GIGAPHOTON

EUV-FEL ワークショップ WORKSHOP

250W LPP-EUV LIGHT SOURCE DEVELOPMENT FOR SEMICONDUCTOR HVM

Dec.13, 2016

EUV-FEL Workshop

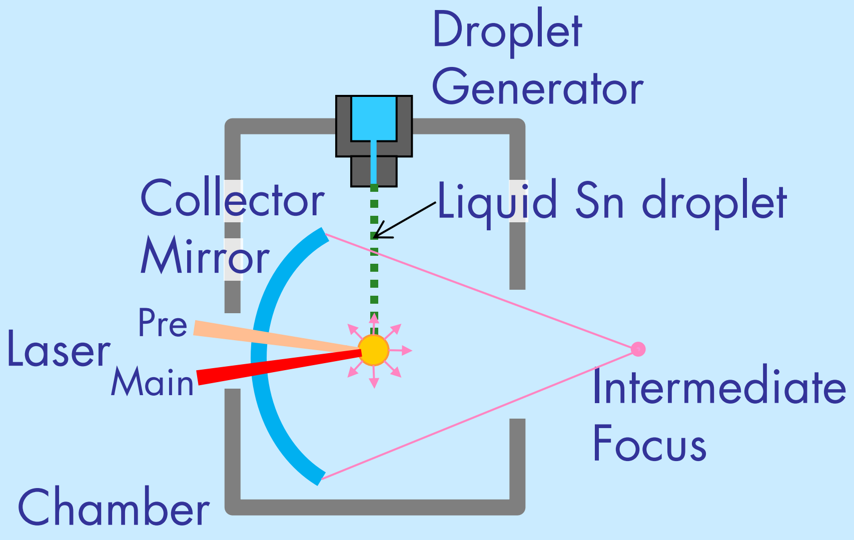
Taku Yamazaki, Deputy General Manager, EUV Development Division,
GIGAPHOTON INC.

AGENDA

- Introduction
- Pilot Update (HVM target)
  - Configuration & Key Component Technologies
  - System is now in Operation
- Proto Update (>250W)
- Higher Power EUV Source Development
- Summary

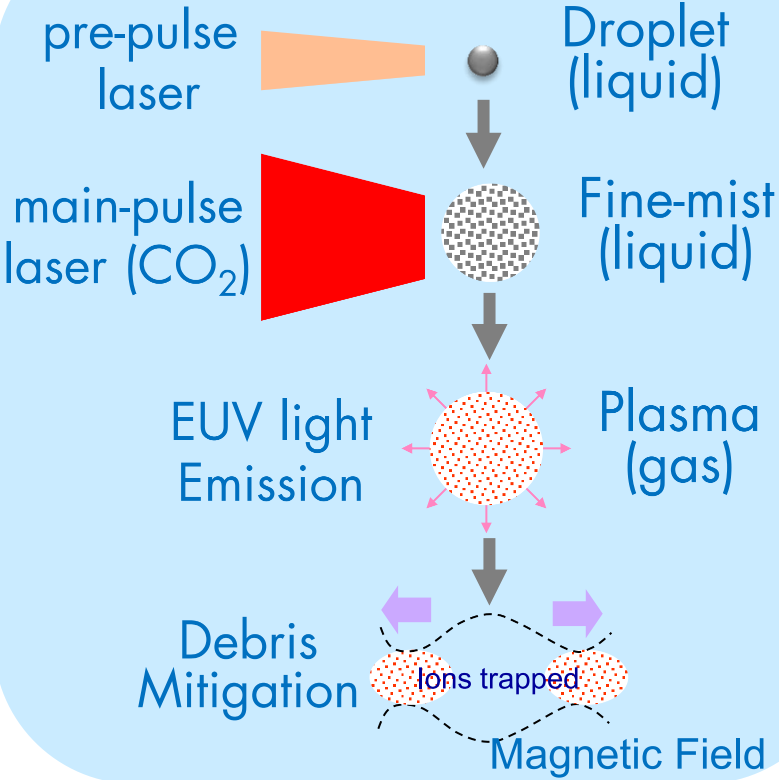
How generate EUV light

Structure



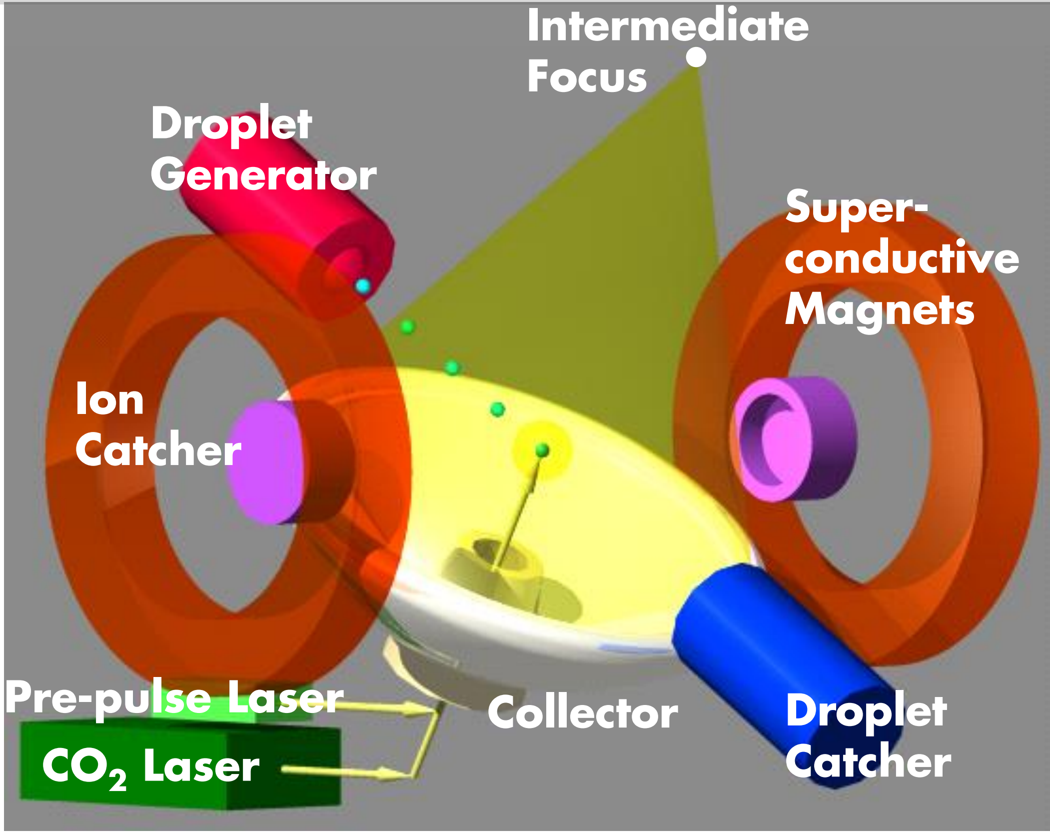
Sn droplet 20um Dia.100kHz ejection with 300km/h
Pre and main lasers shoot every single droplets.
Collector transfer EUV light to the IF point.

Sn life cycle



Gigaphoton's LPP Light Source Concept

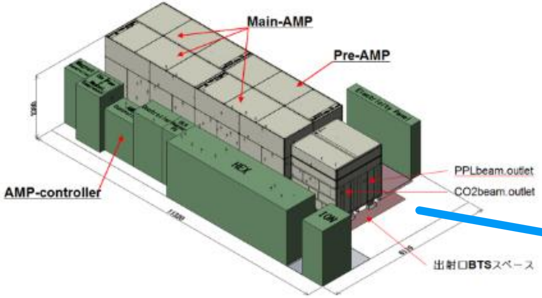
1. **High CE**
   with pre-pulse technology
2. **Powerful CO_2 laser**
   with short pulse
3. **Magnetic mitigation**
   of Tin debris
4. **Accurate shooting control**
   with droplet and laser
5. **High efficient collector**
   with out of band light reduction

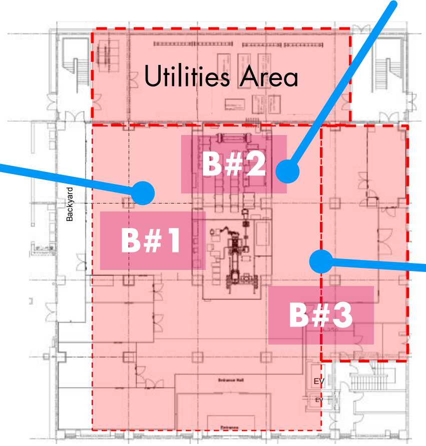


Gigaphoton EUV Sources

Pilot NEW

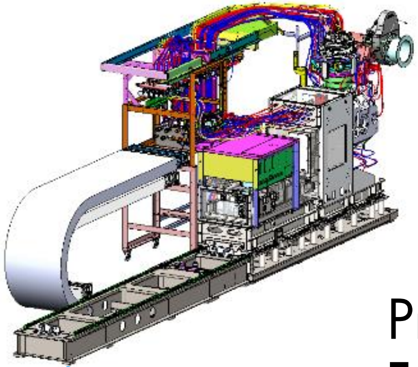
From Feb. 2016





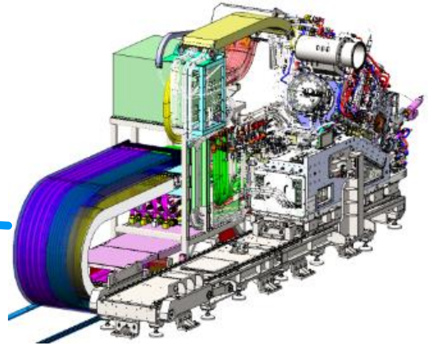
Proto #1

From Oct. 2012



Proto #2

From Nov. 2013



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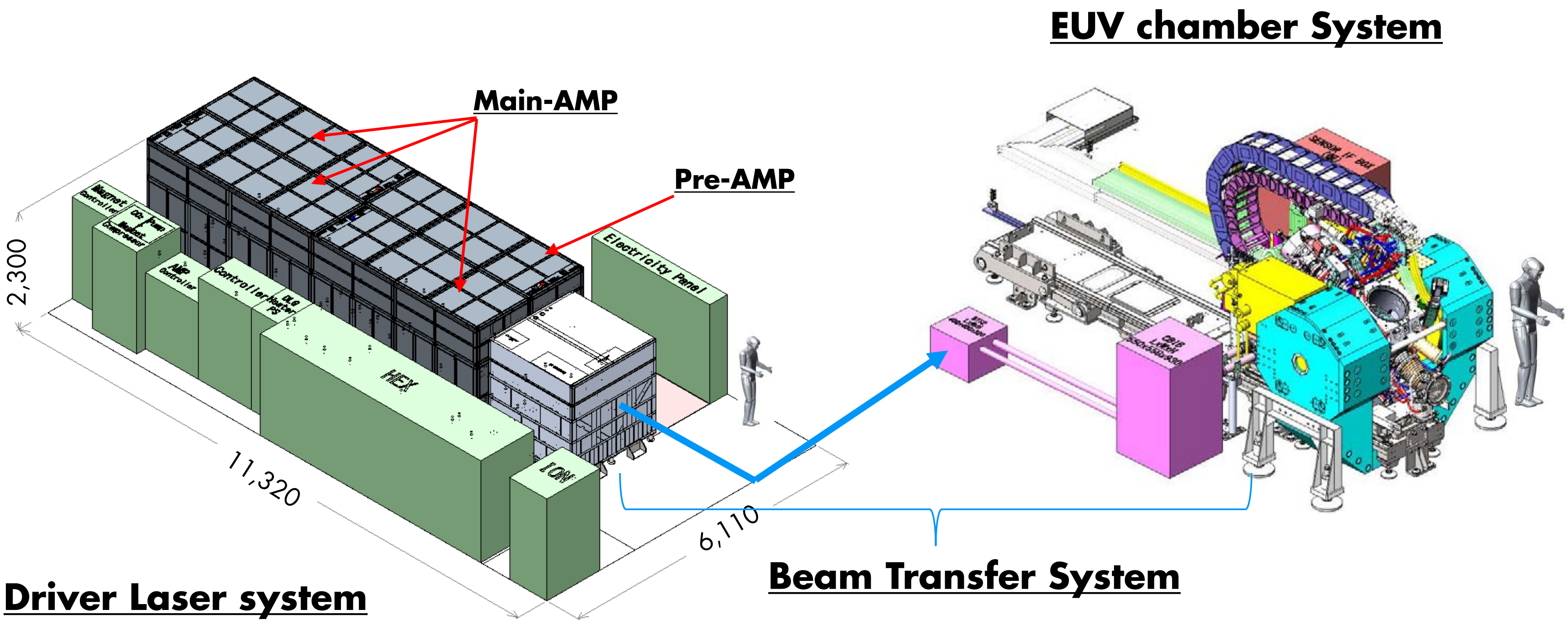
Pilot and Proto Systems Configuration

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

Pilot: High Power EUV Source for HVM



EUV chamber System

Main-AMP

Pre-AMP

Beam Transfer System

Driver Laser system

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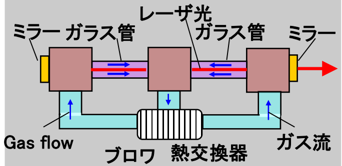
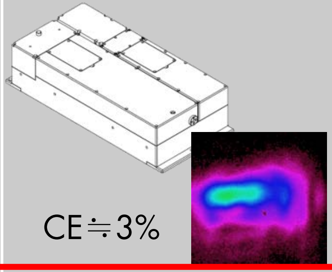
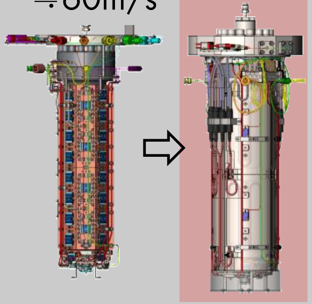
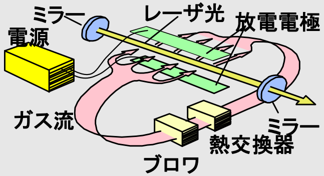
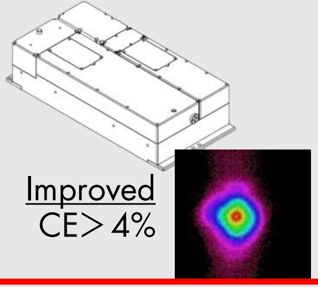
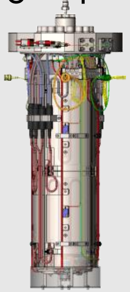
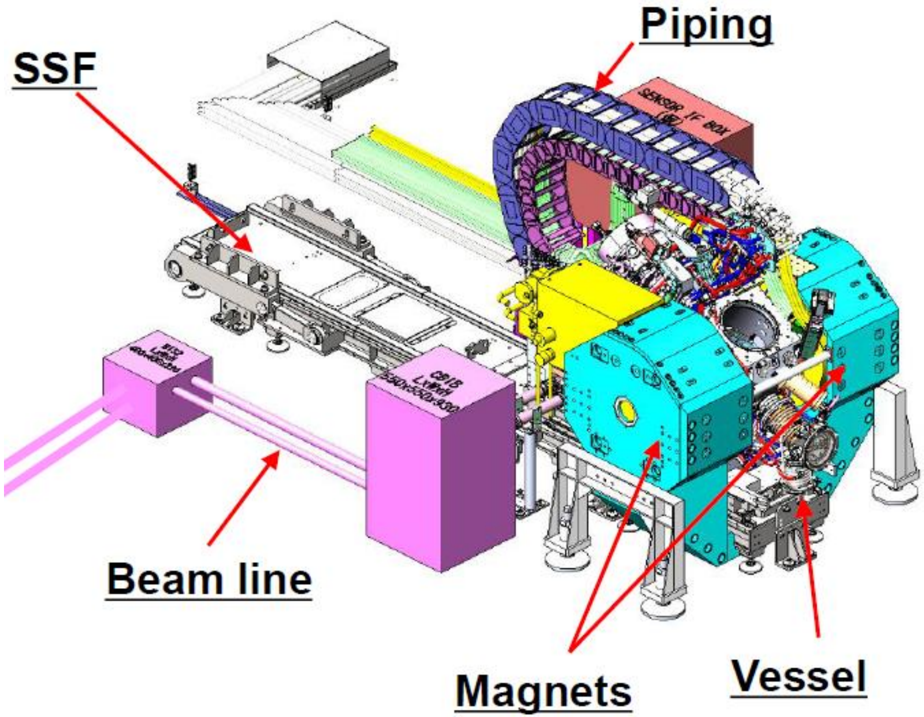
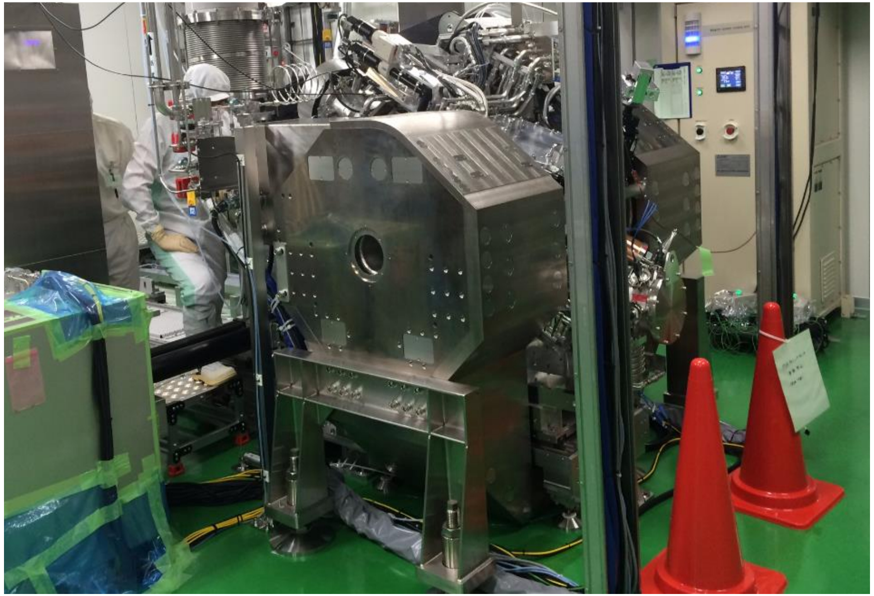
Evolution to Pilot (compared with Proto)

	①CO2 Laser	②Pre-Pulse laser	③DLG	④Debris Mitigation	Target
Proto 	Trans. Gas Flow×1 Fast Axial Flow×3 20kW FAF CO2 laser 	Pico Second Pre-pulse laser  CE≒3%	≒60m/s High Speed 	Type-F Design ＞100H	125W 100H ⇩ 250W 100H
Pilot 	Trans. Gas Flow×4 27kW TGF CO2 laser 	Pico Second Pre-pulse laser  Improved CE＞4%	High Speed  ≒90m/s	**Type-G Design** ＞1000H	250W 1000H

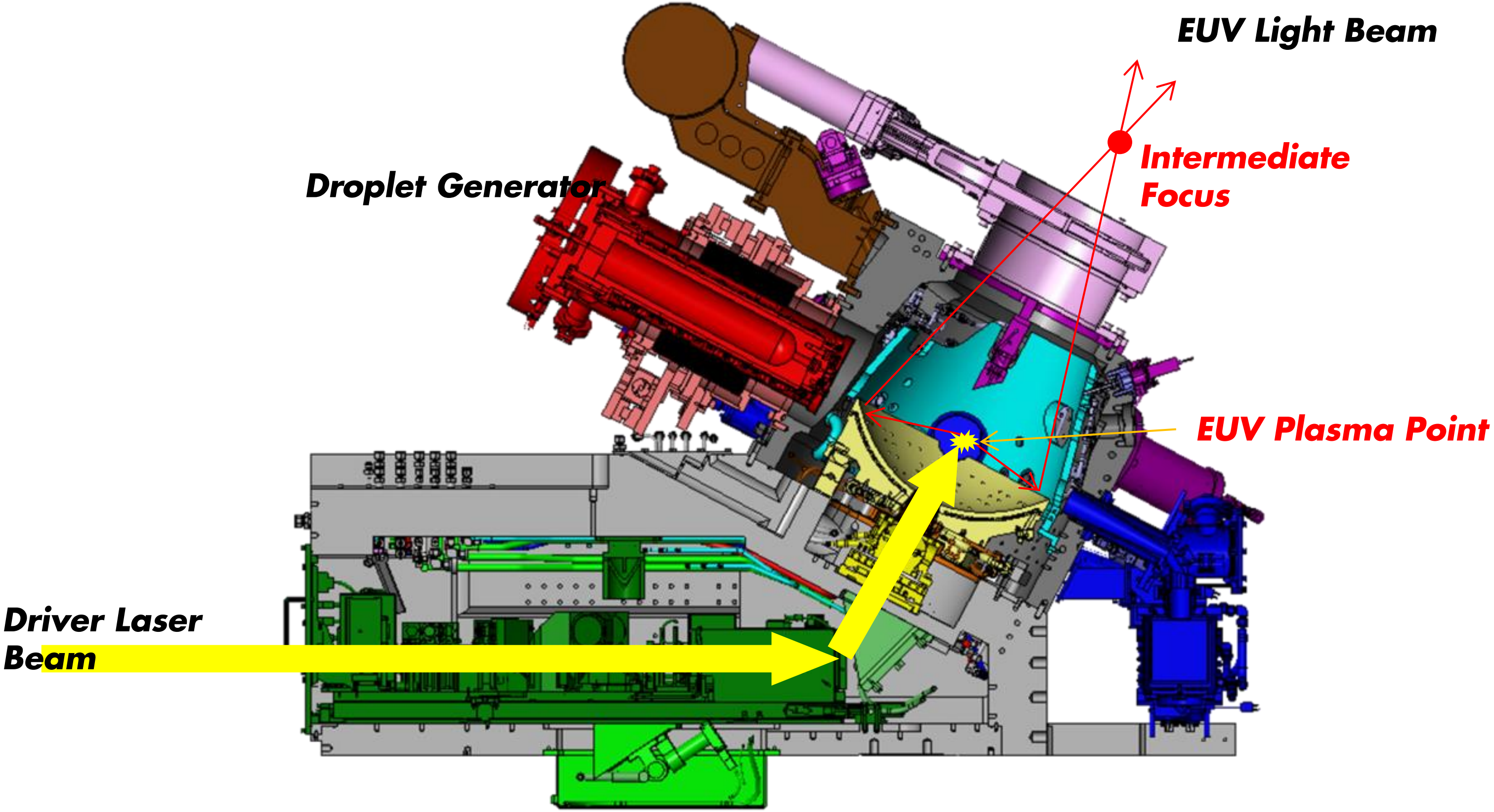
Pilot : EUV Chamber System (1)

EUV chamber system





Pilot : EUV Chamber System (2)

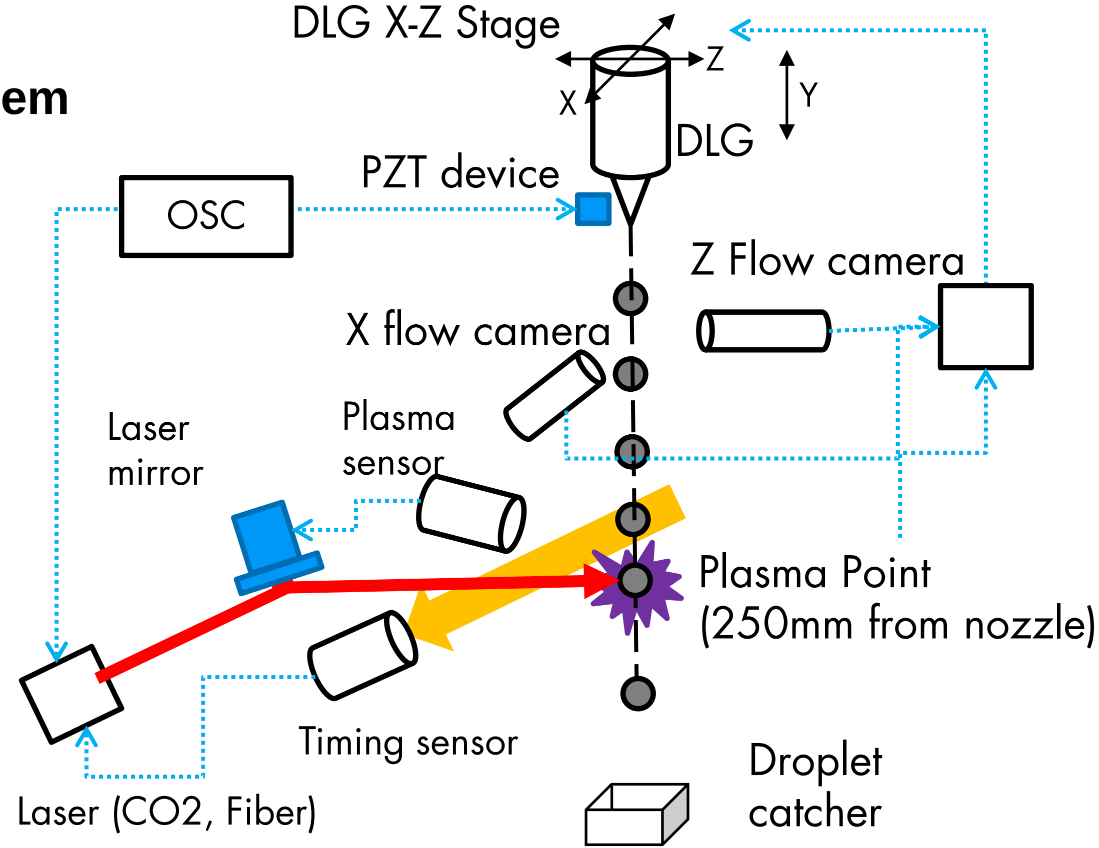


Pilot : EUV Chamber System (3)

LPP EUV Source :
Shooting Control System

Multiple control loop works simultaneously.

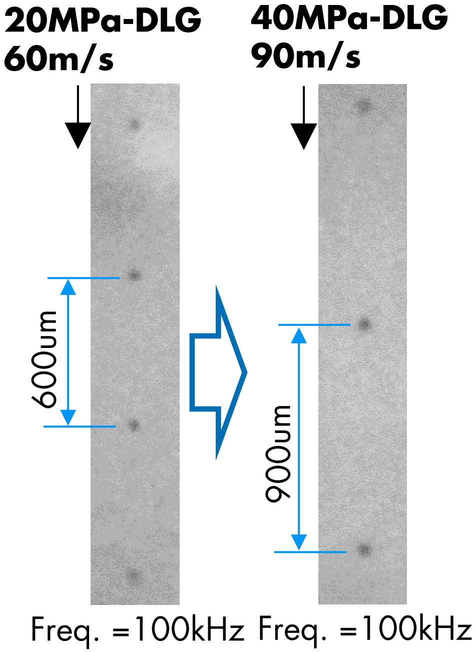
- ✓ Droplet control position & timing
- ✓ Laser axis control position/pointing with approx. 30 mirrors
- ✓ Laser trigger timing
- ✓ Energy dose control



Pilot : EUV Chamber System (4)

- High speed droplet generator was successfully released.

		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



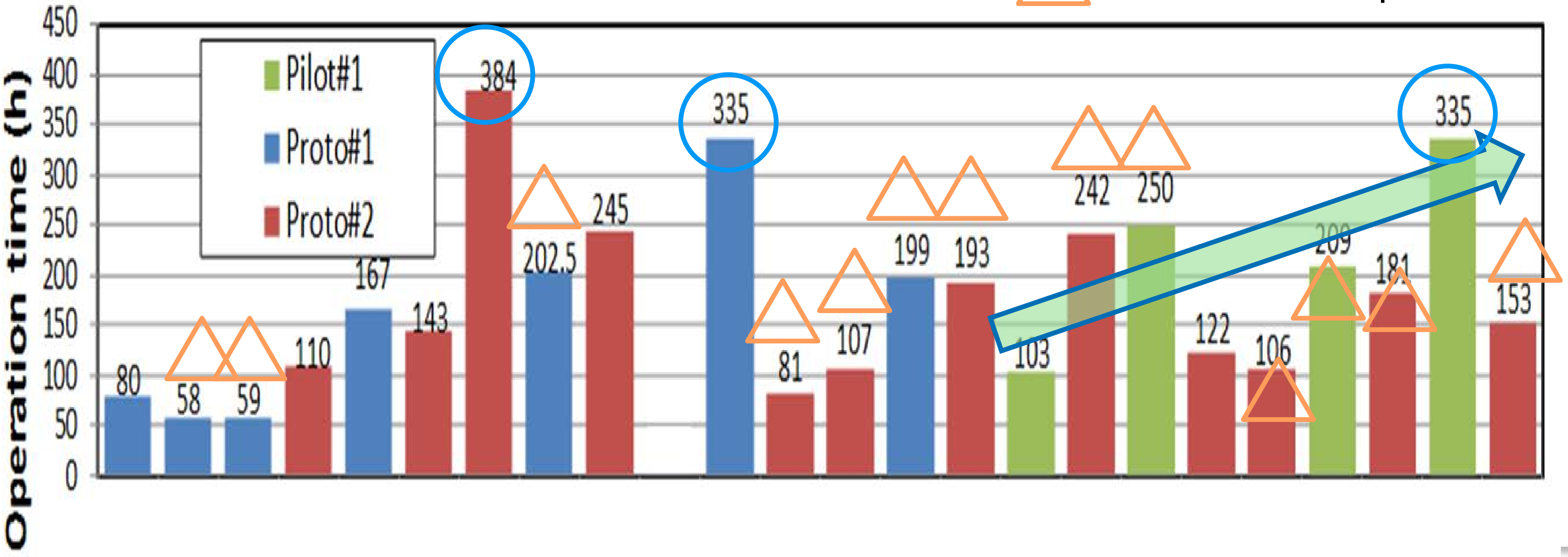
Droplet Status

Pilot : EUV Chamber System (5)

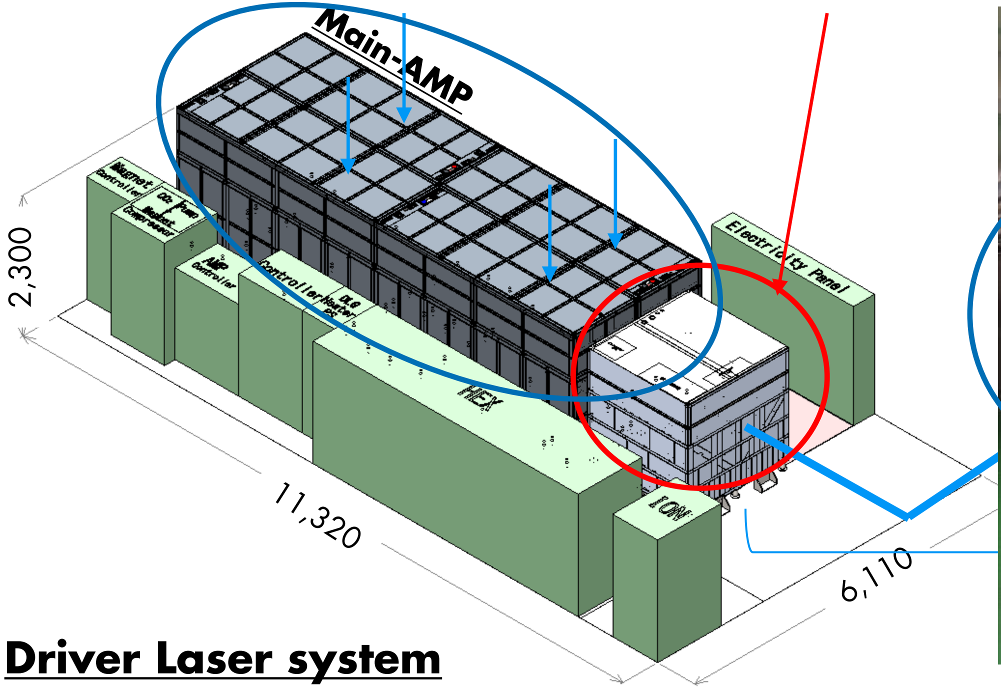
- DLG lifetime extended to > 200 hours.
- Yield also improving.

○ Swapped due to tin empty

△ Scheduled swap

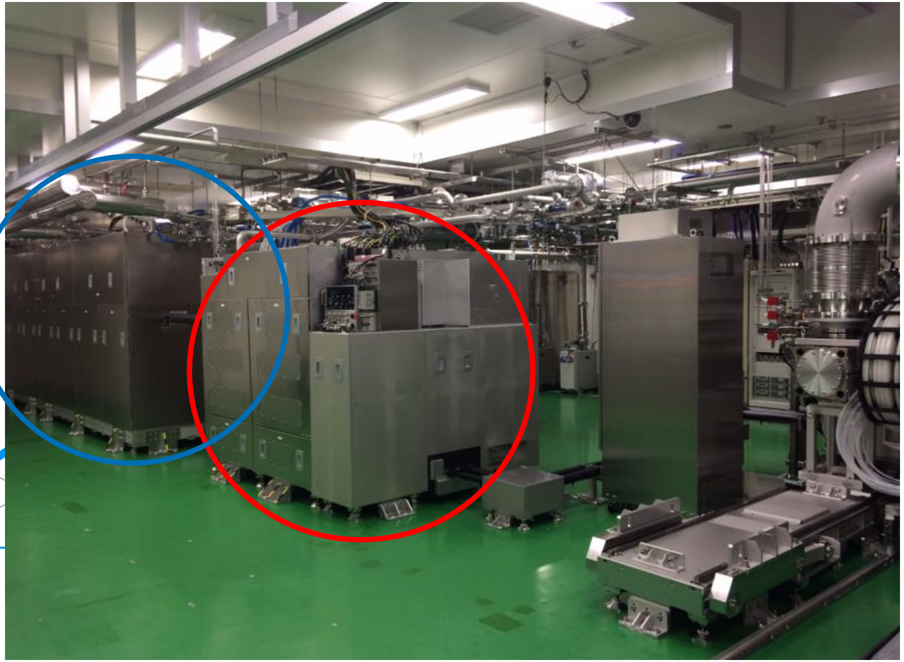


Pilot : Driver laser & PPL system (1)


4-CO_2 laser Amplifier Modules

Oscillator/PPL Module

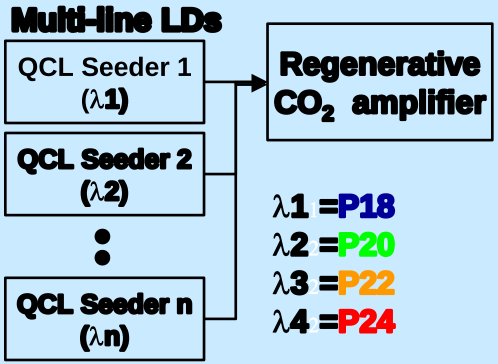
Driver Laser system



Pilot : Driver laser & PPL system (2)

Oscillator

GIGAPHOTON Original



Multi-line LDs

QCL Seeder 1 (λ1)

QCL Seeder 2 (λ2)

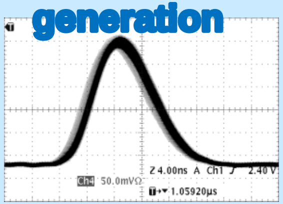
:

QCL Seeder n (λn)

Regenerative CO_2 amplifier

λ1 =**P18**
λ2 =**P20**
λ3 =**P22**
λ4 =**P24**

100kHz pulse generation

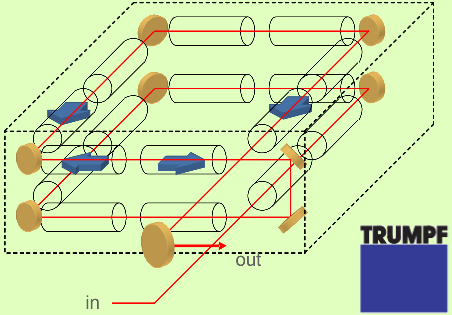


14 ns FWHM

Amplifiers

With partners

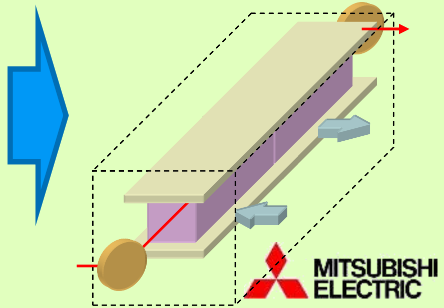
Fast axial flow



NEW

Pilot#1

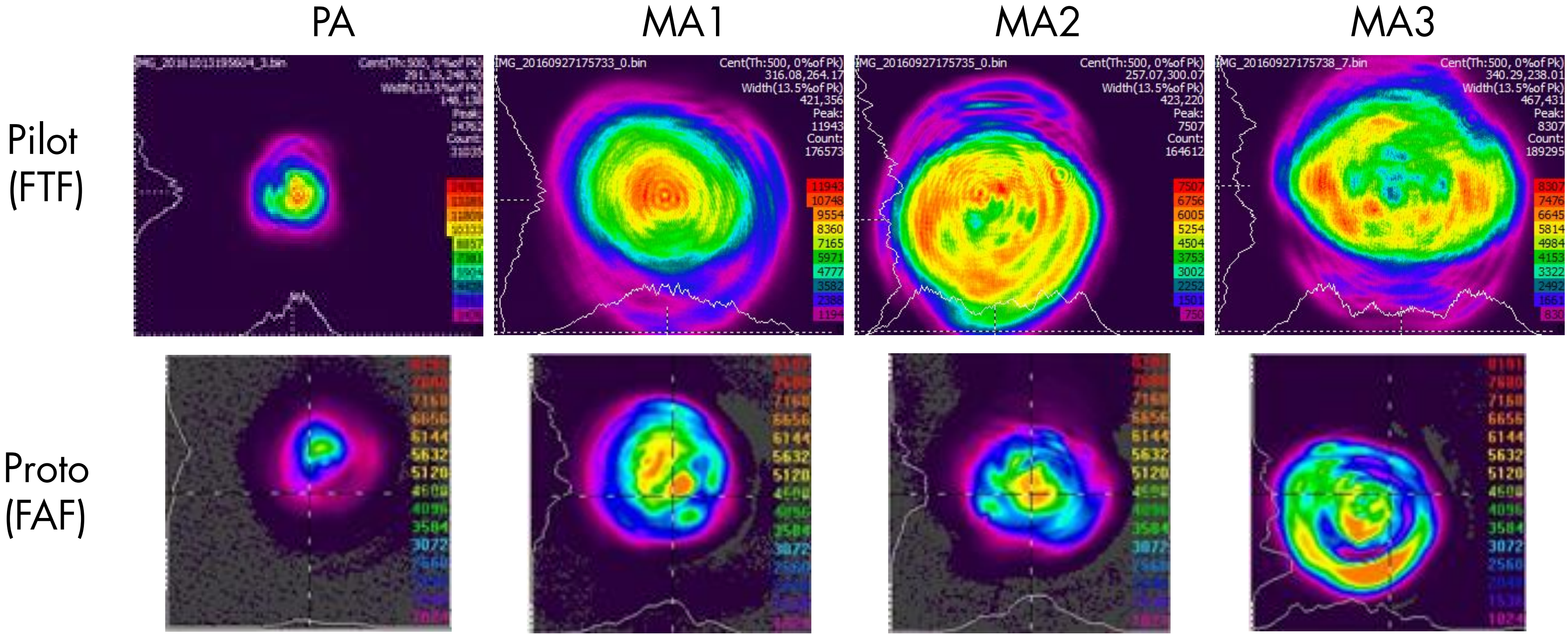
Transverse gas flow



	OSC	PA1	MA1	MA2	MA3	Plasma Point
	OSC → Amp → Amp → EO Isolator →	AMP →	AMP →	AMP →	AMP →	✸
For 250W EUV	100W	5kW	10kW	20kW	30kW	25kW

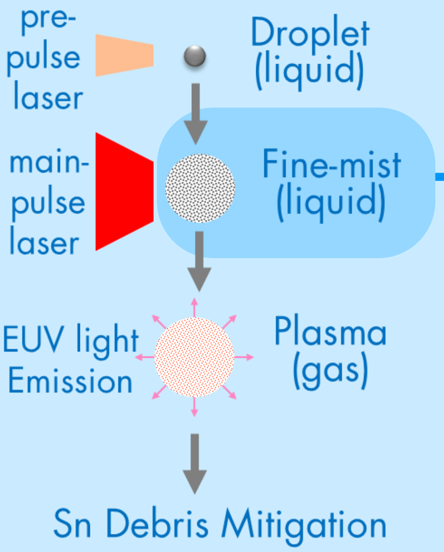
Pilot1: Driver laser & PPL system (3)

Beam profile of CO2 driver laser system at each stage.



Pre-Pulse Technology (1)

Pre-pulse Technology



pre-pulse laser

Droplet (liquid)

main-pulse laser

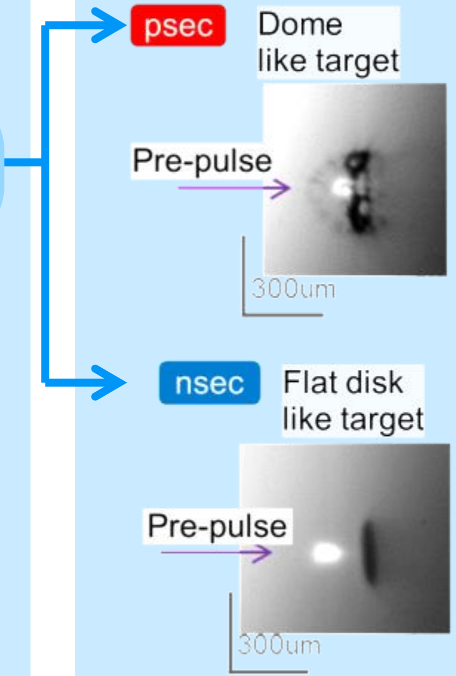
Fine-mist (liquid)

EUV light Emission

Plasma (gas)

Sn Debris Mitigation

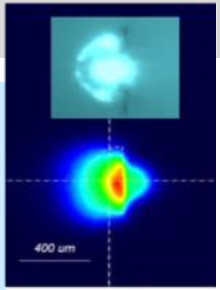
Different Deformation



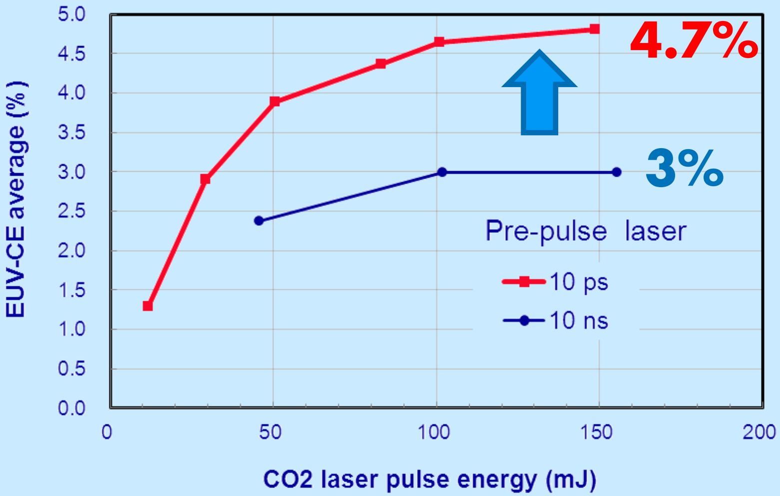
psec Dome like target

nsec Flat disk like target

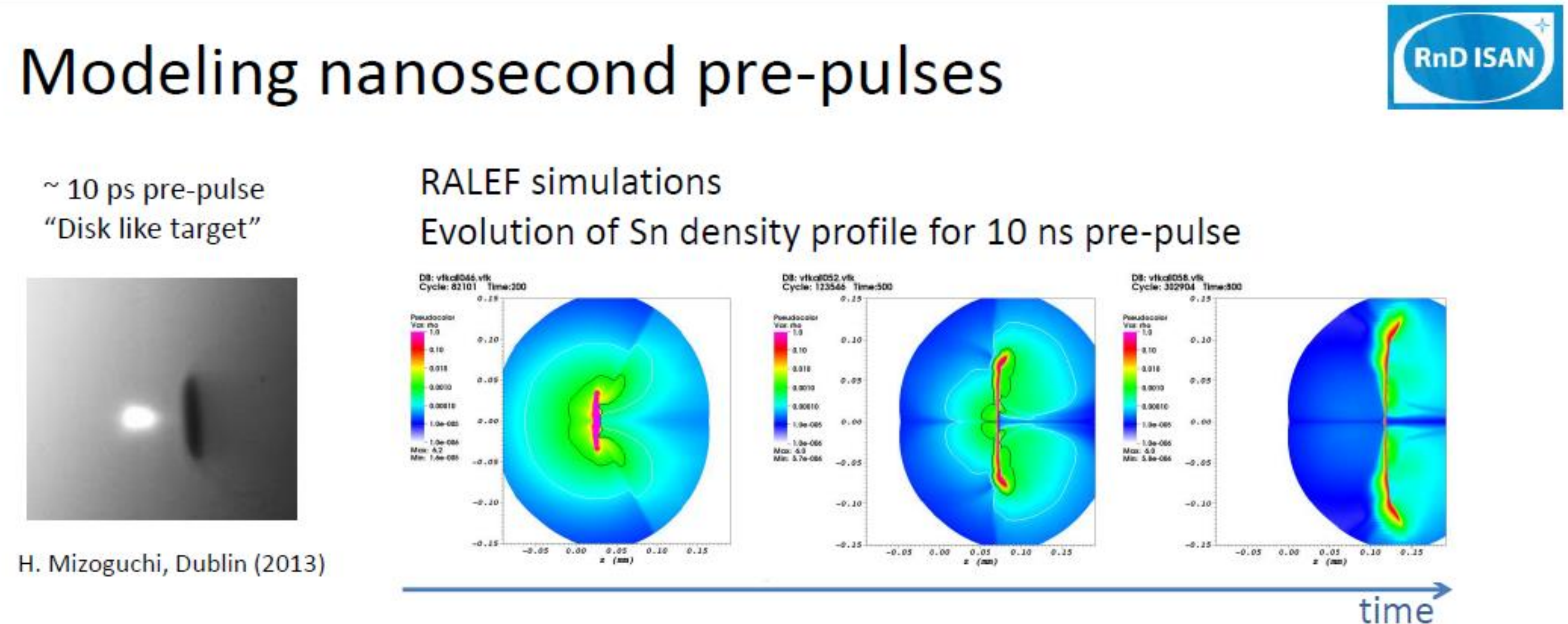
Conversion Efficiency improved



CO2 pulse enegy vs. EUV-CE



Pre-Pulse Technology (2)



Modeling nanosecond pre-pulses

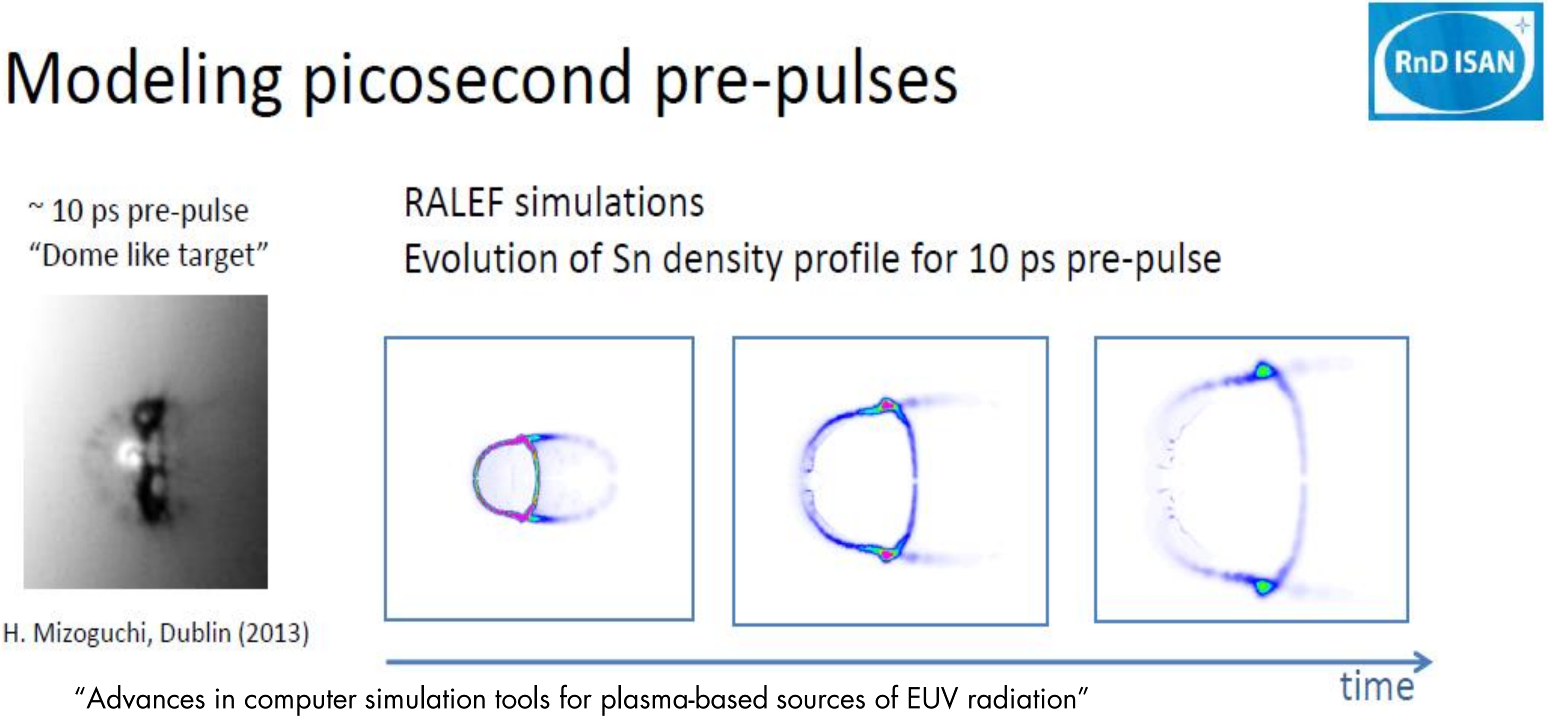
~ 10 ps pre-pulse
“Disk like target”

H. Mizoguchi, Dublin (2013)

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

“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 (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

“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
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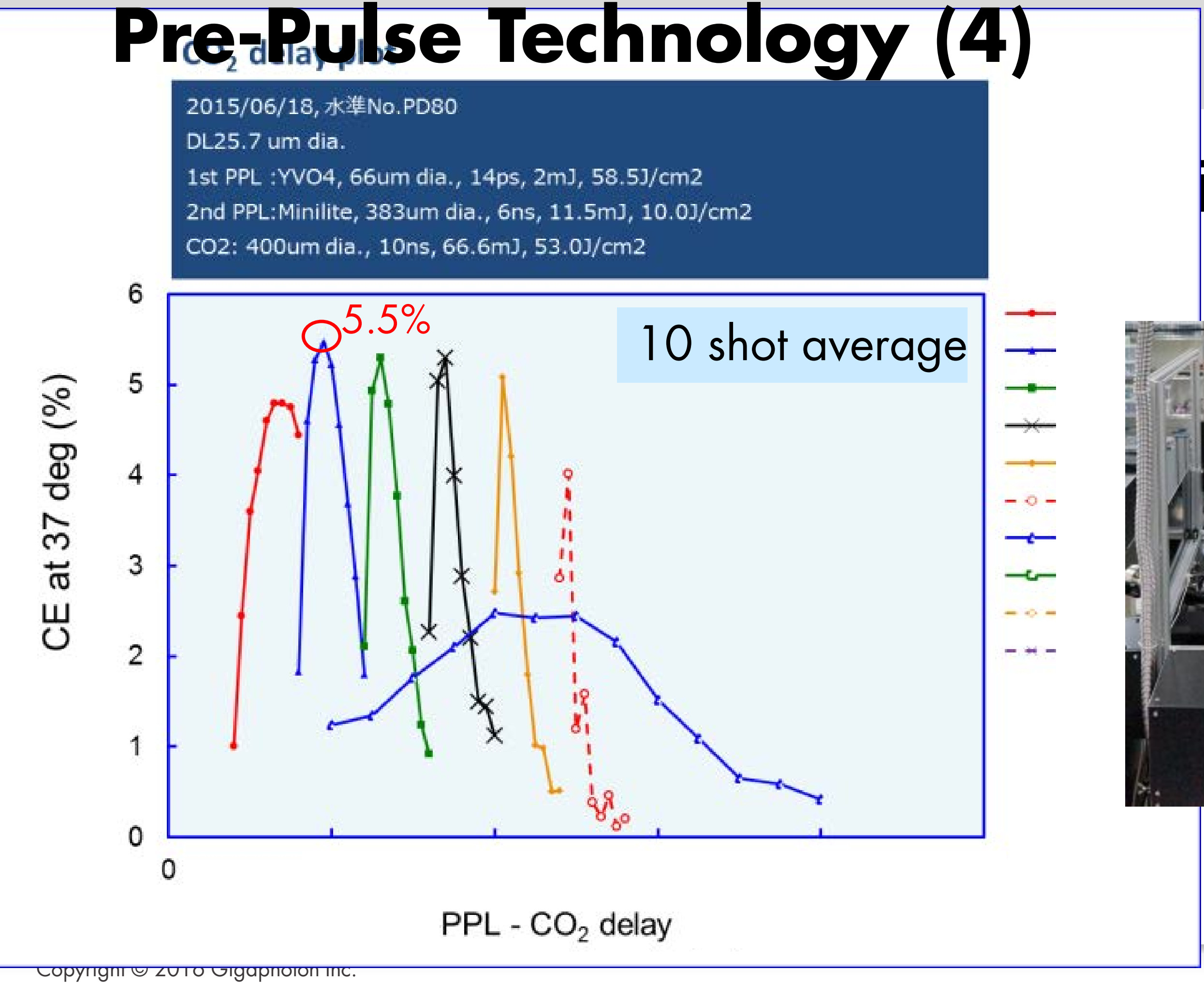
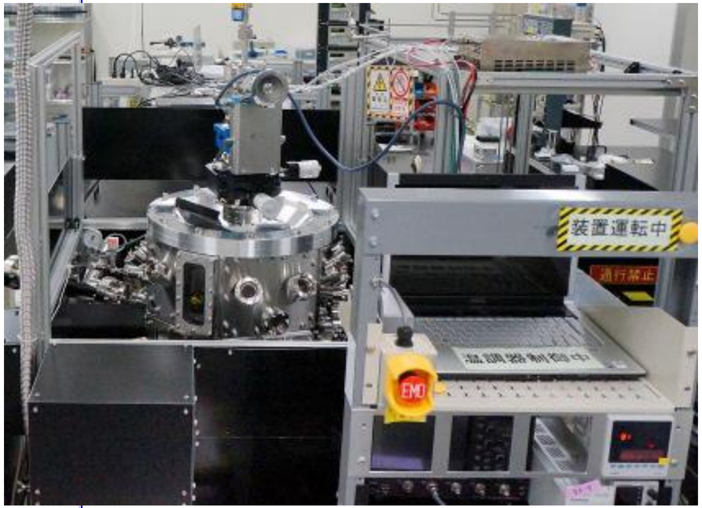
Pre-Pulse Technology (4)



2015/06/18, 水準No.PD80
DL25.7 um dia.
1st PPL :YVO4, 66um dia., 14ps, 2mJ, 58.5J/cm2
2nd PPL:Minilite, 383um dia., 6ns, 11.5mJ, 10.0J/cm2
CO2: 400um dia., 10ns, 66.6mJ, 53.0J/cm2

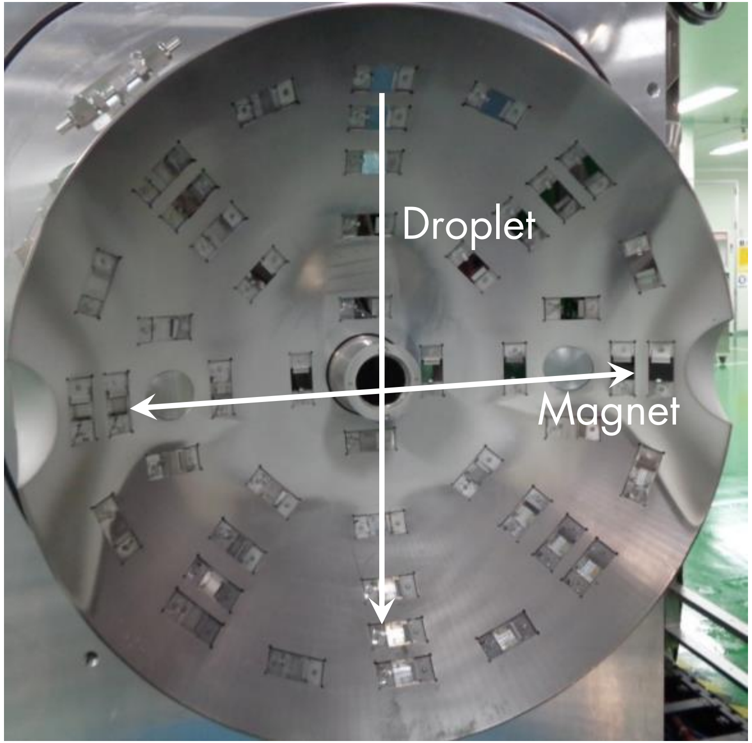
ized condition.



Experimental Device

Debris Mitigation Challenges (1)

Measurement of Sn deposition distribution at recent Proto#1configuration

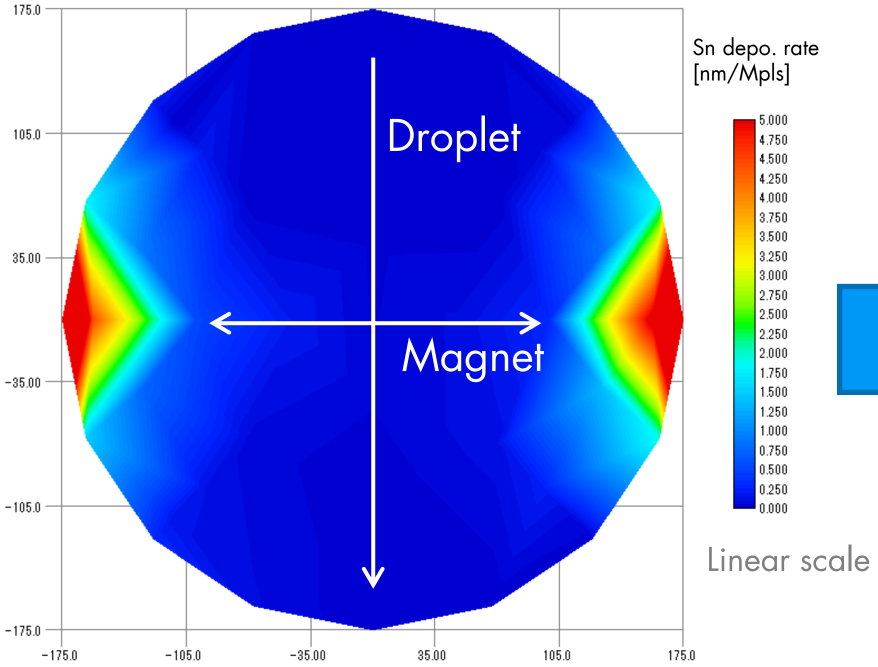


- Purpose
  - Evaluation of tin deposition distribution on the collector mirror
- Method
  - dummy collector mirror (no coating)
  - sampling plate
    size: 15mmx15mmx0.7mmt
    material :Si plate (46 pieces)
- Analysis after test
  - surface condition :SEM
  - deposited tin thickness :XRF

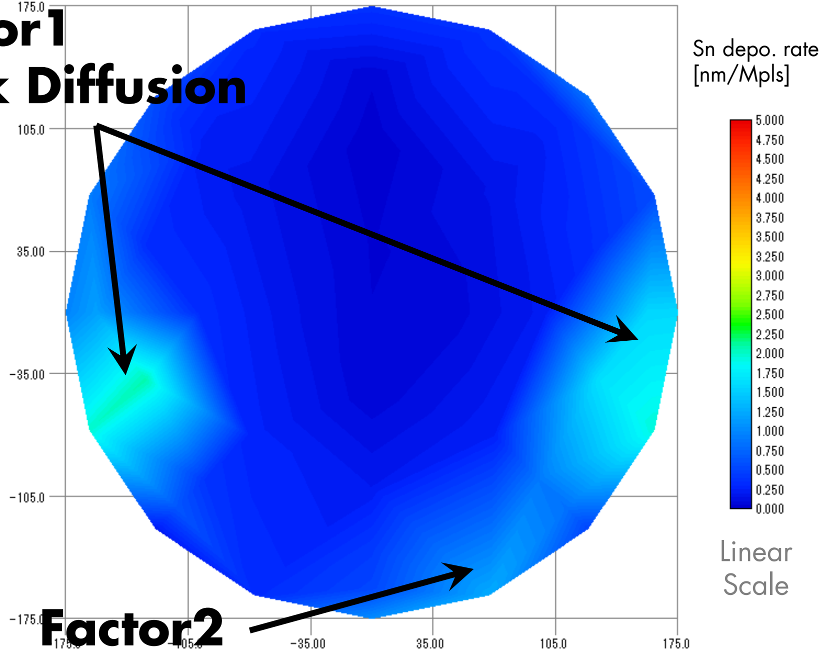
Debris Mitigation Challenges (2)

Improvement of less Sn deposition in Proto is going on

Proto (2015)



Proto (2016)



Factor1
Back Diffusion

Factor2
Offset shooting

Debris Mitigation Challenges (3)

Mitigation-Type G in Pilot

Factor1 Back Diffusion

Countermeasure

1. H2 gas flow design
2. Cooling system

Factor2 Offset shooting

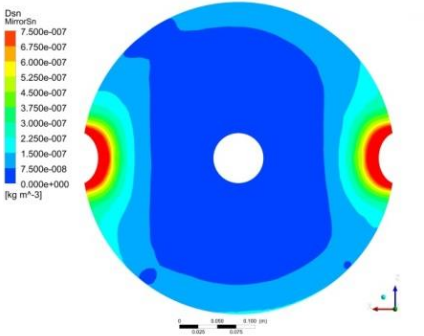
Countermeasure

1. Improve shooting accuracy

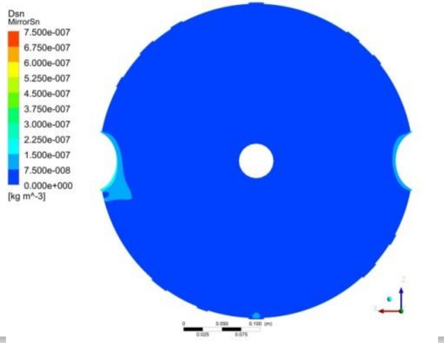
Evaluation in Pilot started.

Distribution of Sn density (Simulation)

Proto Type F



Pilot Type G



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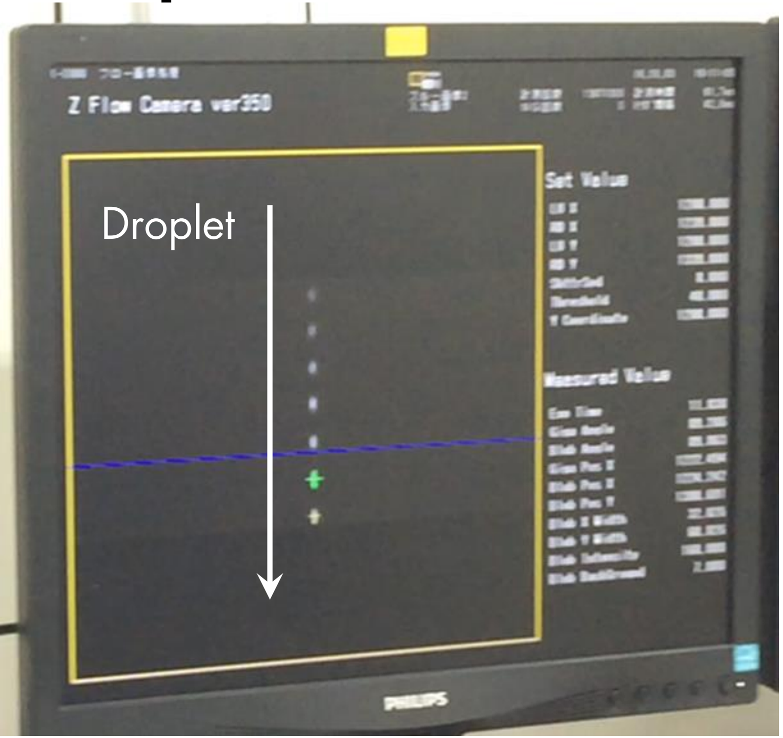
Pilot System is now in Operation (1)

Vessel with Magnetic Shield

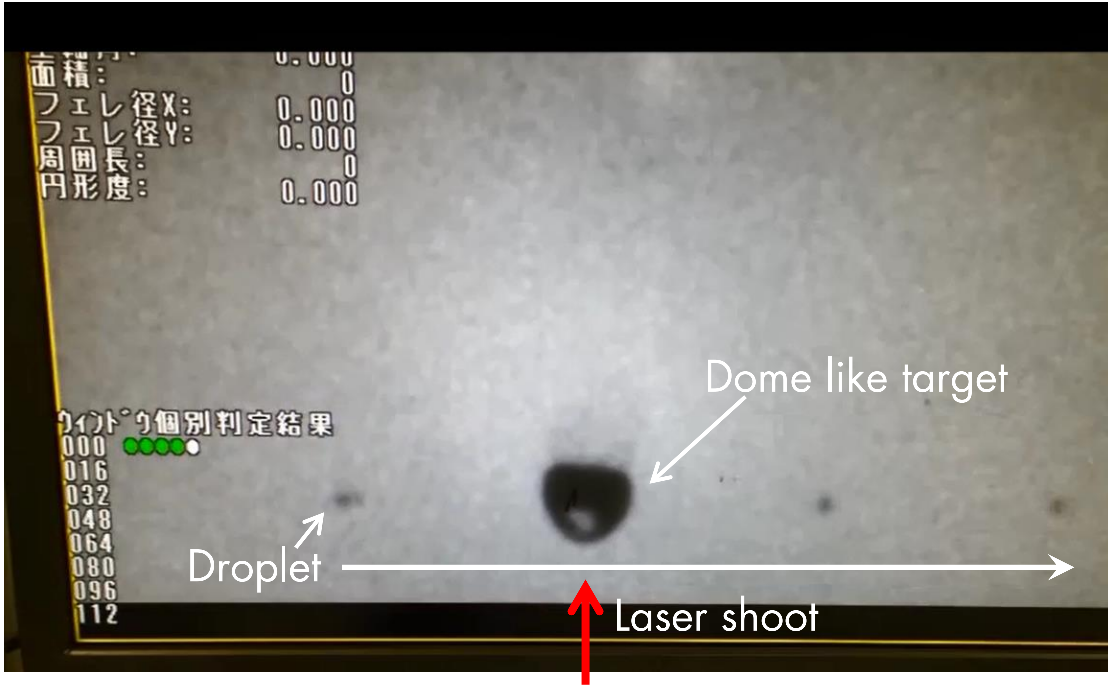
CO$_2$ driver laser

Pilot System is now in Operation (2)

Droplet Flow Monitor



Plasma Point Monitor



```
面積:              0
フェレ径X:      0.000
フェレ径Y:      0.000
周囲長:            0
円形度:         0.000

ｳｨﾝﾄﾞｳ個別判定結果
000
016
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096
112
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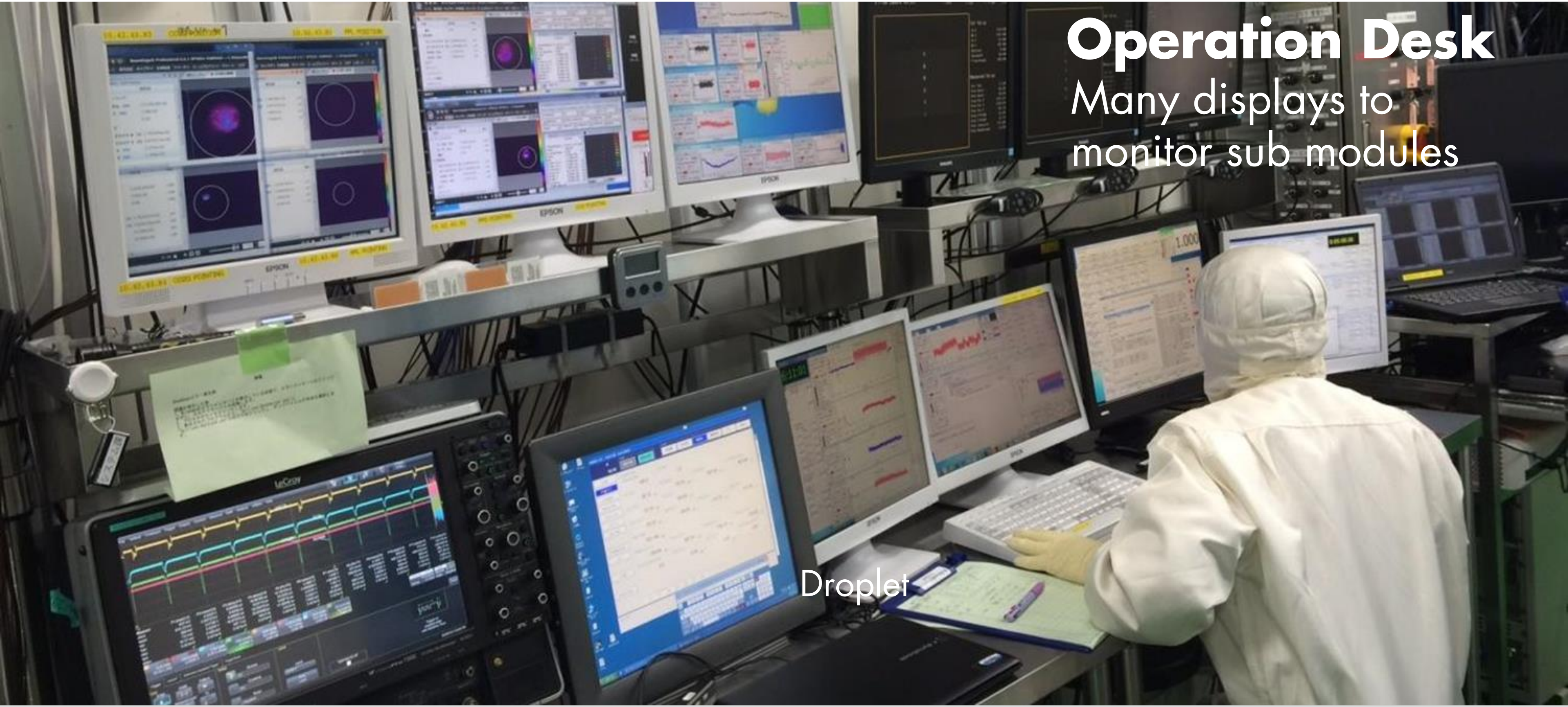
Pilot System is now in Operation (3)



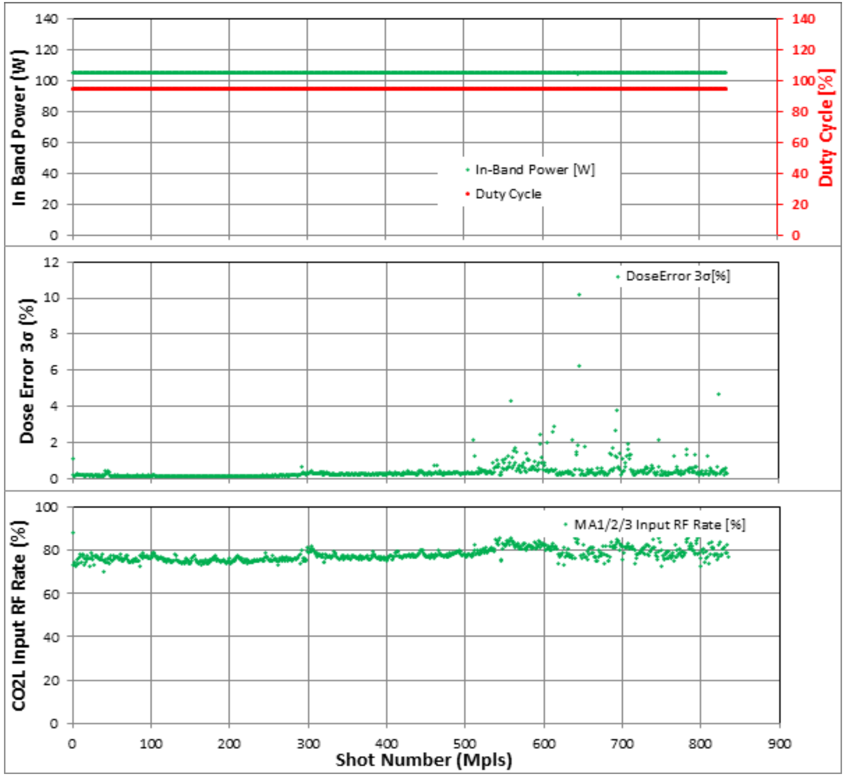
Operation Desk

Many displays to monitor sub modules

Droplet

Pilot 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)

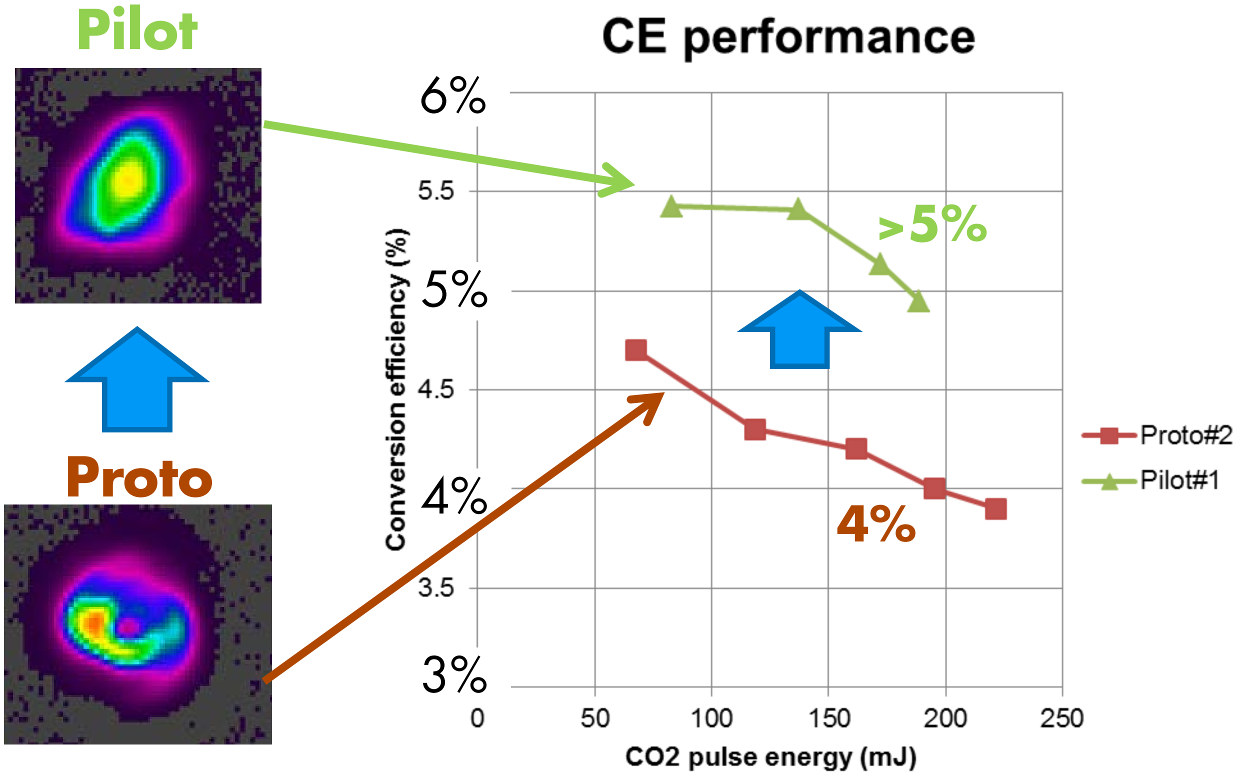
- » OSC+4xAmplifier (Mitsubishi Electric)

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

Pilot #1 System is now in Operation (6)

5% CE achieved in Pilot

Due to CO_2 beam profile improvement.



CO_2 beam profile at plasma point

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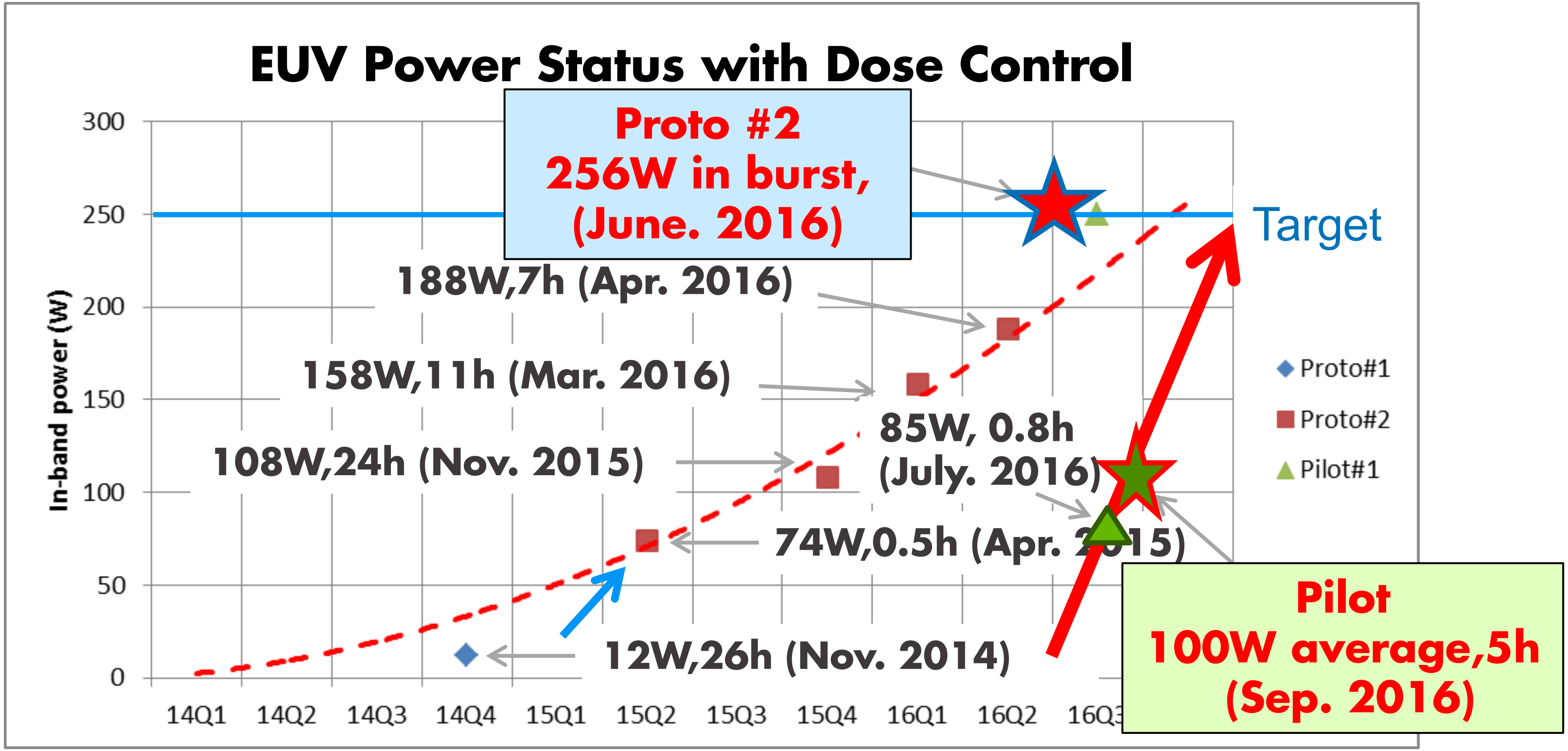
Prototype LPP Source Systems Update (1)

- Prototype high power EUV light source is in operation

Proto #1 POC in Power Scaling & Debris Mitigation

Proto #2 High Power Experiment

Prototype LPP Source Systems Update (2)



Proto #2
256W in burst,
(June. 2016)

188W,7h (Apr. 2016)

158W,11h (Mar. 2016)

108W,24h (Nov. 2015)

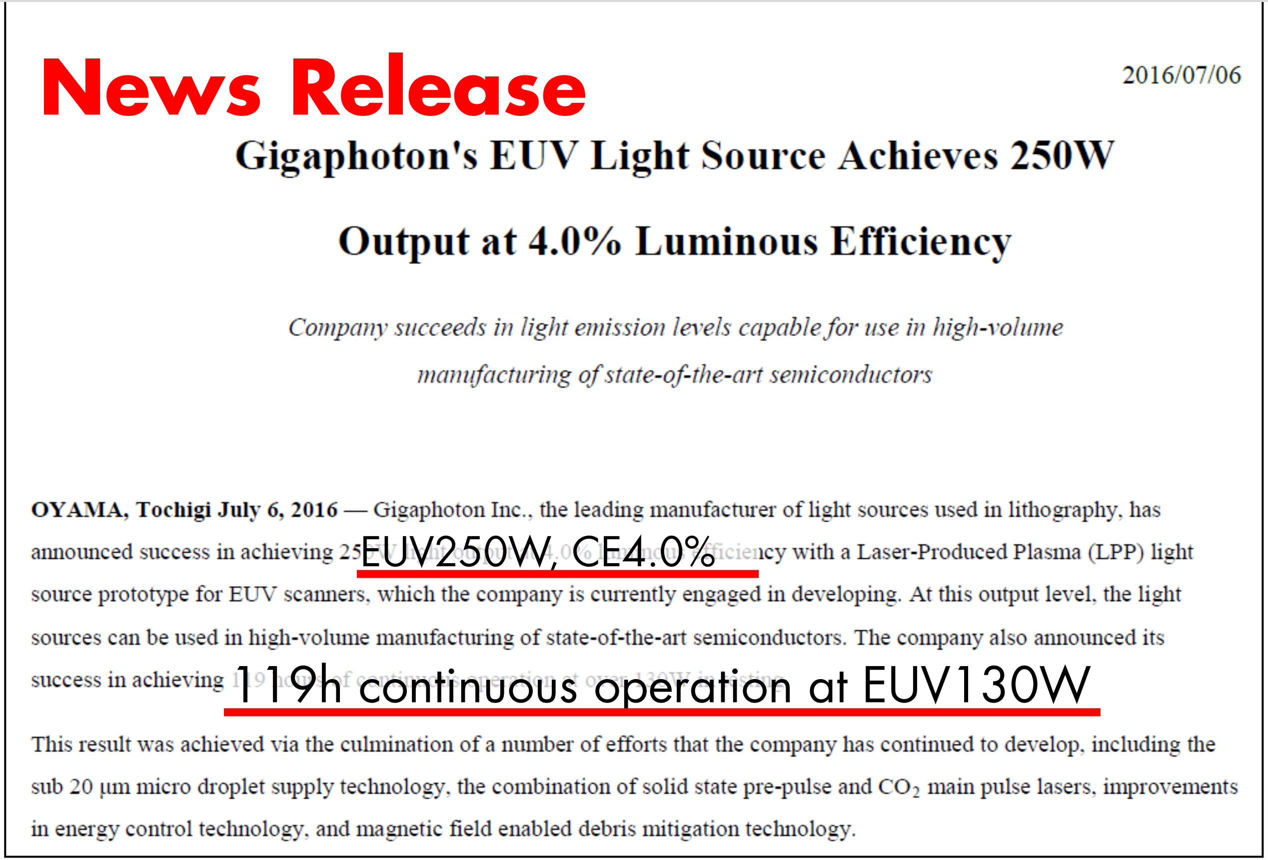
85W, 0.8h
(July. 2016)

74W,0.5h (Apr. 2015)

12W,26h (Nov. 2014)

Pilot
100W average,5h
(Sep. 2016)

Prototype LPP Source Systems Update (3)



News Release

2016/07/06

Gigaphoton's EUV Light Source Achieves 250W Output at 4.0% Luminous Efficiency

Company succeeds in light emission levels capable for use in high-volume manufacturing of state-of-the-art semiconductors

OYAMA, Tochigi July 6, 2016 — Gigaphoton Inc., the leading manufacturer of light sources used in lithography, has announced success in achieving 250W light output at 4.0% luminous efficiency with a Laser-Produced Plasma (LPP) light source prototype for EUV scanners, which the company is currently engaged in developing. At this output level, the light sources can be used in high-volume manufacturing of state-of-the-art semiconductors. The company also announced its success in achieving 119 hours of continuous operation at over 130W in testing.

EUV250W, CE4.0%

119h continuous operation at EUV130W

This result was achieved via the culmination of a number of efforts that the company has continued to develop, including the sub 20 µm micro droplet supply technology, the combination of solid state pre-pulse and CO_2 main pulse lasers, improvements in energy control technology, and magnetic field enabled debris mitigation technology.

日経産業新聞

8日（金曜日）

「究極の露光」実用化へ進展

ギガフォトン　出力250ワットを達成

コマツ子会社で半導体露光用の光源装置を手掛けるギガフォトン（栃木県小山市、都丸仁社長）は「究極の露光技術」と呼ばれるEUV（極端紫外線）露光装置の光源で、実用化に必要とされる出力250ワットを達成したと発表した。現時点では同出力を維持できる時間は短く、今後は出力を長期間安定させる技術の開発に焦点を移す。

EUVは波長が極めて短く、従来の露光装置では不可能だった微細回路を1回の処理で描ける。微細化が進めば半導体の省エネ、高速化、小型化がさらに進む。

ただ投資に見合う毎時125枚の生産速度を実現するには、光源を250ワット以上で安定稼働させる必要があるとされ、実用化への最大の障壁となっている。ギガフォトンは130ワット以上で約5日間連続運転させる実験にも成功し、一定の成果を上げた。

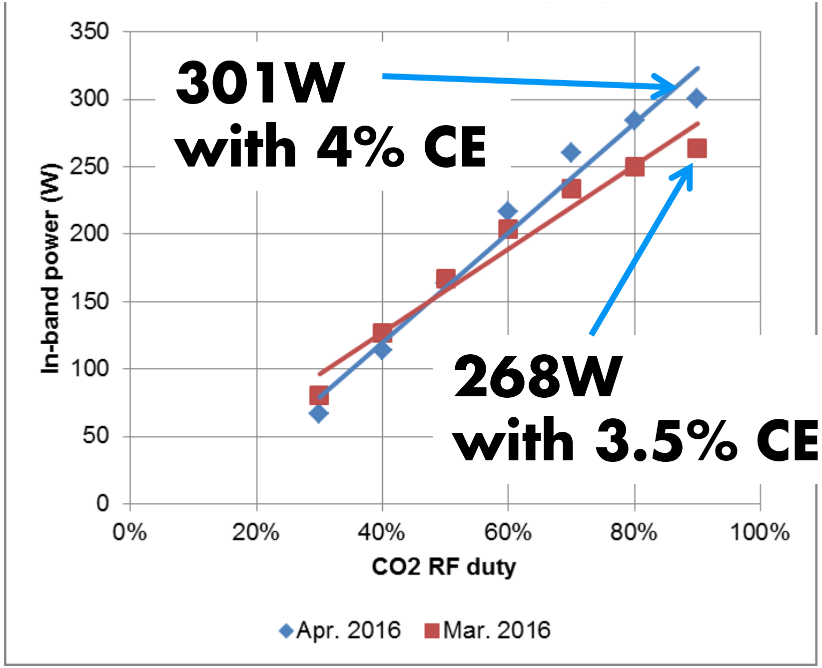
現在、EUV露光装置本体の開発に取り組んでいるのはオランダのASMLのみだ。

光源開発を加速するため、ギガフォトンの競合である光源メーカー、米サイマーを2013年に買収した。試験的に出荷しているEUV露光装置の光源は出力が低めだが、稼働実績の面で先行している。

ギガフォトンは発光効率を高めるのに有利な技術を持つ。高出力化でASML製に対抗できる製品の開発を目指す。

Prototype LPP Source Systems Update (4)

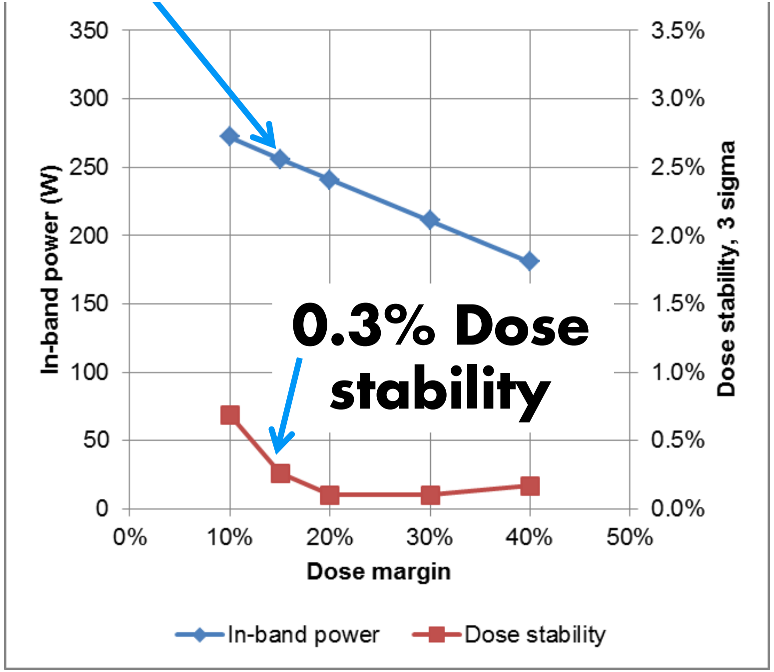
300W with open loop



301W with 4% CE

268W with 3.5% CE

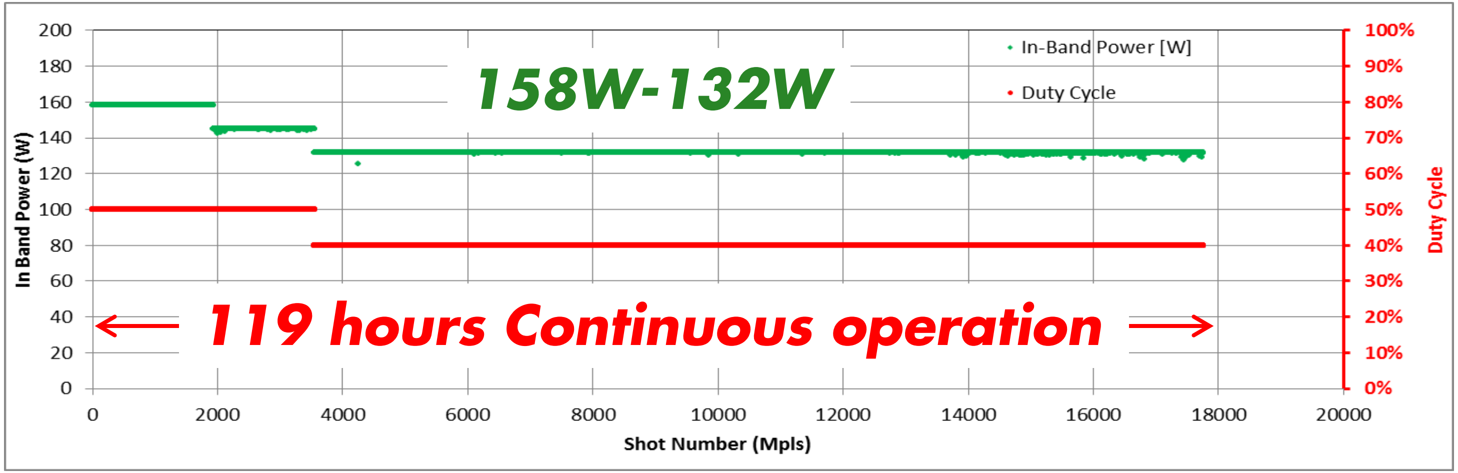
256W with closed loop



0.3% Dose stability

Prototype LPP Source Systems Update (5)

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:

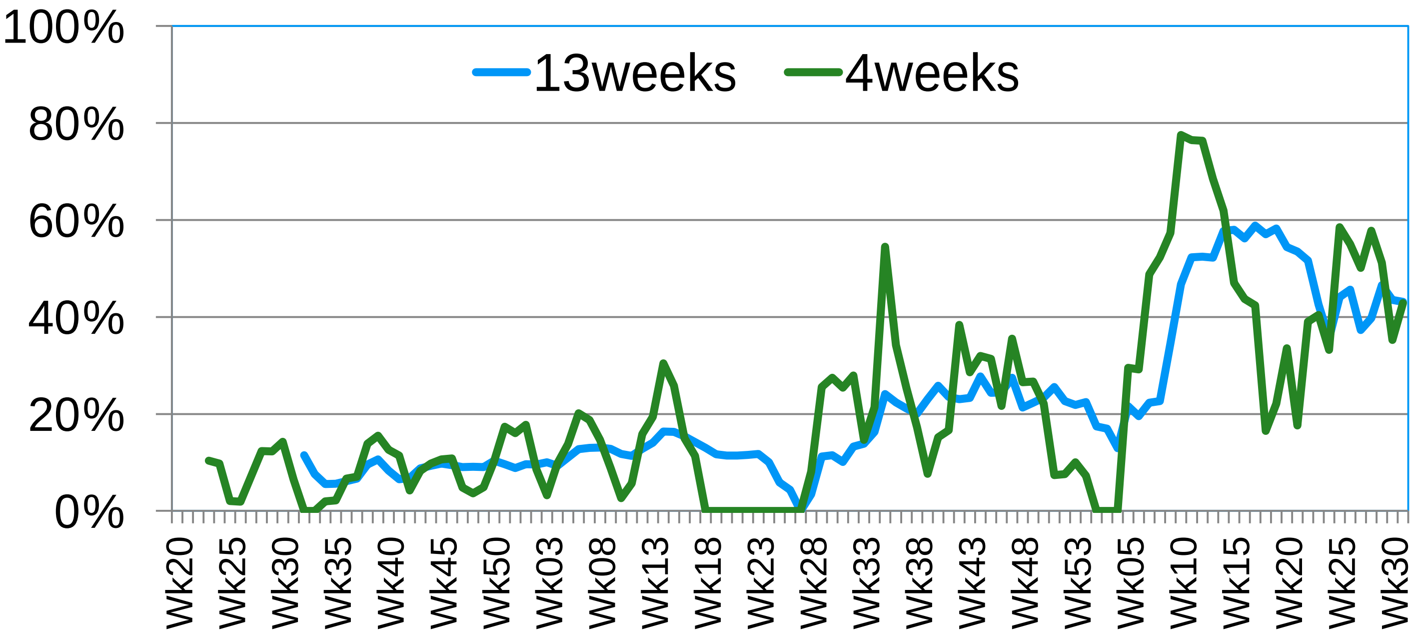
Repetition rate:	100kHz
Duty:	40/50% *
Average power:	79W-52W

With dose control mode

* 10 kpls on/0.15 or 0.1s off

Prototype LPP Source Systems Update (6)

Availability



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- Introduction
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- **Higher Power EUV Source Development**
- Summary

Higher Power EUV Source Development (1)

- Extendibility to 500W EUV Power

EUV Output Power vs. CO_2 Input Power

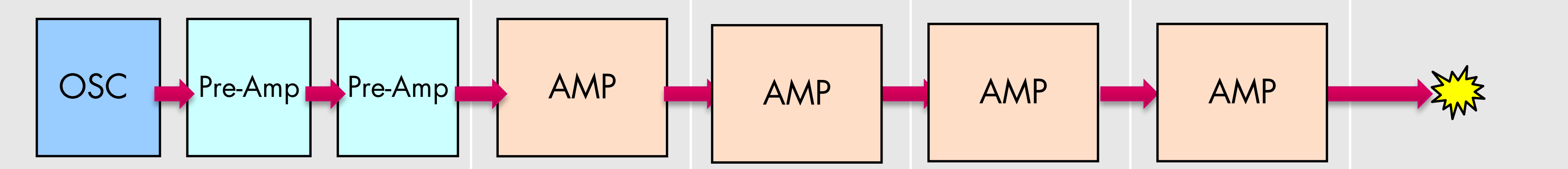
EUV ave.Power[W] @100kHz		Conversion Efficiency [%]						
CO2 laser Energy [mJ]	CO2 laser ave. Power [kW]	2%	3%	4%	5%	6%	7%	8%
15	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	5	19.1	28.7	38.2	47.8	57.3	66.9	76.4
100	10	46.4	69.6	92.8	116.0	139.2	162.4	185.6
150	15	73.7	110.6	147.4	184.3	221.1	258.0	294.8
200	20	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

Higher Power EUV Source Development (2)

Carbolated with MITSUBISHI ELECTRIC



OSC		PA1	MA1	MA2	MA3	Plasma Point
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

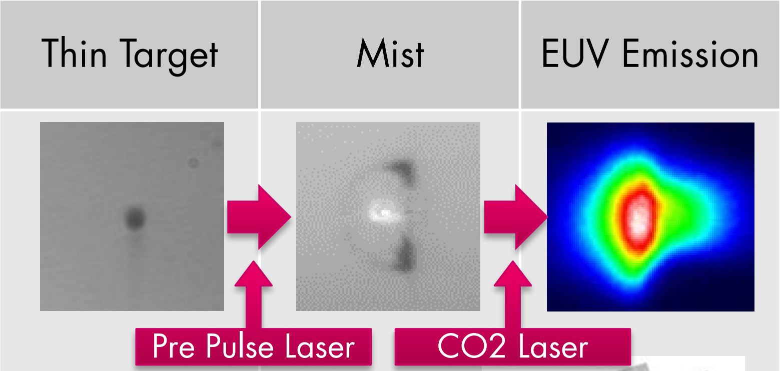
High EUV Conversion Efficiency

Cooperation with

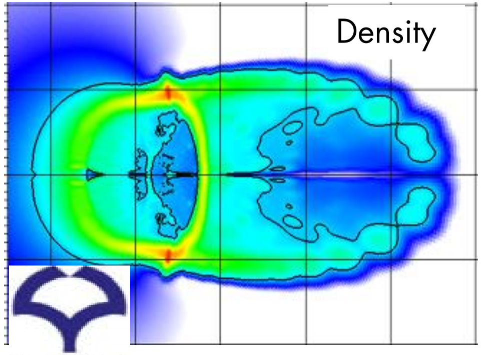
九州大学 Kyushu University

大阪大学 OSAKA UNIVERSITY

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

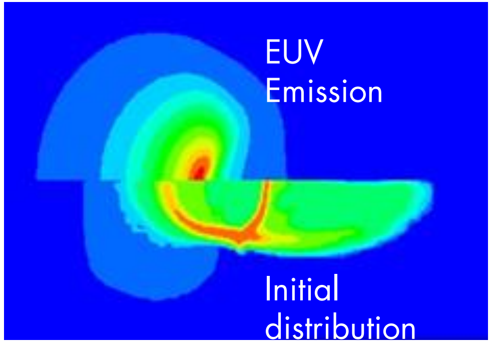


Target Simuration

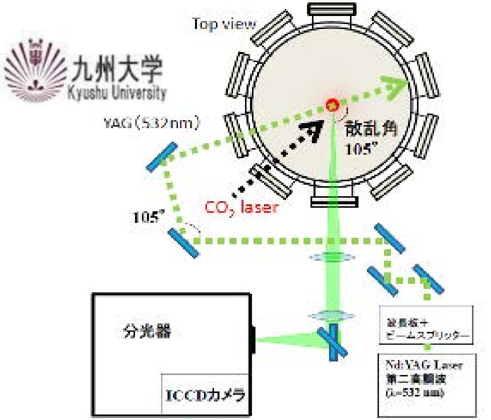


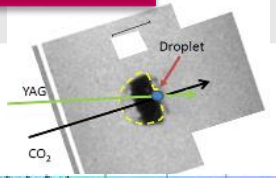
大阪大学 OSAKA UNIVERSITY

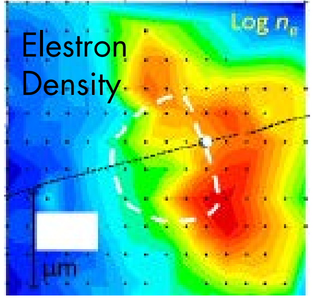
Simuration of EUV Emission



Thomson Scattering







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Summary

- **Pilot 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 Collector full-scale mirror demonstration.
- **Power scaling and availability improvement with Proto 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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THANK YOU
for
Your Attention

GIGAPHOTON