2016 International Symposium on Extreme Ultraviolet Lithography

Hiroshima, Japan 24 - 26 October, 2016

DEVELOPMENT OF 250W EUV LIGHT SOURCE FOR HVM LITHOGRAPHY

25. Oct. 2016 2016 International Symposium on EUVL

Dr. Hakaru Mizoguchi *CTO & Executive Vice President, Gigaphoton*

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AGENDA

- Introduction
- 250W Pilot#1 System Development Update
  - Configuration & Key Component Technologies Update
    - EUV Chamber System
    - Driver laser & PPL system
    - Pre-Pulse Technology
    - Debris Mitigation Challenges
  - » System is now in Operation : Data Update
- Prototype LPP Source Systems Experiment Update
- Higher Power EUV Source Development
- Summary

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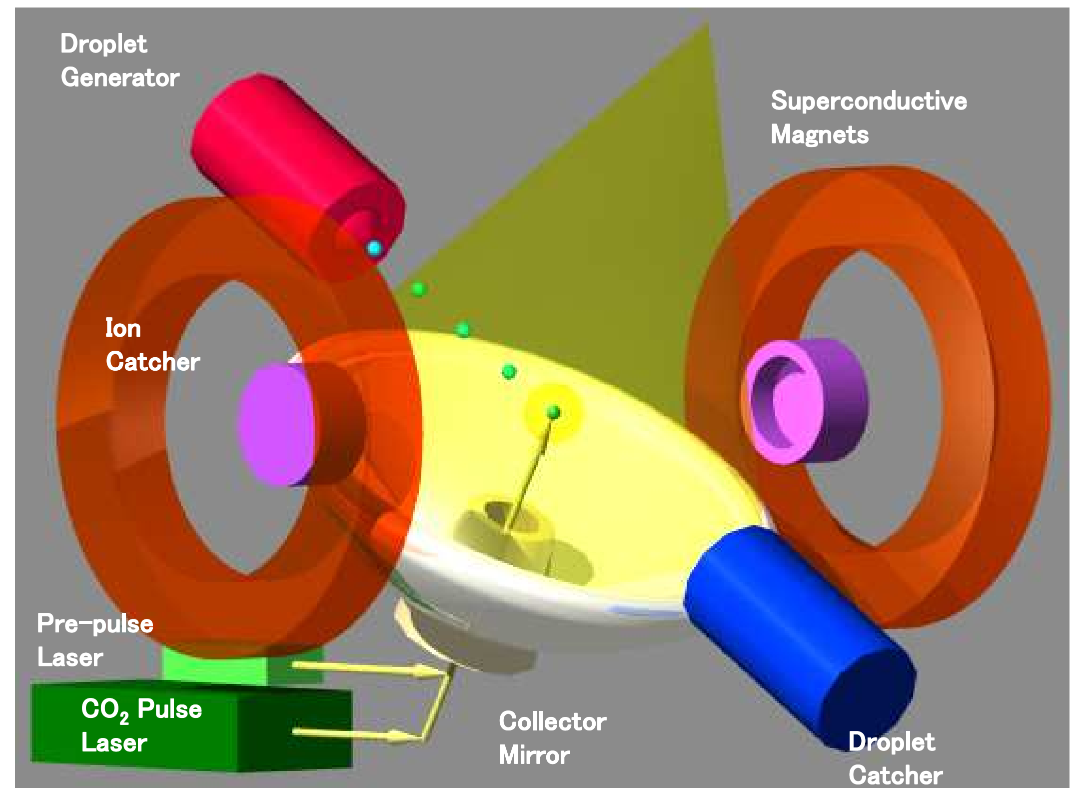
Gigaphoton's LPP Light Source Concept

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



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Gigaphoton EUV Sources

Proto #1
From Oct 2012

Proto #2
From Nov 2013

Main-AMP
Pre-AMP
AMP-controller
PPLbeam outlet
CO2beam outlet
出射口BTSスペース

Pilot #1 NEW

Utilities Area
B#2
B#1
B#3

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Pilot and Proto Systems Configuration

- Target System Specification

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

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Pilot #1: High Power EUV Source for HVM

EUV chamber System

Main-AMP

Pre-AMP

Electricity Panel

Controller

HEX

2,300

11,320

6,110

Beam Transfer System

Driver Laser system

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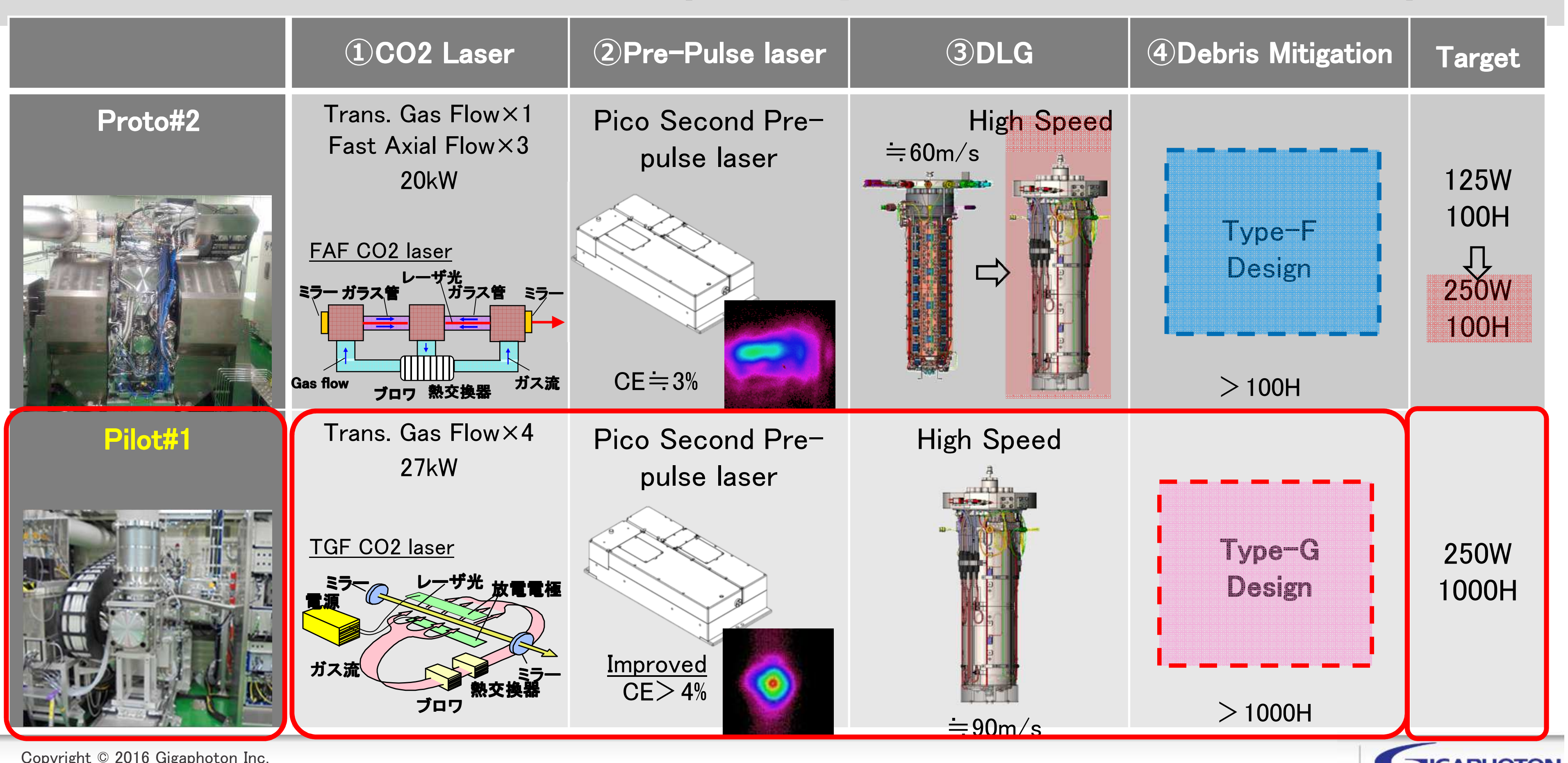
Evolution to Pilot#1 (compared with Proto#2)



	①CO2 Laser	②Pre-Pulse laser	③DLG	④Debris Mitigation	Target
Proto#2	Trans. Gas Flow×1 Fast Axial Flow×3 20kW FAF CO2 laser ミラー ガラス管 レーザ光 ガラス管 ミラー Gas flow ブロワ 熱交換器 ガス流	Pico Second Pre-pulse laser CE≒3%	≒60m/s ⇨ High Speed	Type-F Design ＞100H	125W 100H ⇩ 250W 100H
Pilot#1	Trans. Gas Flow×4 27kW TGF CO2 laser ミラー 電源 レーザ光 放電電極 ガス流 熱交換器 ミラー ブロワ	Pico Second Pre-pulse laser Improved CE＞4%	High Speed ≒90m/s	Type-G Design ＞1000H	250W 1000H

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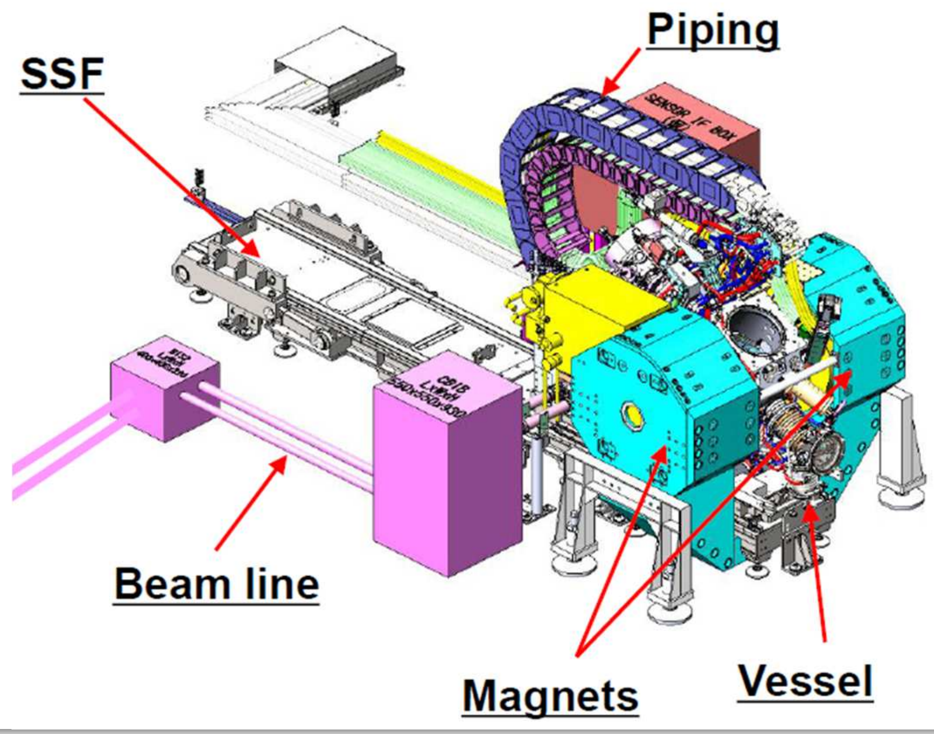
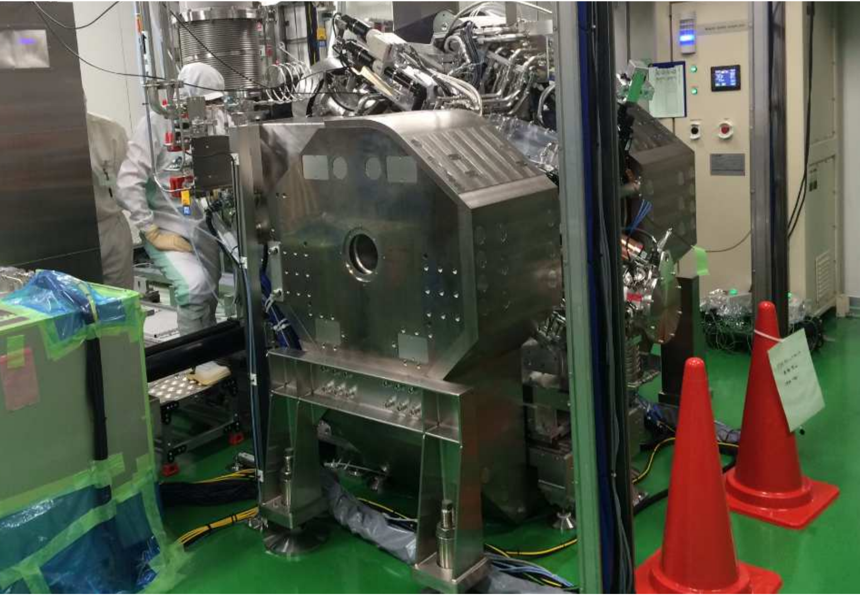
Pilot #1 : EUV Chamber System (1)

EUV chamber system





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Pilot #1 : EUV Chamber System (2)

EUV Light Beam

Intermediate Focus

Droplet Generator

EUV Plasma Point

Driver Laser Beam

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Pilot #1 : EUV Chamber System (3)

LPP EUV Source :
Shooting Control System

DLG X−Z Stage
X
Z
Y
DLG
PZT device
OSC
Z Flow camera
X flow camera
Laser mirror
Plasma sensor
Plasma Point
(250mm from nozzle)
Timing sensor
Laser (CO2, Fiber)
Droplet catcher

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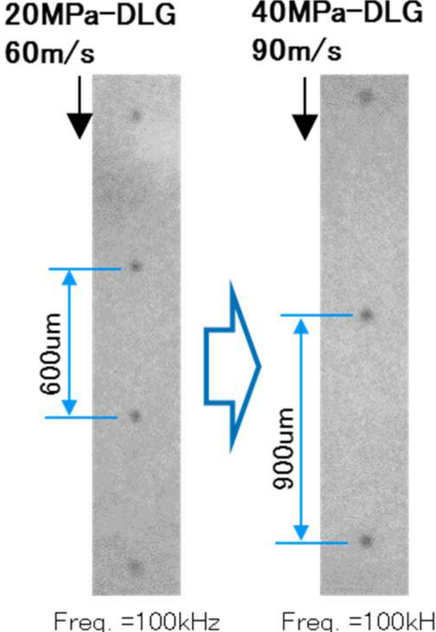
Pilot #1 : EUV Chamber System (4)

- High speed droplet generator was successfully transferred to Pilot system

		2013 Jan Proto#1	2014 Sep Proto#2	2015 Dec Proto#2	2016 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

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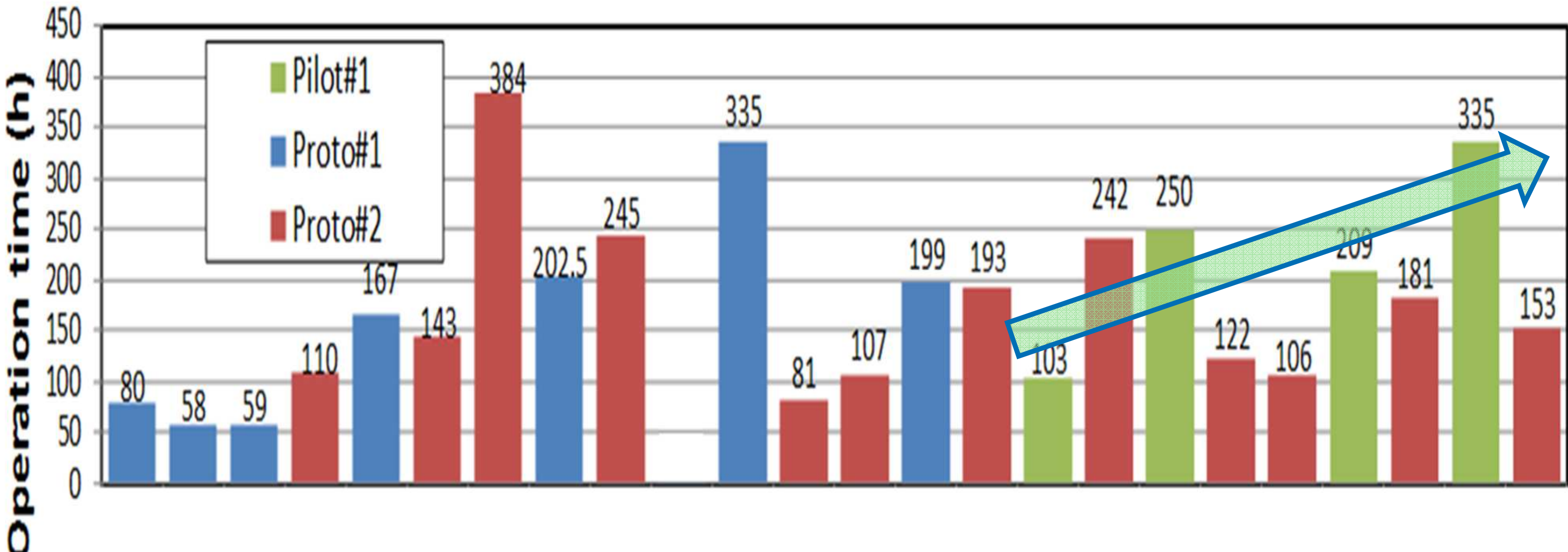
Pilot #1 : EUV Chamber System (5)

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



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Pilot #1: Driver laser & PPL system (1)

4- CO_2 laser Amplifier Modules

Main-AMP

Oscillator/PPL Module

Electricity Panel

HEX

IOM

2,300

11,320

6,110

Driver Laser system

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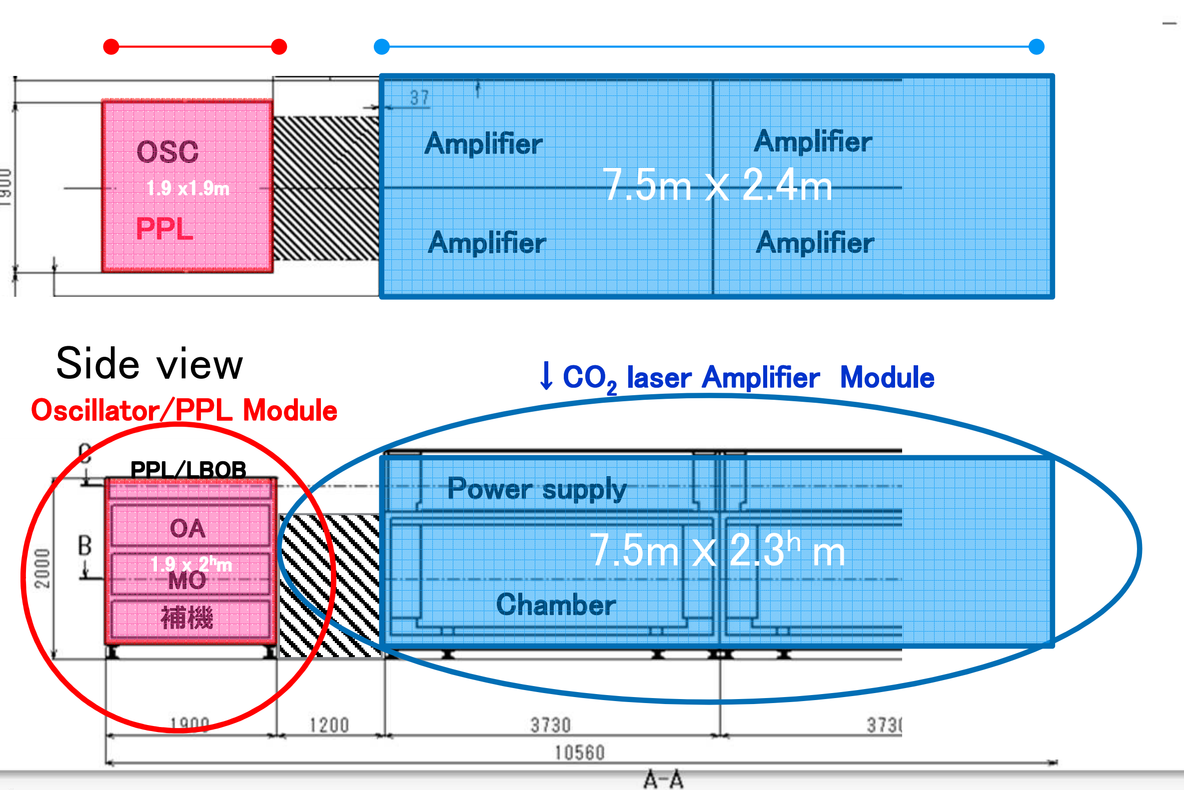
Pilot #1: Driver laser & PPL system (2)



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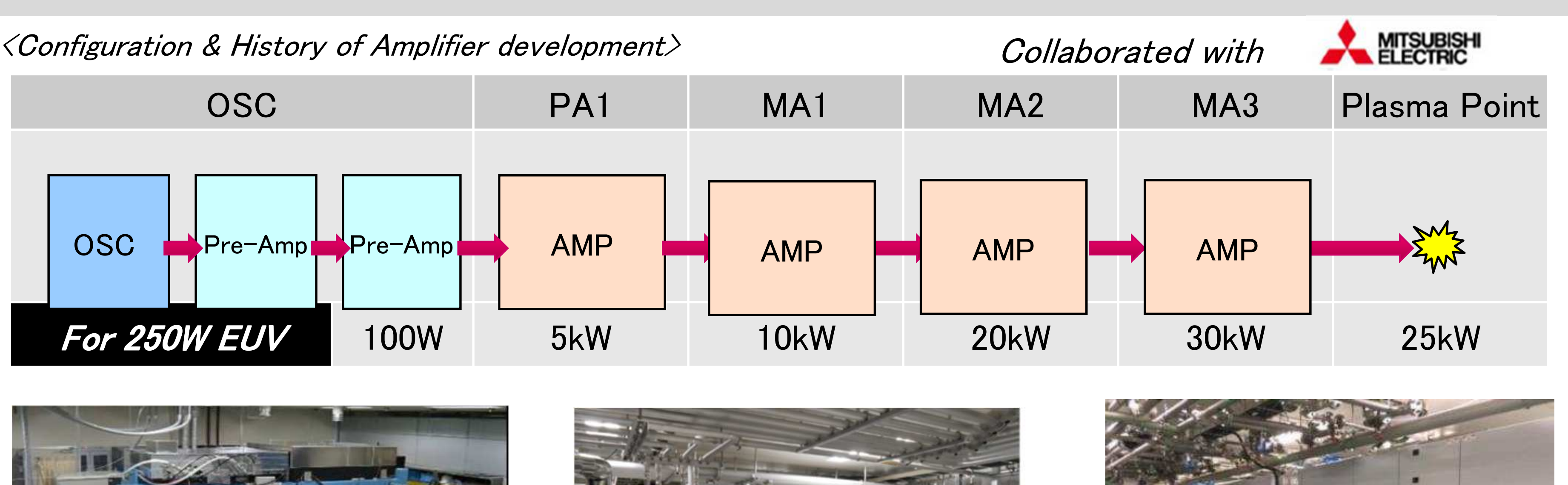
Pilot #1: Driver laser & PPL system (3)

<Configuration & History of Amplifier development>

Collaborated with MITSUBISHI ELECTRIC



Basic Experiment in 2013

1st Amplifier installation in 2015

Amplifier system installation in 2016

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Pilot #1: Driver laser & PPL system (4)

Beam profile of CO2 driver laser system at each stage.

PA MA1 MA2 MA3

Pilot1 (FTF)

Proto2 (FAF)

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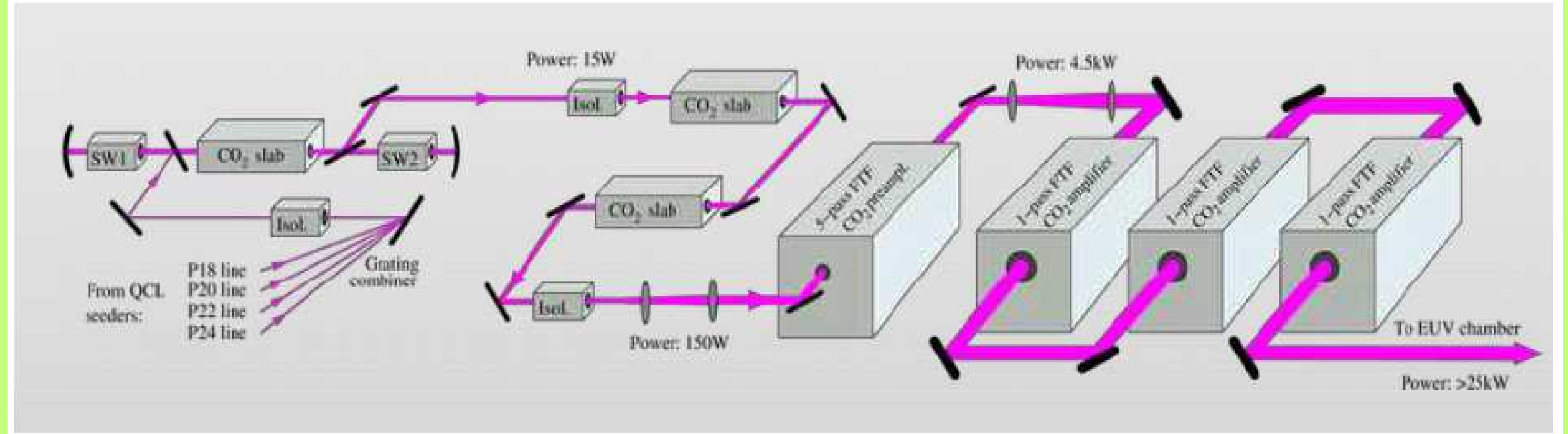
Pilot #1: Driver laser & PPL system (5)

- ***High power drive laser development for EUV Lithography (Gigaphoton)***

  –> Poster P-ET-06 by Mr. Takashi Suganuma



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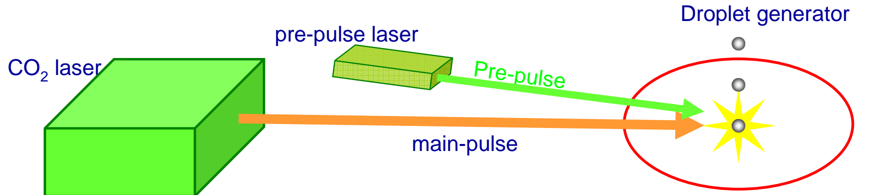
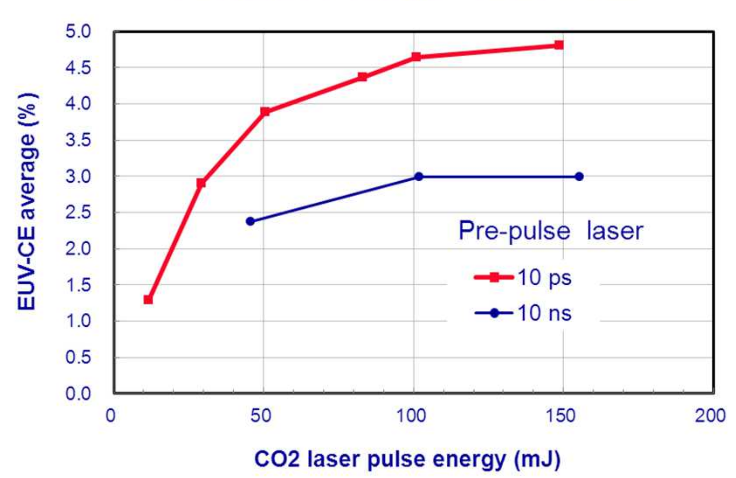
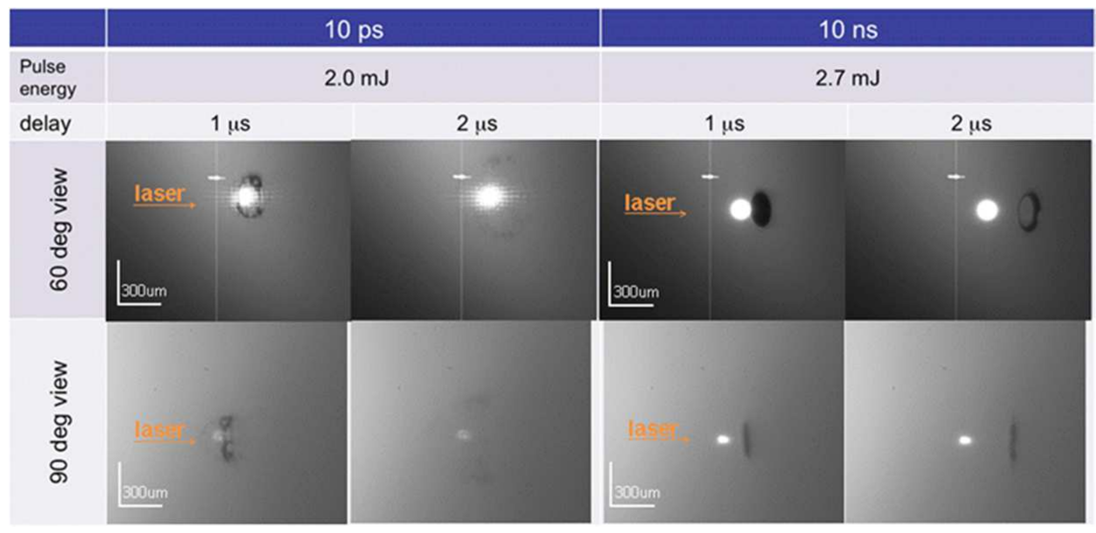
Pre-Pulse Technology (1)





- 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



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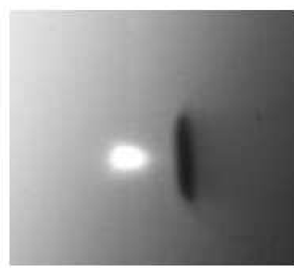
Pre-Pulse Technology (2)

Modeling nanosecond pre-pulses

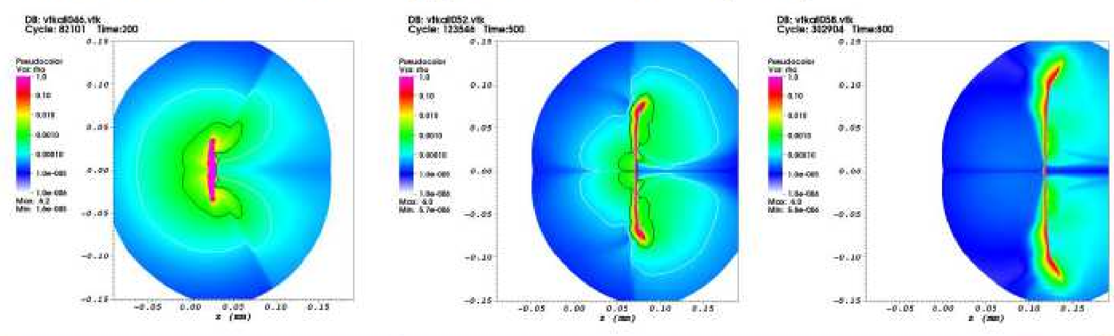
~ 10 ps pre-pulse
"Disk like target"



H. Mizoguchi, Dublin (2013)

RALEF simulations

Evolution of Sn density profile for 10 ns pre-pulse



time

"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

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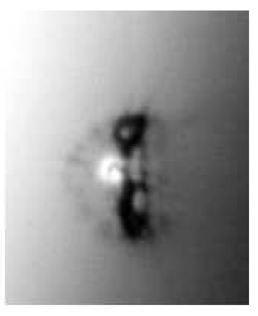
Pre-Pulse Technology (3)

-

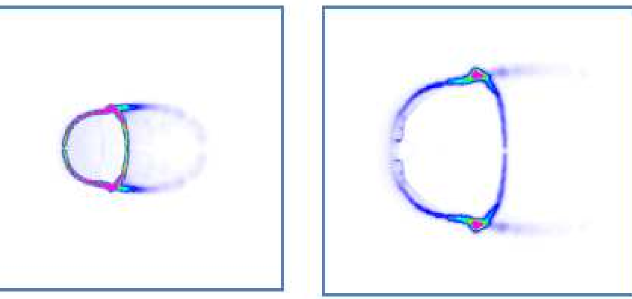
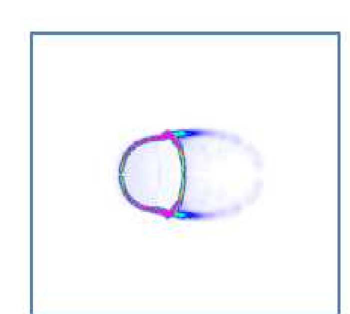
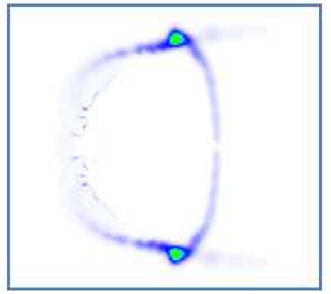
Modeling picosecond pre-pulses

~ 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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[2] Institute for Spectroscopy RAS, Moscow, Troitsk, Russia
[3] KeldyshInstitute of Applied Mathematics RAS, Moscow, Russia

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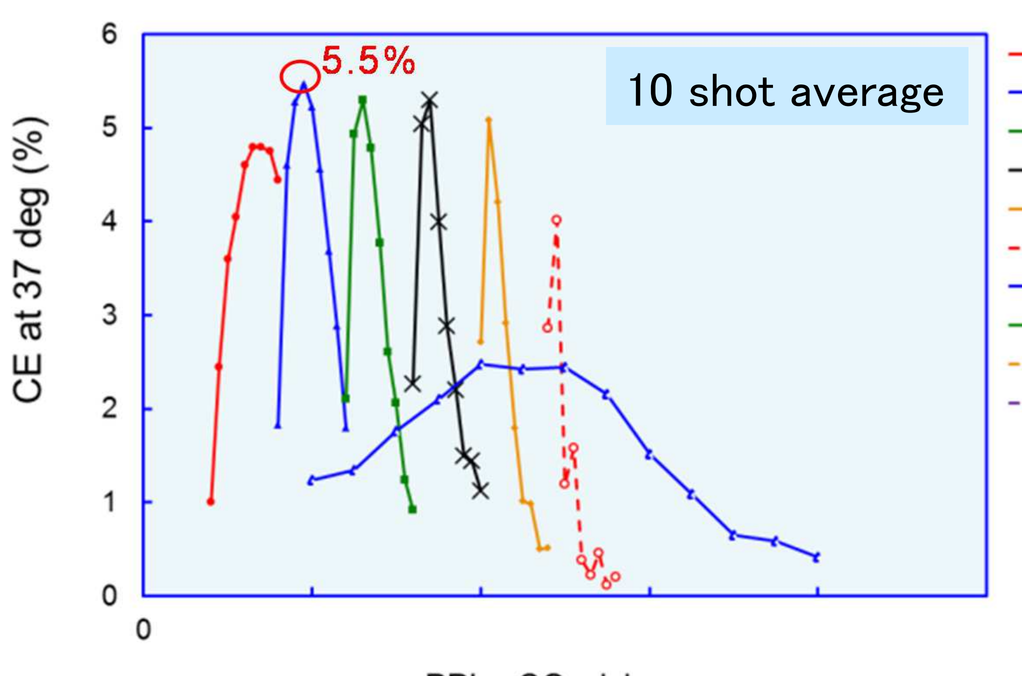
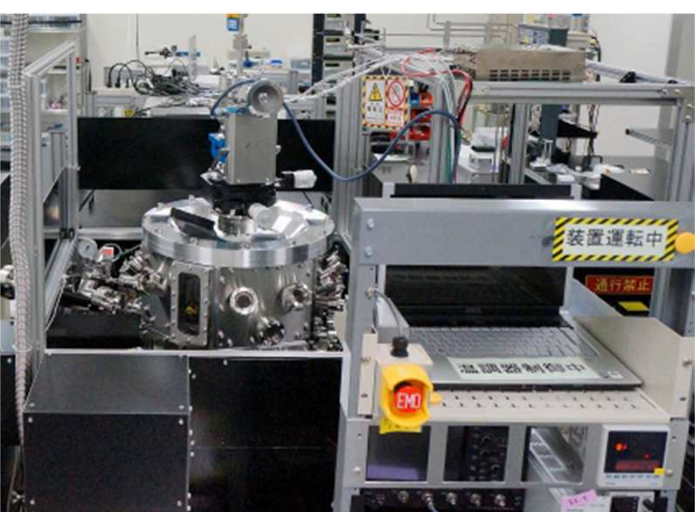
Pre-Pulse Technology (4)

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





Experimental Device

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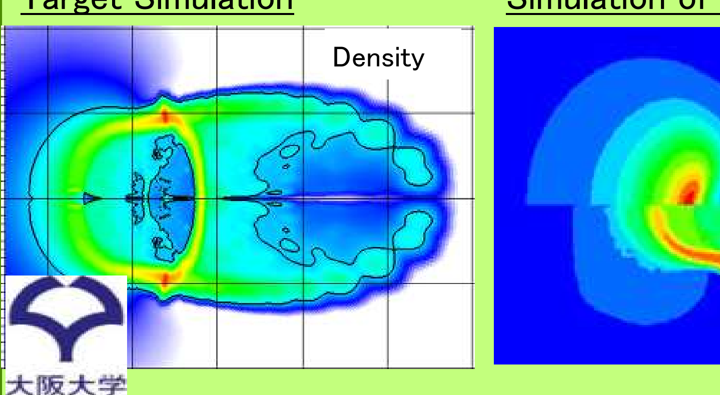
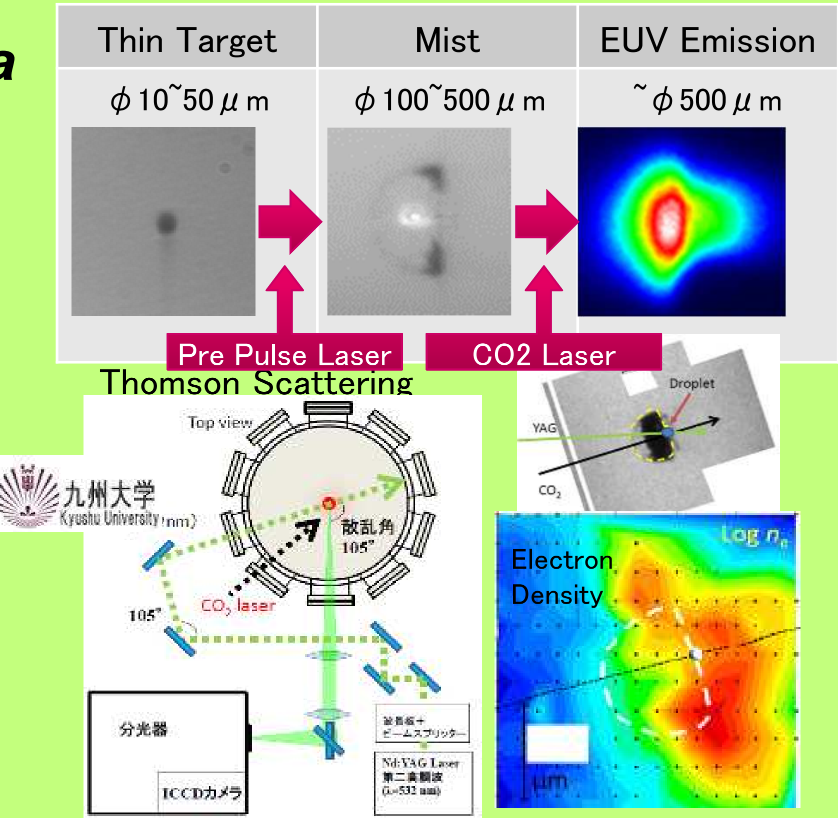
Pre-Pulse Technology (5)

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





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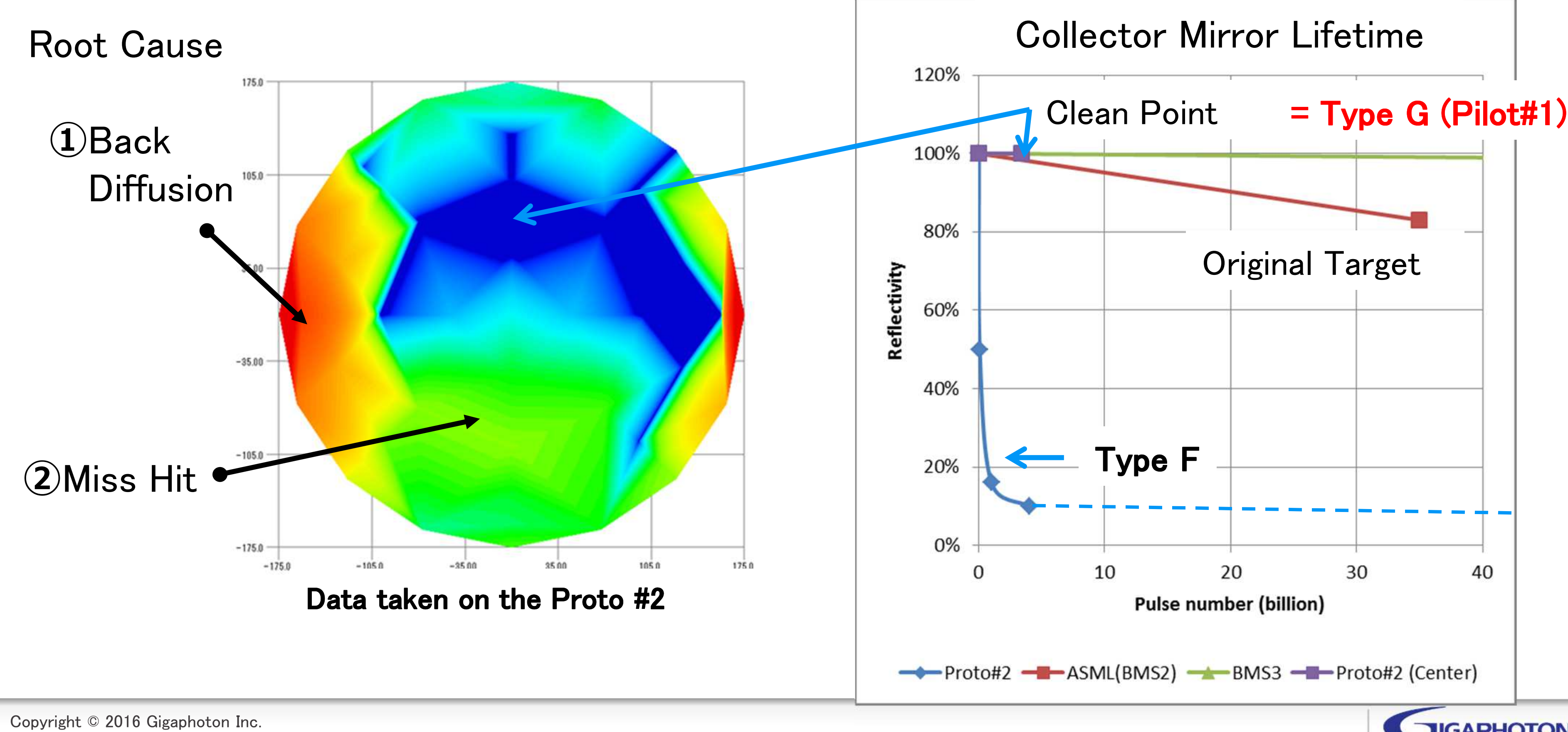
Debris Mitigation Challenges from Proto#2 (1)



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Debris Mitigation Challenges from Proto#2 (2)

For Pilot #1　Type F -> Type G

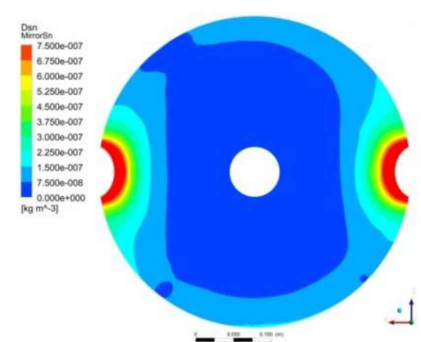
① Improvement of Back Diffusion

1. H2 gas flow design
2. Cooling system

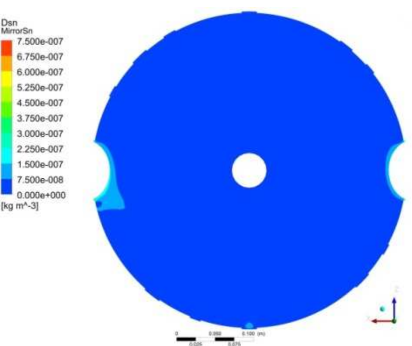
② Improvement of shooting accuracy

Reduction of miss hit

Proto#2
Type F



Pilot#1
Type G



Distribution of Sn density (Simulation)

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Pilot #1 System is now in Operation (1)

Vessel with Magnetic Shield

CO_2 driver laser

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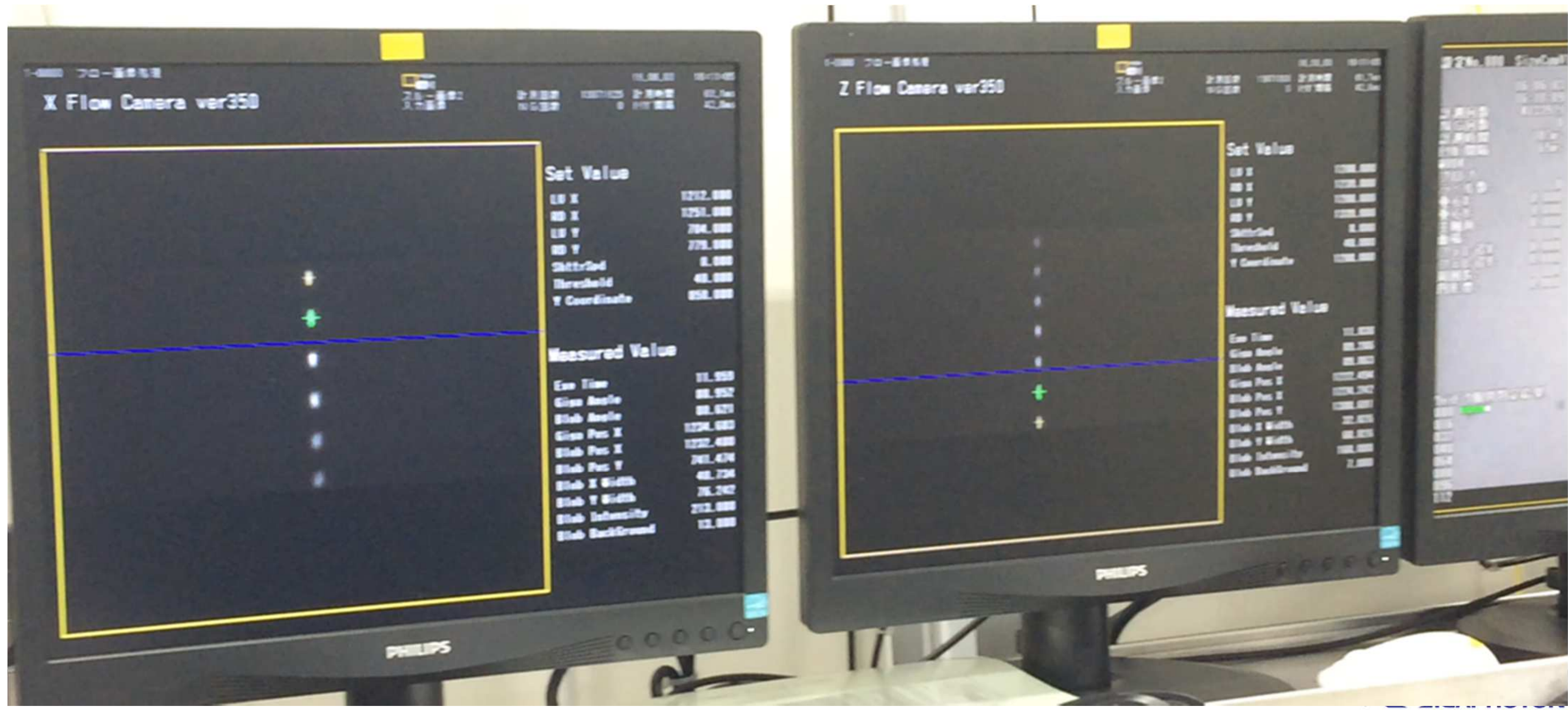
Pilot #1 System is now in Operation (2)

EUV Source: Droplet Flow Monitor



Pilot #1 System is now in Operation (3)

EUV Source: Operation Desk

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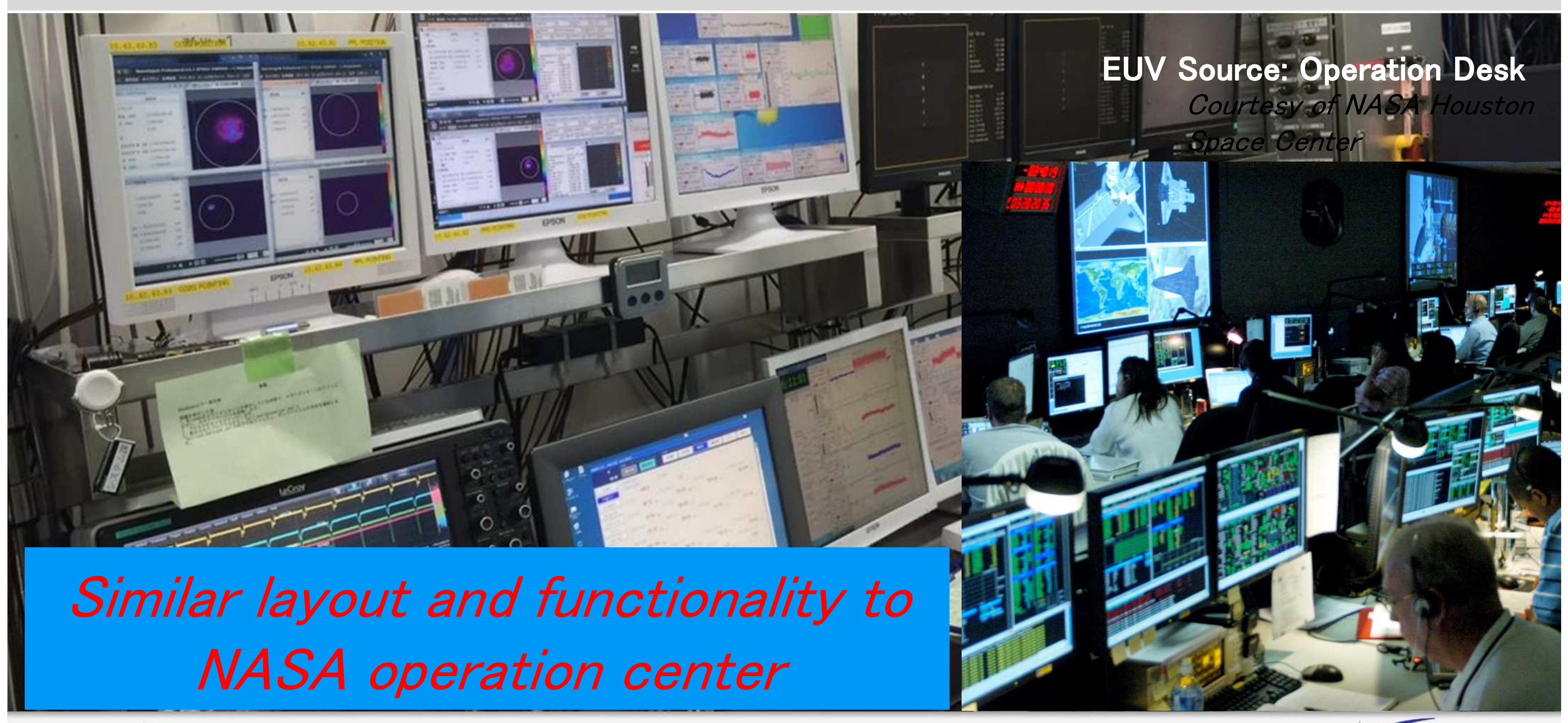
Pilot #1 System is now in Operation (4)



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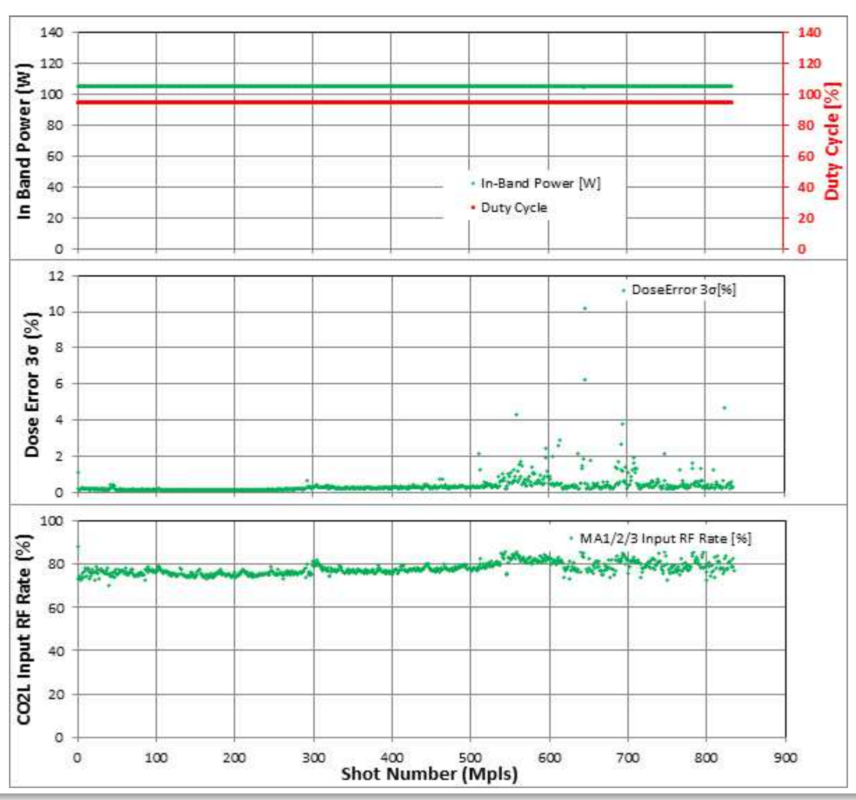
Pilot #1 System is now in Operation (5)

Pilot#1 has been demonstrating at 100W average power with 5% CE !



- Pilot #1 Data

Conversion Eff.	5.0%
Power (in burst)	105W
Duty cycle	95%
Power (average)	100W
Operation Pls Num.	0.83Bpls
Operation Time	5hr
Dose Stab. (av.)	0.39%(3σ)

- OSC＋4xAmplifier （Mitsubishi Electric）

CO2 Laser Power	9.1kW
Pulse Rate	50kHz
Pulse Duration	～10ns

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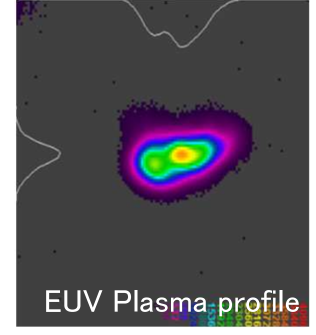
Pilot #1 System is now in Operation (6)

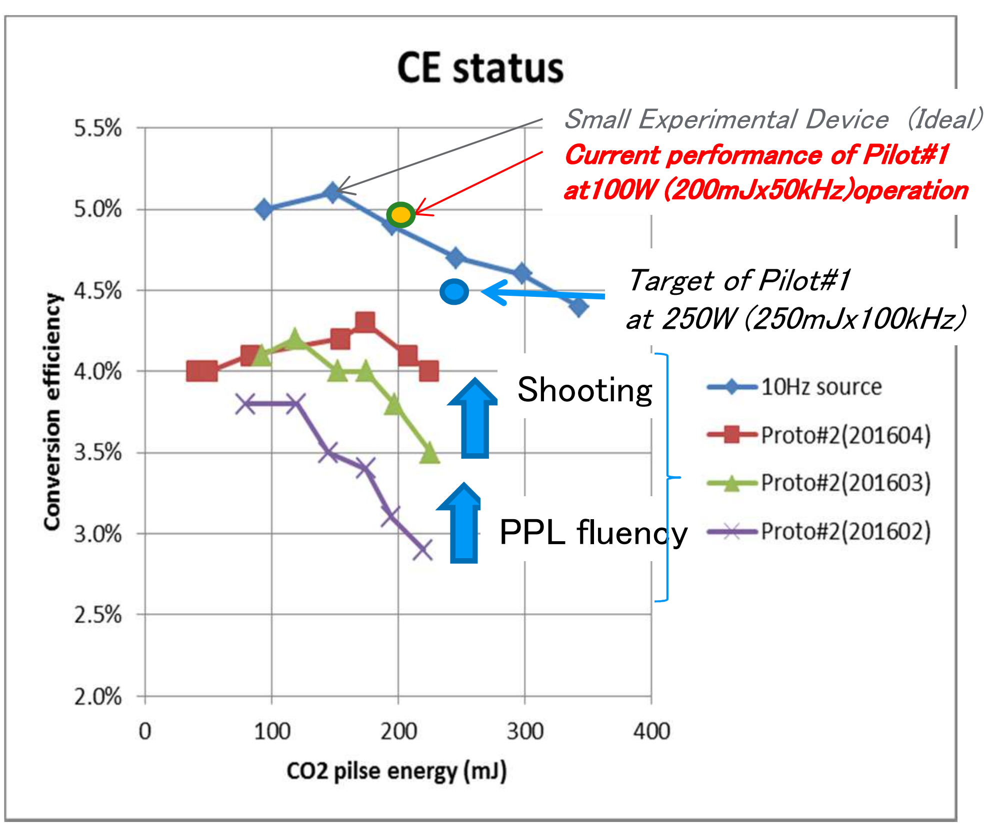
Conversion efficiency history

CE improvement

- Proto#2 : CE is improved to 4.0% at 250W operation
- Pilot #1 followed by

  4.5-5.0% target at 100-250W operation





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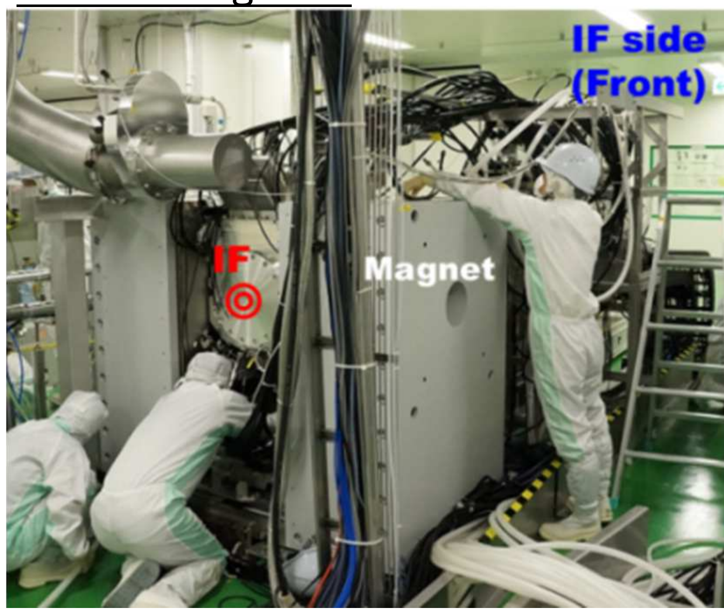
Prototype LPP Source Systems Experiment Update (1)

- Prototype high power EUV light source is in operation

Proto #1 POC in Power Scaling & Debris Mitigation



Proto #2 High Power Experiment

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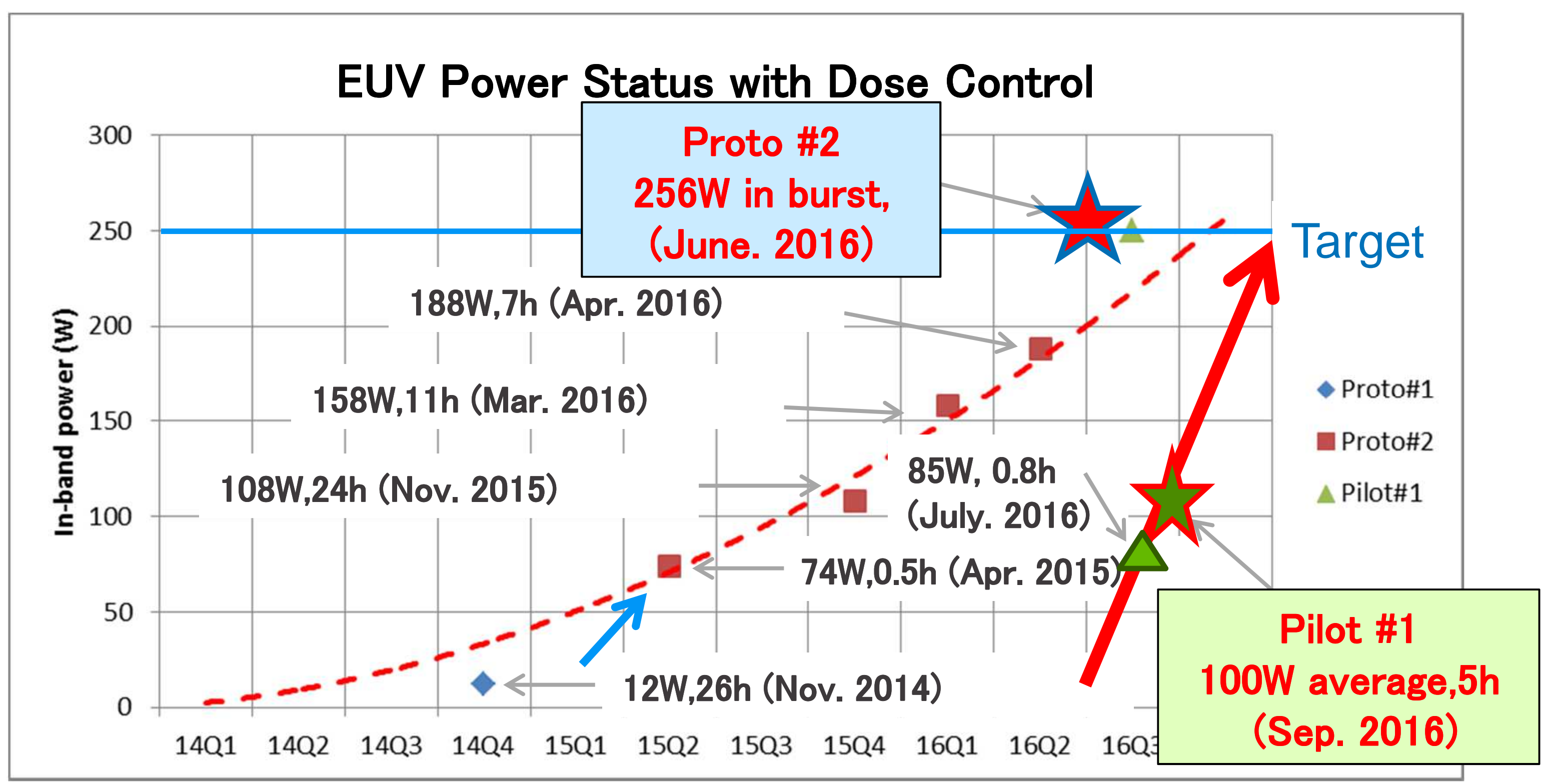
Prototype LPP Source Systems Experiment Update (2)

Power Status of Proto#2 / Pilot#1



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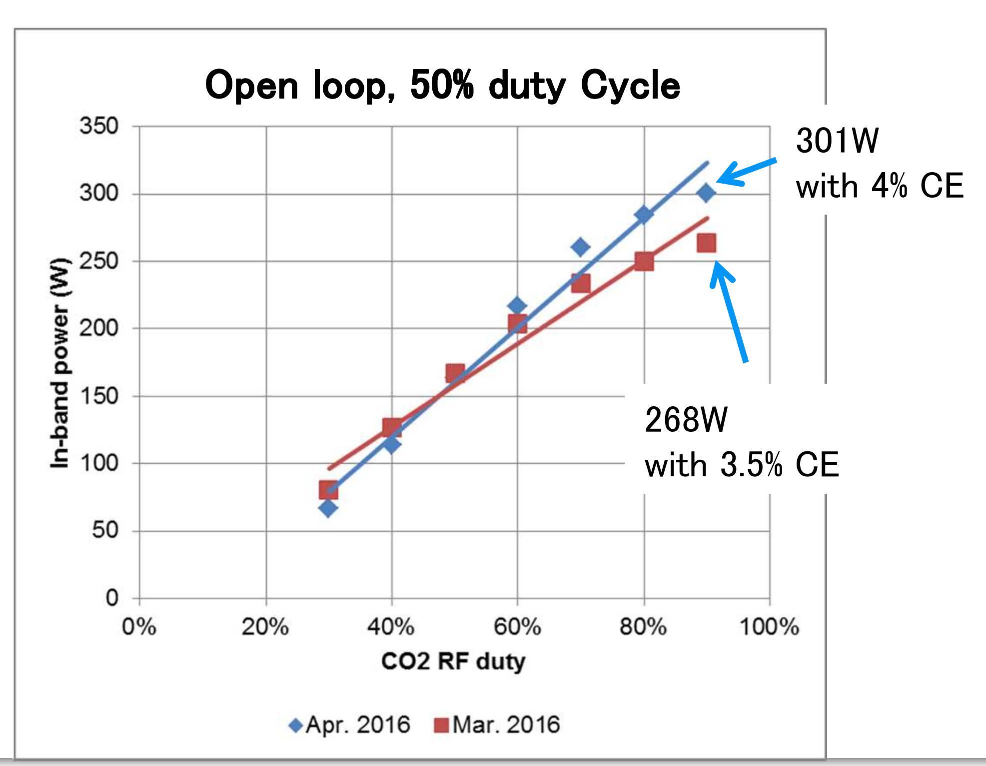
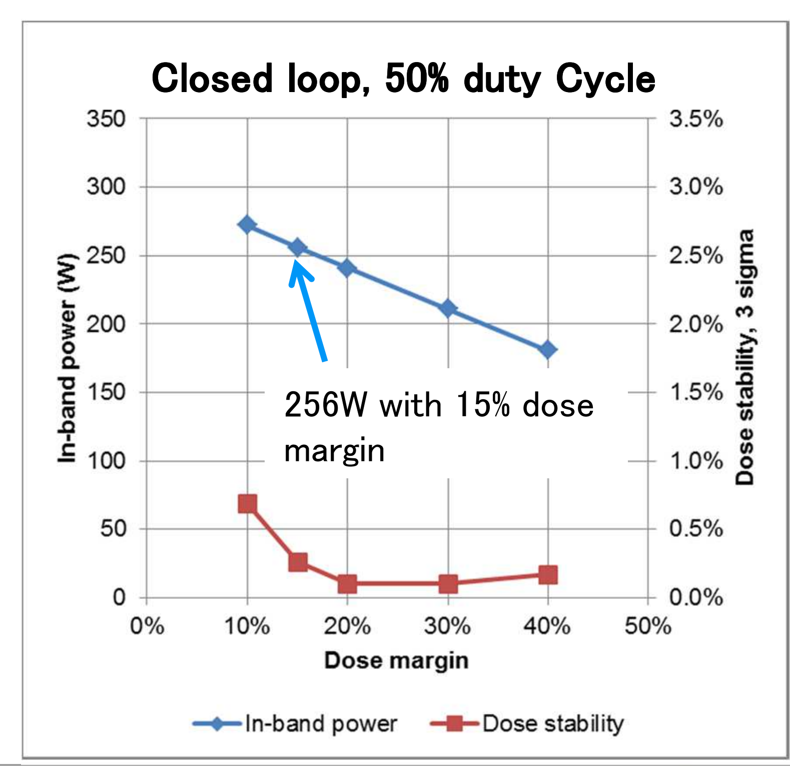
Prototype LPP Source Systems Experiment Update (3)

- Proto#2: 250W、4%CE(100kHz)





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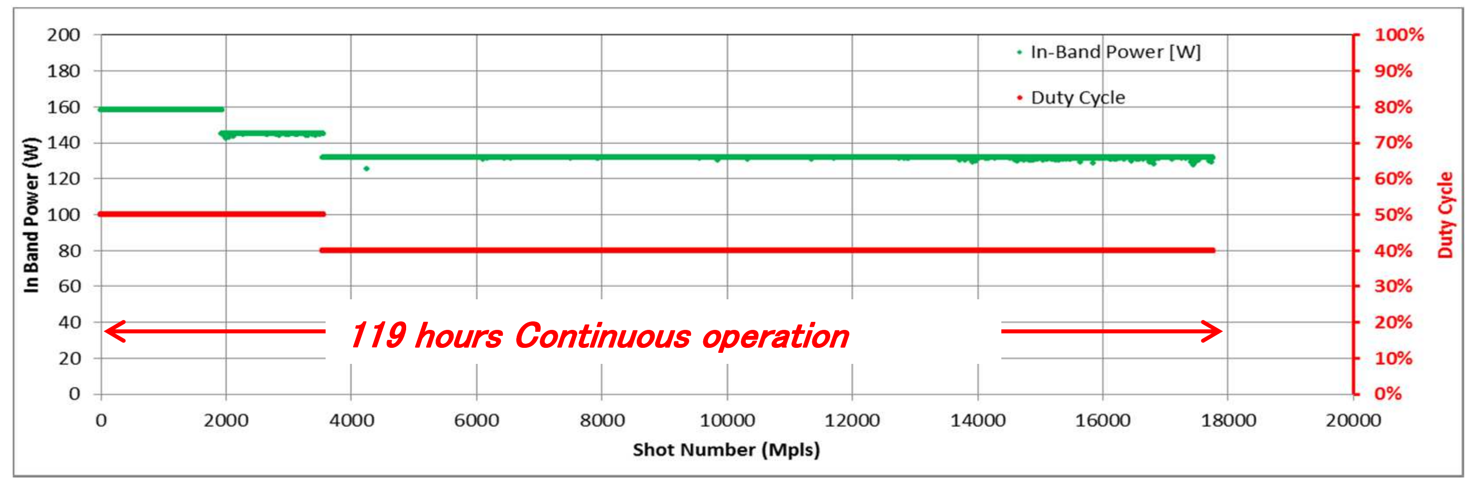
Prototype LPP Source Systems Experiment Update (4)

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



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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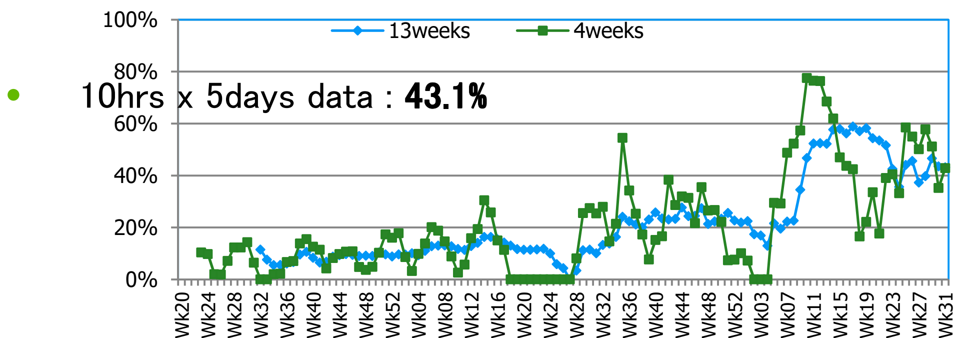
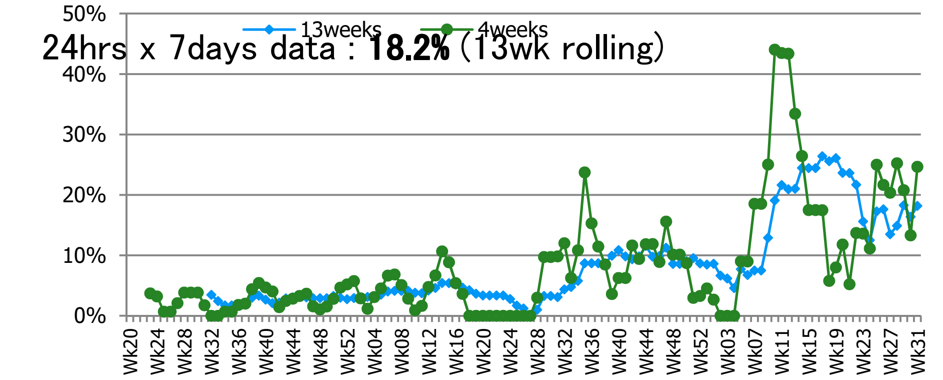
Prototype LPP Source Systems Experiment Update (5)

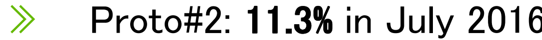
- 10hrs x 5days data : **43.1%**

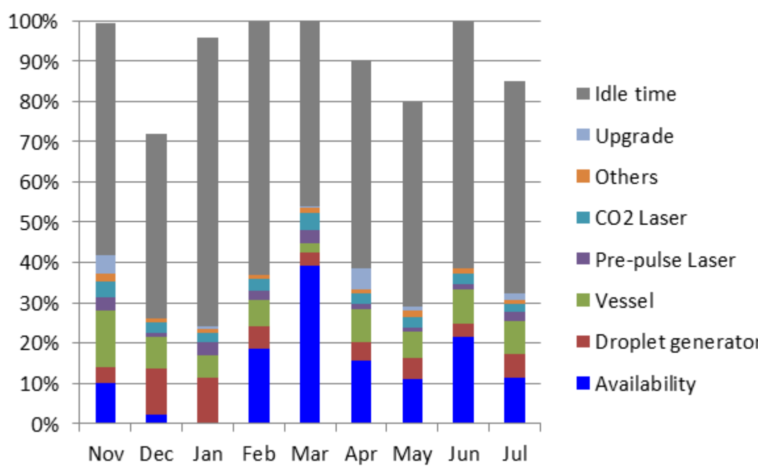


- 24hrs x 7days data : **18.2%** (13wk rolling)



- Month to Month Stats based on 24x7





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Higher Power EUV Source Development (1)

- Extendibility to 500W EUV Power

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%	**5%**	6%
CO_2 Laser Power	25kW	**40kW**	65kW

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Higher Power EUV Source Development (2)

Carbolated with MITSUBISHI ELECTRIC

OSC		PA1	MA1	MA2	MA3	Plasma Point
OSC → Pre-Amp → Pre-Amp		AMP	AMP	AMP	AMP	
250W	100W	5kW	1 0kW	20kW	30kW	25kW
500W	**100W**	**10kW**	**20kW**	**30kW**	**50kW**	**40kW**

<History of Amplifier development>

Basic Experiment in 2013

1st Amplifier installation in 2015

RF Power Source

Preamplifier

Main Amplifier

25kW Amplifier system installation in 2016

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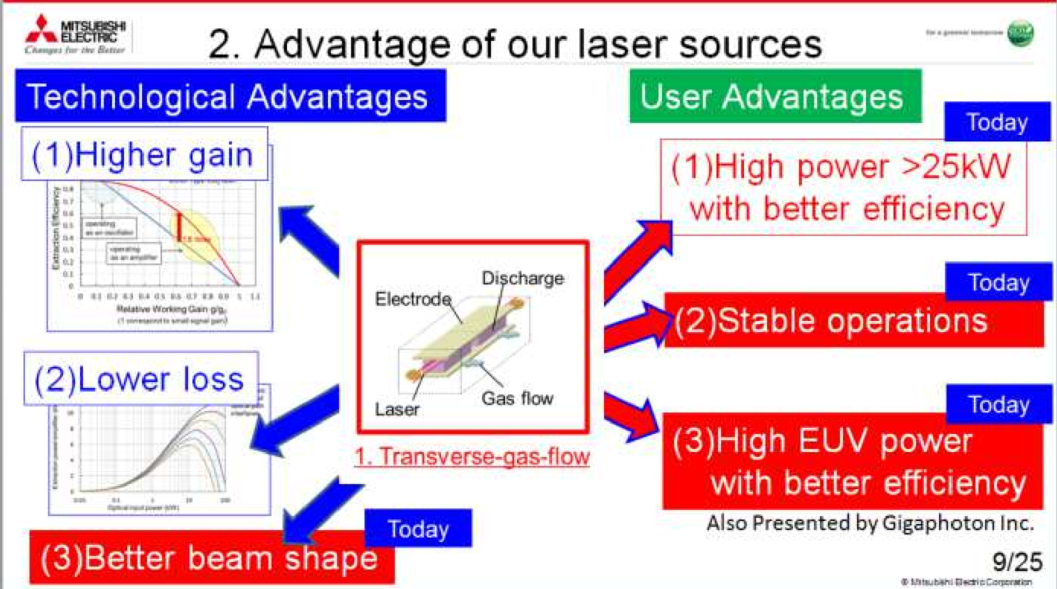
Higher Power EUV Source Development (3)

- ***Stable and scalable CO2 laser drivers for high-volume-manufacturing extreme ultraviolet lithography applications (Mitsubishi Electric)***

-> Next Presentation: Dr. Koji Yasui



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- Introduction
- 250W Pilot#1 System Development Update
  - Configuration & Key Component Technologies Update
    - EUV Chamber System
    - Driver laser & PPL system
    - Pre-Pulse Technology
    - Debris Mitigation Challenges
  - System is now in Operation : Data Update
- Prototype LPP Source Systems Experiment Update
- Higher Power EUV Source Development
- **Summary**

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Summary

- **Pilot #1 is up running and its to demonstrate HVM capability**
  - EUV power recorded **100W average (105W stabilized, 95% duty) with 5% conversion efficiency** for 5hours operation in September 2016.
  - High conversion efficiency is realized with several key engineering efforts.
  - CO_2 driver laser power test up to 27kW in process.
  - Next target is >100W average power with high duty cycle operation with C1 full-scale mirror demonstration.
- **Power scaling and availability improvement with Proto #2 system in process**
  - 256W in burst power, closed loop operation with Ce=4.0% were demonstrated.
  - 119 hours 158-132 W power (in burst power, 50% duty) under closed loop was successfully demonstrated.
  - Proto#2 unit recorded 43% availability during 13 week average (10h x 5 day).
- Further scalability scenario toward 500W EUV source power is under investigation.

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Summary of Operation Data and Target (Proto#2, Pilot#1)

	2016 Mar.	2016 Jun.	2016 Aug.	2016 Sep.	2016 Sep.	2016 Dec.
	Proto#2	**Proto#2**	Proto#2	Proto#2	**Pilot#1**	**Pilot#1 target**
Power (av.)	79-52W	128W	62-99W	**101W**	**100W**	250W
Duty Cycle	40-50%	50%	50-80%	**95%**	**95%**	100%
Power (in Burst)	158-132W	256W	115-124W	**106W**	**105W**	250W
Dose Margine	**40%**	**15%**	**30-35%**	**30%**	**30%**	30%
Power (open loop)	221-184W	301W	177W	**151W**	**150W**	325W
Conv. Eff. (CE)	**3.5**	**4.0%**	**4.0%**	**3.8%**	**5.0%**	4.5%
Operation time	**119h**	**-**	56h	**49h**	**5h**	>1000h
Rep. Rate	100kHz	100kHz	50kHz	**50kHz**	**50kHz**	100kHz
CO2 Laser Power	15kW	20kW	13kW	**11.9kW**	**9.1kW**	25 kW

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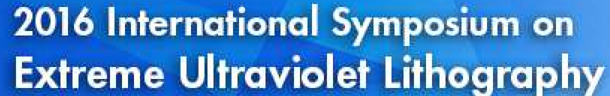

THANK YOU