DEVELOPMENT OF 250W EUV LIGHT SOURCE FOR HVM LITHOGRAPHY

EUVL Workshop 2016

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AGENDA

- Introduction
- Issue of EUV Light Source and History of Source Power-Up
- 250W Pilot System Development Update
  - Key Component Technologies Update
- Prototype LPP Source Systems Experiment Update
  - Proto Device #1
  - Proto Device #2
- For Future Development of 500W LPP Source
- Summary

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G10K

G20K

G41K

GT40A

GT60A

GT64A

Gigaphoton's Growth

2000

130 Laser Installed
- ✓ **15%** Market Share
- ✓ **250** Employees

2005

400 Laser Installed
- ✓ **25%** Market Share
- ✓ **200** Employees

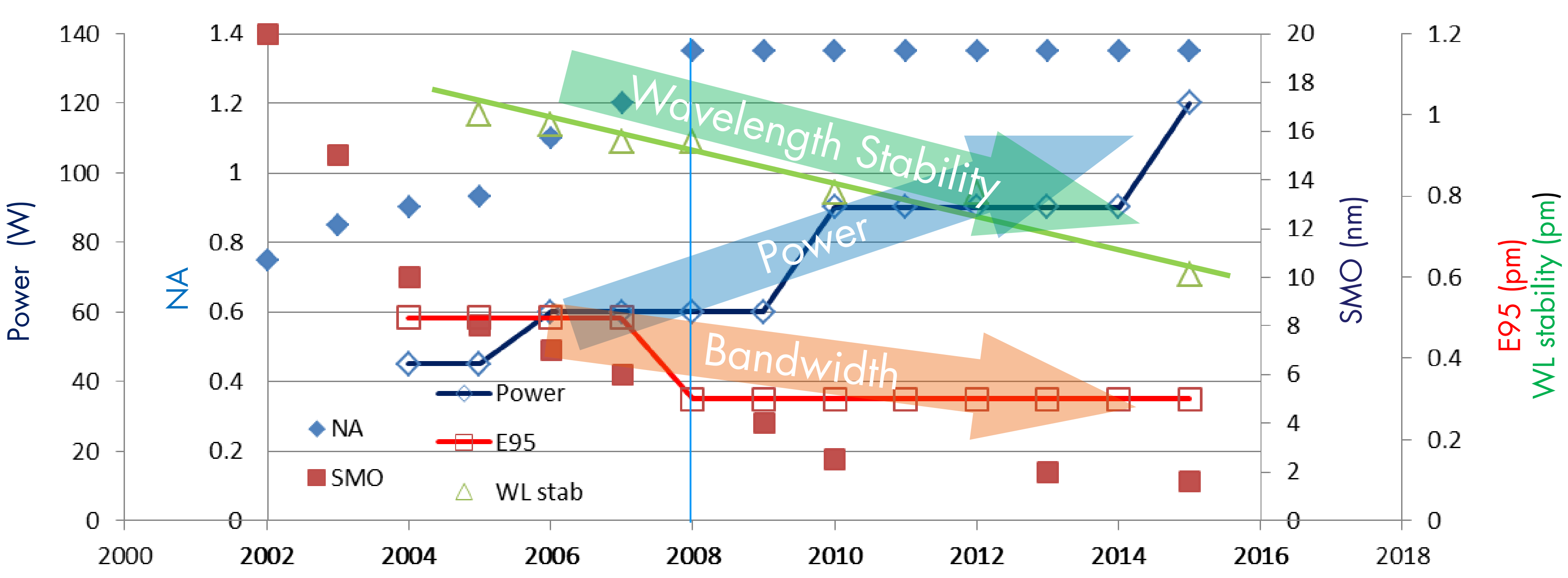
2010

900 Laser Installed
- ✓ **40%** Market Share
- ✓ **370** Employees

2015

1300 Laser Installed
- ✓ **64%** Market Share
- ✓ **700** Employees

Improvement of ArF Laser Performance during Multiple-Exposure



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New Fab will Open for Expanding Demand of DUV Laser

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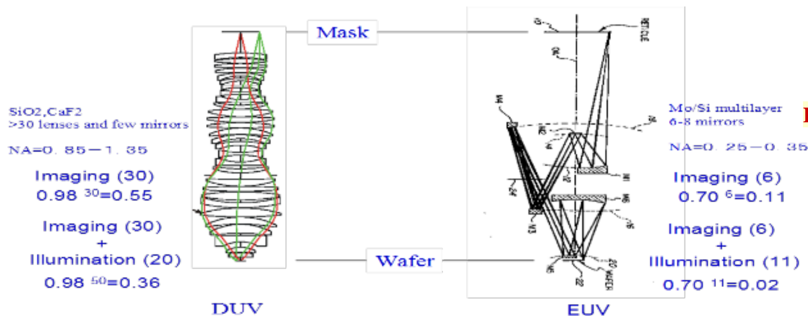
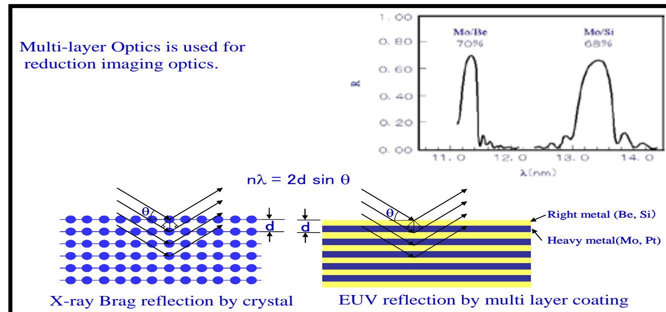
Issue of EUV lithography (1)

EUV light transmittance is only 2% at 11 refection mirror system

High power light source for HVM exposure tools is the **KEY** Issue

Demand: >250W at 1st stage HVM





Illumination Optics
- Optical design for minimizing the number of mirrors

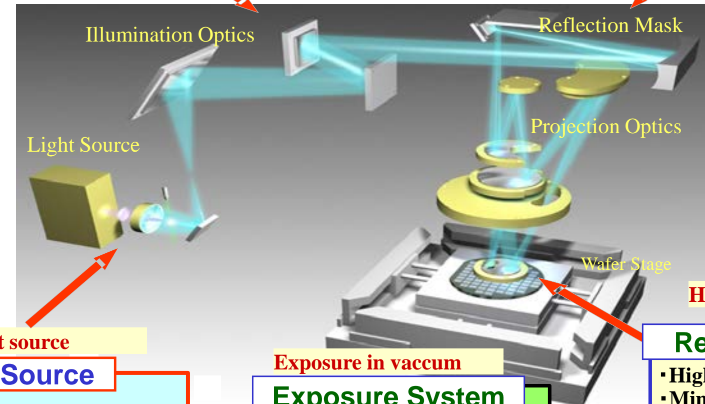
Low reflectivity of Mo/Si mirror

Projection Optics
- High accuracy figuring
- Metrology
- Contamination control

Highly accurate mirror surface

Mask
- Low defect blanks
- Defect inspection
- Defect repair

Reflection mask



High sensitive resist

Resist
- High sensitivity
- Minimizing line edge roughness (LER)
- Low out gassing

New light source

Light Source
- High power source
- Debris mitigation
- Low etandue

Exposure in vaccum

Exposure System
- Stage in vacuum
- Electrostatic chuck
- Accurate alignment

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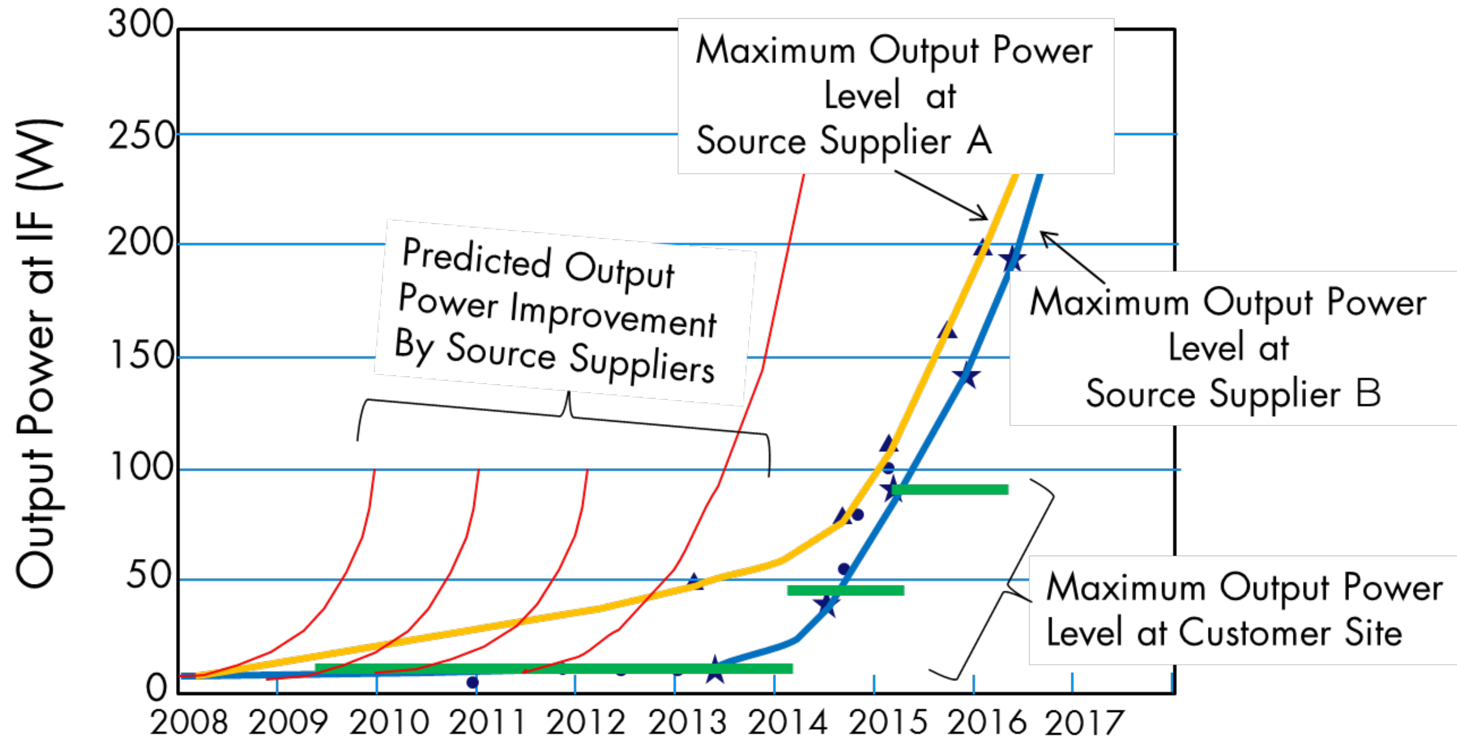
Issue of EUV lithography (2)

History of EUV source output power improvement



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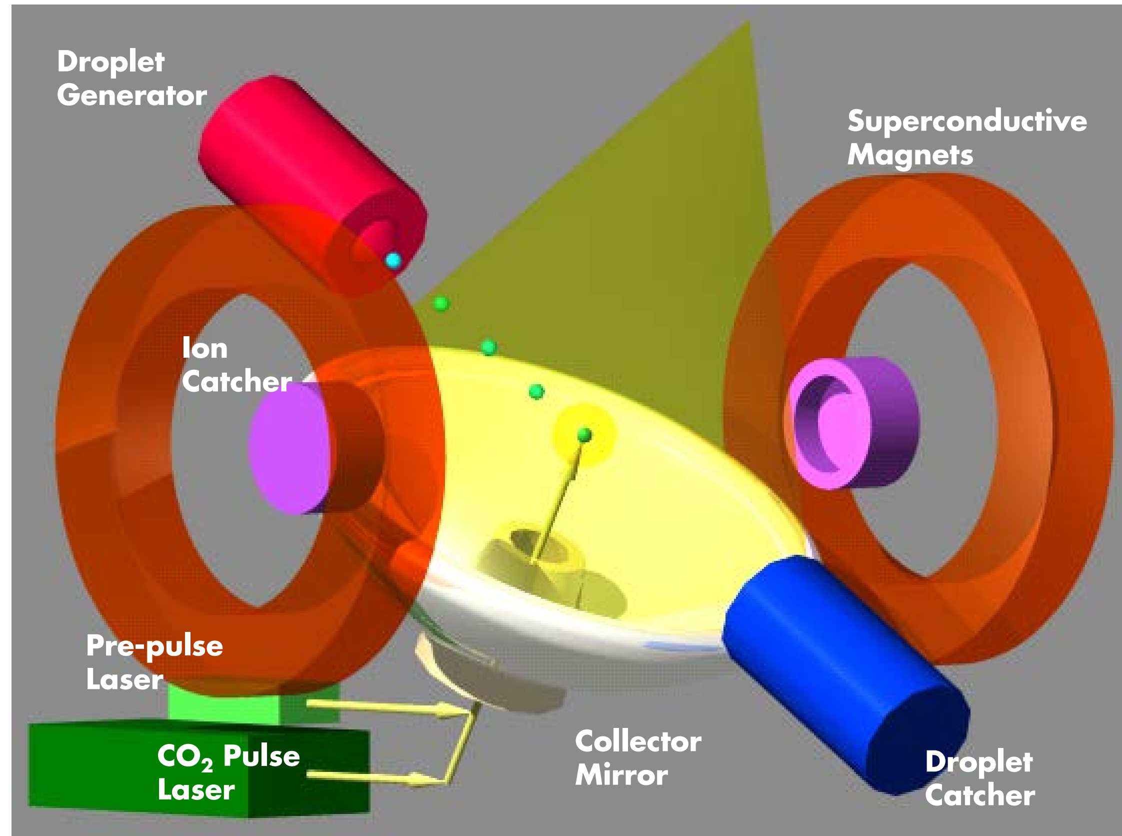
Gigaphoton's LPP Light Source Concept

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



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Pilot and Proto Systems Configuration

Target System Specification

Operational Specification		Pilot #1	Proto #1	Proto #2
Target Performance	EUV Power	250 W	25 W	> 100 W
	CE	4%	3%	3.5%
	Pulse rate	100 kHz	100 kHz	100 kHz
	Output angle	62°upper (matched to NXE)	Horizontal	62°upper (matched to NXE)
	Availability	> 75%	1 week operation	1 week operation
Technology	Droplet generator	< 20 μm	20 – 25 μm	20 μm
	CO_2 laser	**27 kW**	5 kW	**20 kW**
	Pre-pulse laser	picosecond	picosecond	picosecond
	Debris mitigation	> 3 month	validation of magnetic mitigation in system	10 days

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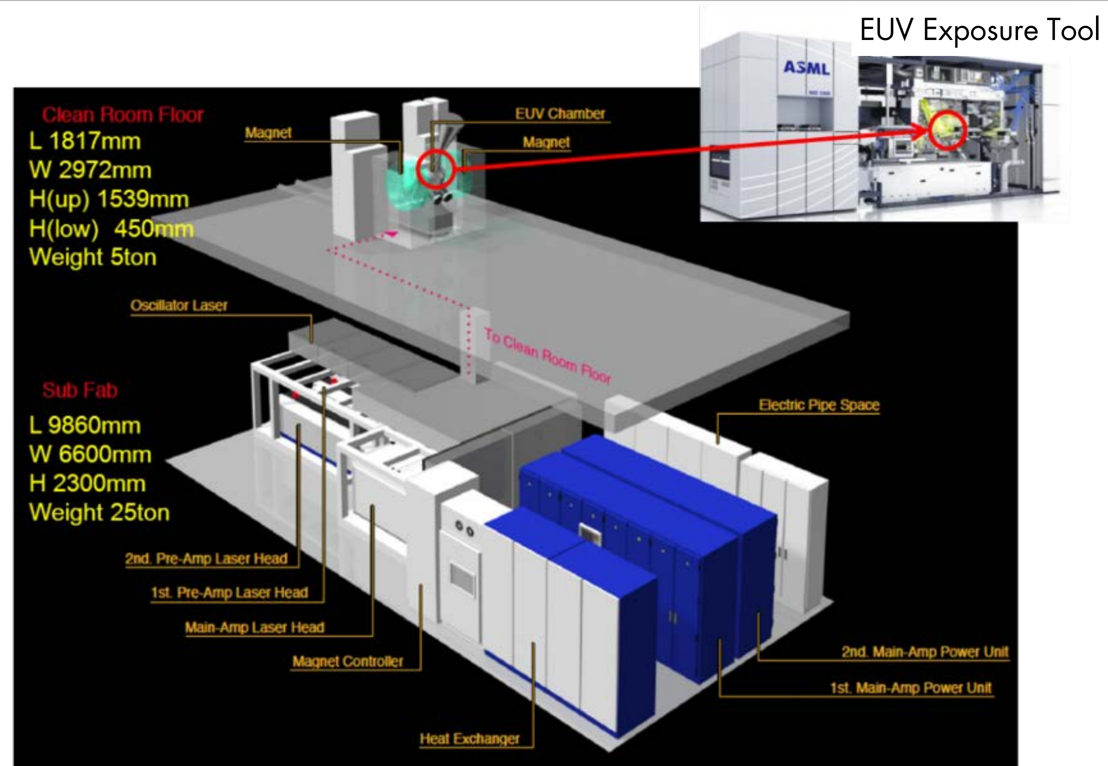
Pilot #1 EUV Light Source for HVM

Layout of 250W EUV Light Source

First HVM Source will be 250W

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)



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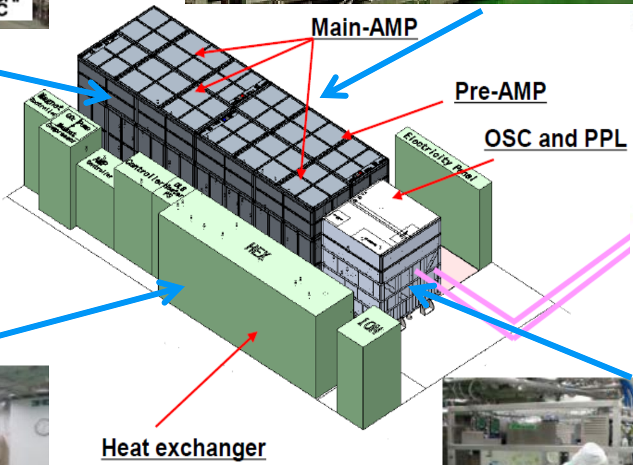
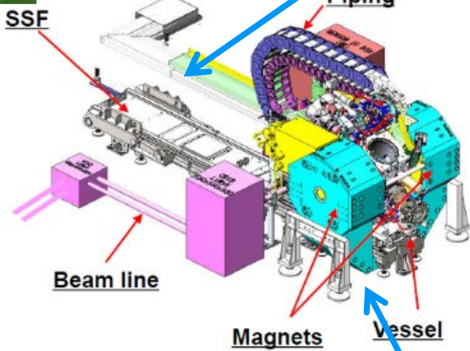
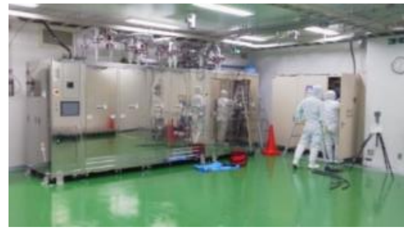
Pilot #1: Picture of construction (2015.6 – 2016.1)

Driver laser





EUV chamber



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Pilot #1: Construction is Completed ! (2016.02)

EUV chamber and Magnet

CO_2 driver laser system

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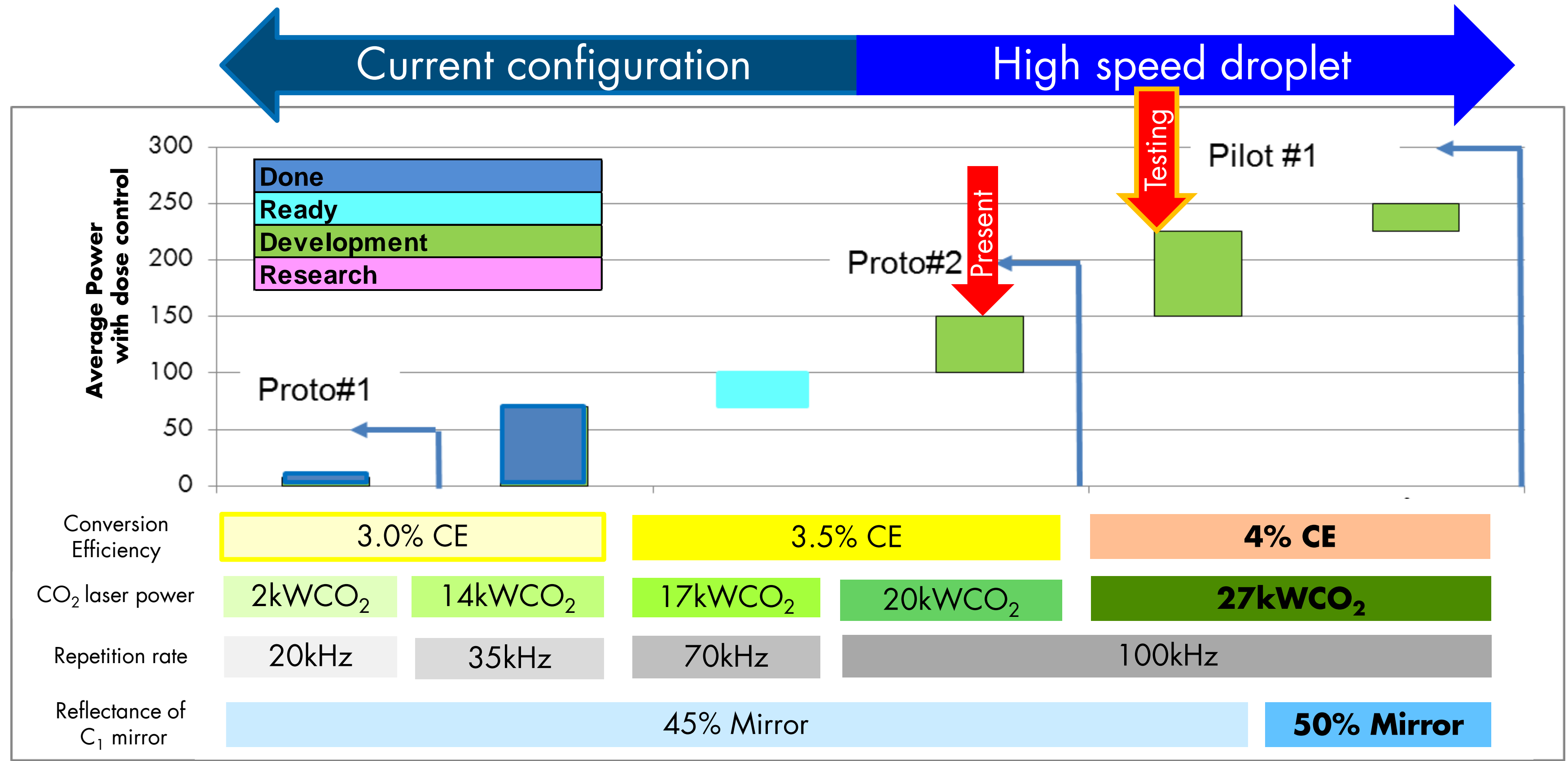
Power-up Scenario



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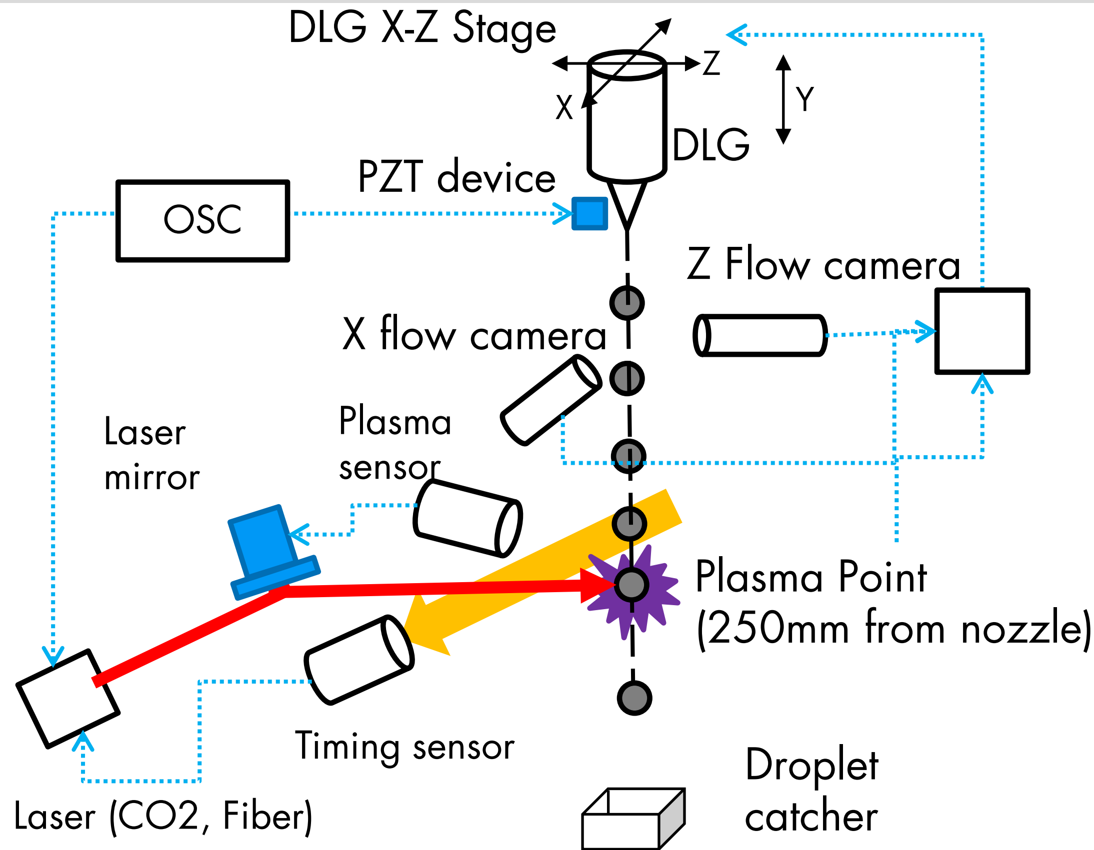
LPP EUV Source : Shooting Control System



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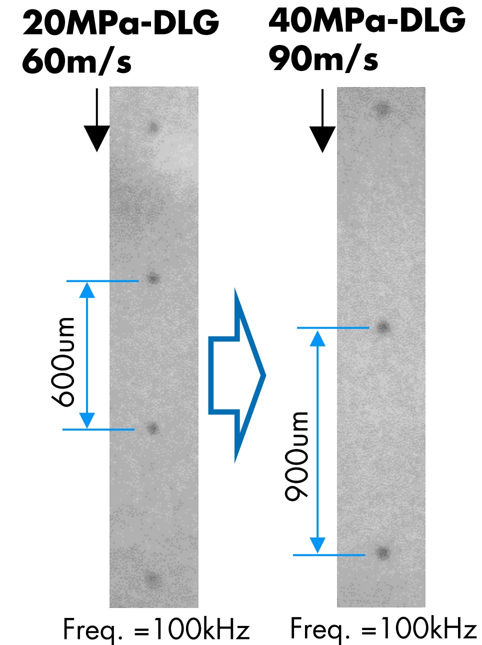
LPP EUV Source: Operation Desk

Droplet Generator technology (1)

High speed droplet generator was successfully released to Proto system

		2013 Jan Proto#1	2014 Sep Proto#2	2015 Dec Proto#2 and Pilot#1
Droplet speed	m/s	45	60	90
Back pressure	MPa	12	20	40
Repetition rate limit	kHz	50	80	>100
Status		Proven	Proven	Proven



Droplet Status

New Data

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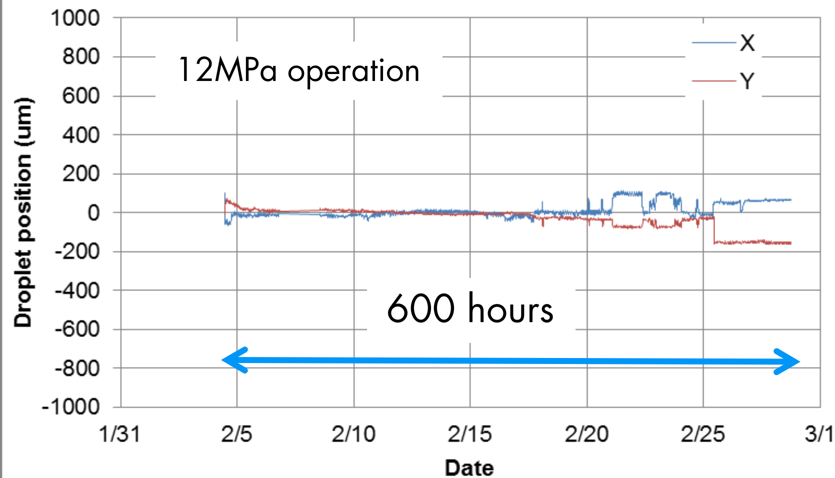
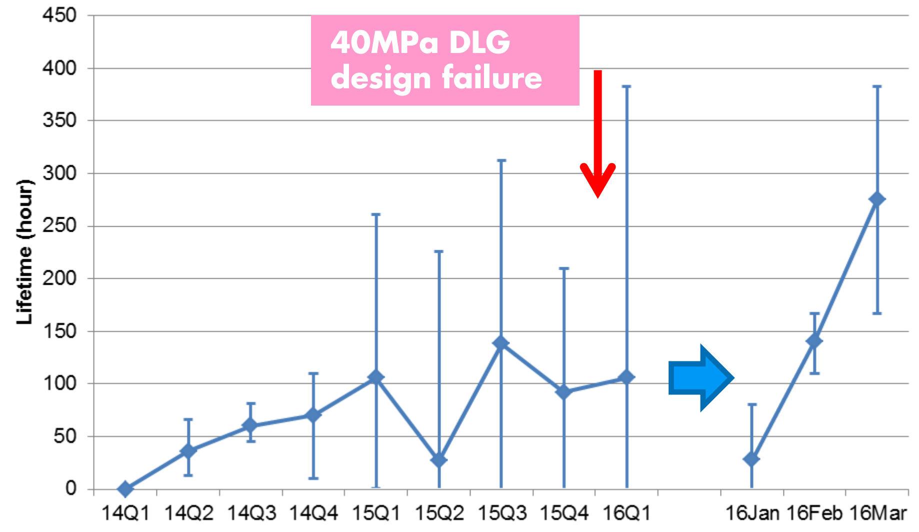
Droplet Generator technology (2)

- 600 hours lifetime in 12MPa was confirmed in test bench.
- Average lifetime in 40MPa is 260 hours at present.





New Data

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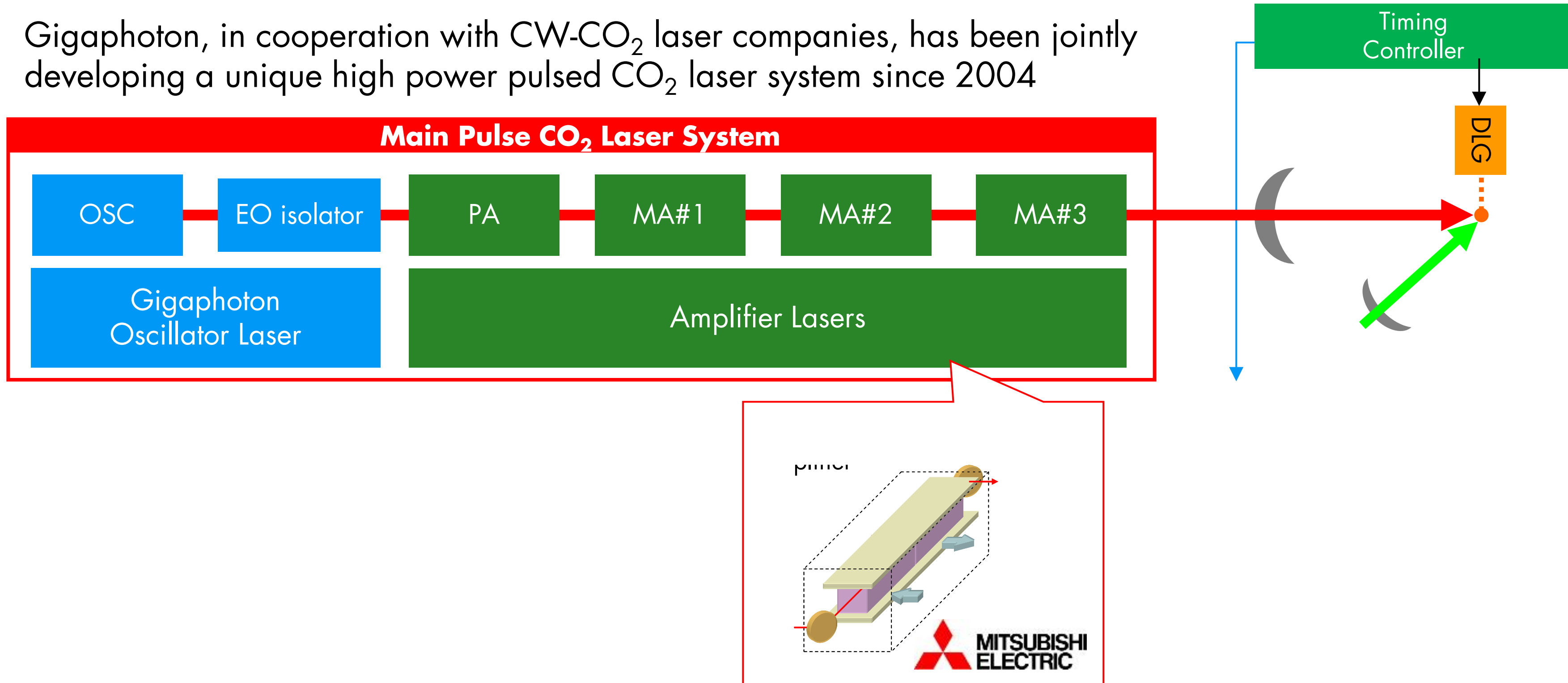
High Power CO2 Laser Technology (1)

Driver Laser System

Gigaphoton, in cooperation with CW-CO_2 laser companies, has been jointly developing a unique high power pulsed CO_2 laser system since 2004



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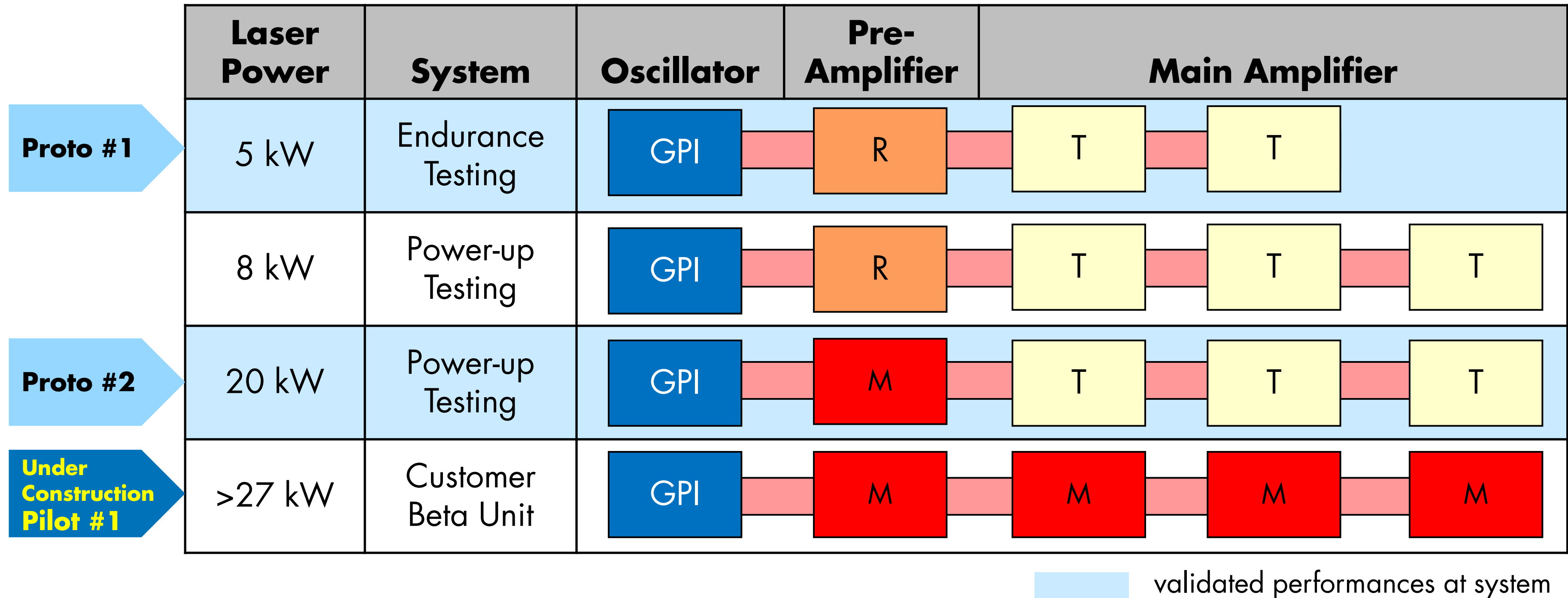
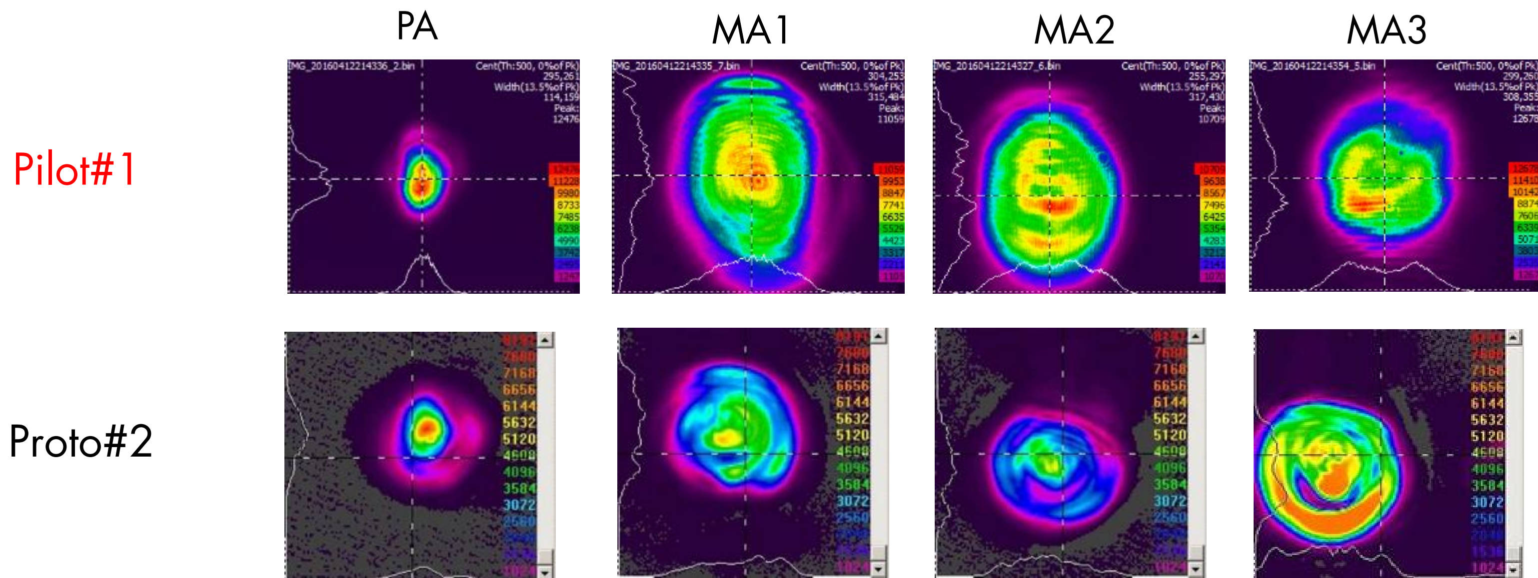
High Power CO_2 Laser Technology



Pilot #1: CO_2 Laser System is Ramping-up (Apr.2016)

CO2 Laser system beam profile in Pilot#1 is dramatically improved.
It will contribute higher CE operation



New Data

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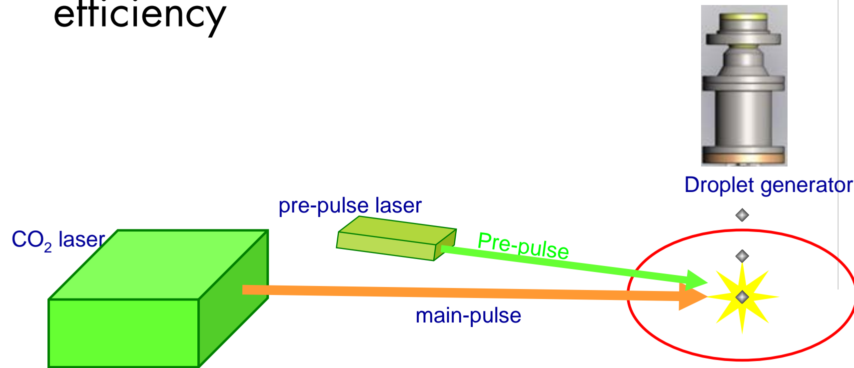
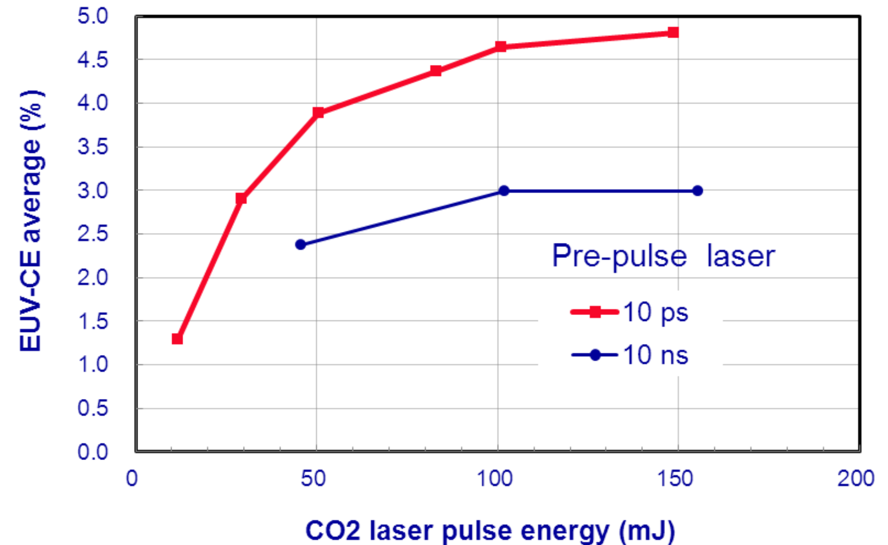
Pre-Pulse Technology (1)

- Based on basic physical consideration and experiments, Gigaphoton has chosen to adopt the pre-pulse technology since 2009
- In 2012 Gigaphoton discovered that shortening the pre-pulses duration dramatically enhance the conversion efficiency





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Pre-Pulse Technology (2)

In small experimental device, we observed **5.5% CE** under optimized condition. **17 % increase** from old champion data (CE=4.7%).

CE at 37 deg (%)

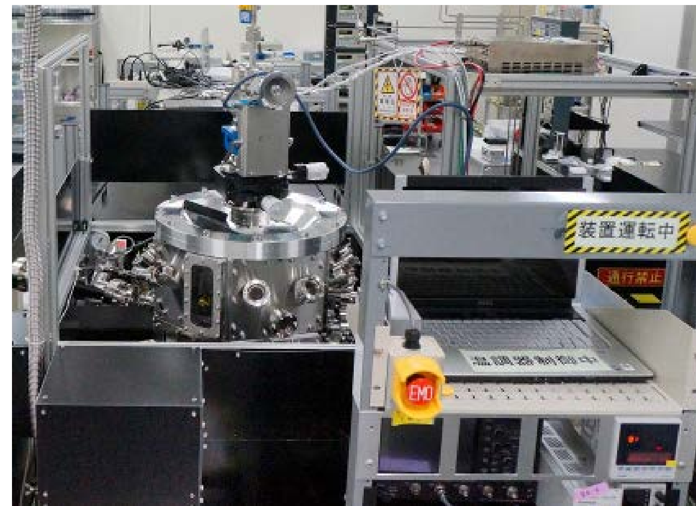
6
5
4
3
2
1
0

5.5%

10ショット平均値

0

PPL - CO_2 delay



Experrimental Device

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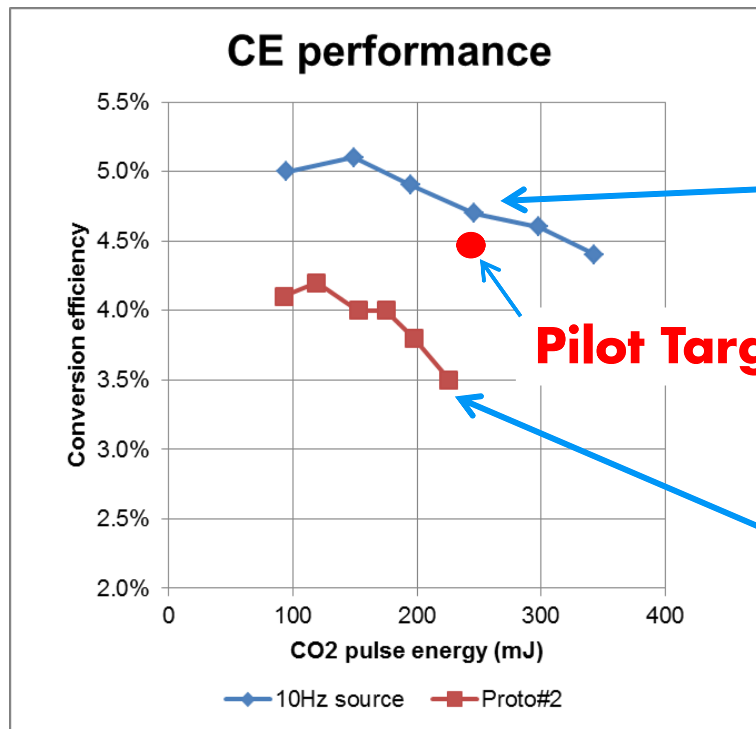
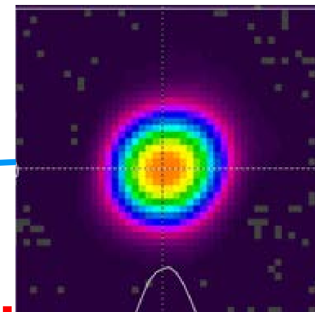
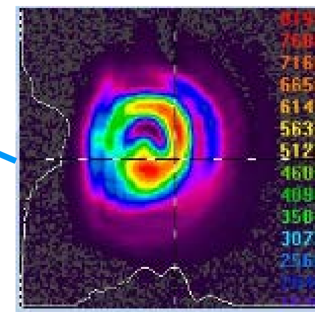
Pre-Pulse Technology (3)

- Issue
  - » CE in Proto#2 is 1% lower than 10Hz source. This would be due to CO2 laser beam inhomogeneity.
- Next Step
  - » CO2 laser beam homogeneity would be improved in Pilot#1 system.



CO_2 Laser Profile





New Data

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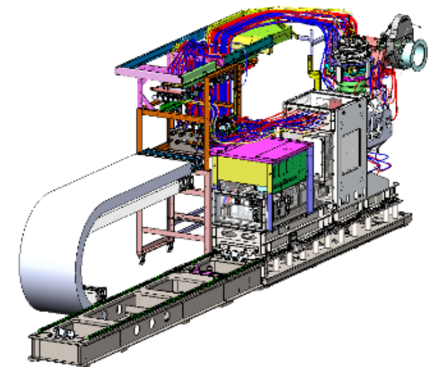
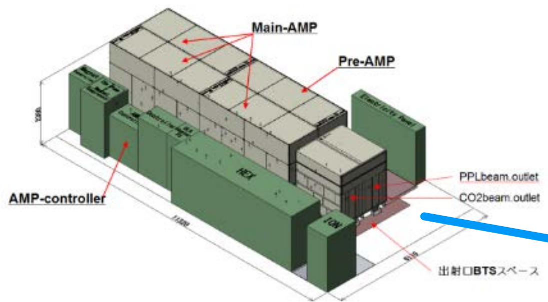
Gigaphoton EUV Sources

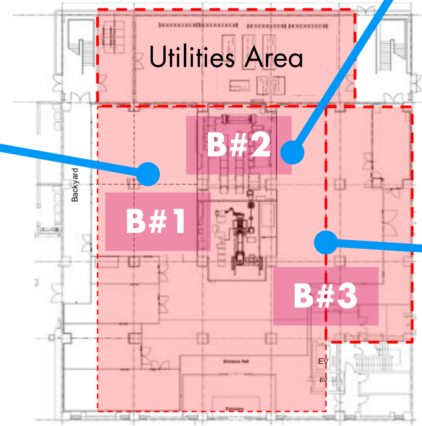
2 – proto system are in operation
1 – pilot system is under construction

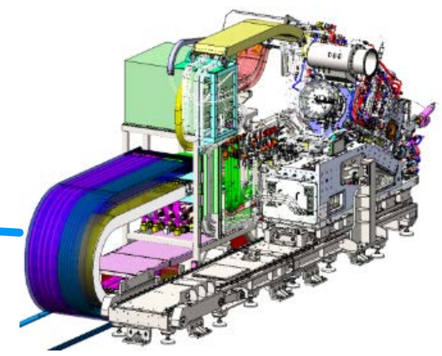


Proto #1
From Oct 2012

Proto #2
From Nov 2013







Pilot #1 NEW
(under construction)

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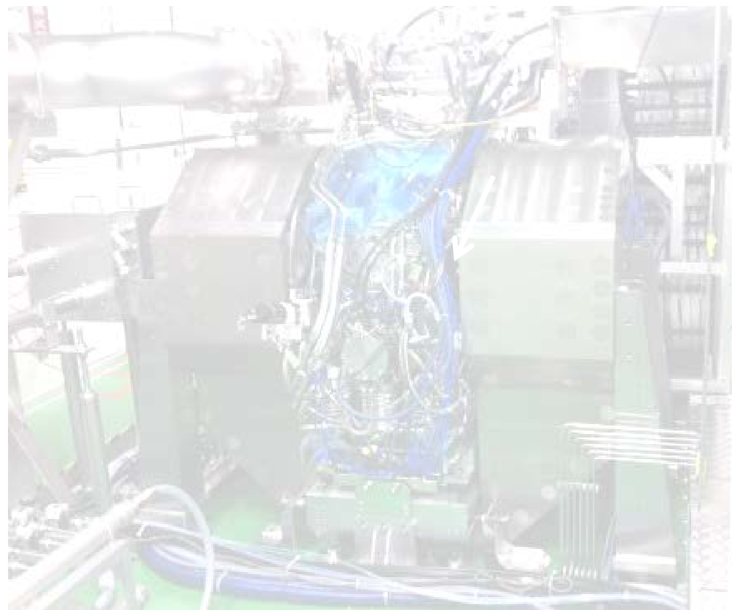
Gigaphoton's High Power EUV Light Source

Prototype high power EUV light source is in operation

Proto 1 Exposure & Mitigation test

Proto 2 High power Experiment



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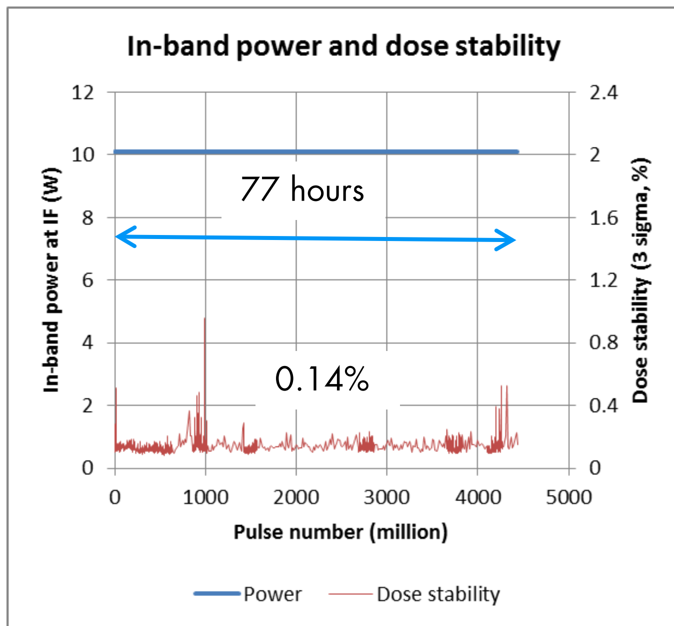
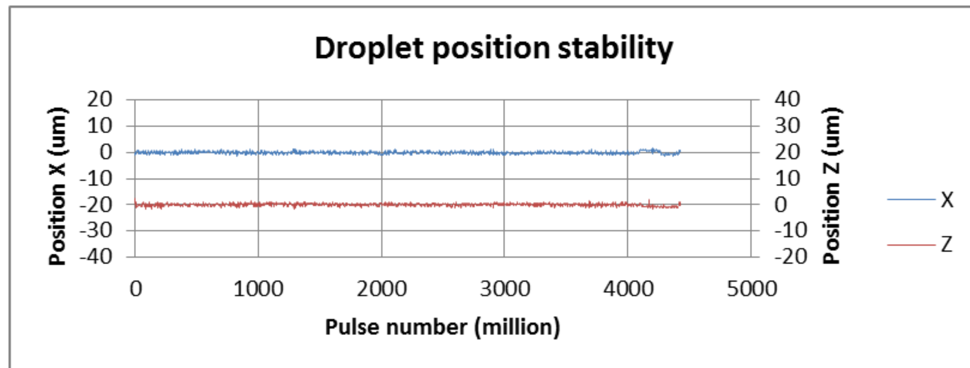
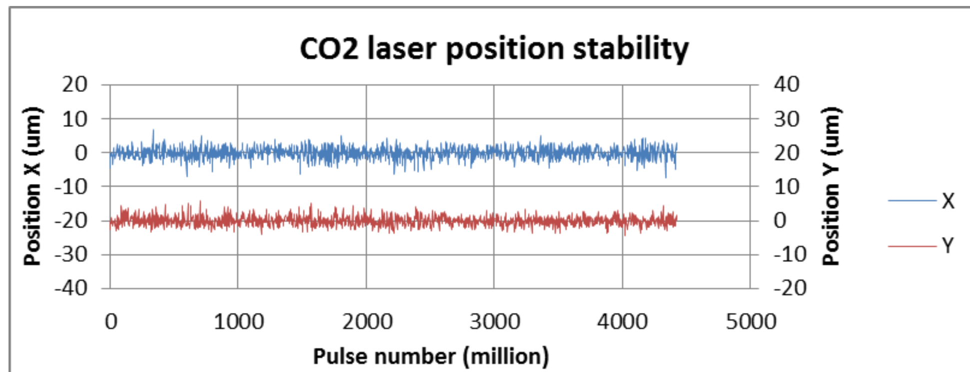
Long Lifetime Operation in Proto#1 System

77 hours operation with 25% dose margin







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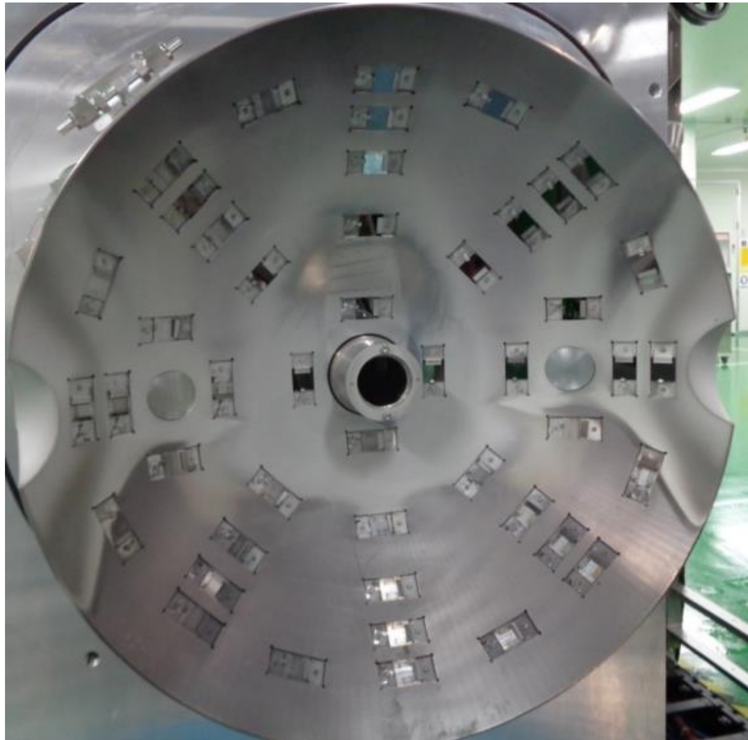
Proto#1: Sampling Evaluation

Measurement of Sn deposition distribution at recent Proto#1configuration



- Purpose
  - » Evaluation of tin deposition distribution on the collector mirror
- Method
  - » dummy collector mirror (no coating)
  - » sampling plate
    size: 15mmx15mmx0.7mmt
    material :Si plate (46 pieces)
- Analysis after test
  - » surface condition :SEM
  - » deposited tin thickness :XRF

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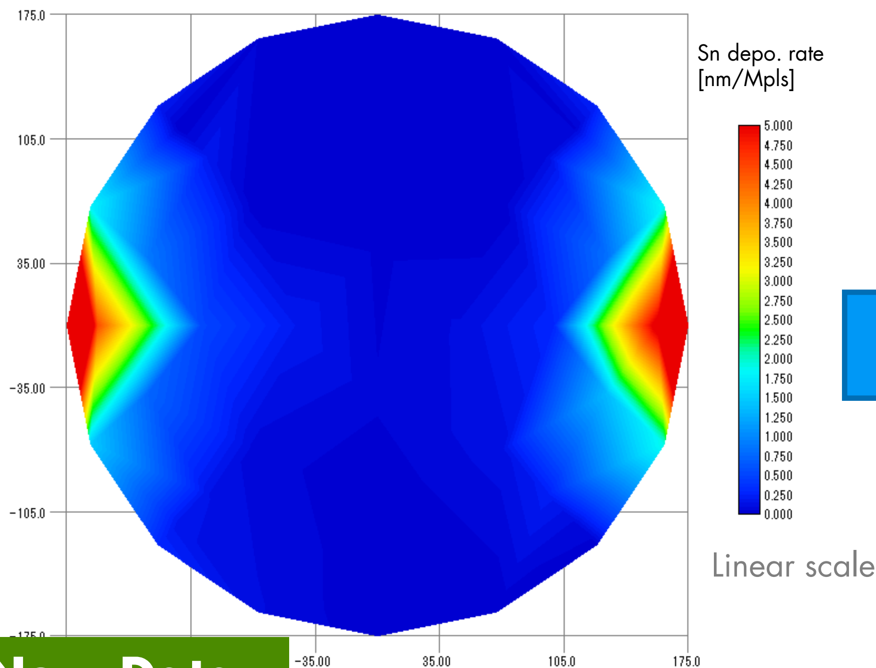
Proto#1: Comparison of tin Deposition Distribution

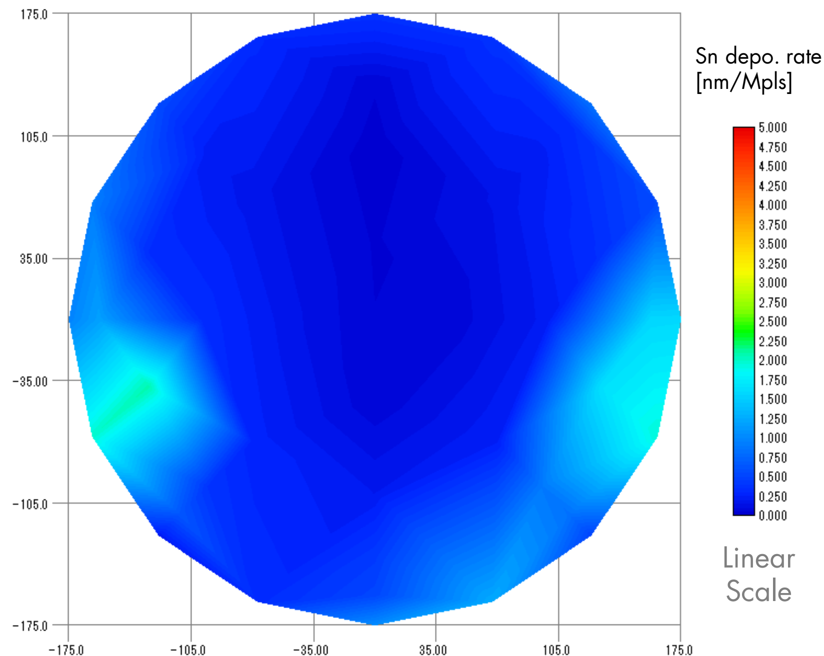
Mapping of Sn deposition distribution (measured data) at recent Proto#1configuration

P#1(2015.08)



Linear scale

P#1(2016.01)



Linear Scale

New Data

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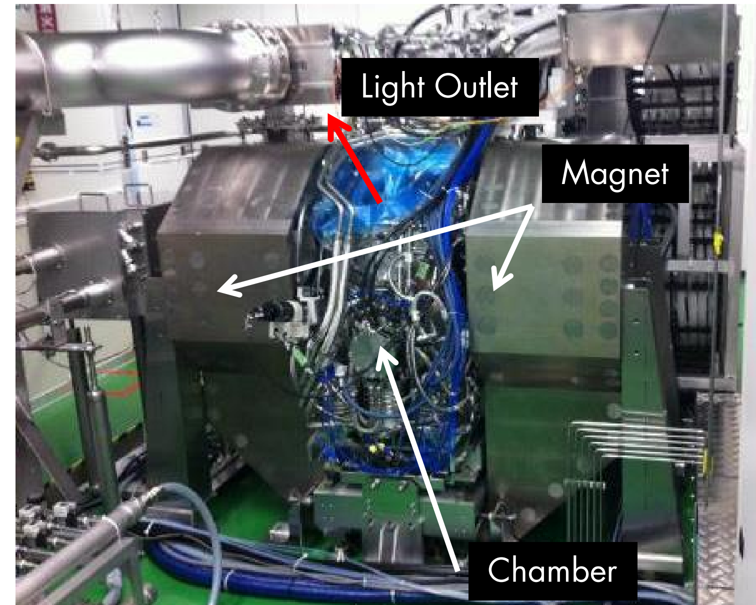
Gigaphoton's High Power EUV Light Source

Prototype high power EUV light source is in operation

Proto 1 Exposure & Mitigation test

Proto 2 High power Experiment



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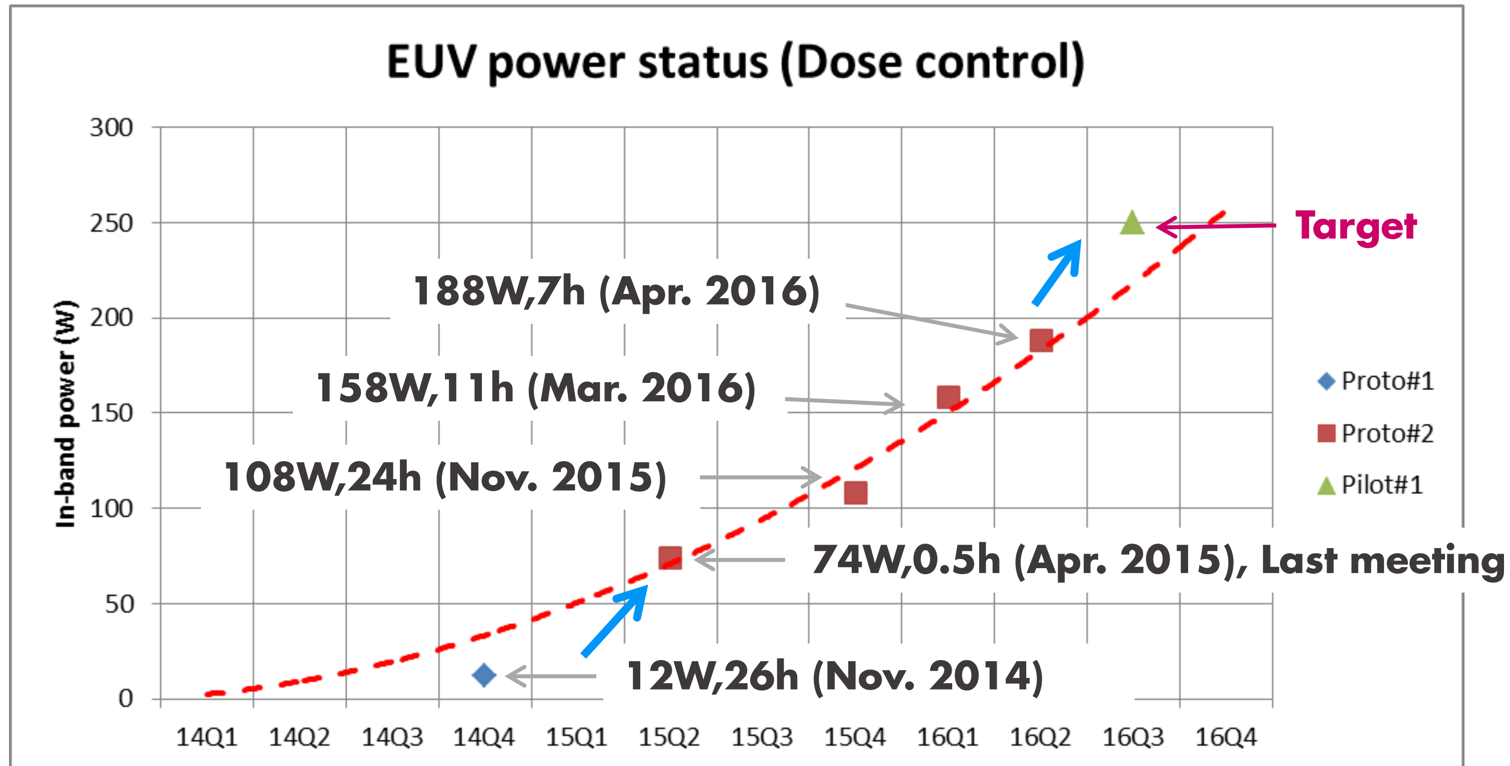
Power Status



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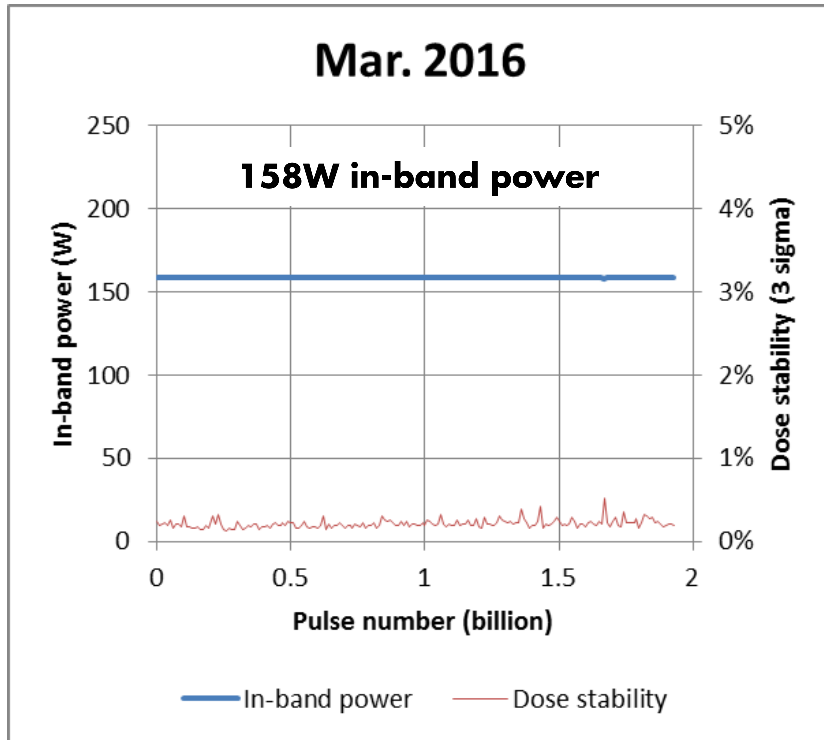
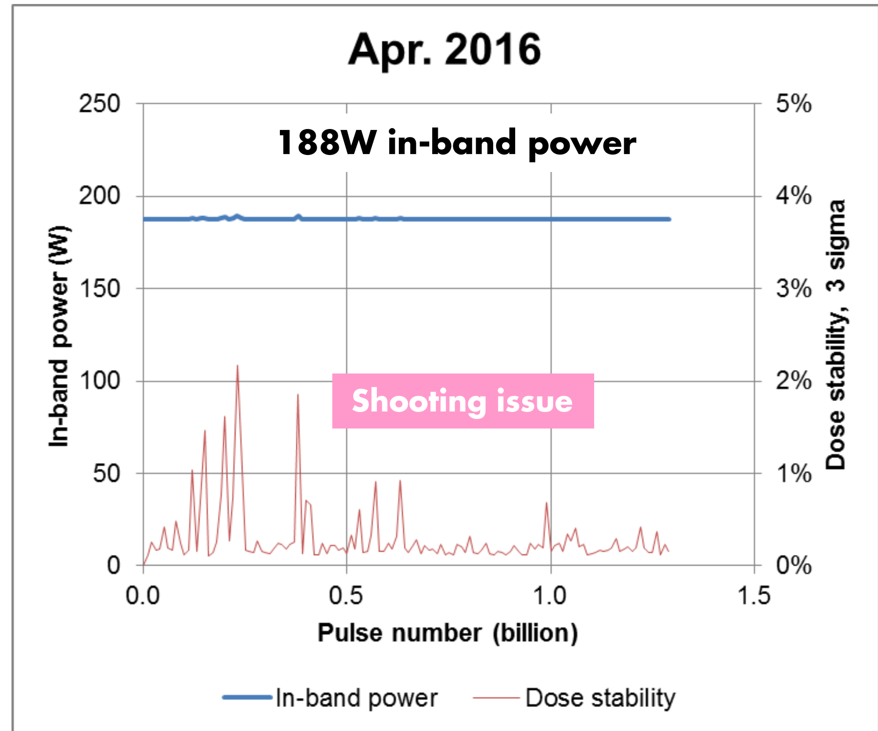
High Power Operation (Proto#2)



100kHz, 50% duty cycle, 40% dose margin,
Operation time: 11 hours



100kHz, 50% duty cycle, 30% dose margin,
Operation time: 7 hours

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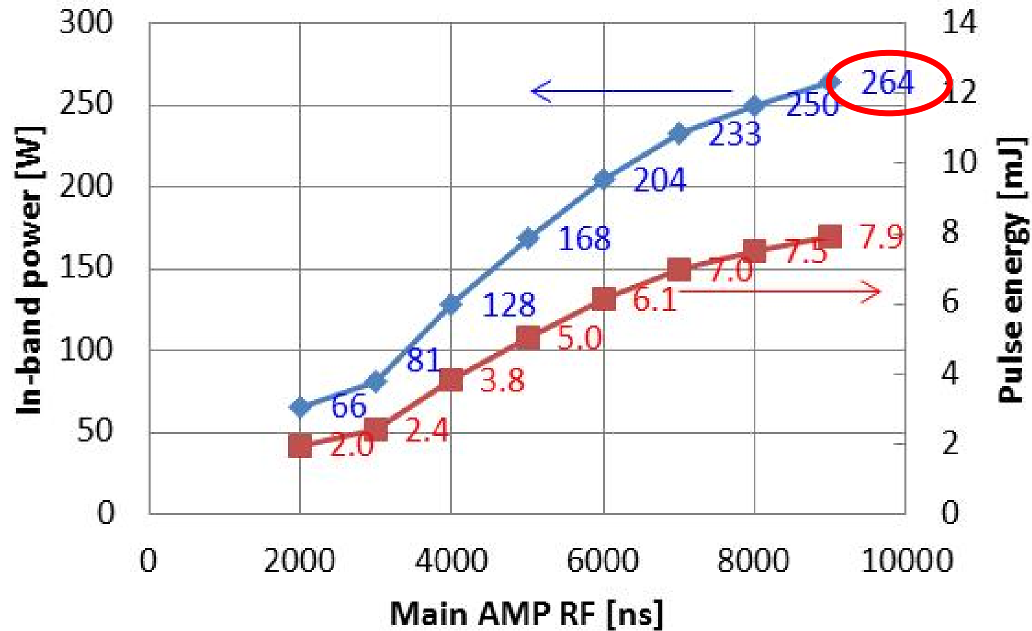
Proto #2: Power Data 1 (Mar. 2, 2016 data)

RF - EUV



- Maximum power 264W (In-burst)
- Open Loop

New Data

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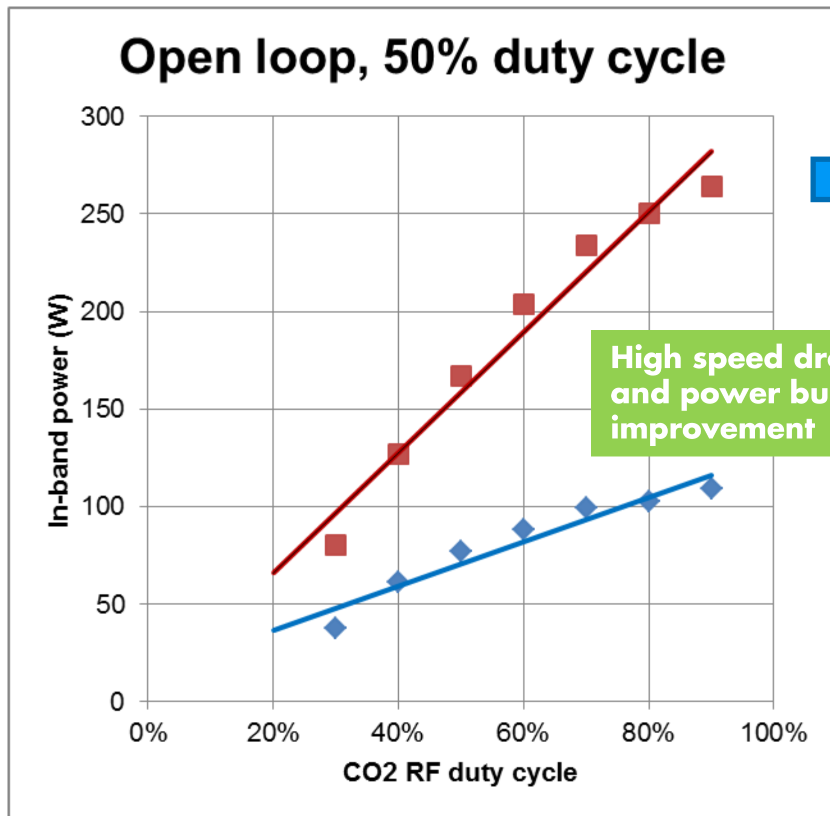
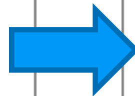
Proto #2: Power Data 2 (Mar. 2, 2016 data)



High speed droplet and power budget improvement



Closed loop, 50% duty cycle

In-band power (W)
300
250
200
150
100
50
0

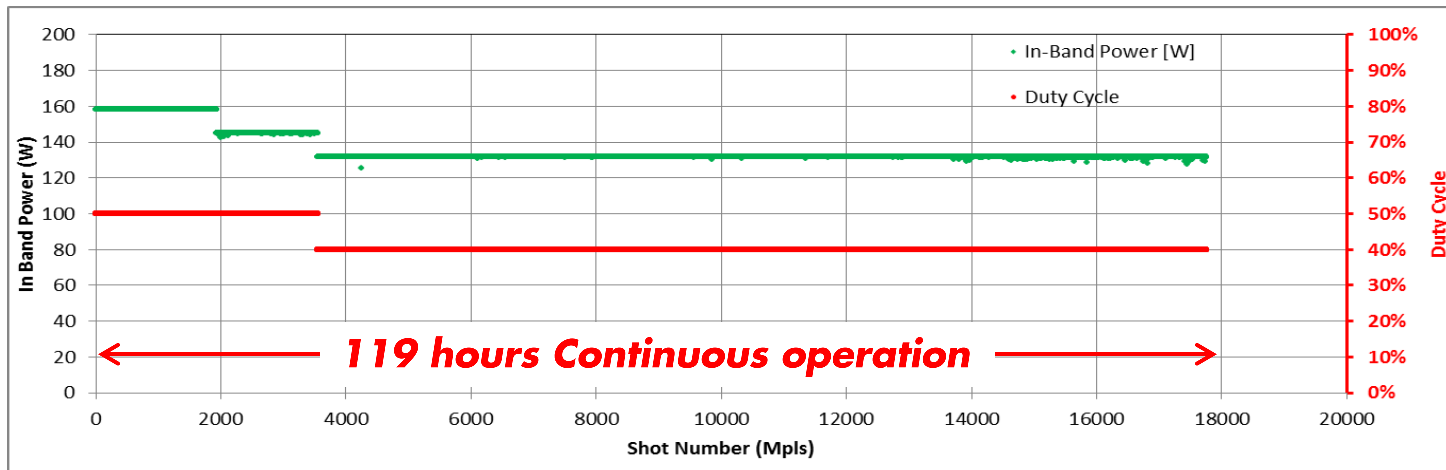
Dose stability, 3 sigma
6%
5%
4%
3%
2%
1%
0%

0% 10% 20% 30% 40% 50% 60%

Dose margin

In-band power — Dose stability

Proto #2: Power Data 3 (Mar. 3-17, 2016 data)



Result:

In-band power:	158W-132W
Operation time:	119 h
Number of Pulse:	>17.8 Bpls
Dose stability3σ:	< 0.19 %

Condition:

Repetition rate:	100kHz
Duty:	40/50% *
Average power:	79W-52W

With dose control mode

* 10 kpls on/0.15 or 0.1s off

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Technology History and Future Scenario

- 24hours operation with 108W average power was confirmed
- Next target of Proto#2 is 200W、Target of Pilot #1 is 250W, 1week continuous operation until June 2016

	Status				Target		
	Feb 2015	Apr 2014	Dec 2016	**Mar 2016**	May 2016	Jun 2016	Dec 2016
System	Proto#1	Proto#2	Proto#2	**Proto#2**	Proto#2	Pilot#1	Pilot#1
In band power	10W	74W	108W	**158/132W**	200W	250W	250W
Average power at IF dose control	8W	70W	54W	**79/52W**	100W	250W	250W
Operation time	77hour	0.5hour	24hour	**119hour**	> 100hour	>1week	>1month
Duty cycle	80%	95%	50%	**50/40%**	>50%	100%	100%
Repetition rate	20kHz	35kHz	80kHz	**100kHz**	100kHz	100kHz	100kHz
CO_2 power at plasma	1.1kW	10kW	14kW	**15kW**	17kW	>23kW	>23kW
CE	3.2%	3.2%	3.5%	**3.5%**	3.5%	4.0%	4.0%
Power budget from plasma to IF	31.6%	31.6%	31.6%	**31.6%**	31.6%	35.1%	35.1%
Dose margin	25%	20%	40%	**40%**	20%	20%	20%
Availability based on 24x7	13.5%	5.3%	>20%	**>30%**	>50%	>60%	>90%

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Extendibility to 500W EUV Power

Possible scale up scenario of EUV Output Power vs. CO_2 Input Power

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	116.0	139.2	162.4	185.6
150	15	73.7	110.6	147.4	184.3	221.1	258.0	294.8
200	20	101.0	151.5	202.0	252.5	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	311.2	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

Our possible scale-up scenario

	HVM (1st)	HVM (2nd)	HVM (3rd)
EUV power	250W	**500W**	1000W
Pulse Rate	100 kHz	**100kHz**	100kHz
CE	4%	**5%**	6%
CO_2 Laser Power	25kW	**40kW**	65kW

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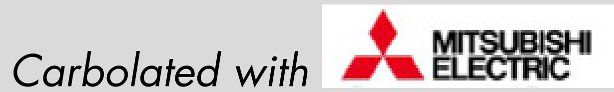
High Power CO_2 Laser System

Carbolated with 

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

<History of Amplifier development>

Basic Experiment in 2013

Ist Amplifier installation in 2015

25kW Amplifier system installation in 2016

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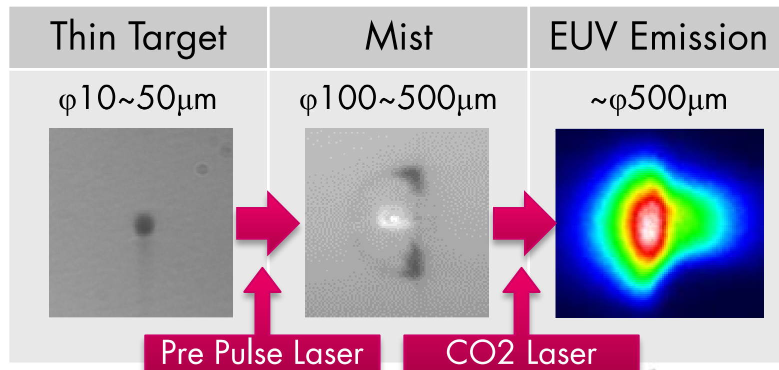
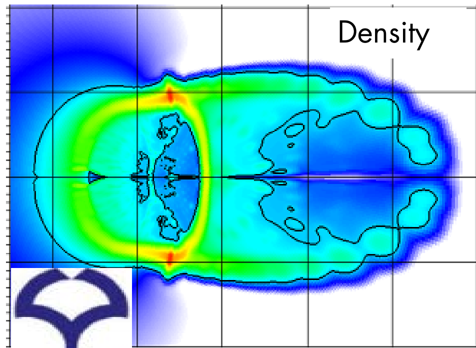
High EUV Conversion Efficiency

Cooperation with

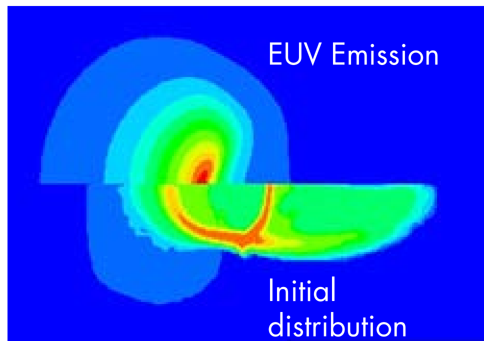
	CO2 Pulse Energy	Ce	EUV Energy	Density
250W	250mJ	4%	10mJ	>0.3J/mm3
500W	360mJ	5%	18mJ	>0.5J/mm3



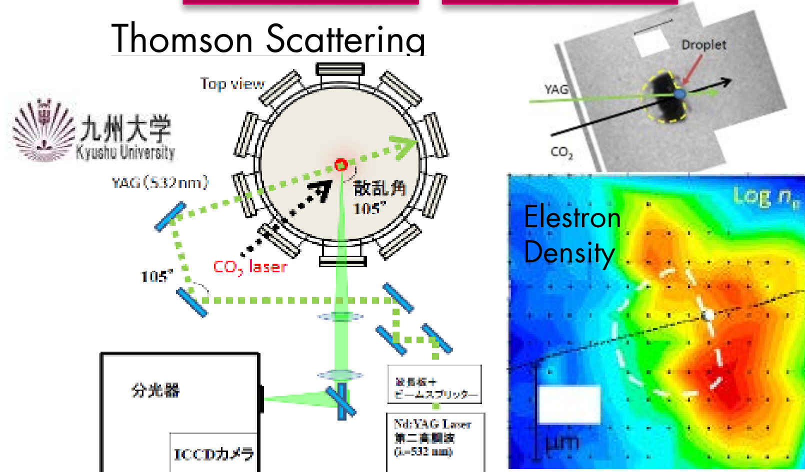
Target Simuration



Simuration of EUV Emission



Thomson Scattering



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Summary

- Recent Topics of LPP Source component technologies are reported.
- **Pilot #1 is starting operation**
  - » Construction has finished at Feb. 2016.
  - » Now we are starting CO2 driver laser power test up to 20kW .
  - » First data will be expected in July 2016.
- Progress of Proto #1 unit
  - » Further improvement of "Magnetic debris mitigation"
  - » Magnetic mitigation capability is discussed by using Tin distribution measurement.
  - » Up time is improved dramatically current 6 month. Utilize test for EIDEC
- Progress of Proto #2 unit
  - » **264W in-bound Power was demonstrated.**
  - » **119 hours 158-132 W power (in burst) under closed loop stable operation was successfully demonstrated**
- Discussion of 500W Light Source

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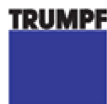

WASEDA University

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THANK YOU