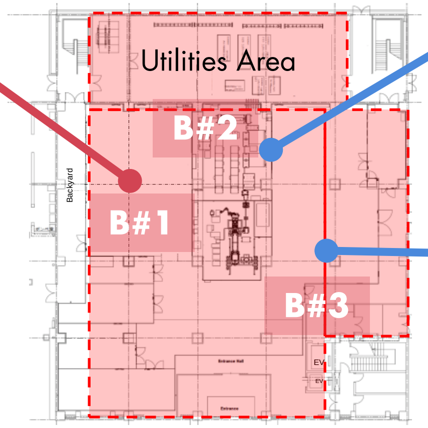
Current EUV Sources at Gigaphoton

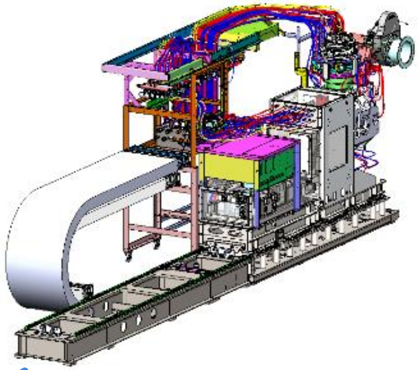


NEW **Pilot#1**

Operational since 2015

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

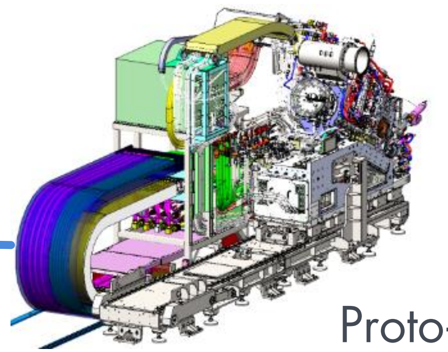




Proto#1

Operational since October 2012

Elemental technology research and proof of concept



Proto#2

Operational since November 2013

Key technology development for HVM

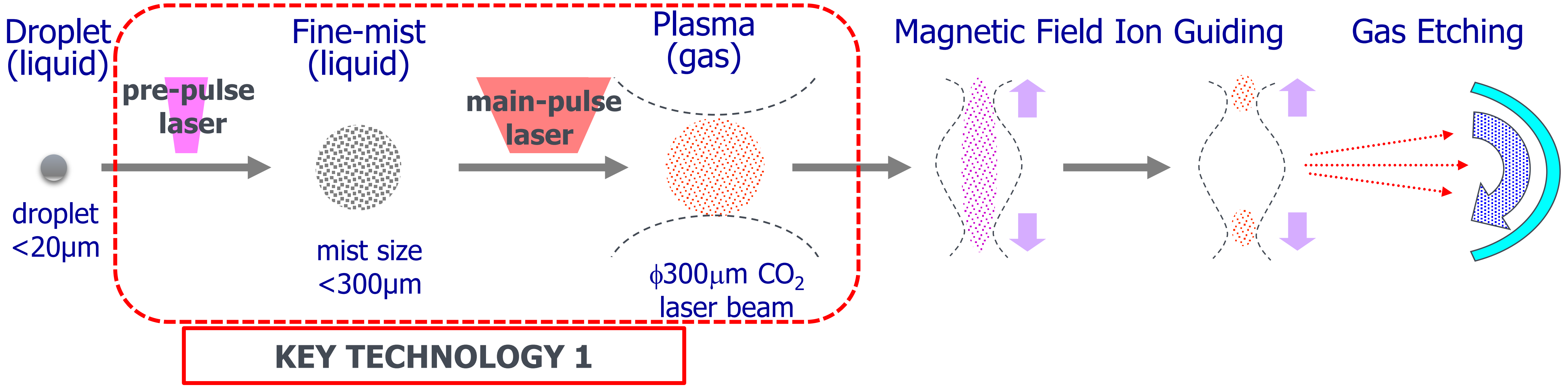
Pre-pulse Technology

Higher CE and Power

- Optimum wavelength to transform droplets into fine mists
- High CE is achieved with ideal expansion of the fine mists to match the CO_2 laser beam diameter

Long Life Chamber

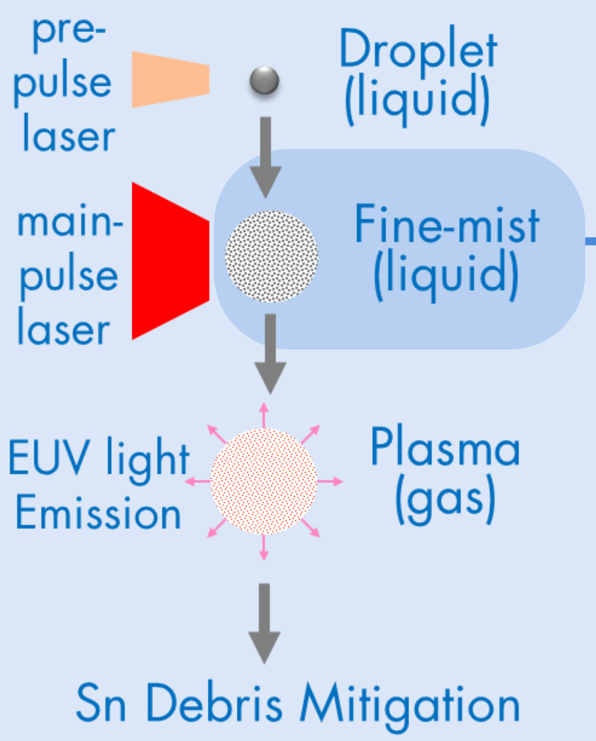
- Debris mitigation by superconducting magnets
- Ionized tin atoms are guided to tin catchers by the magnetic field



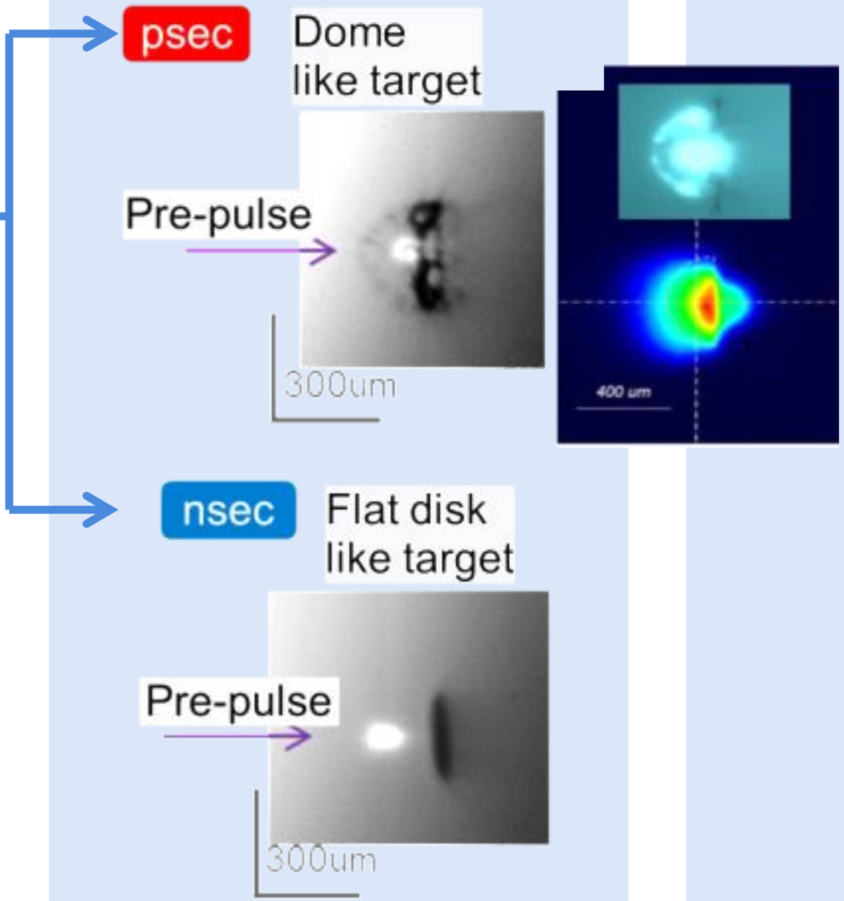
Pre-pulse enables the size matching between a droplet and CO_2 laser beam to achieve high CE.

Pre-Pulse Technology

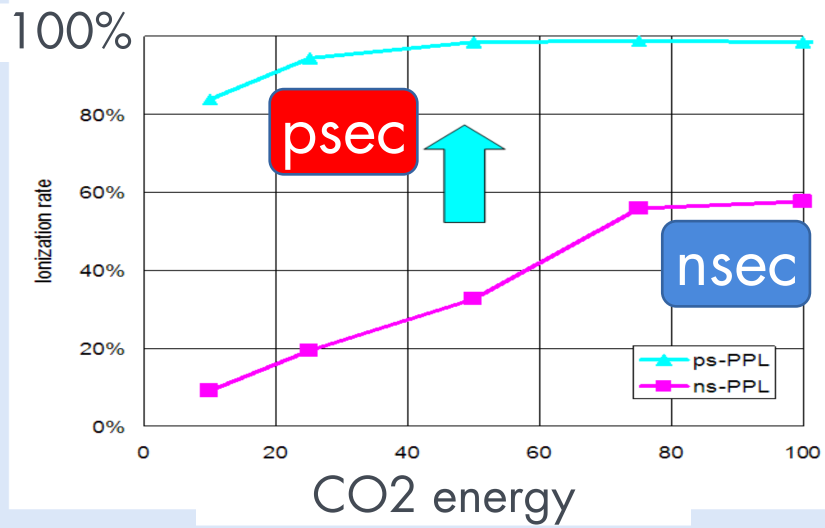
Pre-pulse Technology



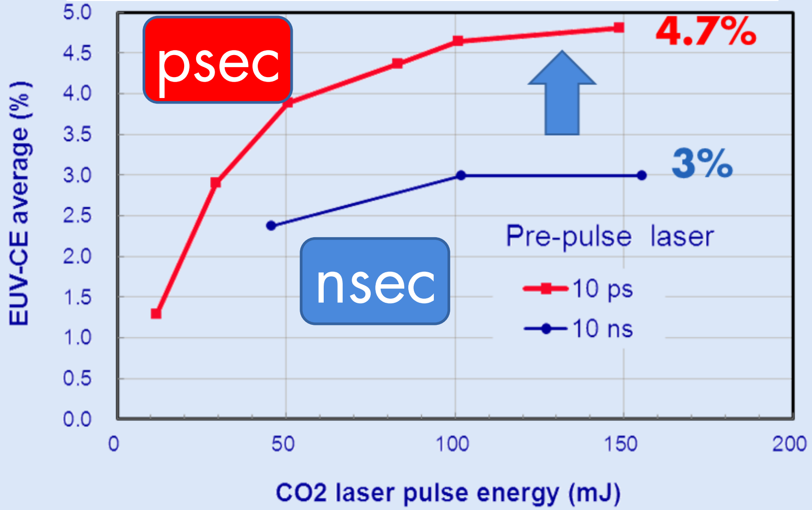
Different Deformation



Ionization rate

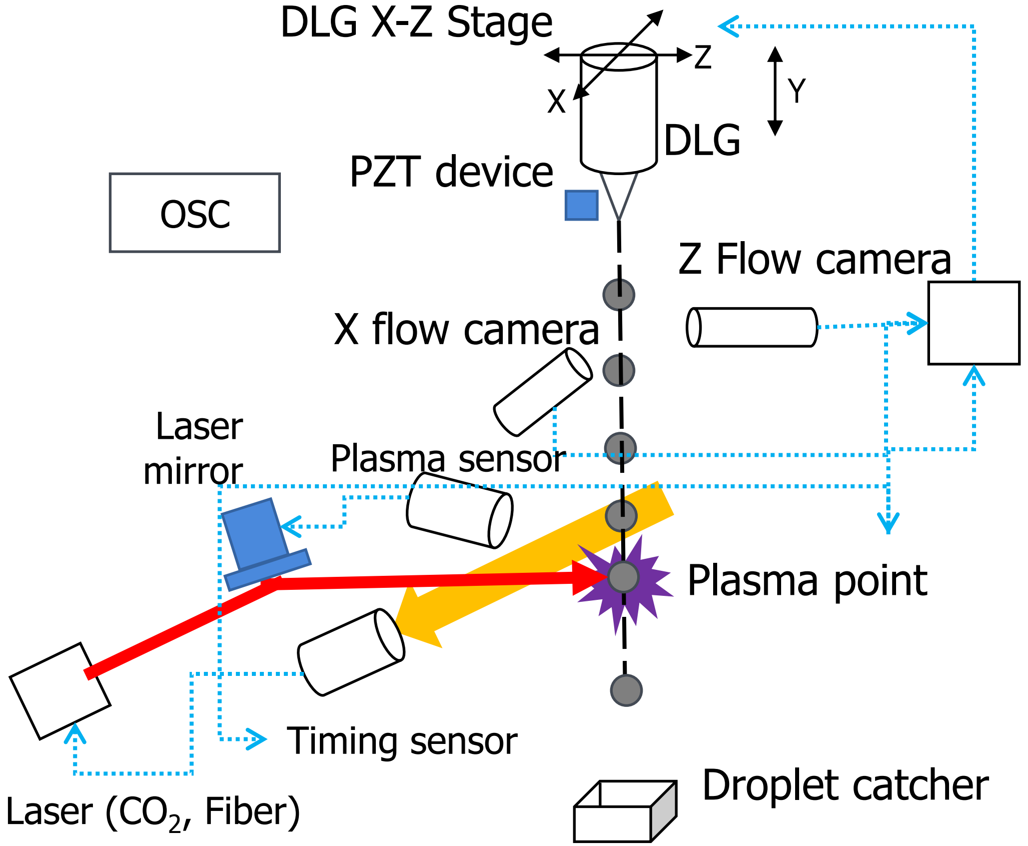


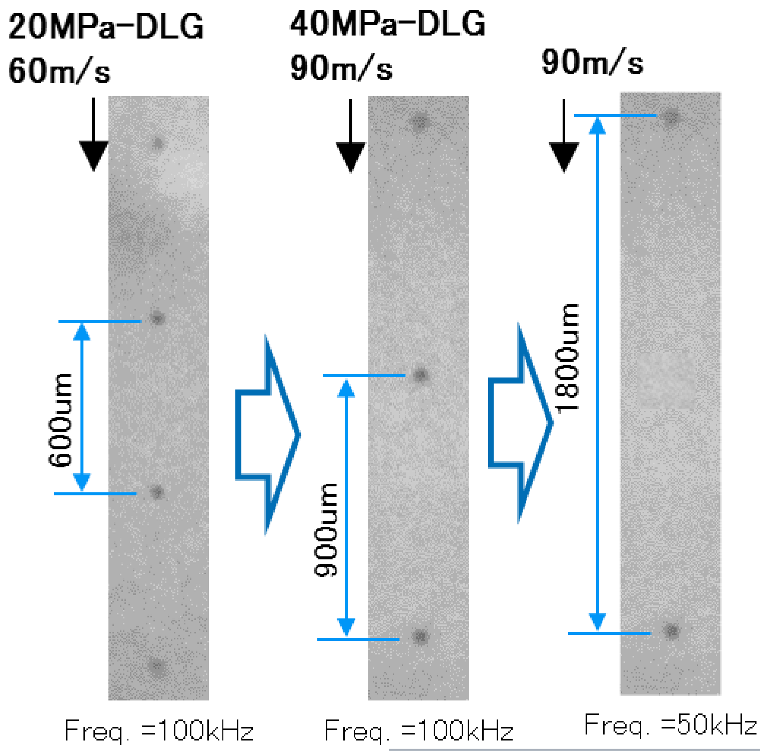
Conversion Efficiency



Droplet Generator and Shooting System

LPP EUV Source Shooting Control System





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

20um diameter-droplets with 900 um interval are ejected at 100kHz.

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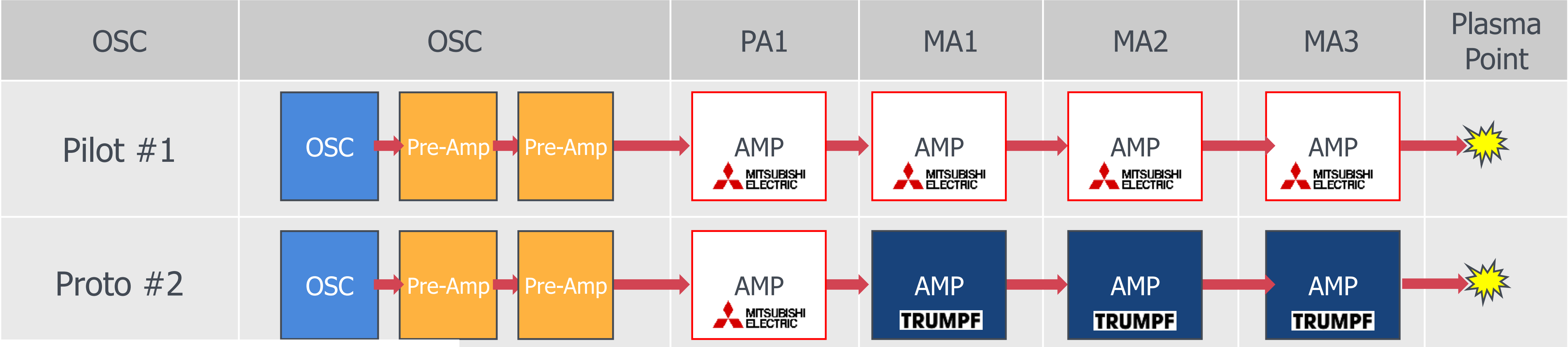
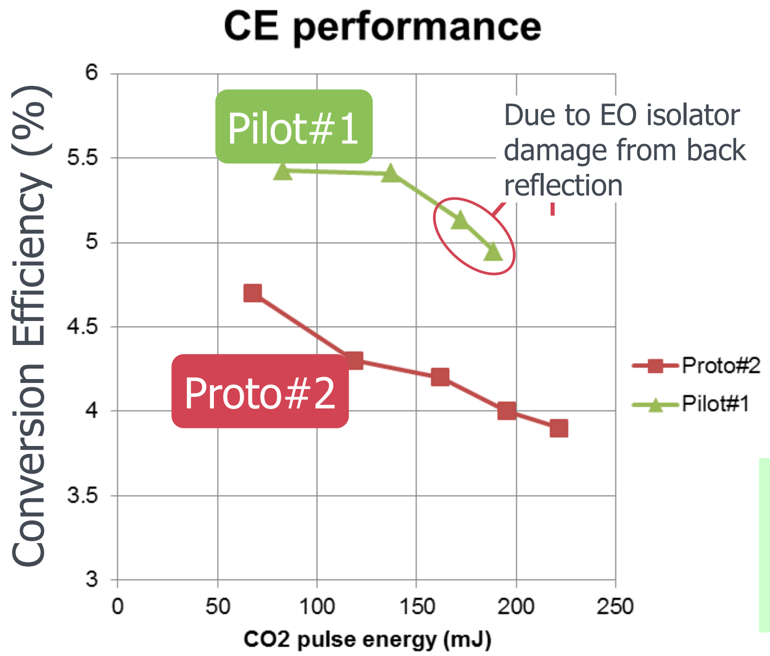
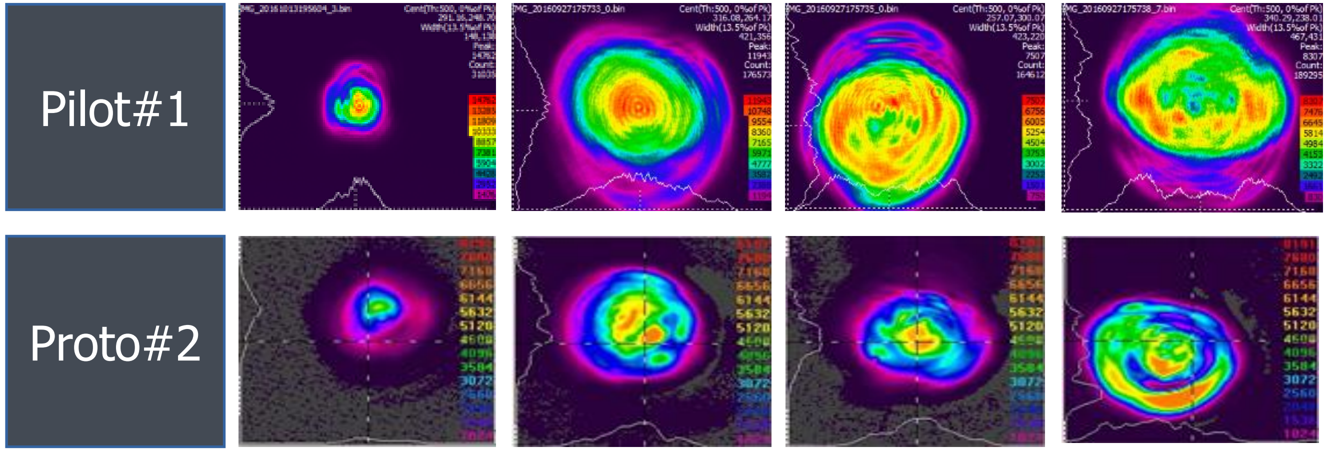
Pilot System Driver Laser and PPL System







Specially designed new CO_2 lasers have improved beam quality to give higher CE.

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 - 25㎛	< 20㎛	**< 20㎛**
	CO_2 Laser	5kW	20kW	**27kW**
	Pre-pulse Laser	picosecond	picosecond	**picosecond**
	Collector Mirror Lifetime	Used as development platform	10 days	**> 3 months**

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Key Performance Status and its target

	2015	2016	**2017 Current**	**2018**
In-band power (Average Power)	87W (83W)	113W (111W)	**113W (91W)**	**250W**
Collector lifetime*1	No data	-10%/Bpls *3	**-0.4%/Bpls**	**-0.2%/Bpls**
Availability*2	15%	44%	**53%**	**> 80%**

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.

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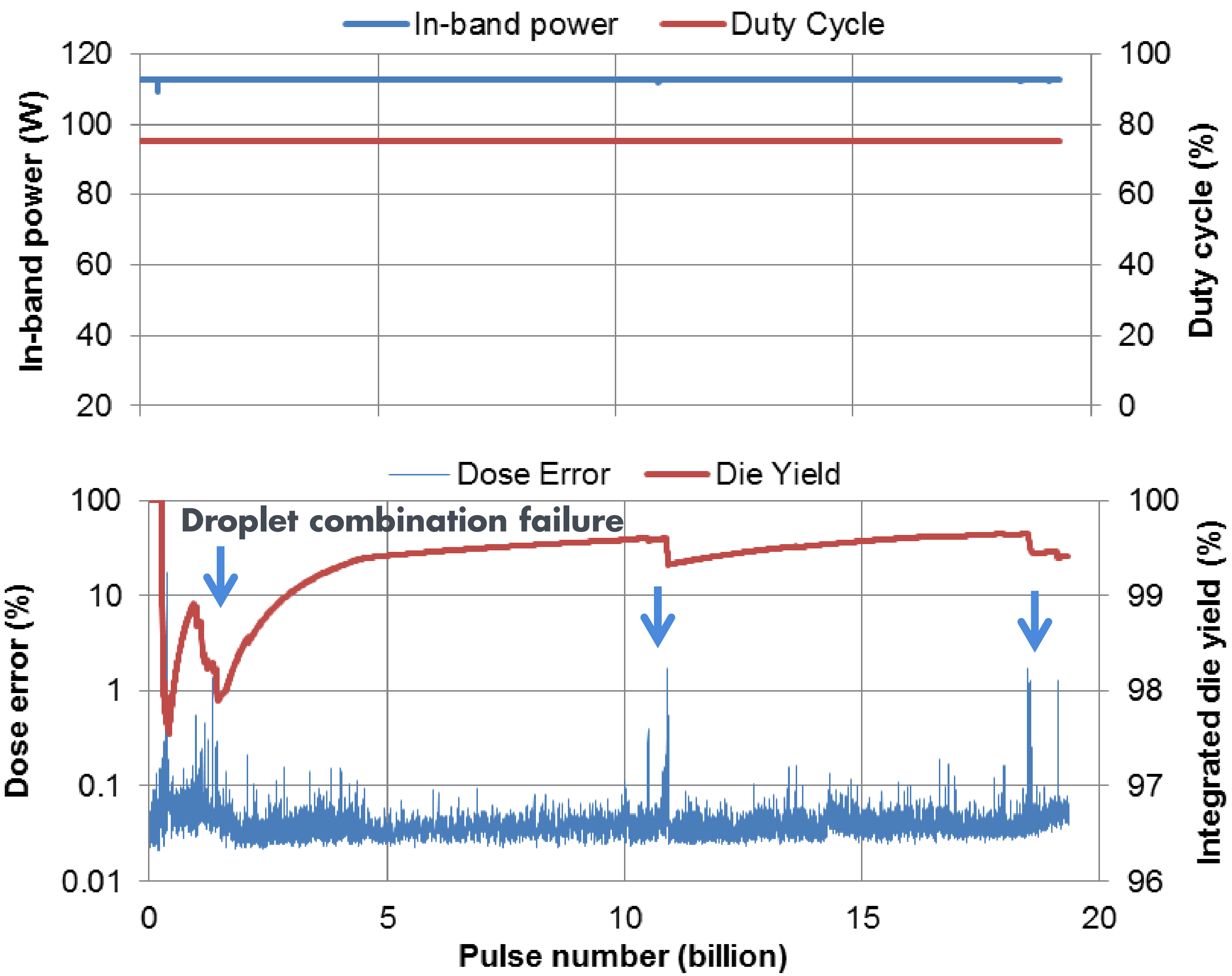
Power and Stability at Continuous Operation

	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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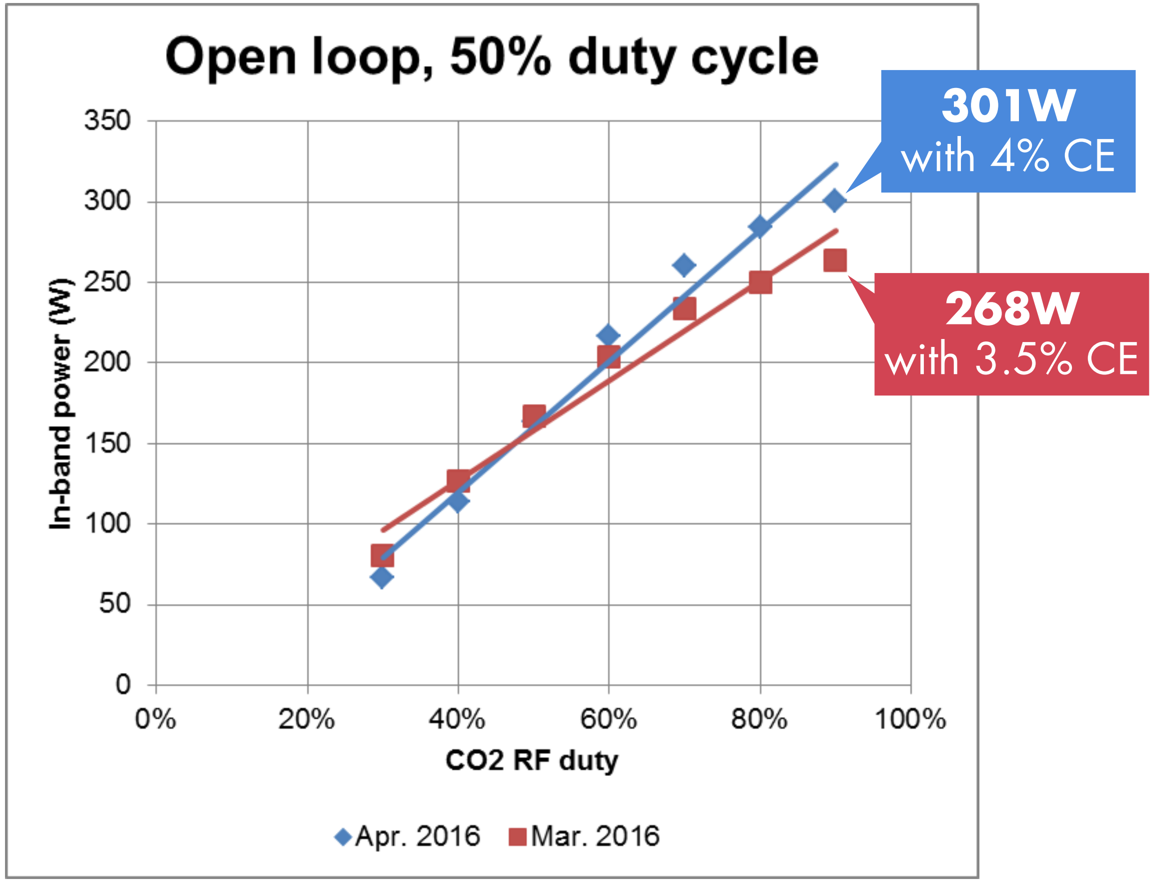
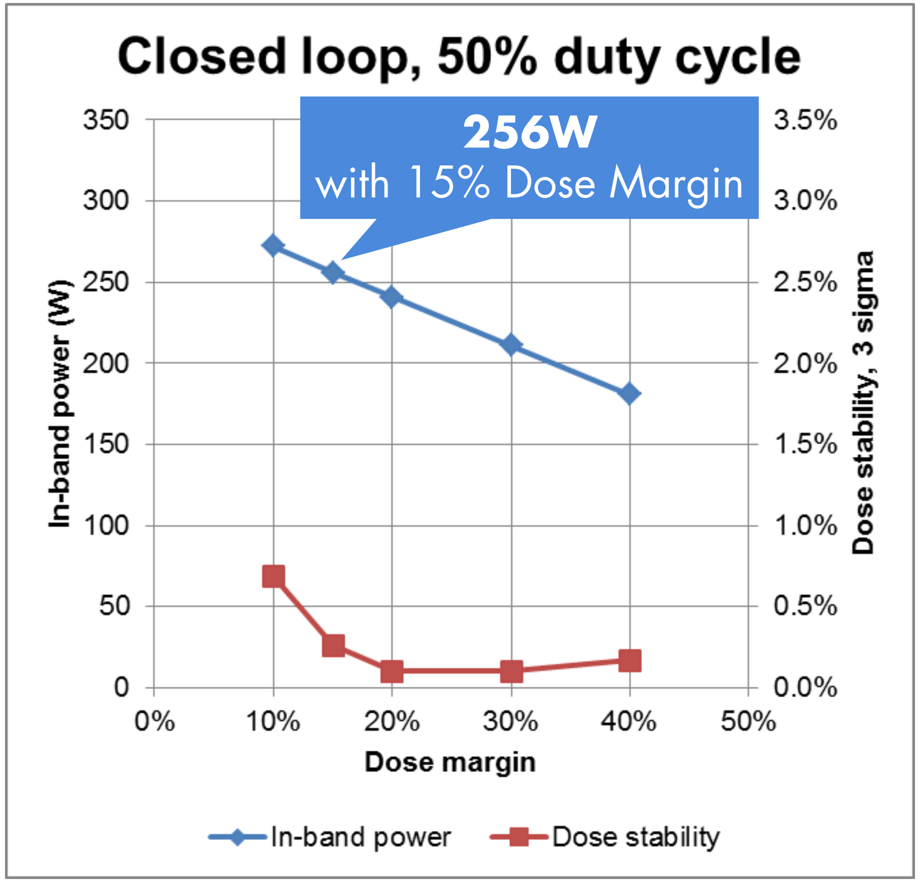
EUV power: 250W achieved

Experimental data

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

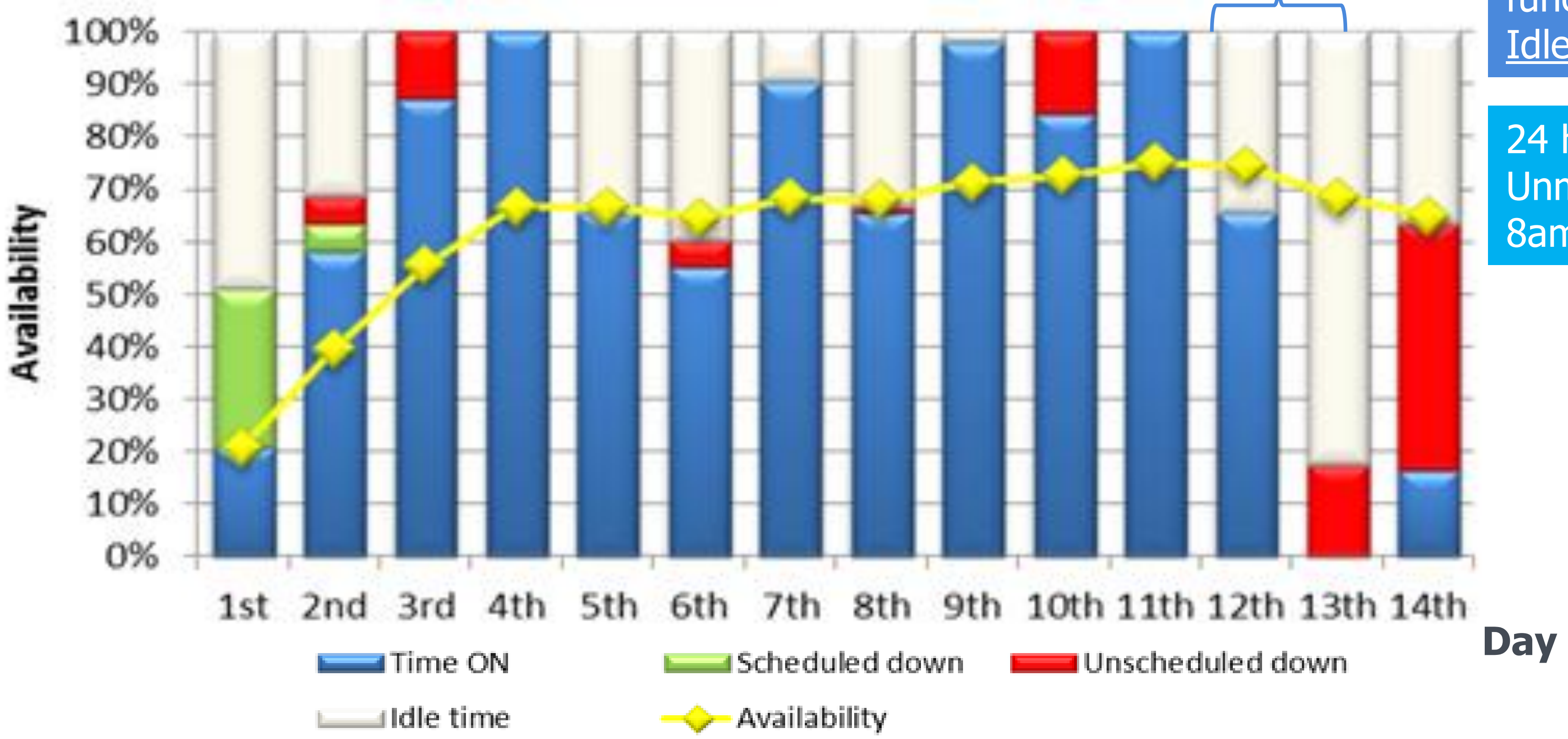




Availability potential test

2 week availability potential test

There were no operators on Sat. and Sun.

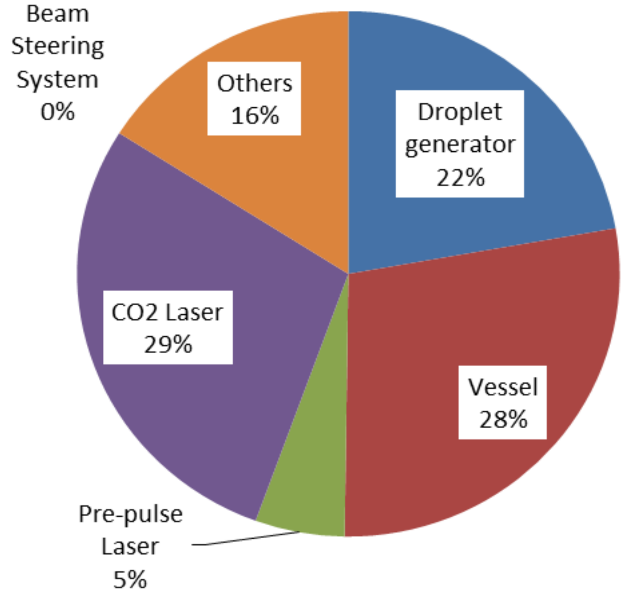


Dose error : System stopped at > 2% dose error (3 sigma) /10kpls slit and error was not recovered by automatic function

Idle time: Time for waiting operators.

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

Downtime breakdown



The potential availability is 89%.
(Availability: 64% / Idle time: 25%)

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High Power EUV Source for High NA EUV Exposure Tool

CO2 laser Energy [mJ]	CO2 laser ave. Power [kW]	EUV ave.Power[W] @100kHz – Conversion Efficiency [%] 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	[illegible]	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

Our LPP system has capability to give 300~500W output power.

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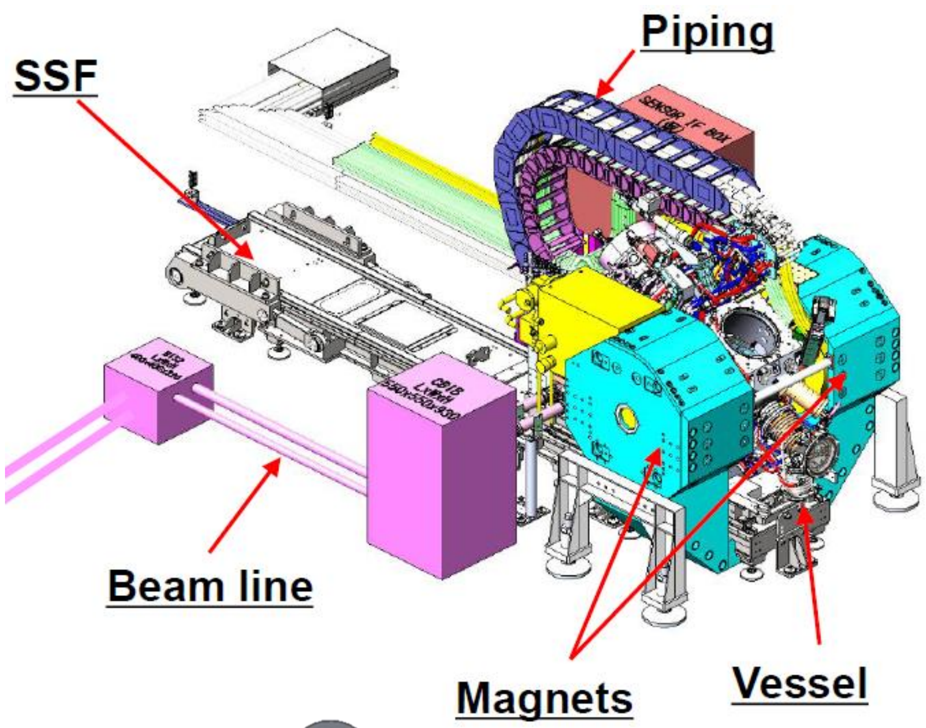
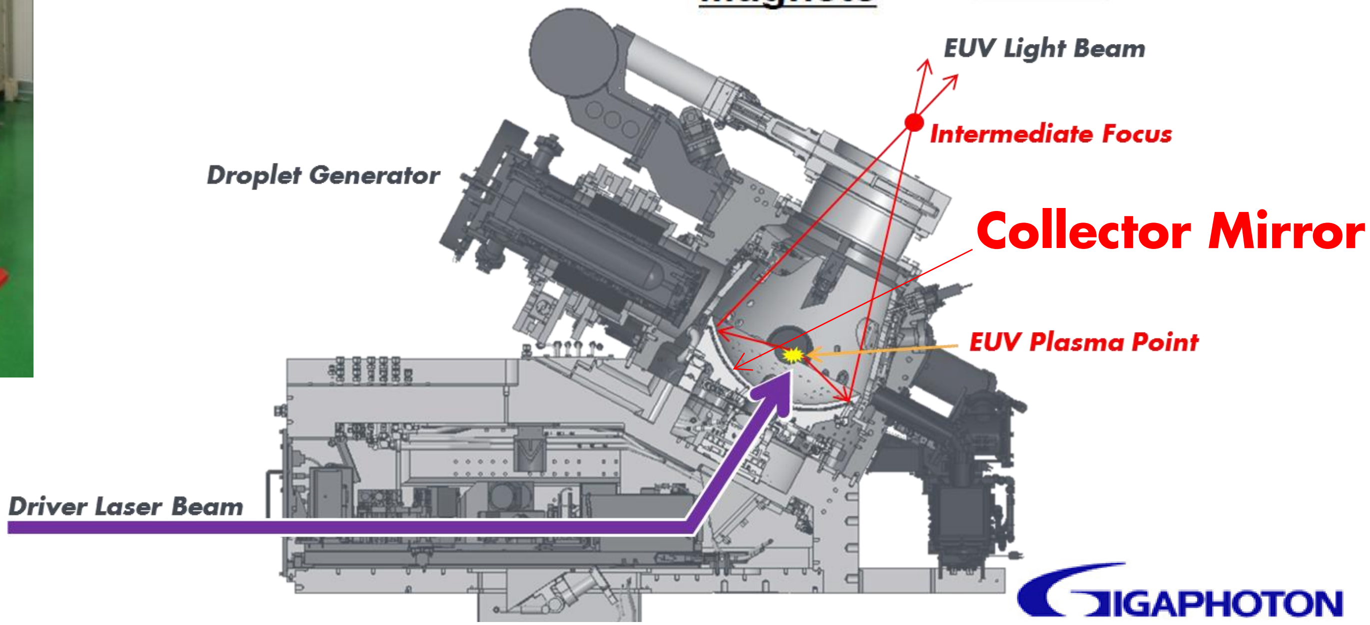
HVM READY LONG-LIFETIME COLLECTOR MIRROR

Pilot System EUV Chamber





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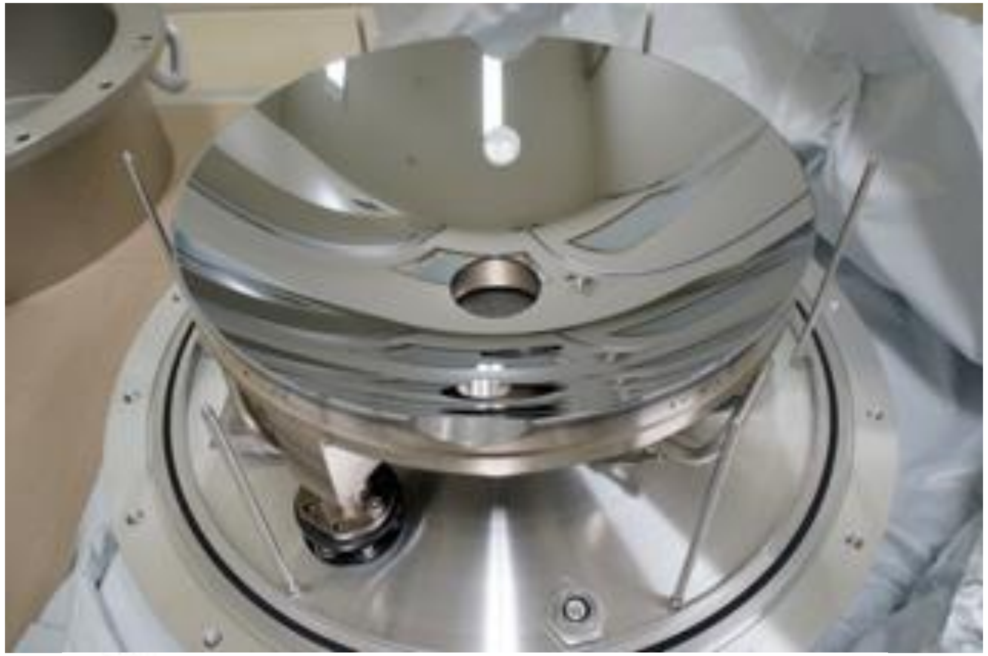
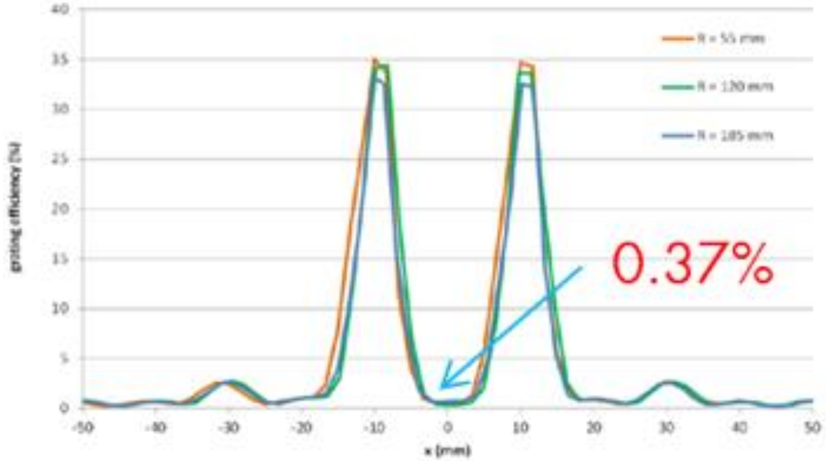
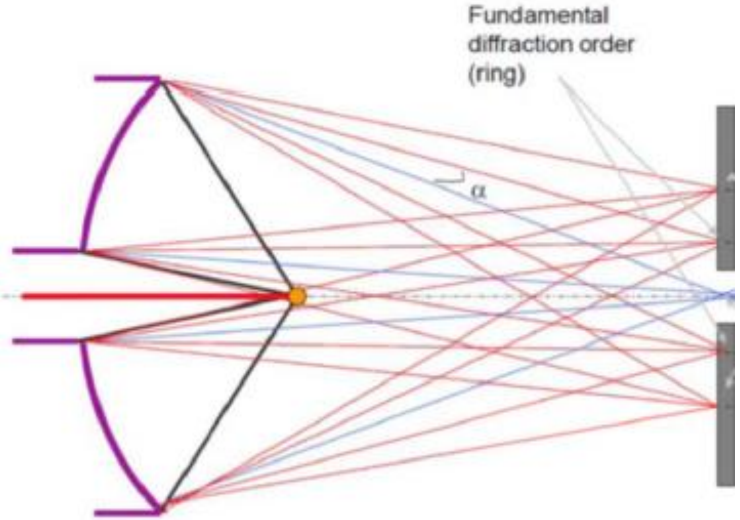
HVM Collector Mirror Specifications



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



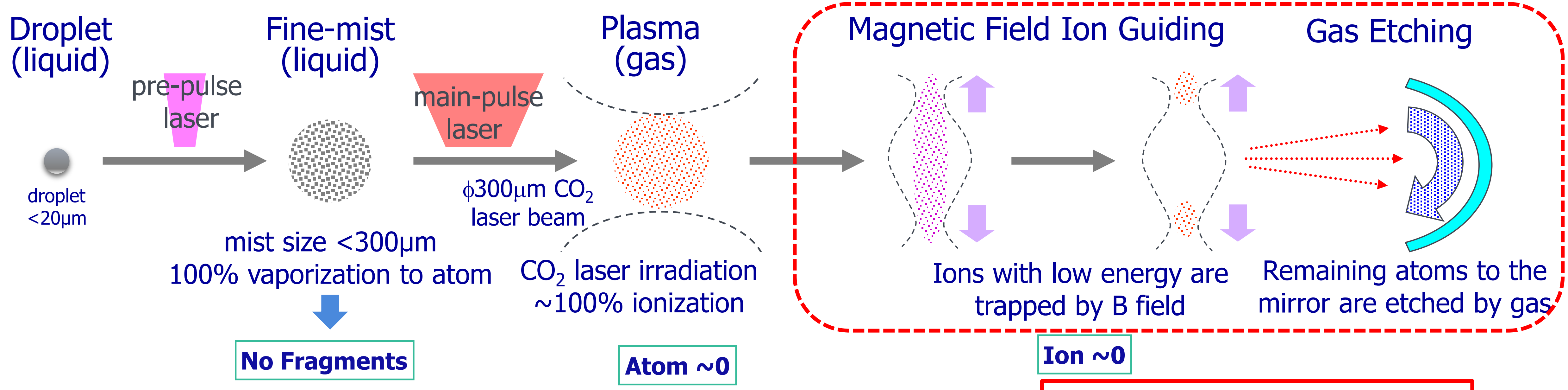


- Measured IR reflectivity: 0.37%

"SM3": Superconducting Magnet Mitigation Method

Higher CE and Power
- Optimum wavelength to transform droplets into fine mists
- High CE is achieved with ideal expansion of the fine mists to match the CO_2 laser beam diameter

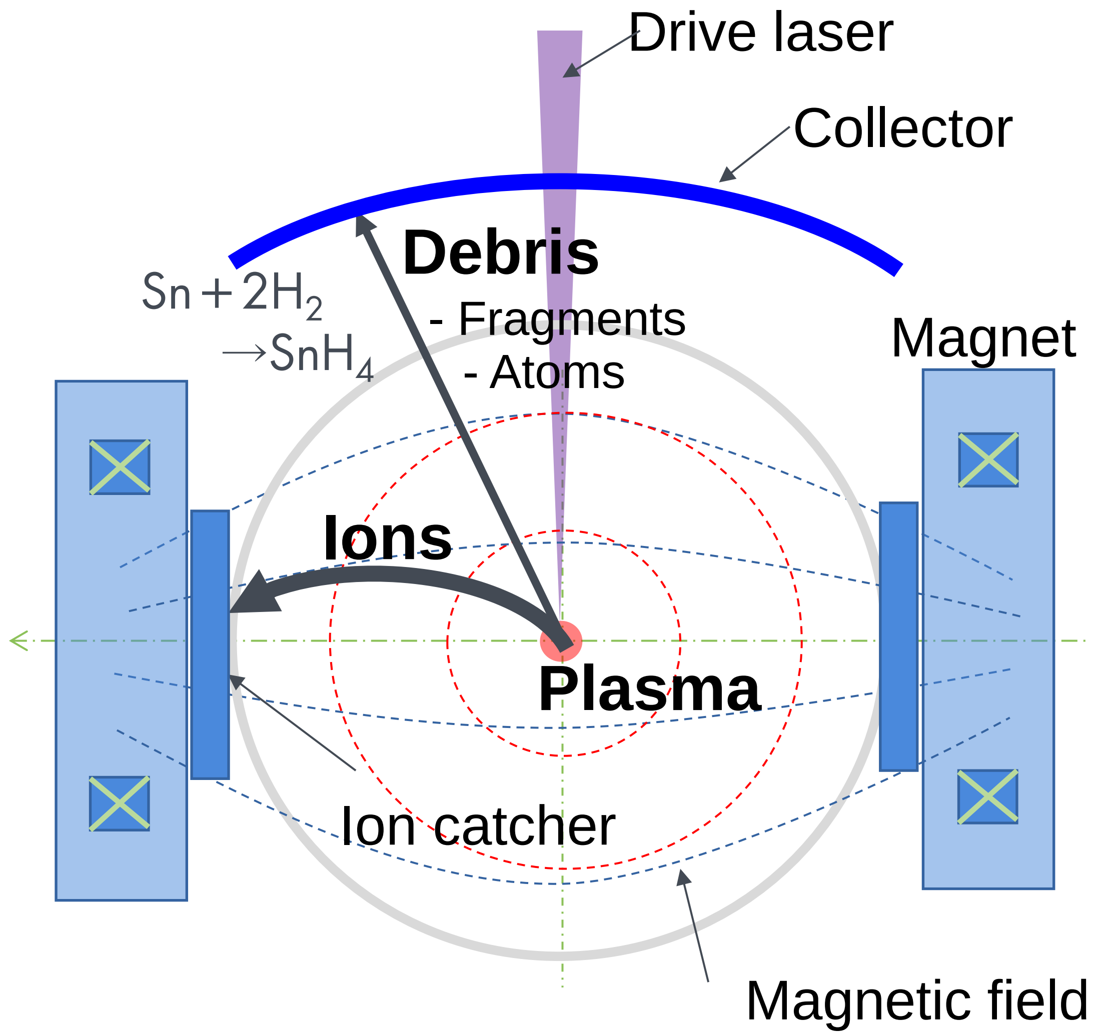
Long Life Chamber
- Debris mitigation by superconducting magnets
- Ionized tin atoms are guided to tin catchers by the magnetic field



KEY TECHNOLOGY 2

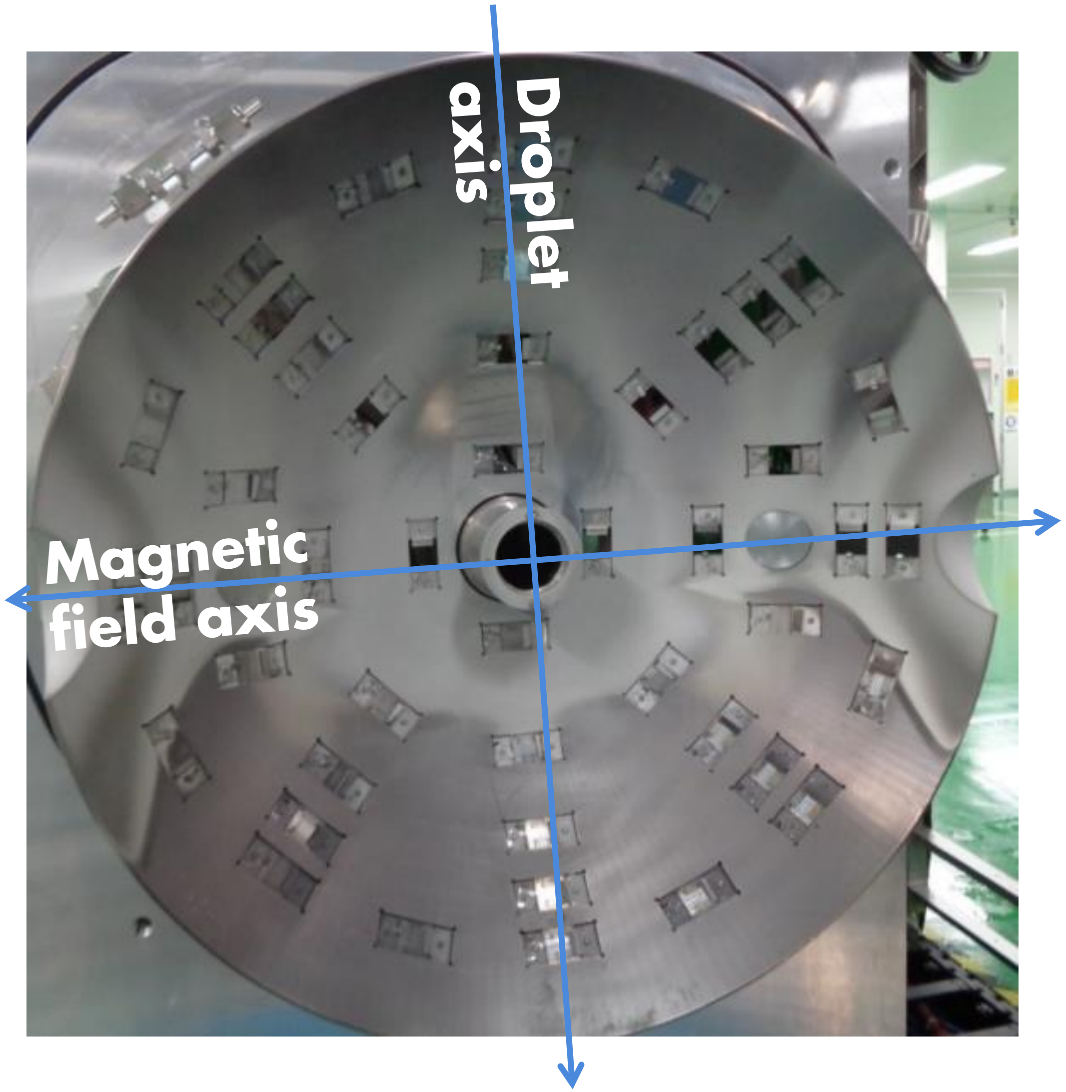
SM3 is the basis of debris mitigation system.

"SM3": Superconducting Magnet Mitigation Method



- Minimum amount of Sn
  - 20um diameter droplet
- 100% ionization in plasma emission
  - Pre pulse technology
  - Precise shooting control
  - Solid beam profile of laser
- Sn ion trap by magnetic field
  - Not to reach the collector surface
- Sn etching even after deposition
  - $Sn + 2H_2 + EUV \rightarrow SnH_4$

Debris Mitigation and Capping Layer Evaluations with a 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

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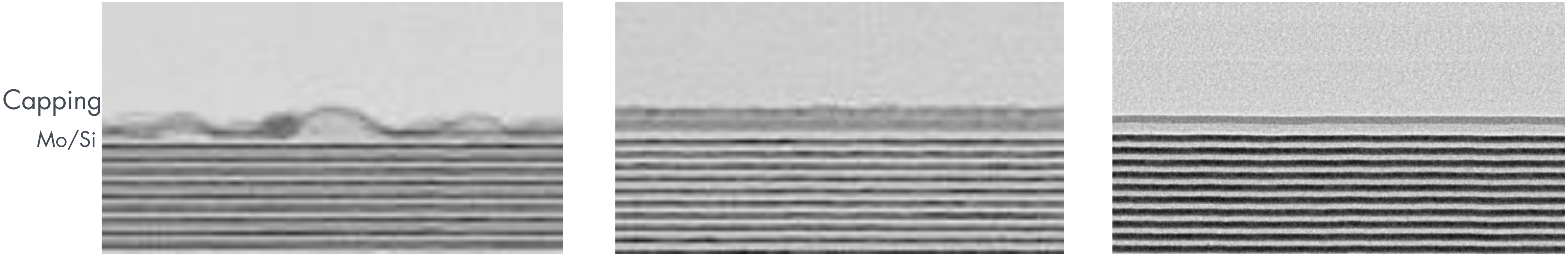
Difference of Deposition on the Sample Coupons of a Dummy Mirror

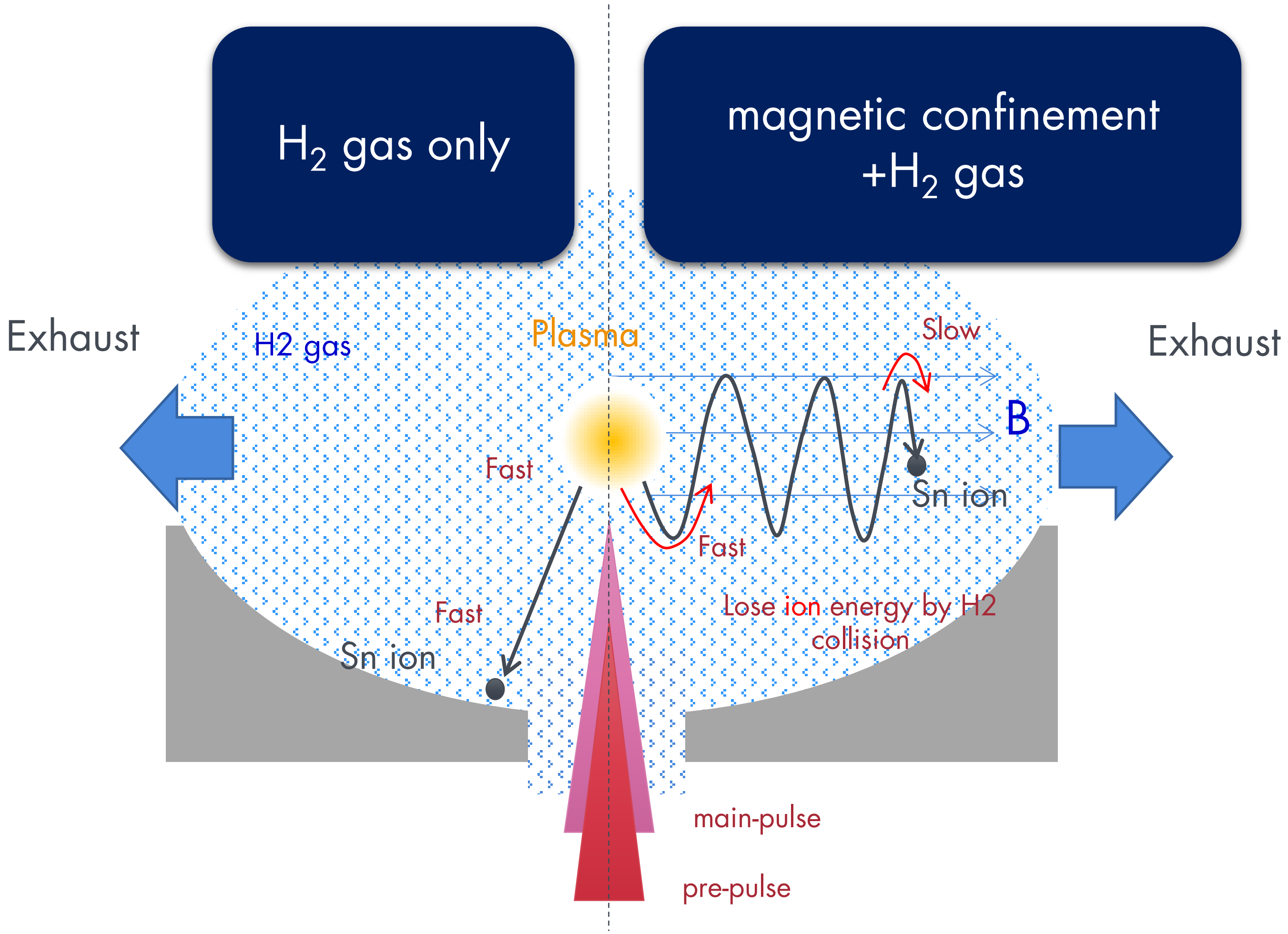
Capping layer disappearance Blister generation	Capping layer deformation Blister generation	Capping layer survived No blister generation



A 124W, 7.3Bpls	**B** 124W, 6.1Bpls	**C** 124W, 7.3Bpls

The capping layer material has great influence on ML durability.

Debris Mitigation Concept; Tin Stopping



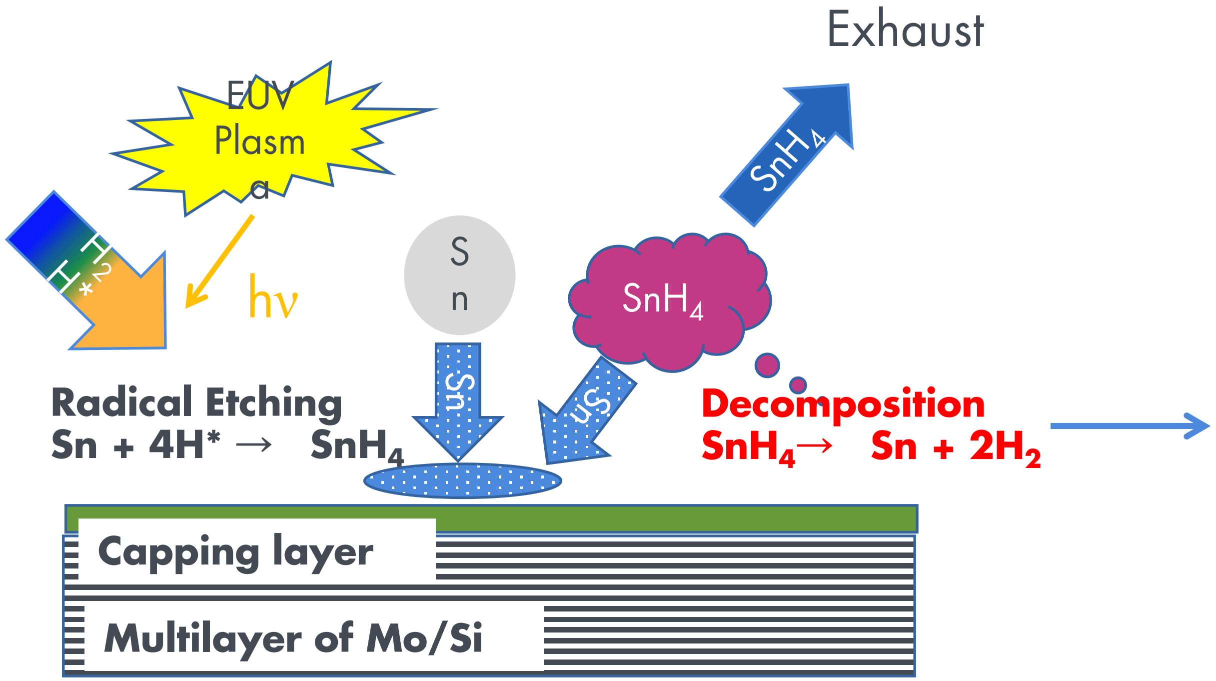
Tin stopping

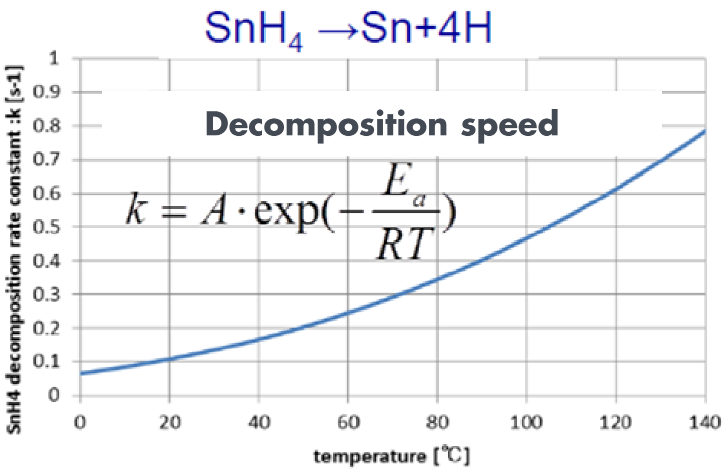
1. Tin is ionized effectively by double pulse irradiation and precise shooting control
2. **Tin ions are confined by magnetic field and stopped by H_2 gas to prevent the sputtering to the coating of mirror.**
3. **Confined tin ions are guided and exhausted by H_2 flow from vessel.**

Debris Mitigation Concept; Tin Cleaning

Tin cleaning

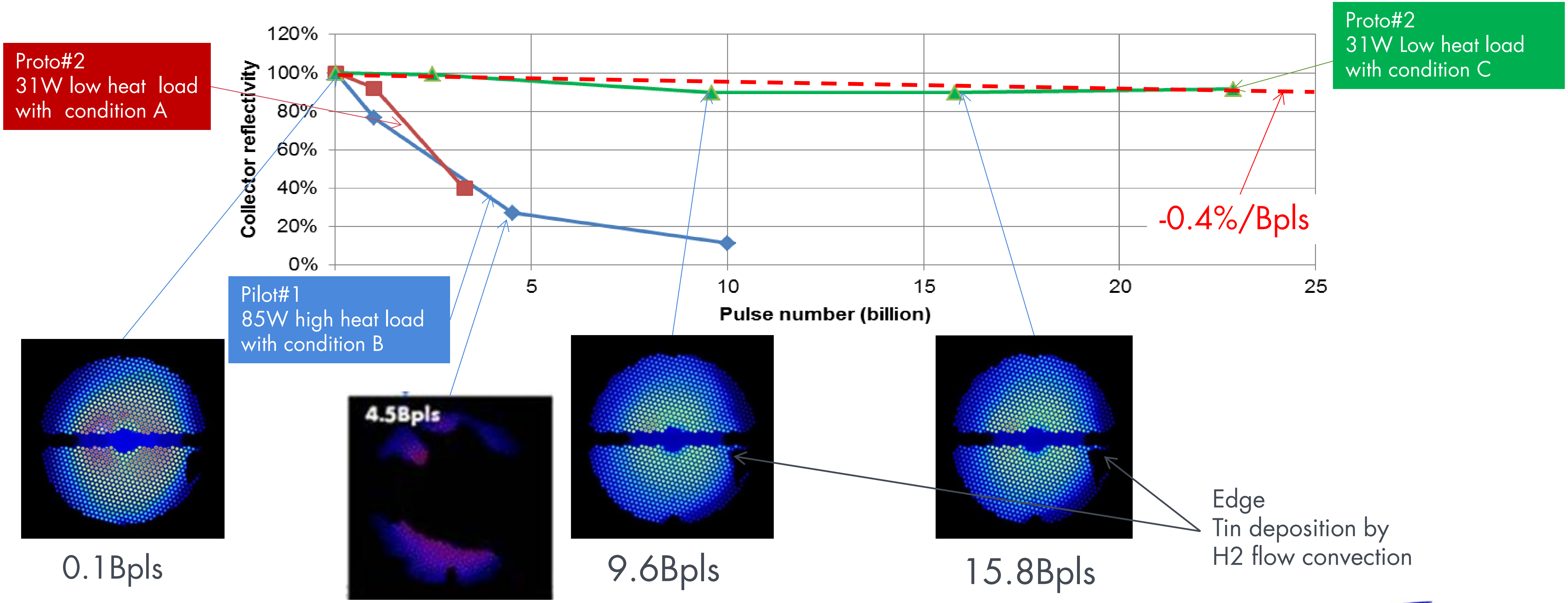
1. Tin, not confined by magnetic field, are stopped by H_2 gas in order to prevent the sputtering to the coating of collector.
2. Deposited tin on the collector is etched by H radical gas.
3. **Cooling and gas flow systems for preventing decomposition of SnH_4**





Collector lifetime status after improvement

- Power level of EUV: 100W in Burst, (= 2mJ x 50kHz), 33% duty cycle, 30W in average.
- Collector lifetime was improved to -0.4%/Bpls by magnetic debris mitigation technology optimization.



Far field pattern in test condition C

SUMMARY

Summary

- **Pilot#1 for HVM is now under construction, and shows promising results**;
  - Demonstrated 113W in-burst power at 75% duty (85W average) for 143 hours based on the preliminary results of CE 5%, 250W power with Proto#2
  - Next target : 250W full specification operation with long term by 1H 2018.
- **Pilot#1 Collector Mirror test shows HVM capable lifetime**;
  - Superconducting Magnet Mitigation Method "SM3" realized the reflectance degradation rate of 0.4%/Bpls at over 100W level operation (in burst mode, up to 30Bp).
- **Pilot#1 shows HVM ready availability**;
  - Pilot#1 system achieved the potential availability of 89% (2week-average).

Will Gigaphoton's Source be in time to meet145wph HVM by 2019 ?

Yes, Gigaphoton's Source will be in time to meet145wph HVM by 2019 .

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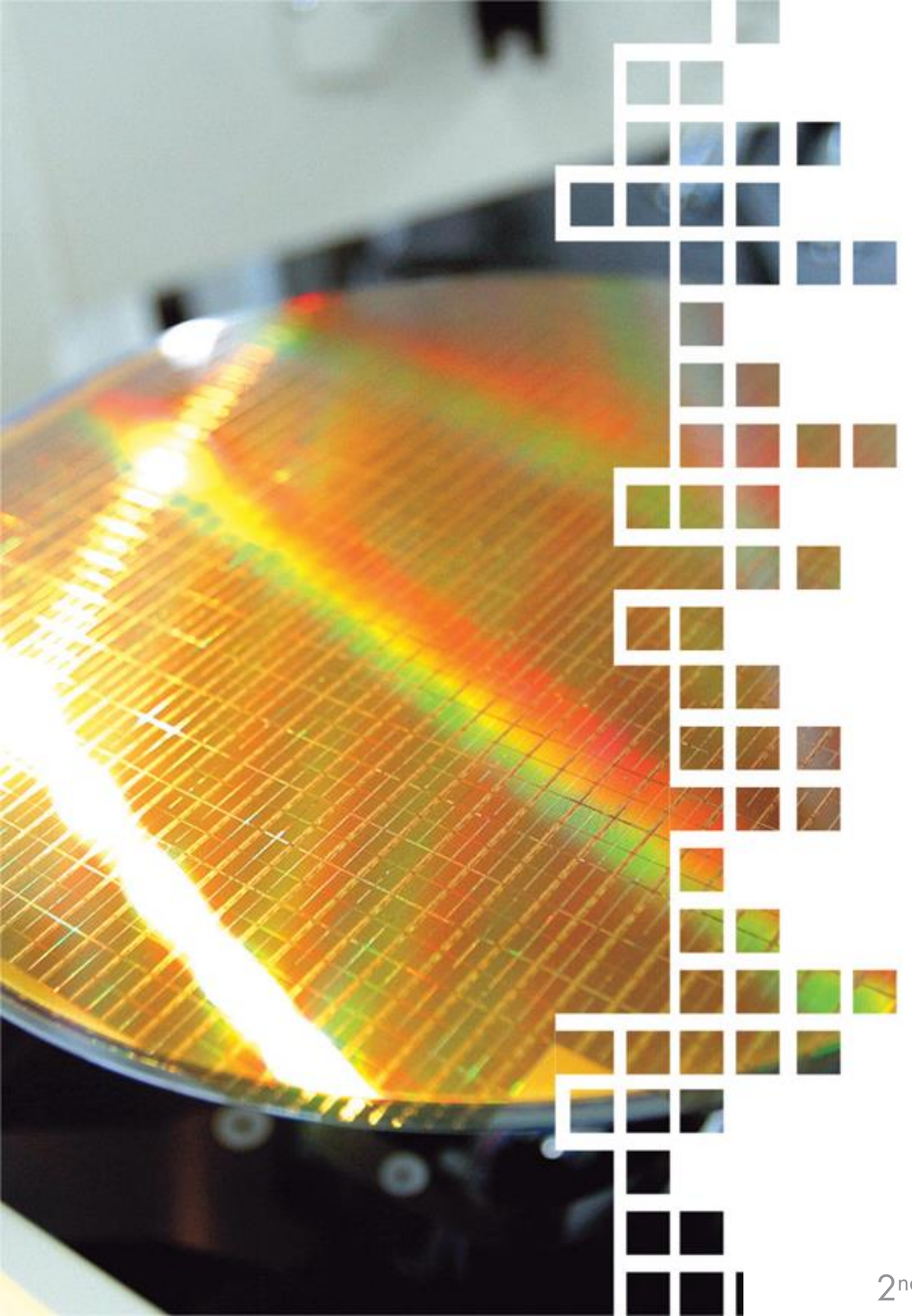

THANK YOU