One Hundred Watt Operation Demonstration of HVM LPP-EUV Source

2014 International Workshop on EUV Lithography

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AGENDA

- Key Technical Points of EUV LPP Light Source
  - » Issues of EUV Light Source Power
  - » History of LPP Technology
- Gigaphoton's LPP Light Source Concept
  - » Droplet Generator
  - » Pre-pulse Technology
  - » Collector Mirror and IR Reduction Technology
  - » Debris Mitigation Technology
- Gigaphoton's High Power LPP Light Source System Development
  - » Debris Mitigation Technology Update
  - » Output Power Update
- Power-up Scenarios of HVM EUV Light Sources
- Summary

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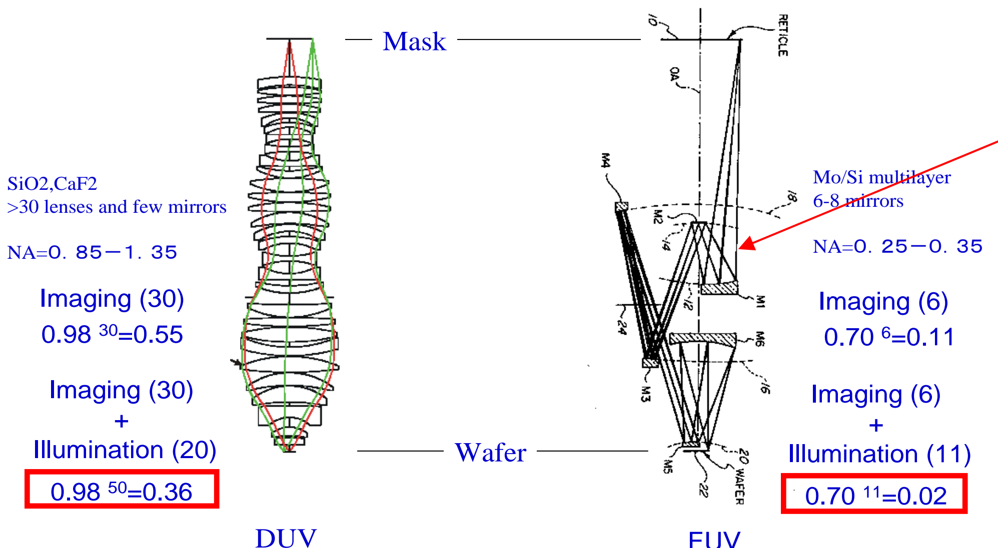
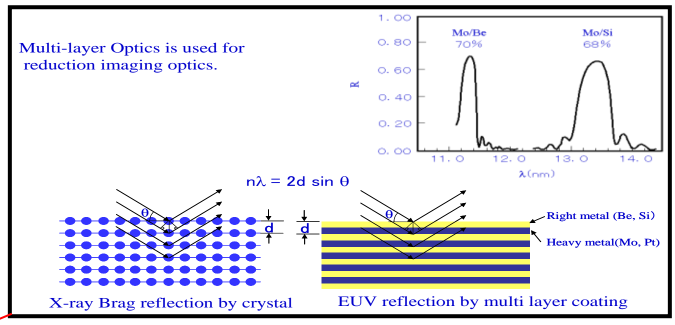
Technical Issues of EUV Lithography

EUV light transmittance is only 2% with 11 reflection mirror systems





70% reflection

High power light sources for HVM exposure tools is the key issue

Demand is > 250W at first stage HVM

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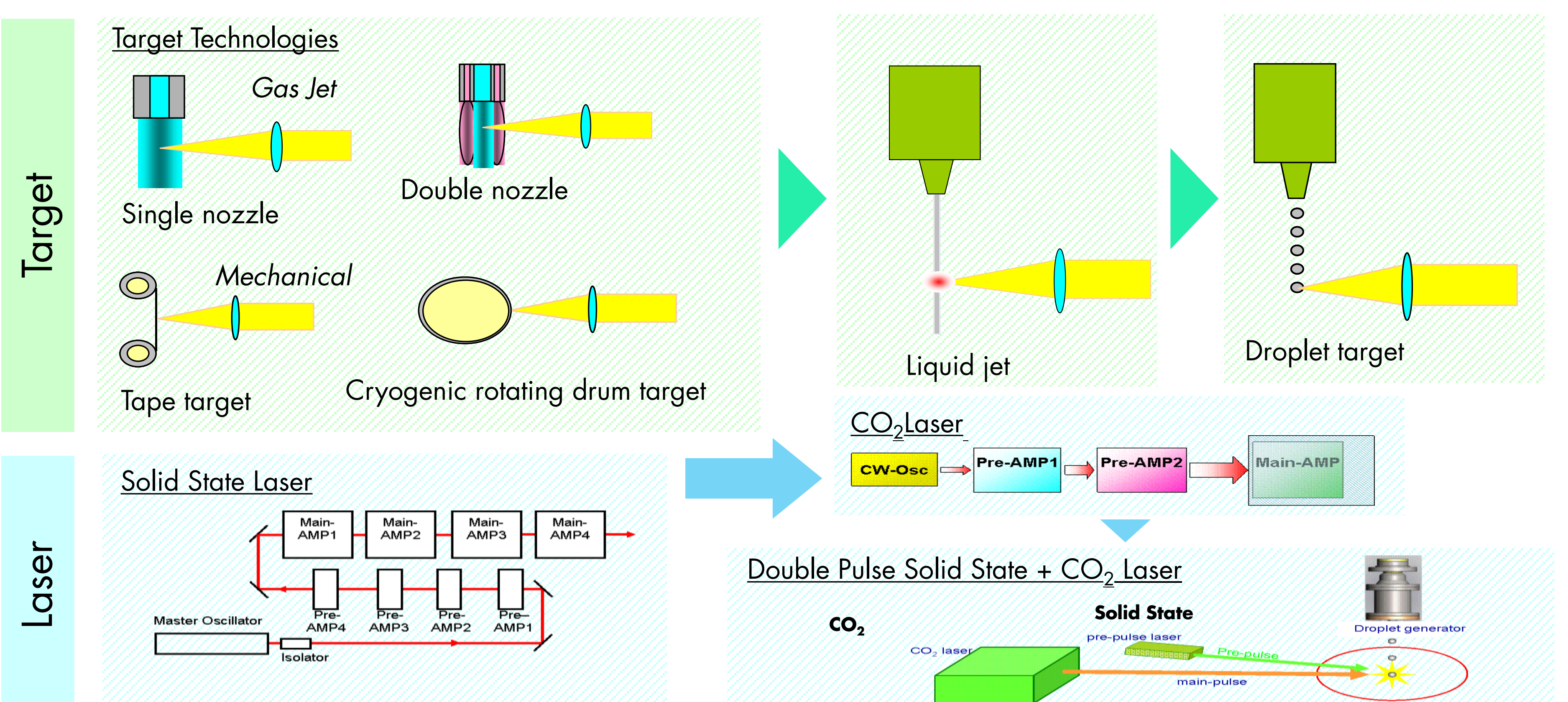
History of LPP Source Development in Japan



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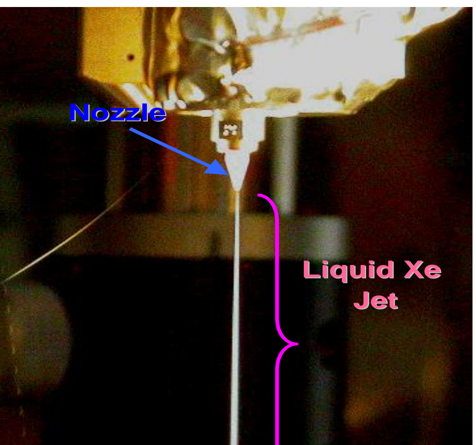
History of LPP Source Development in Japan

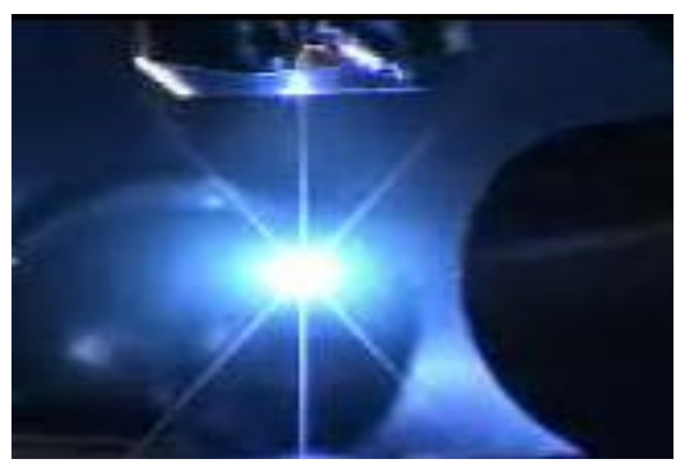
Liquid Xe jet target experiment with YAG laser driver

Liquid Xenon Jet System



Xe Jet

Velocity : 30 m/s
Stability σ : 10μm@10mm



Xe Jet and Plasma

Xe Temperature : 160K - 190K
Xe Pressure : < 5MPa

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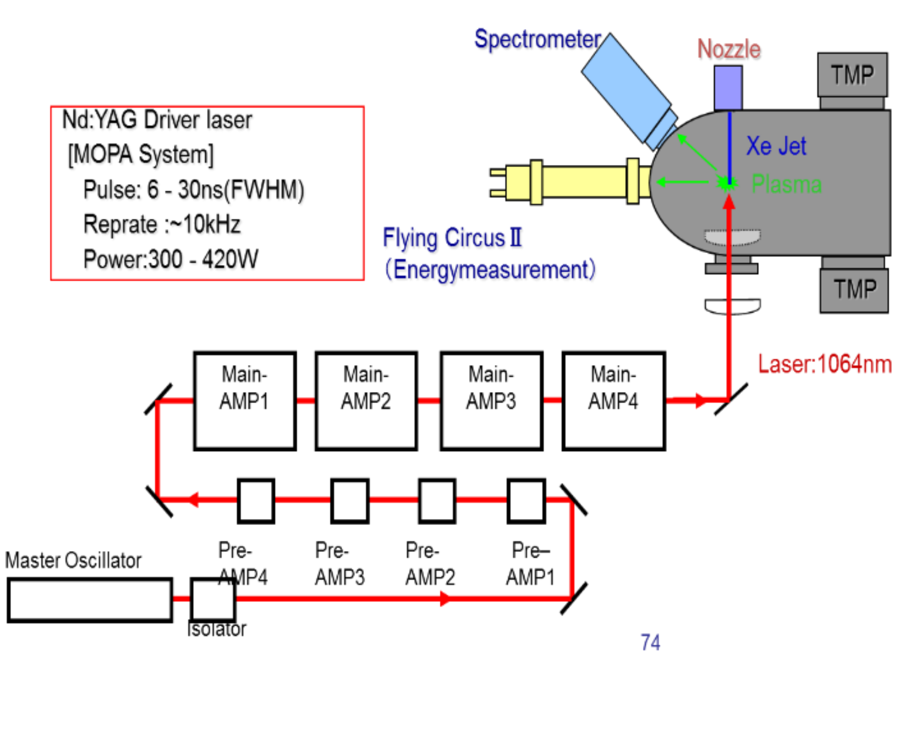
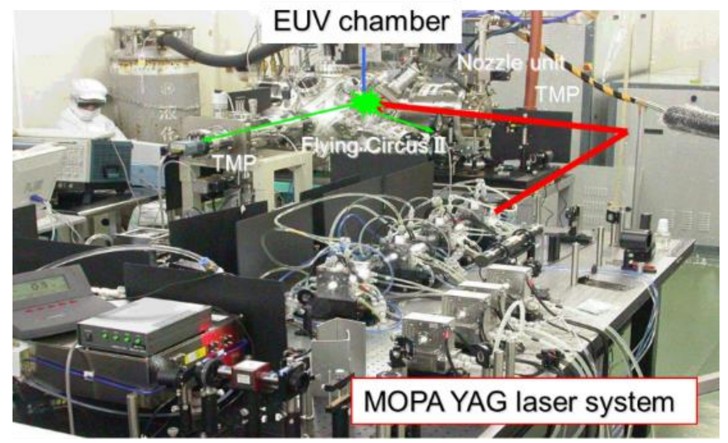
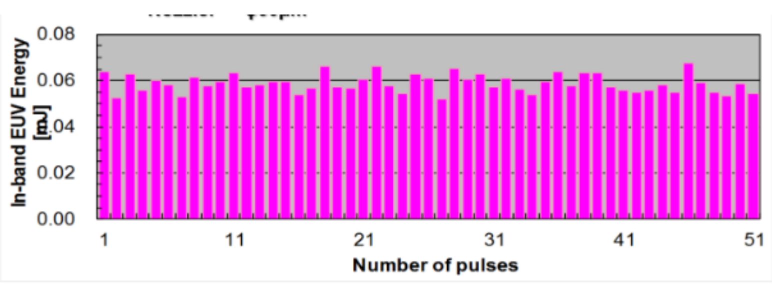
History of LPP Source Development in Japan

LPP EUV light generation test (2004) with Xe Jet + YAG laser system







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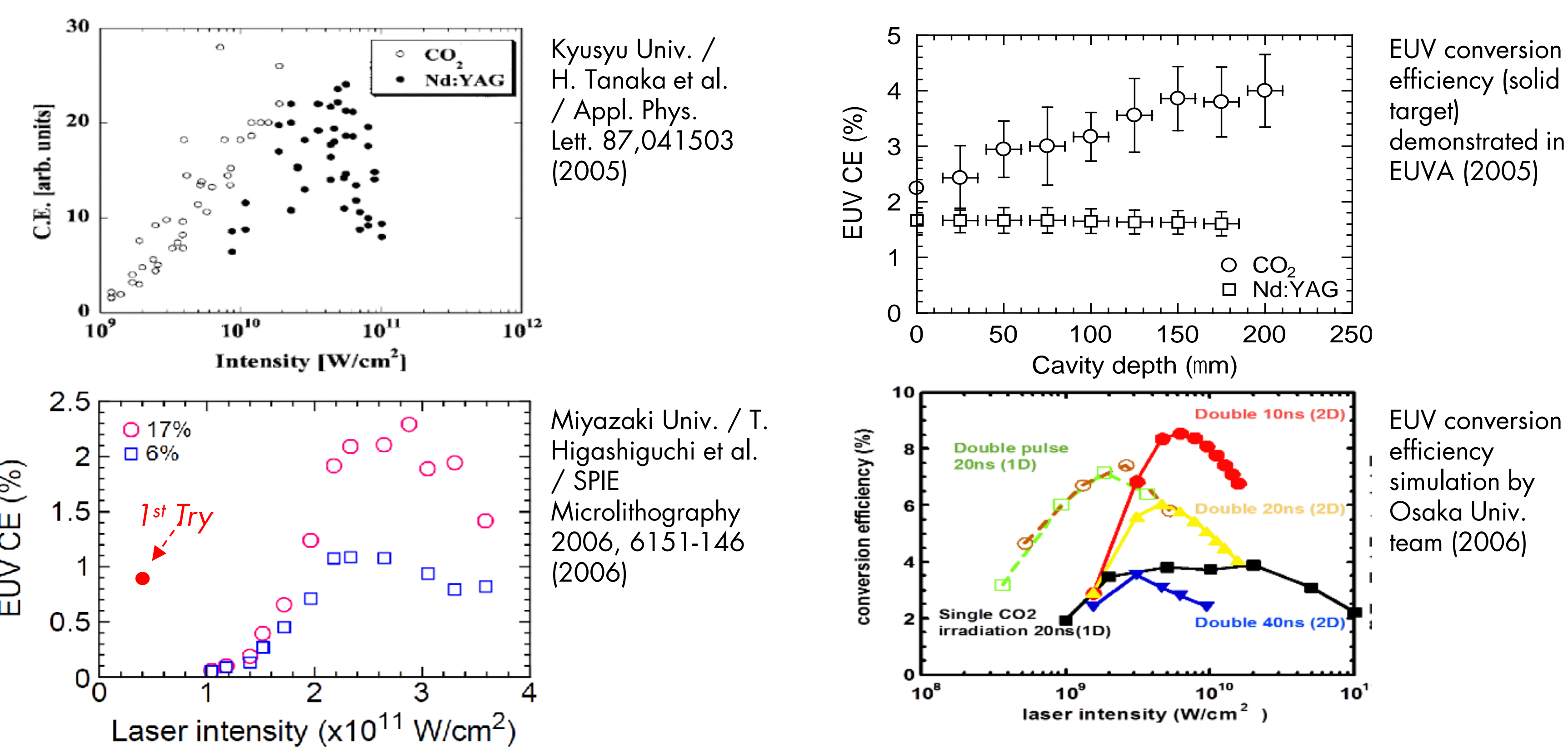
History of LPP Source Development in Japan



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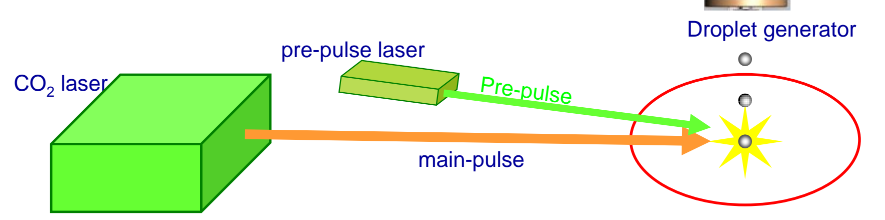
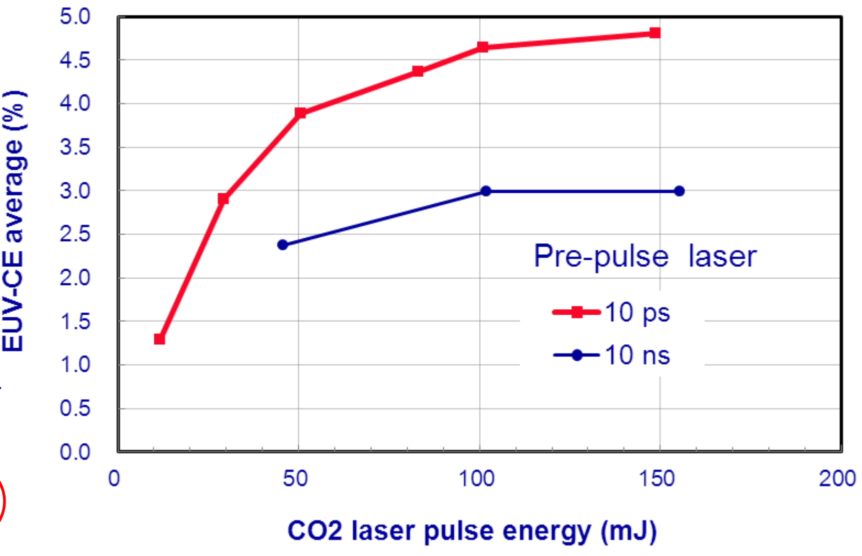
History of LPP Source Development in Japan

- 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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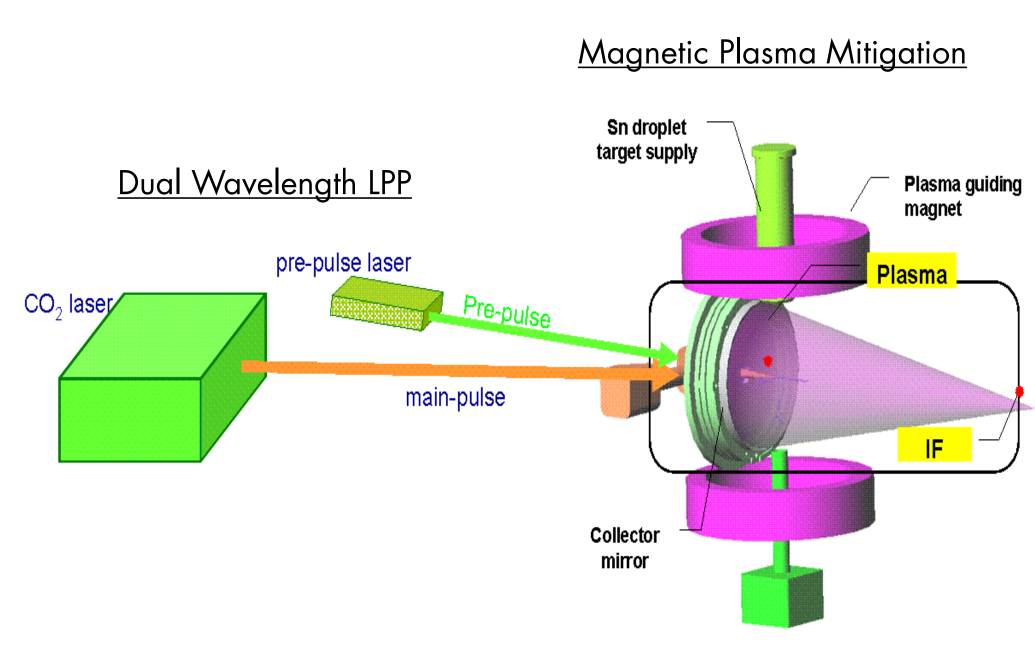
Gigaphoton's LPP Light Source Concept

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



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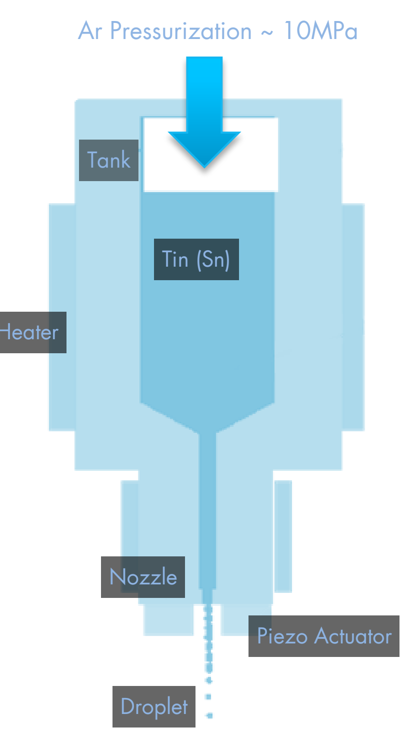
Droplet Generator Technology

- The Droplet Generator is one of the key technologies for achieving HVM level EUV light sources
- Requirement for droplet generator
  - » Size of droplet is 20μm
    - Smaller droplet is better
      - – Debris mitigation
      - – Longer lifetime of droplet generator
    - Technical barrier is higher
      - – Clogging due to smaller nozzle
  - » Stability is ±20μm
    - Short and long term stability is necessarily to achieve stable dose control



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Droplet Generator Technology

Improvements over time:

	2012 Q4	2013 Q2	2014 Q1
Size (Diameter)	30 μm	25 μm	20 μm
Volume	118 pico-liter	65 pico-liter	34 pico-liter
Frequency	100 kHz	200 kHz	100 kHz
Spacing	500 μm	250 μm	480 μm

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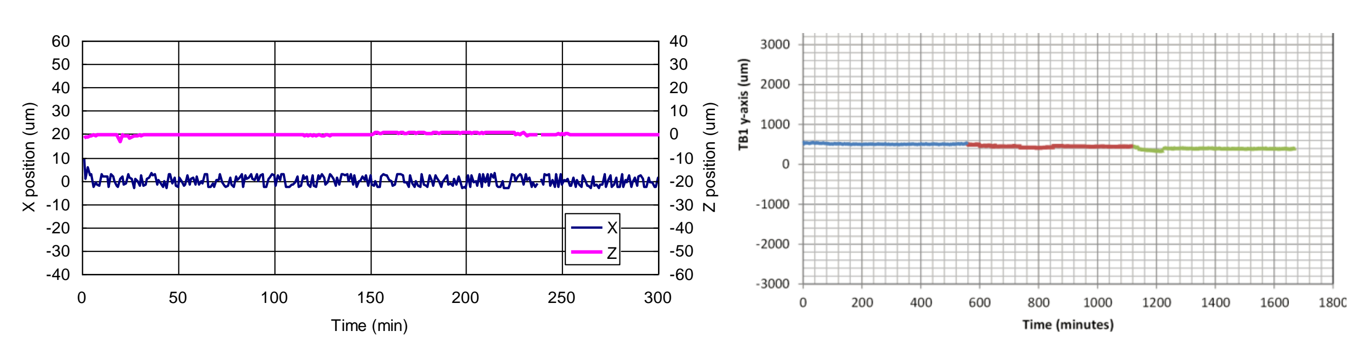
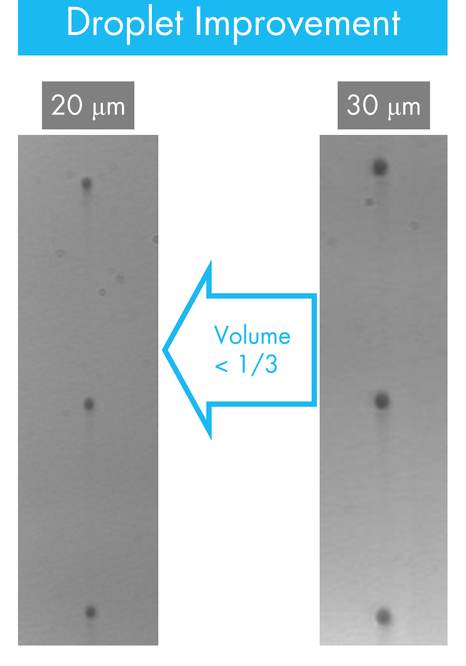
Droplet Generator Technology

- 100 kHz, 20 μm droplet generation was confirmed
- Short & middle term stability was confirmed
  - » Good margin compare to the target ±20 μm
  - » No clogging / stability change even with cool down & re-start





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Pre-Pulse Technology

Experiment shows picosecond pre-pulse dramatically enhances ionization rate and CE

Sn Droplet Smash

psec — Dome like target

laser

300um

nsec — Flat disk like target

laser

300um

Data in 10 Hz Experimental Device

10Hz source data

Ioniation performance

Ionization rate: 100%, 80%, 60%, 40%, 20%, 0%

CO2 pulse energy on droplet: 0, 20, 40, 60, 80, 100

Proto performance

ns-pulse laser, ps-pulse laser

CE performance

Conversion efficiency (%): 5, 4, 3, 2, 1, 0

CO2 pulse energy (mJ): 0, 20, 40, 60, 80, 100

Proto performance

ns-pulse laser, ps-pulse laser

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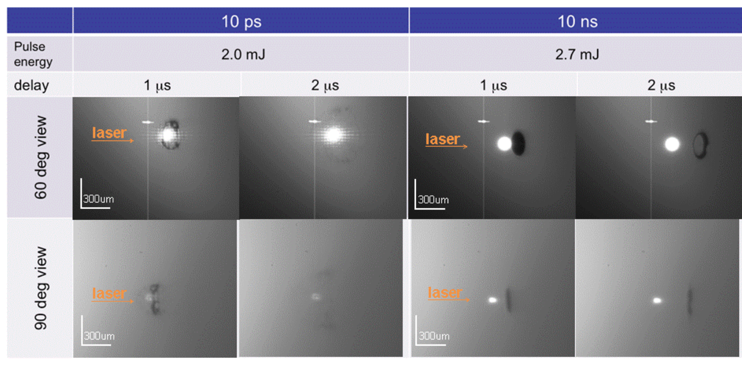
Pre-Pulse Technology

Fragment distribution measurement and modeling

- The mist shape of a picosecond pre-pulse is different from the nanosecond pre-pulse (ps = dome vs. Ns=thin disk or ring)
- Fragment distribution could be a key factor for high CE



	10 ps		10 ns	
Pulse energy	2.0 mJ		2.7 mJ	
delay	1 μs	2 μs	1 μs	2 μs
60 deg view				
90 deg view				

Modeling of pre-pulse plasma

0 ns
10ns
Pre-pulse
20μm
10 ns
Pre-pulse plasma Expansion
~50μm
(=10nsx5 km/s)
Liquid Tin move to opposite of pre-pulse plasma expansion.
Thicker disk like fragment
20 ns
Pre-pulse plasma Expansion
~100μm
(=20nsx5 km/s)
~Φ 60μm

0 ns
10ps
Pre-pulse
10 ps
20μm
All laser energy irradiated before plasma expansion
Pre-pulse plasma Expansion ~50nm (=10psx5 km/s)
50nm
Φ40μm
10 ns
Liquid deformation speed ~ 1000m/s (Sonic speed)
Thinner Isotropic Spherical fragment
Φ60μm
Fragment expansion
20 ns

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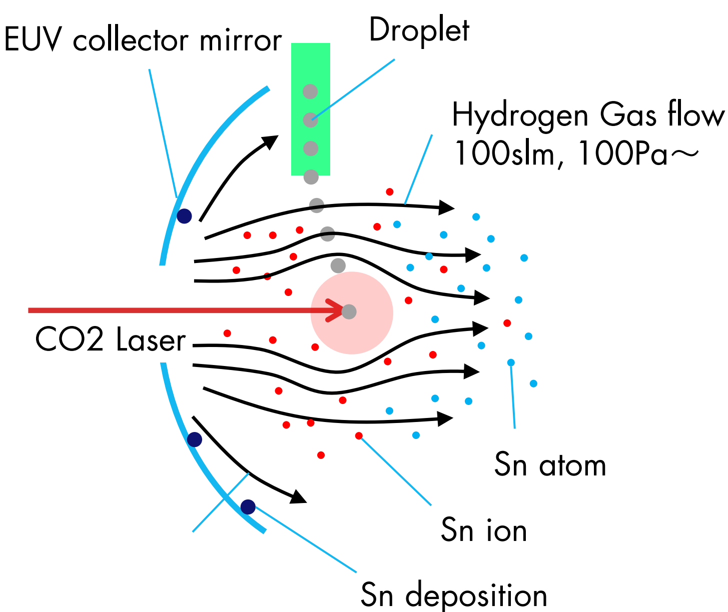
Debris Mitigation Technology

Gas mitigation method



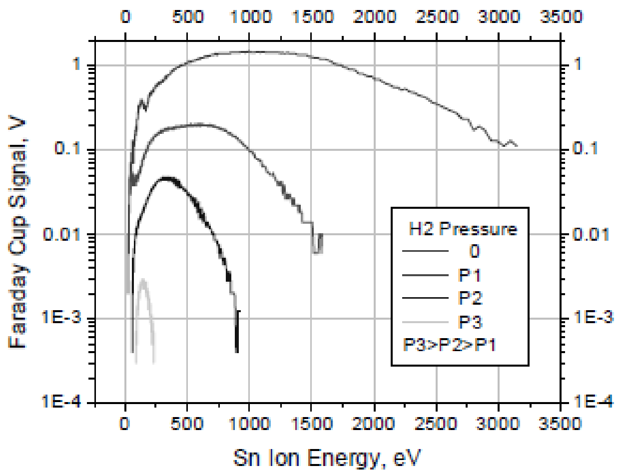


Figure 10: Hydrogen buffer gas pressure vs. ion energy and flux at the location of the collector surface

Proc. of SPIE Vol. 7636 763639 (2010)

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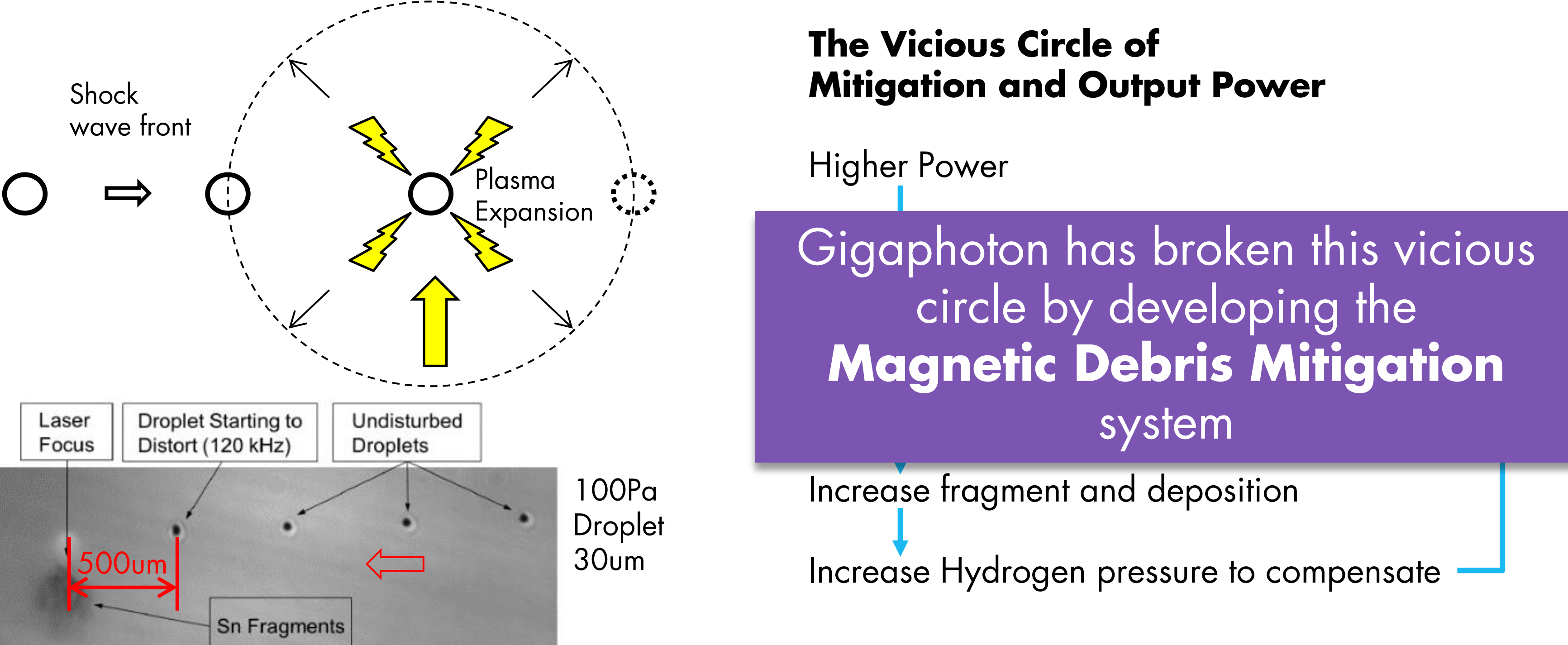
Debris Mitigation Technology

Issue with previous gas mitigation techniques



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Debris Mitigation Technology

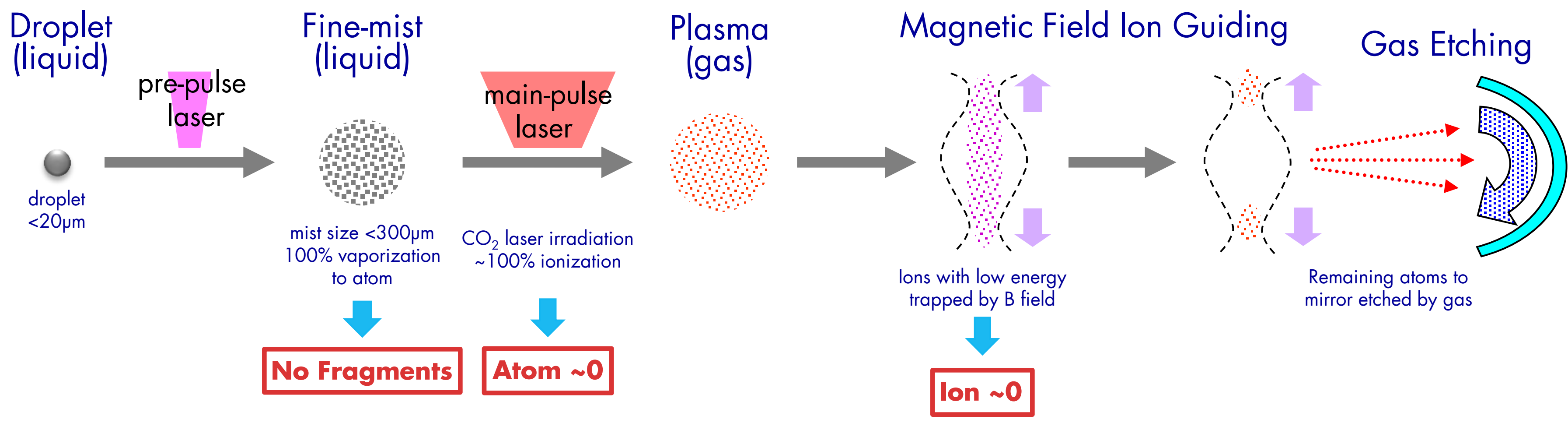
Gigaphoton's Magnetic Debris Mitigation concept

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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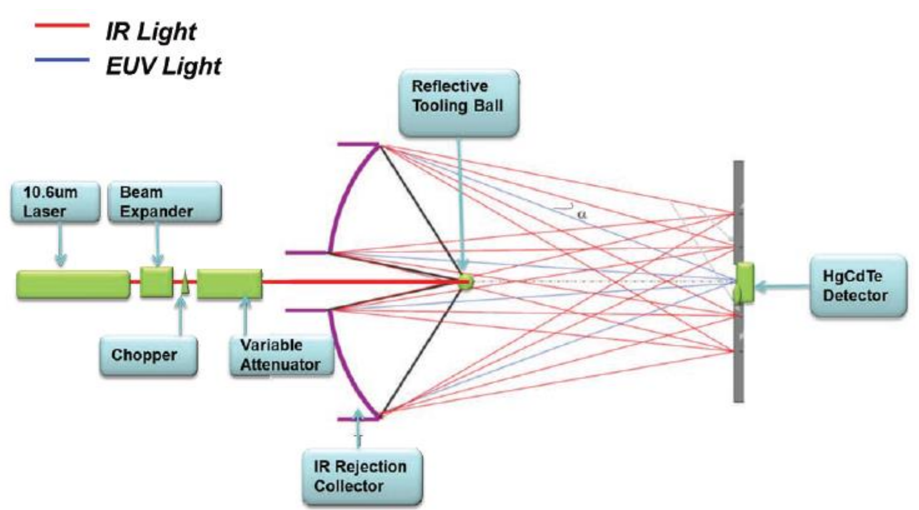
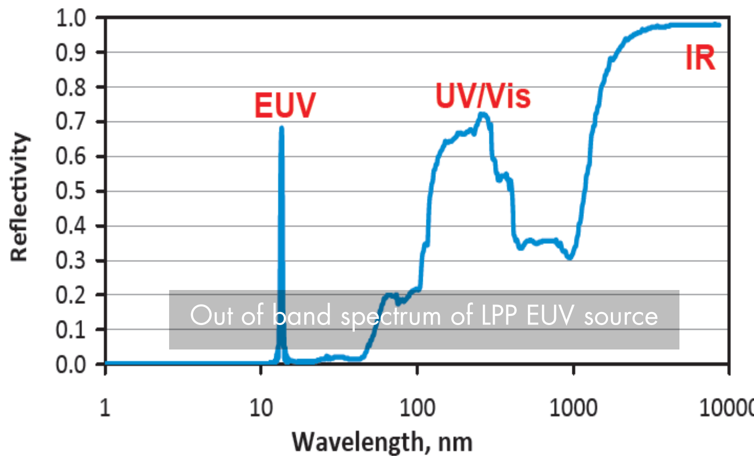
Collector Mirror Technology

Collector Mirror progress

IR Reduction Technology is Advancing

Gigaphoton is developing IR reduction mirror in co-operation with multiple mirror suppliers.





Gigaphoton's Patent Pending IR Reduction Technology

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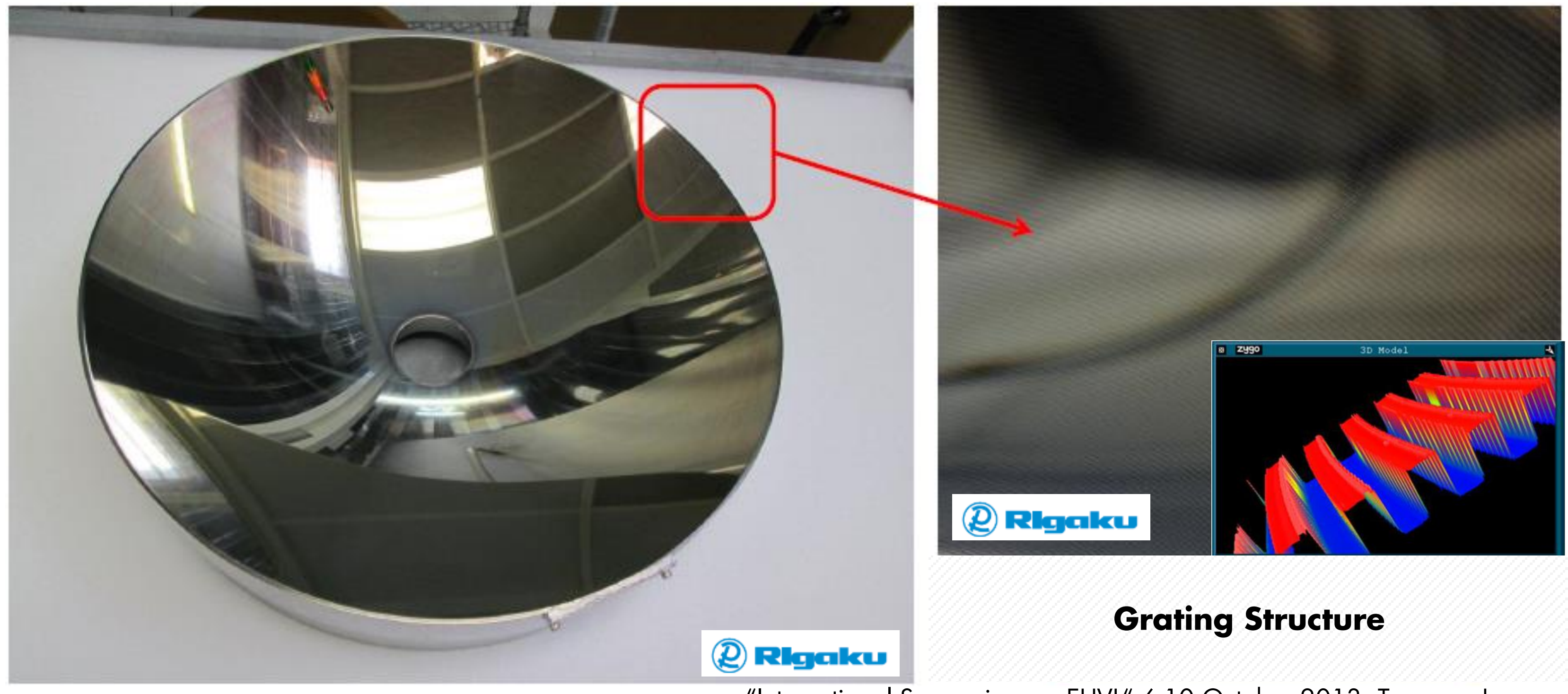
Collector Mirror and IR Reduction Technology

Rigaku succeeded in producing a unique Diffraction Grating Collector Mirror (DGCM)



Grating Structure

"International Symposium on EUVL" 6-10 October 2013, Toyama, Japan

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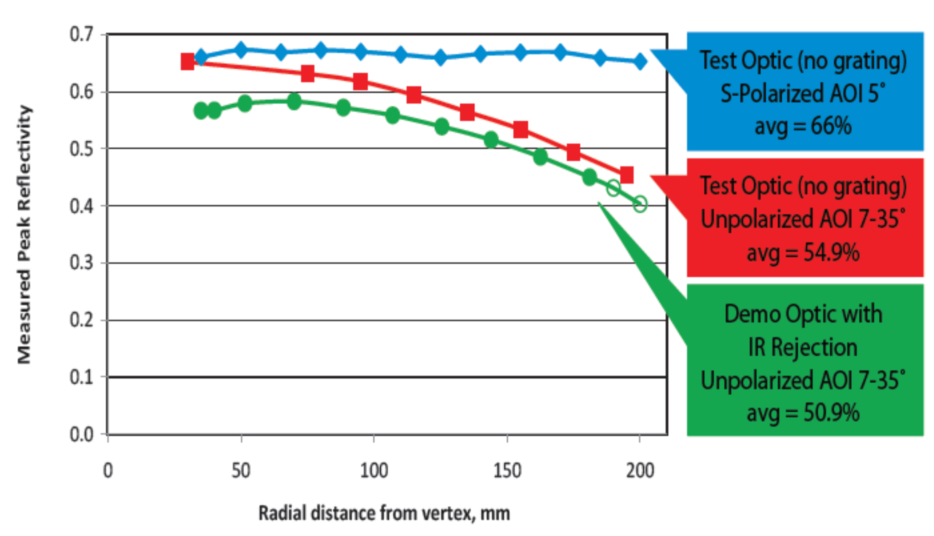
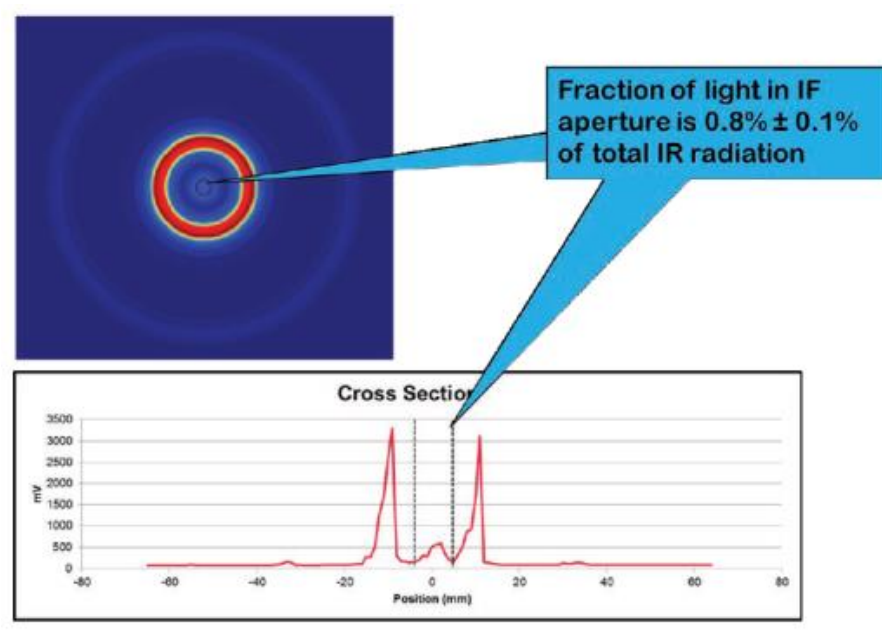
Collector Mirror and IR Reduction Technology

- Rigaku demonstrated efficient and dramatic IR reduction by putting gratings on the mirror surface
- Prefabrication test completed
  (data is reported EUV symposium 2013 in Toyama)
- Next step is proto type fabrication and evaluation





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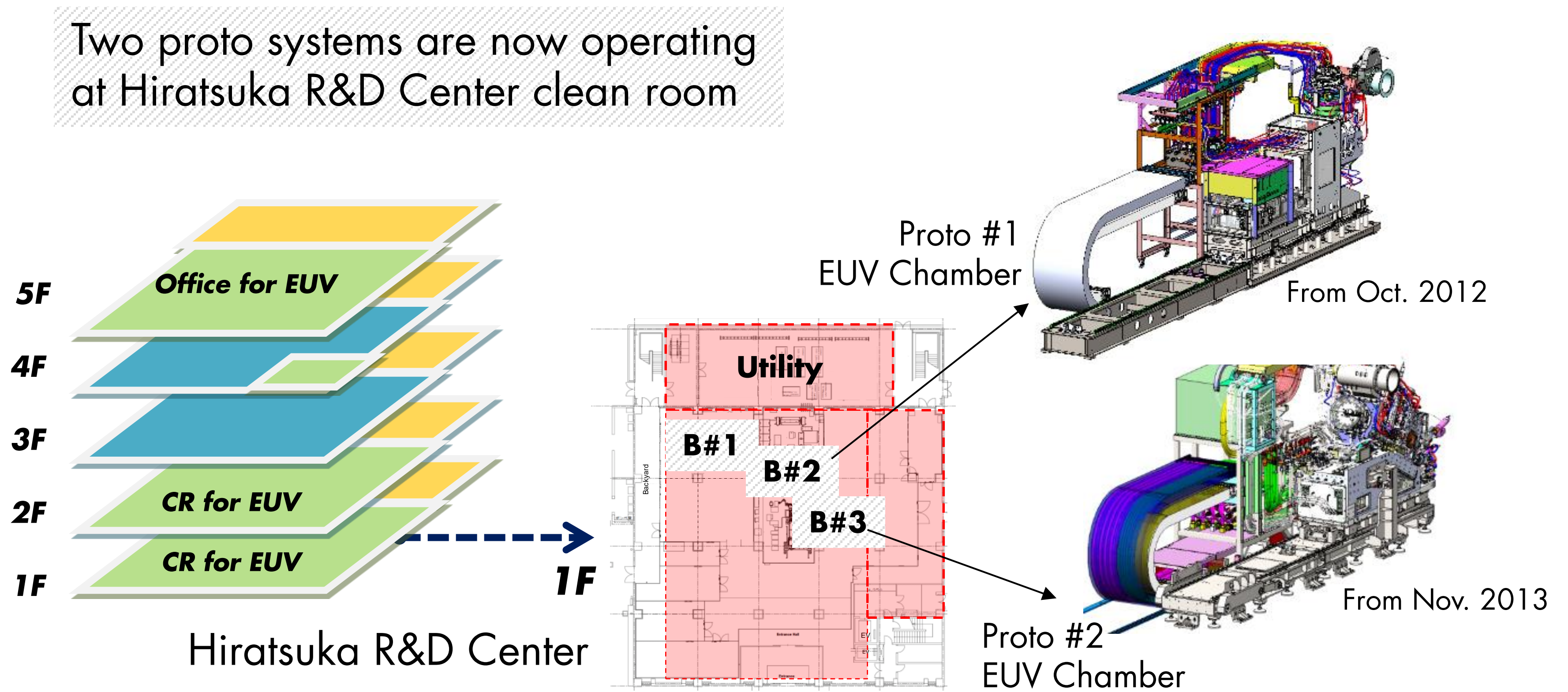
Proto Systems in Operation

Two proto systems are now operating at Hiratsuka R&D Center clean room



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Proto Systems in Operation

Target System Specifications

Operational Specification		Proto #1	Proto #2	Customer Beta Unit
Target Performance	EUV Power	25 W	100 W	250 W
	CE	3%	4%	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
	CO2 laser	> 8 kW	> 12 kW	25 kW
	Pre-pulse laser	picosecond	picosecond	picosecond
	Debris mitigation	validation of magnetic mitigation in system	10 days	15 days

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Proto Systems in Operation

- Proto #1
  - » 5 kW CO_2 power by 2 MA CO_2 laser system
  - » Target is > 25 W EUV clean power
- Proto #2
  - » 8 -14 kW CO_2 power by 3 MA CO_2 laser systems
  - » Target is > 100 W EUV clean power
  - » EUV chamber around 60° angle setup

Main Amp.
Power supply for main amp
Pre. Amp.
Osc.

EUV Chamber system
vessel, collector mirror, droplet generator, magnet

combiner unit
focus unit
Beam transfer system
pre-pulse
osc.
isolator
pre-amp
MA1
MA2
MA3

Laser system
CO_2 laser, pre-pulse laser, optics

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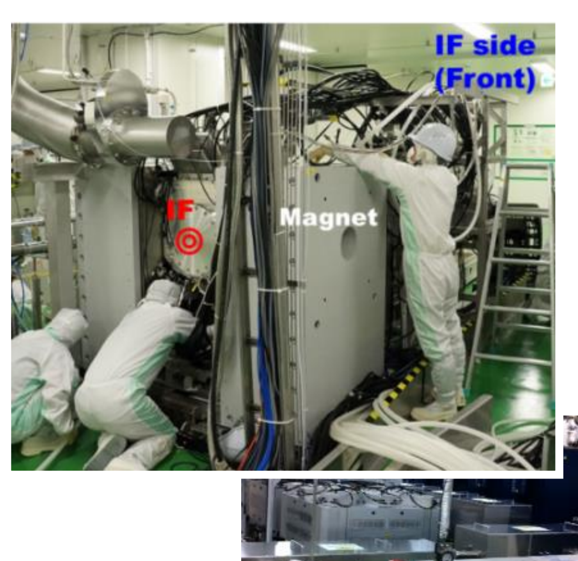
EUV Light Source for Debris Mitigation Testing

- Proto #1 for Debris mitigation test
  - » Complete system (laser and chamber) is working now
  - » Currently using for mitigation technology development
- Proto #2 for high power development
  - » Assembly and adjustment has completed
  - » The first EUV emission data in January 2014.



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EUV Light Source for Debris Mitigation Testing

In-burst power performance improvements on Proto #1

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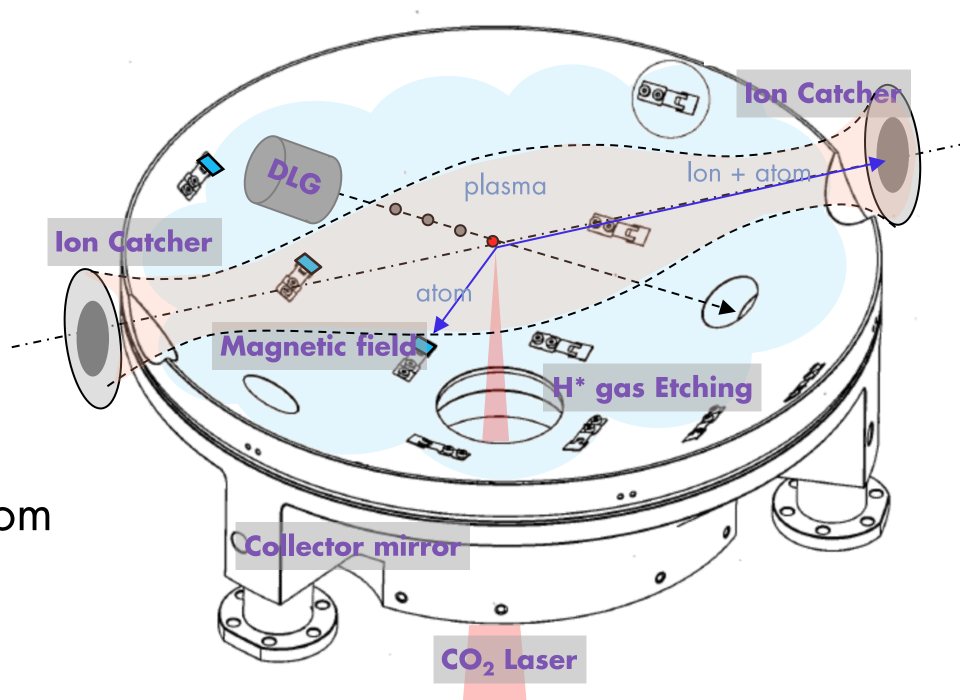
EUV Light Source for Debris Mitigation Testing

Gigaphoton's unique magnetic field + gas etching technology

- The collector mirror lifetime (i.e. debris mitigation technology) is one of the key items for reducing cost of consumables for HVM
- Gigaphoton's unique technology for debris mitigation:
  - » Magnetic field to catch Sn ion/atom
  - » H* gas to etch out Sn atom



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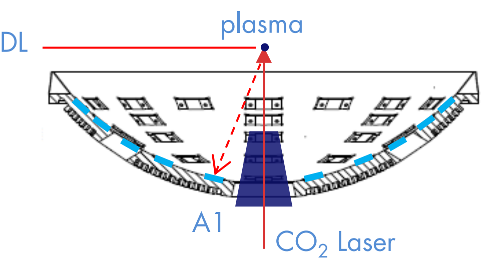
EUV Light Source for Debris Mitigation Testing

First results with 20 μm droplets

Promising result with 20 μm droplet has been confirmed

✓ Sn deposition rate drastically improved toward 1/5 compared to 25 μm droplets
✓ With shooting error improvement, deposition rate is expected to be very small

	25μm Droplet	**20μm Droplet**
Pulse number	152 Mpls	80 Mpls
H_2 pressure	15 Pa	15 Pa
EUV Energy (3σ)	23.3%	73.4%
A1 sample Center of collector mirror (SEM x10,000)		
Sn deposition rate	0.5nm/Mpls	**0.1nm/Mpls**



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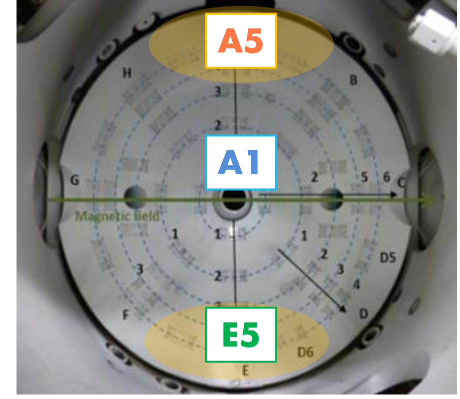
EUV Light Source for Debris Mitigation Testing

	2013 Oct	2014 Jan	2014. Apr	2014 May
A1 sample (SEM x10,000) *Center*			0.075nm/Mpls	0.03nm/Mpls
E5 sample (SEM x1,000) *Lower*			1.1nm/Mpls	0.8nm/Mpls
A5 sample (SEM x1,000) *Upper*			0.16nm/Mpls	0.024nm/Mpls



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High Power EUV Light Source

- Proto #1 for Debris mitigation test
  - » Complete system (laser and chamber) is working now
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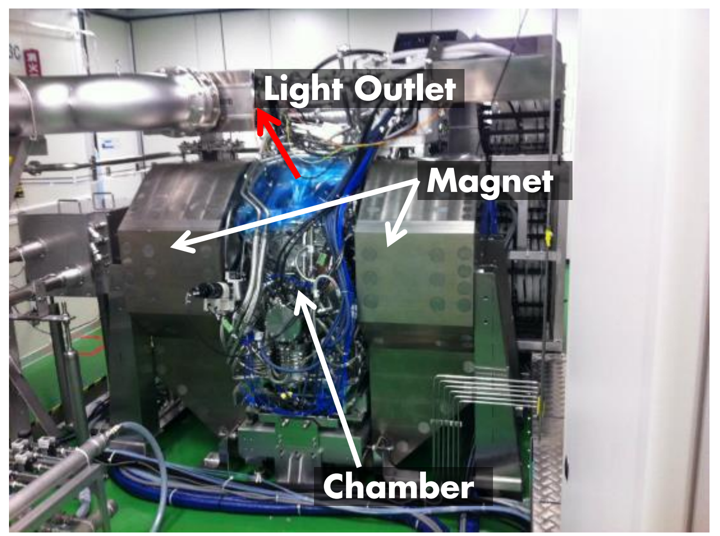
- Proto #2 for high power development
  - » Assembly and adjustment is completed
  - » First EUV emission data on January 2014



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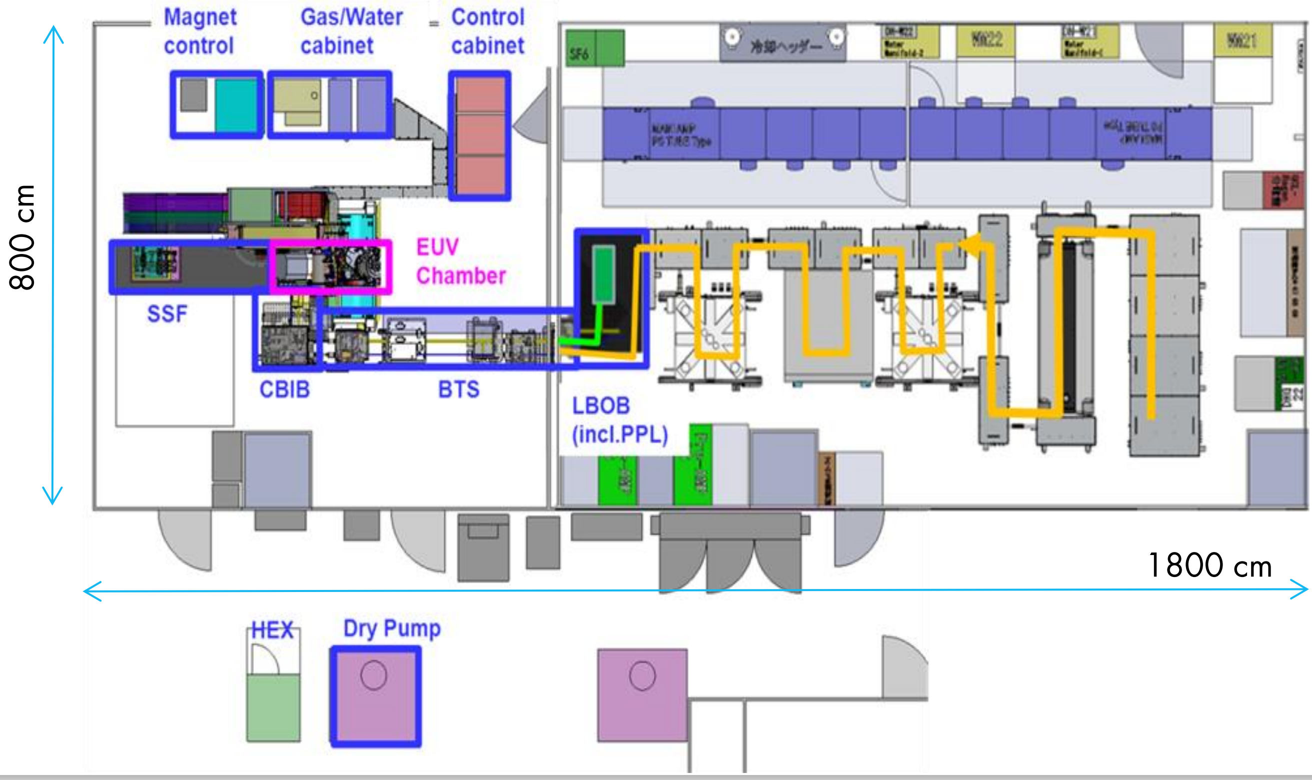
High Power EUV Light Source

The layout



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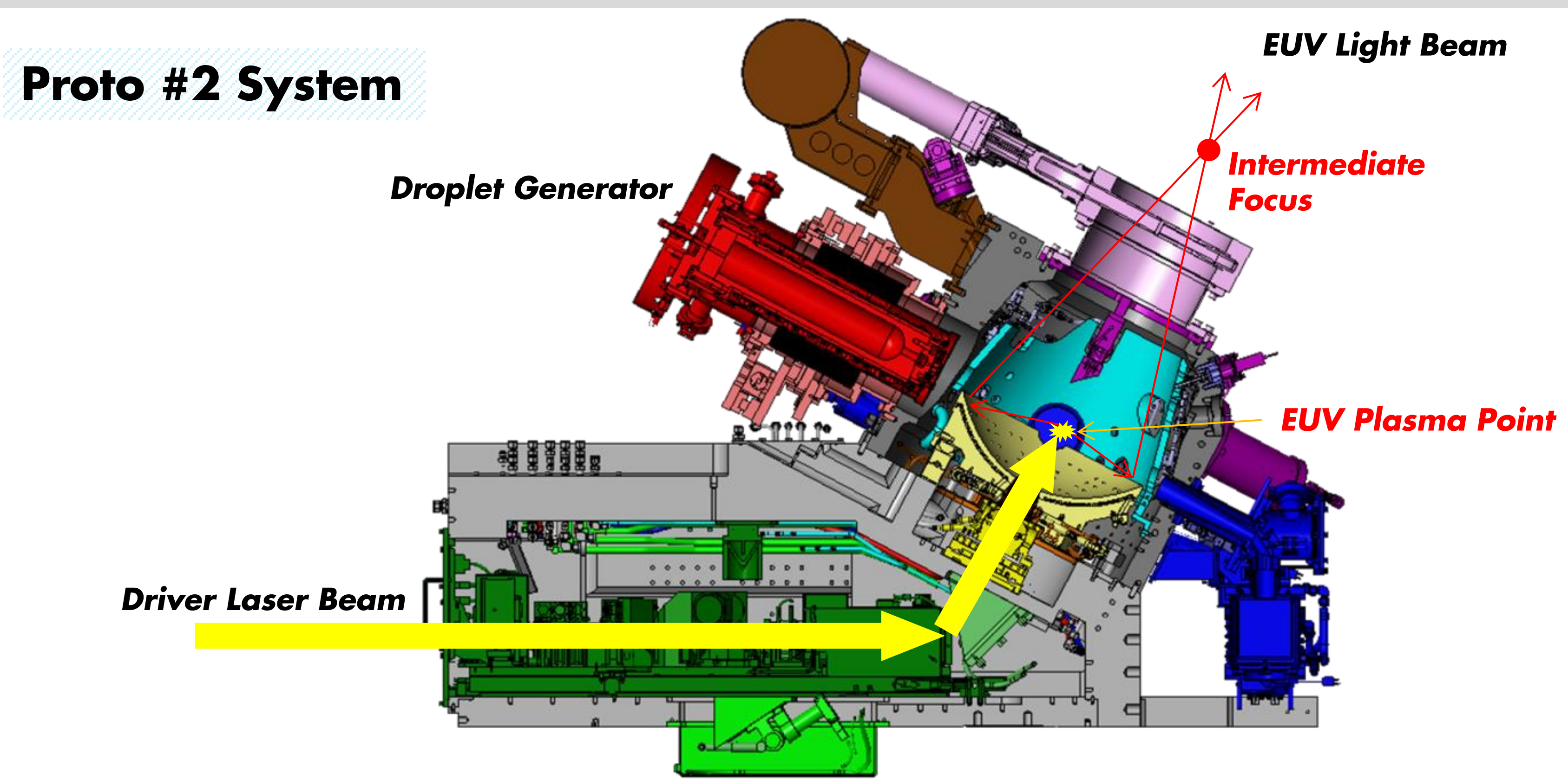
High Power EUV Light Source



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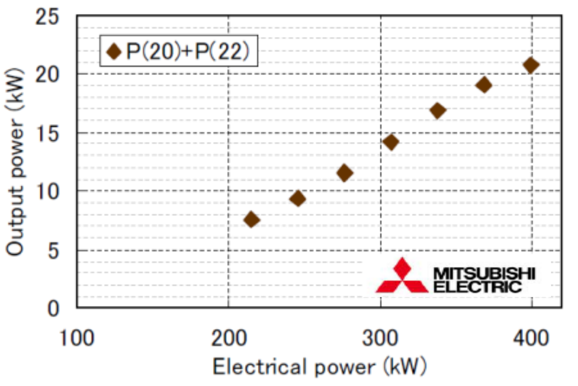
High Power EUV Light Source

Amplification Test @ Mitsubishi Electric (2013)



EUV power >100W @ I/F clean trial status

- ✓ 1st pre-amplifier installation is completed
- ✓ Driver laser system test is completed (>12kW OK)
- ✓ Laser shooting system test is ready.
- ✓ EUV test ongoing (collecting first high power data now)

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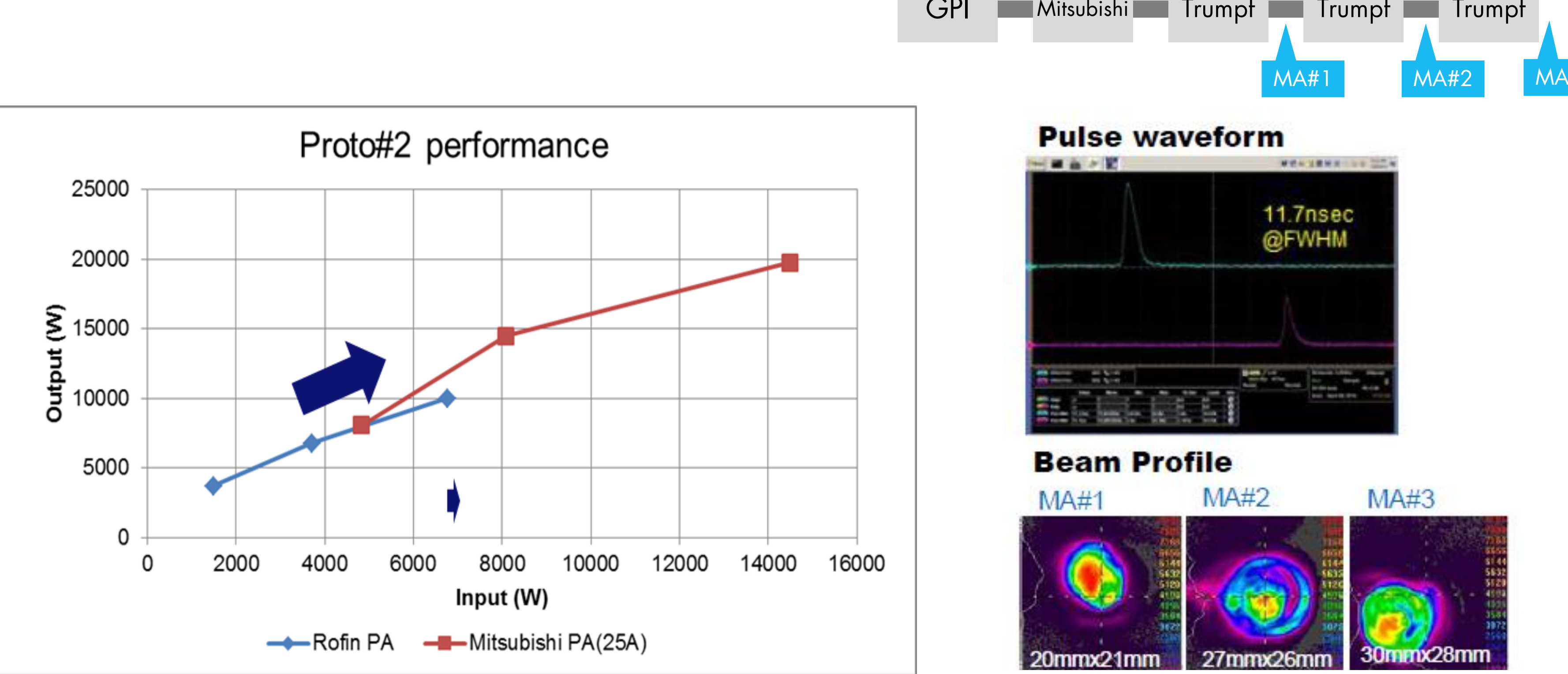
High Power EUV Light Source



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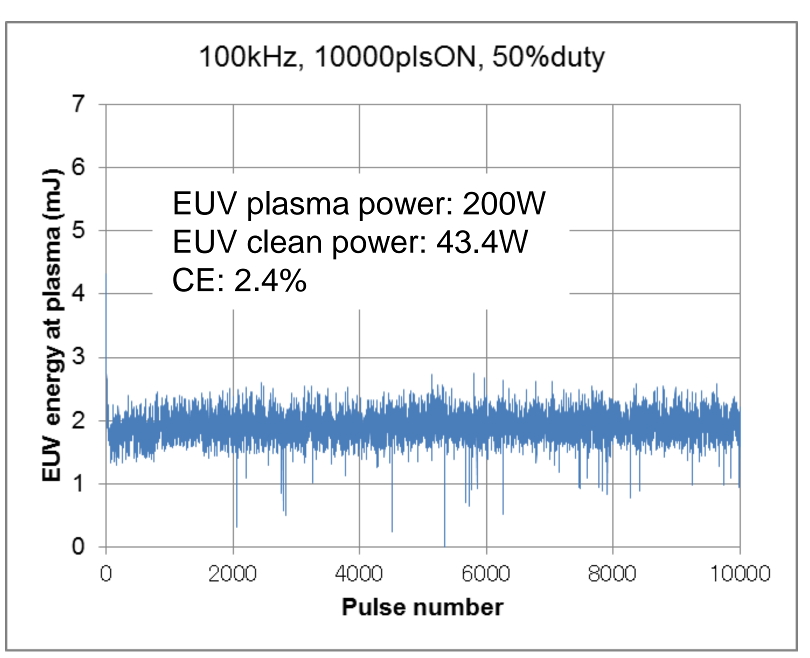
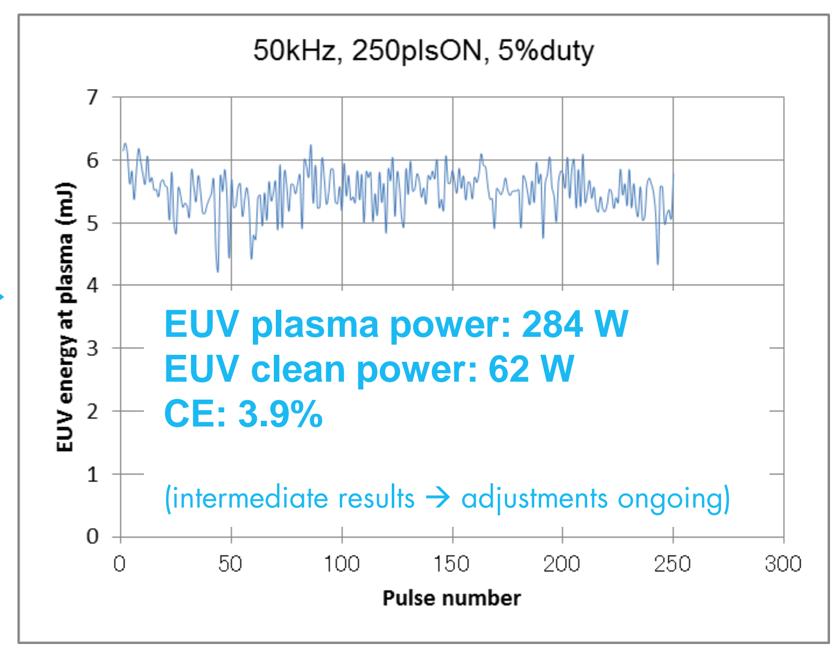
High Power EUV Light Source

2014 Jan





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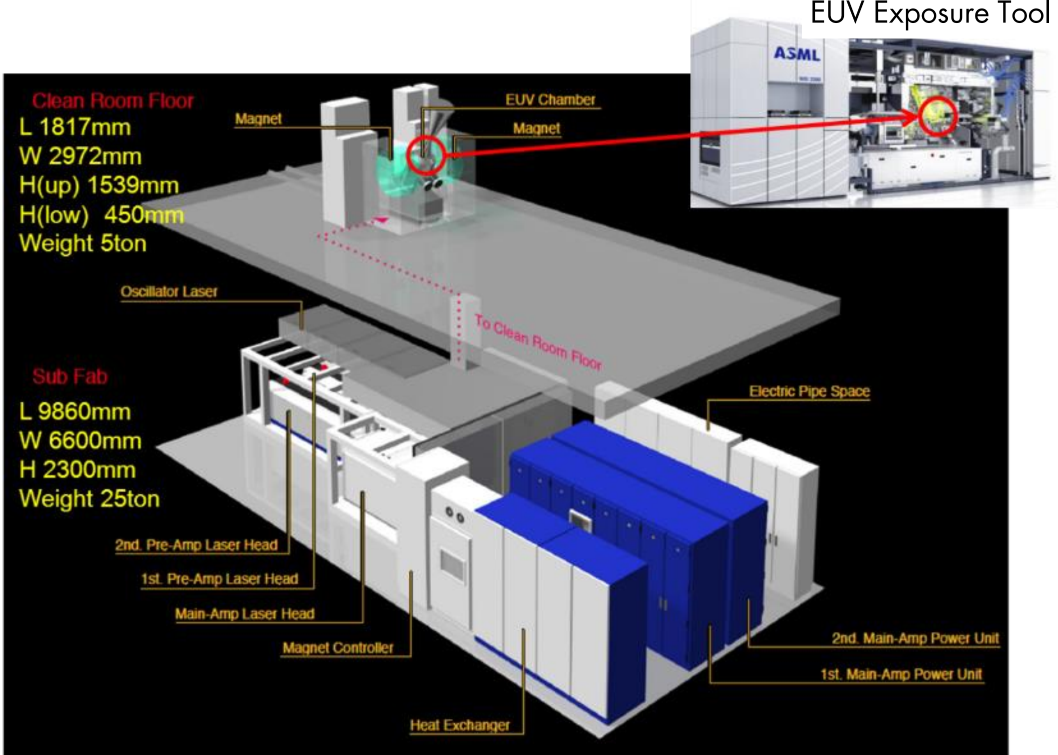
Power-up Scenario of HVM Sources

Layout of 250W EUV light source

First HVM EUV Source

- Gigaphoton is developing 250W EUV source
- Target is 2015

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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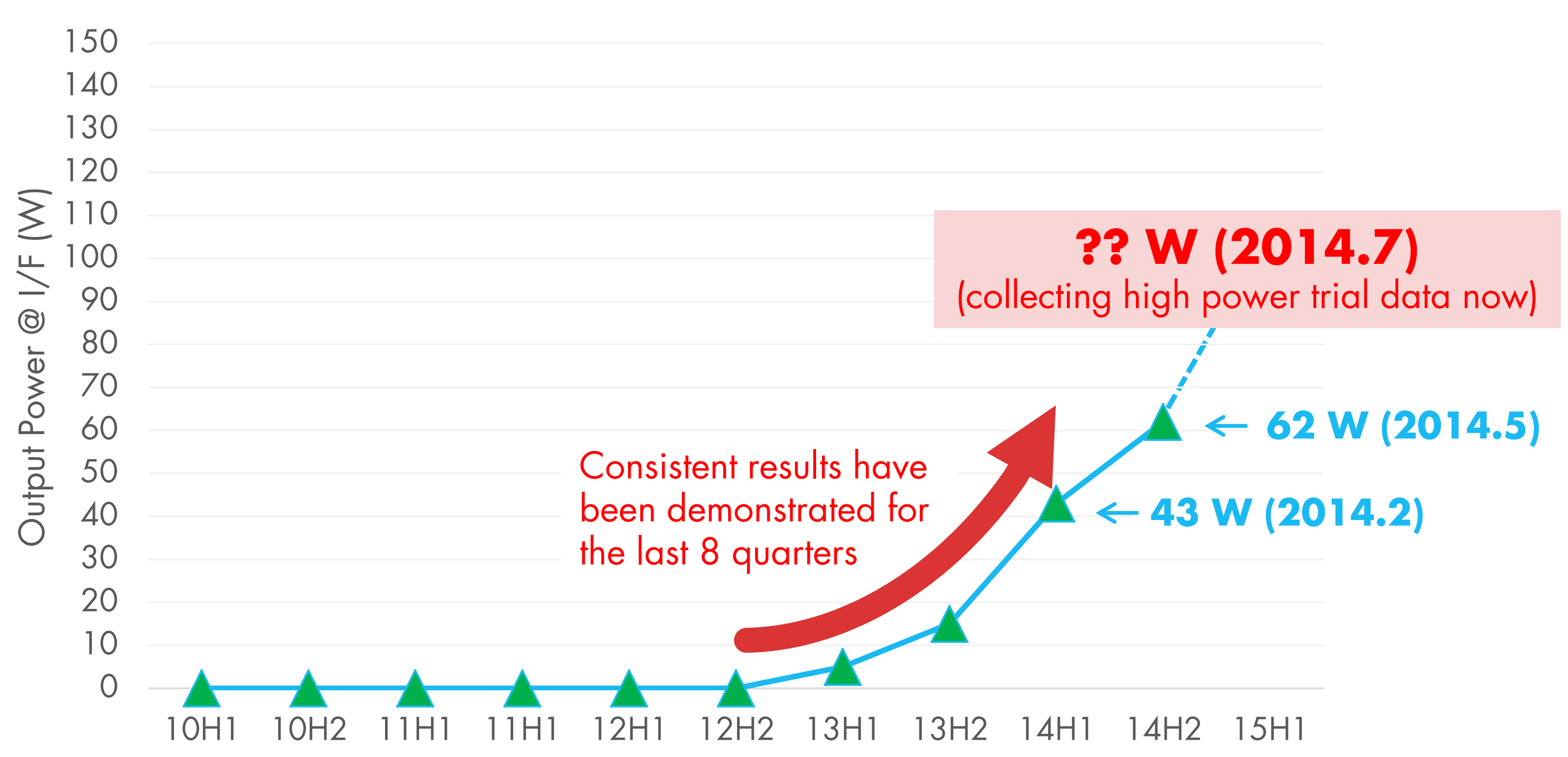
Power-up Scenario of HVM Sources



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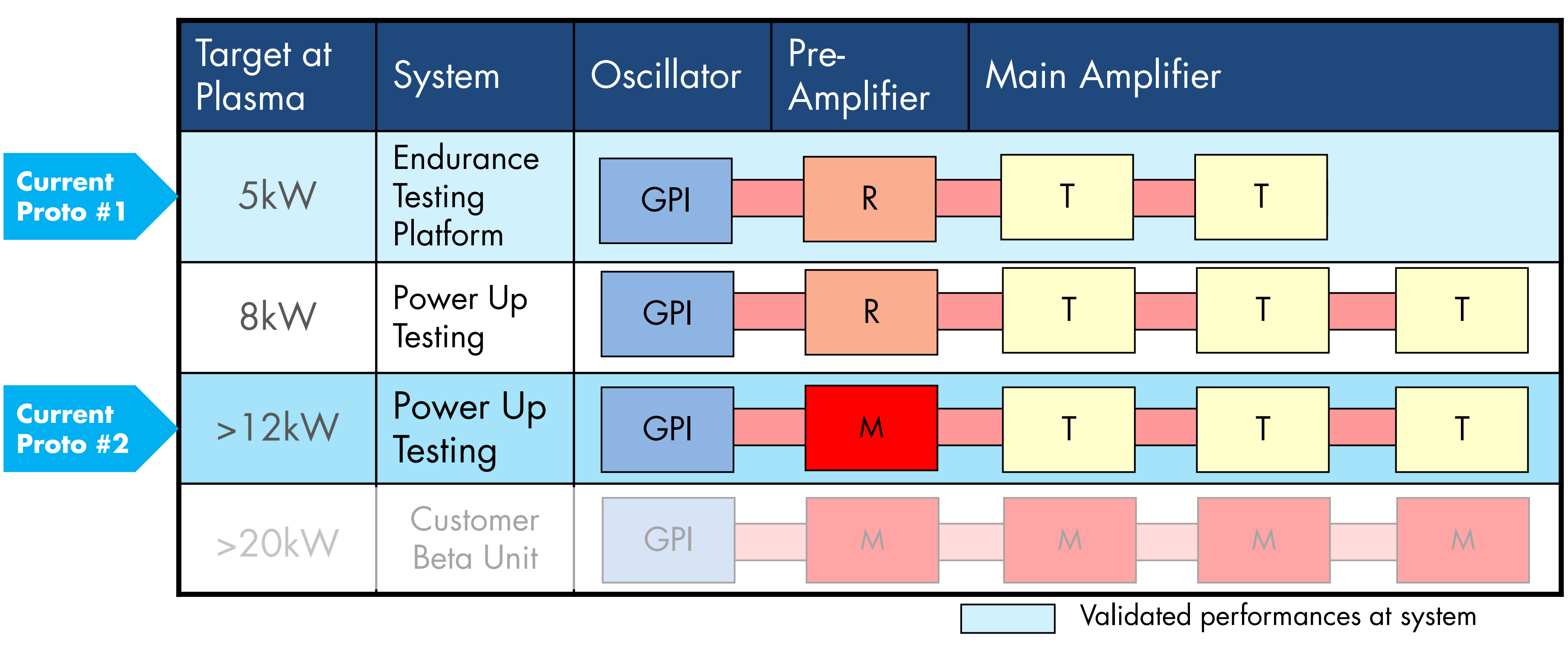
Power-up Scenario of HVM Sources

Next target is 12 kW by upgrading the pre-amplifier (installation is on going now)



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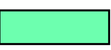
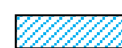
Power-up Scenario of HVM Sources

We are achieving **solid** and **steady** progress towards realizing our HVM EUV source

New Data Available Very Soon!

Next Target

EUV clean power	25W	43W	**??W**	150W	**250W**
Target	2013, Q4	2014, Q1	2014,Q2	2014,Q4	2015,Q2
CO_2 power at plasma	5kW	8kW	14kW	>14kW	> 20kW
CE	2.5%	3%	**??%**	4%	> 4.5%
Plasma to IF clean	21.7%	21.7%	**??%**	26.7%	26.7%
CO_2 laser	2 main amp. system	3 main amp. system	Mitsubishi pre. amp.	Mitsubishi pre. amp	Mitsubishi main amp. system
Pre-pulse laser	ps-laser	ps-laser	ps-laser	ps-laser	ps-laser
Collector mirror	V3 type	V3 type	V5 type	V5 type	V5 type

 Performance was confirmed at 100kHz system  Performance was confirmed at 10Hz source or parts level

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AGENDA

- Key Technical Points of EUV LPP Light Source
  - » Issues of EUV Light Source Power
  - » History of LPP Technology
- Gigaphoton's LPP Light Source Concept
  - » Droplet Generator
  - » Pre-pulse Technology
  - » Collector Mirror and IR Reduction Technology
  - » Debris Mitigation Technology
- Gigaphoton's High Power LPP Light Source System Development
  - » Debris Mitigation Technology Update
  - » Output Power Update
- Power-up Scenarios of HVM EUV Light Sources
- Summary

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Summary

- Component technology progress
  - 20 μm droplets at 100 kHz operation was successfully ejected by downsized nozzle.
  - Development of new generation collector mirror with IR reduction technology is on going.
- Proto #2 LPP source
  - Intermediate results showing 62 W EUV clean power @ I/F at 50 kHz operation was seen in May. EUV energy drop in high repetition rate operation is currently undergoing improvements.
  - High conversion efficiency (CE) of 3.9% at 50 kHz operation was seen using picosecond pre-pulse laser.
- Proto #1 LPP source
  - Promising results from debris mitigation performance tests were obtained using 20 μm droplets.
  - Next step is to eliminate the Sn depositions caused by the ion catcher.
- Power-up scenario of HVM source
  - Plan to upgrade CO_2 power to 20 kW is in progress.
  - New >20 kW CO_2 laser amplifier is under development in co-operation with Mitsubishi electric.
  - Target shipment of first customer beta LPP light source unit is 2015.

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Thank You