International Symposium on
Extreme Ultraviolet Lithography

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Performance of One Hundred Watt HVM LPP-EUV Source

2014 International EUVL Symposium @ Washington D.C., USA

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AGENDA

- LPP Light Source Concept and Component technology
  - » Pre-pulse Technology
  - » Collector Mirror and IR Reduction Technology
  - » Debris Mitigation Technology
  - » Driver CO2 laser
- Gigaphoton's High Power LPP Light Source System Development
  - » Output Power Update
  - » Potential performance
- Power-up Scenarios of HVM EUV Light Sources
- Summary

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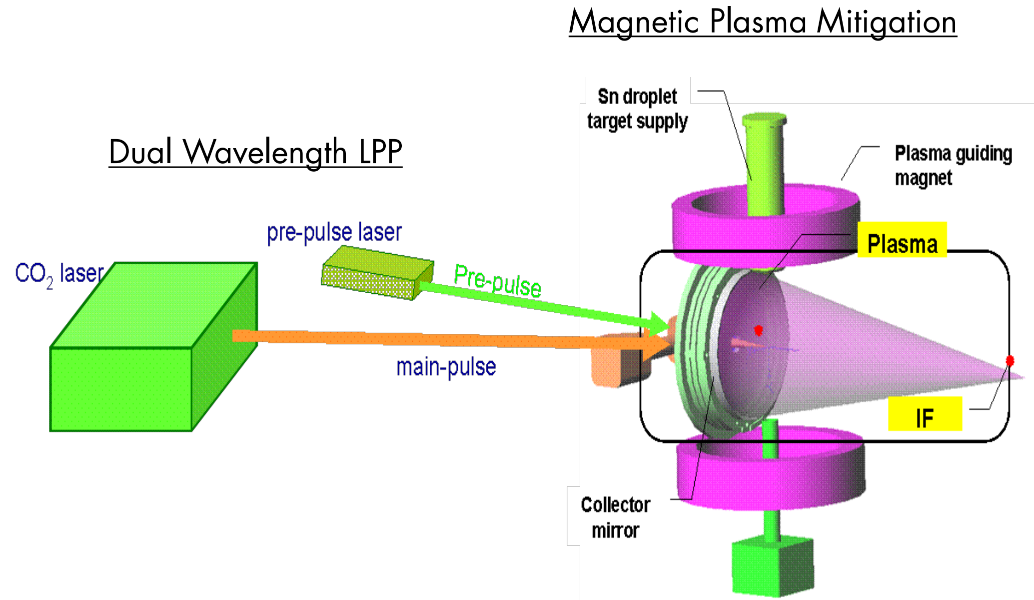
Gigaphoton's LPP Light Source Concept

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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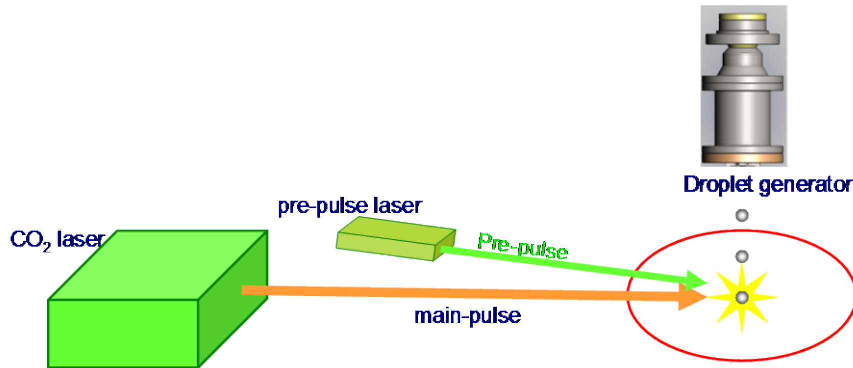
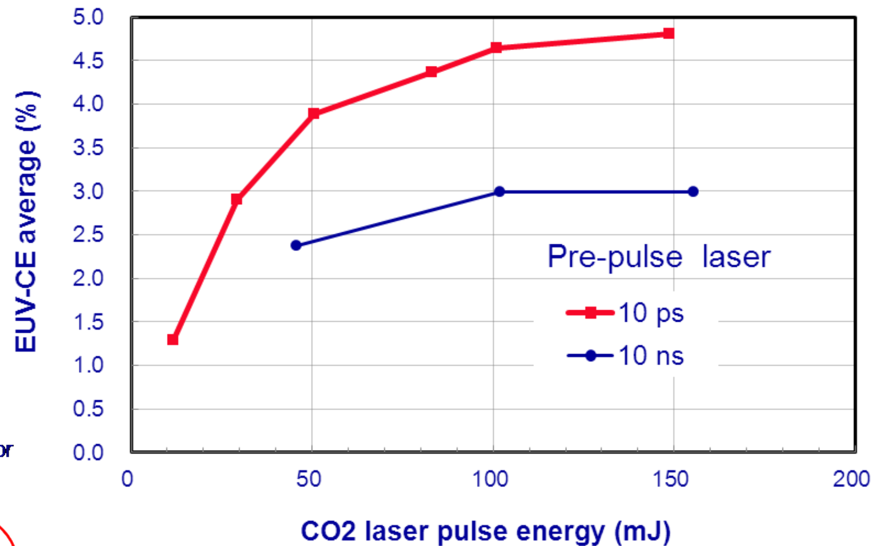
Pre-Pulse Technology (1)

- 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 in low repetition rate (2Hz).
- **We are achieving this high Ce operation under high repetition rate, high duty cycle operation condition.**





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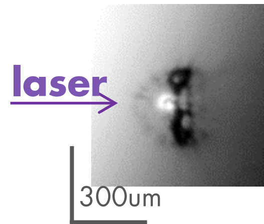
Pre-Pulse Technology (2)

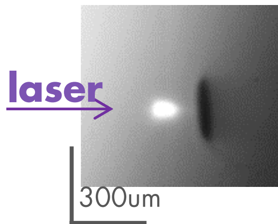
Experiment shows picosecond pre-pulse dramatically enhances ionization rate and CE

Sn Droplet Smash

psec — Dome like target



nsec — Flat disk like target



Data in 10 Hz Experimental Device

10Hz source data

Ioniation performance

Ionization rate

100%
80%
60%
40%
20%
0%

0 20 40 60 80 100

CO2 pulse energy on droplet

Proto performance

ns-pulse laser — ps-pulse laser

CE performance

Conversion efficiency (%)

5
4
3
2
1
0

0 20 40 60 80 100

CO2 pulse energy (mJ)

Proto performance

ns-pulse laser — ps-pulse laser

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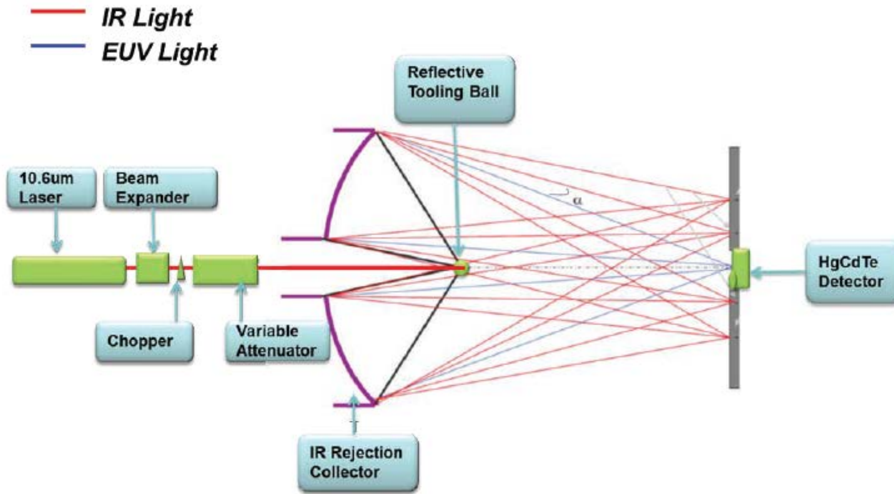
Collector Mirror Technology (1)

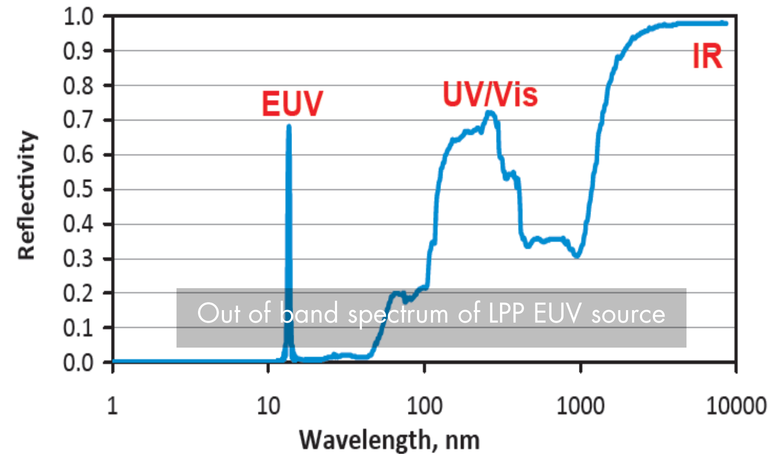
Collector Mirror progress

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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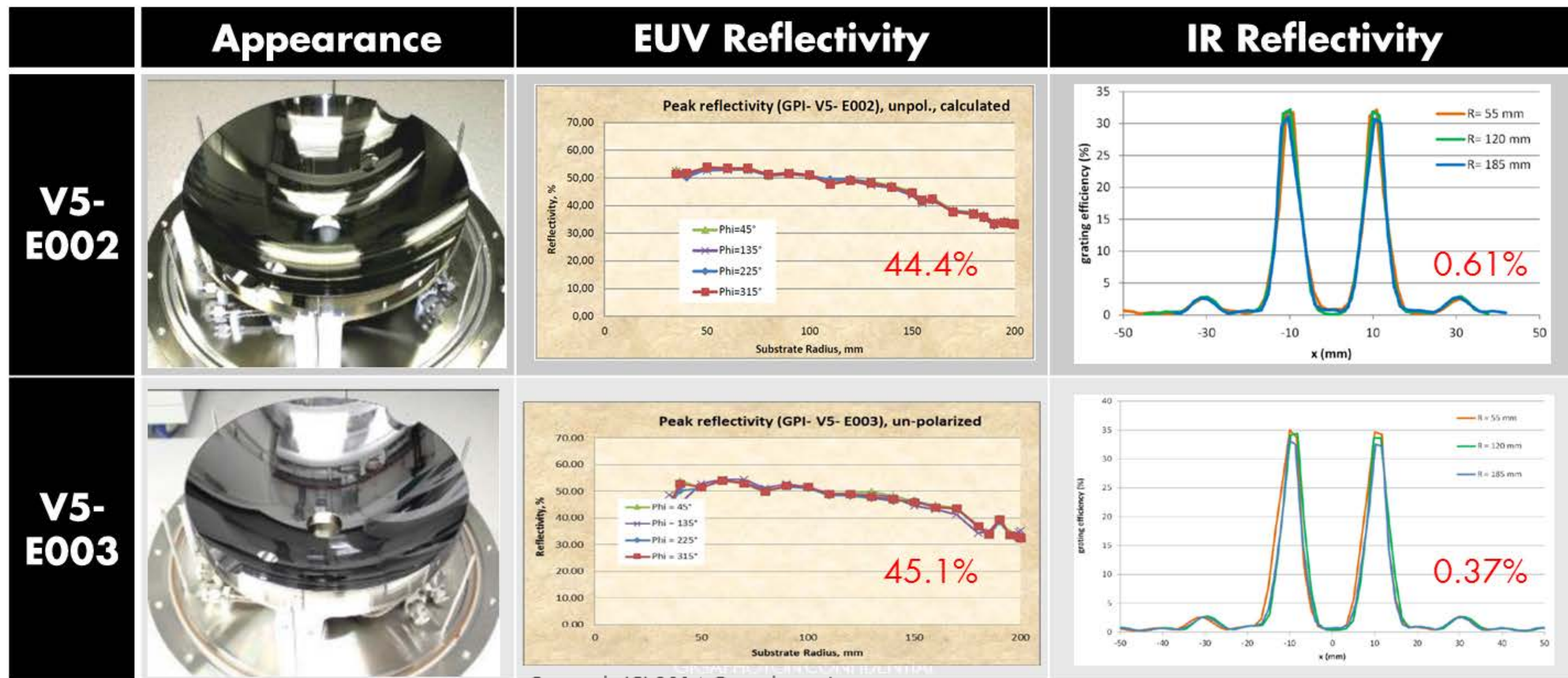
Collector Mirror Technology (2)

Collector mirror status

- Collector mirror with grating structure (V5 type) was successfully developed. Efficiency from plasma to clean would be improved from 21.6% to 26.7%.



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Debris Mitigation Technology (1)

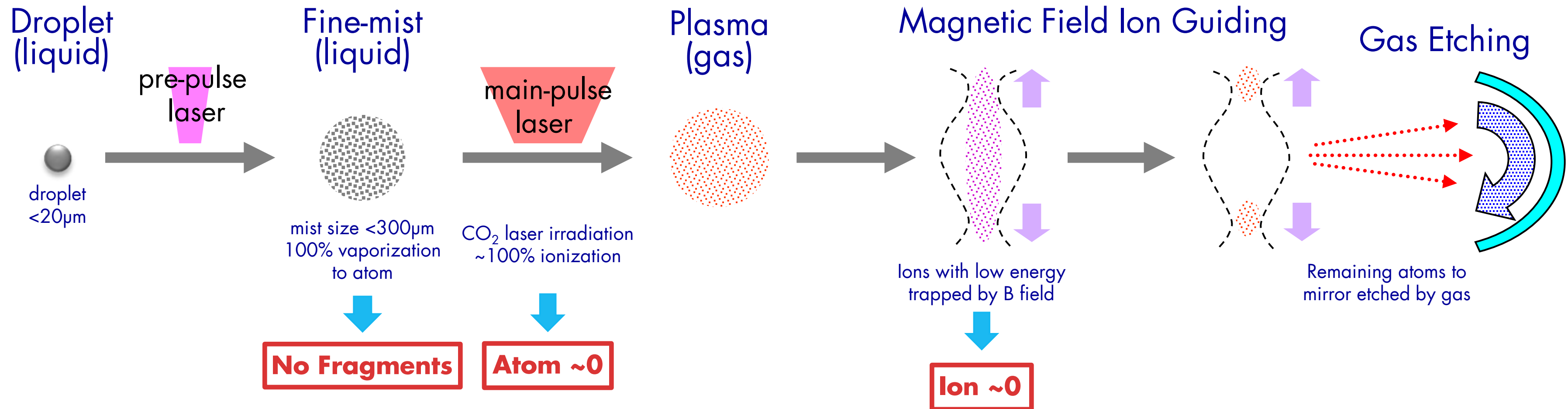
Gigaphoton's Magnetic Debris Mitigation concept

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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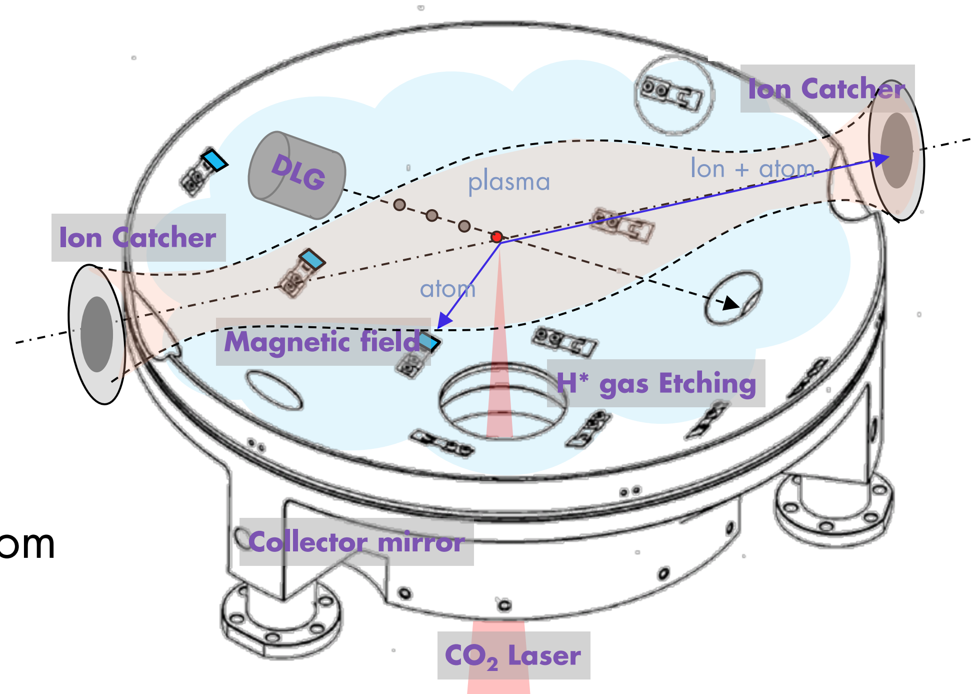
Debris Mitigation Technology (2)

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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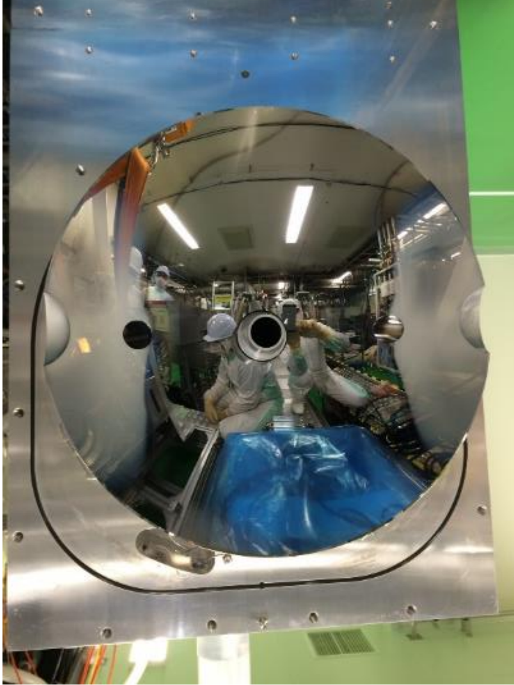
Debris Mitigation Technology (3)

EUV Light Source for Debris Mitigation Testing



Mounting the collector mirror

Clean area is maintained during day level operation

B field

After 27Mpulse/3days with P(I/F)=10W@20kHz

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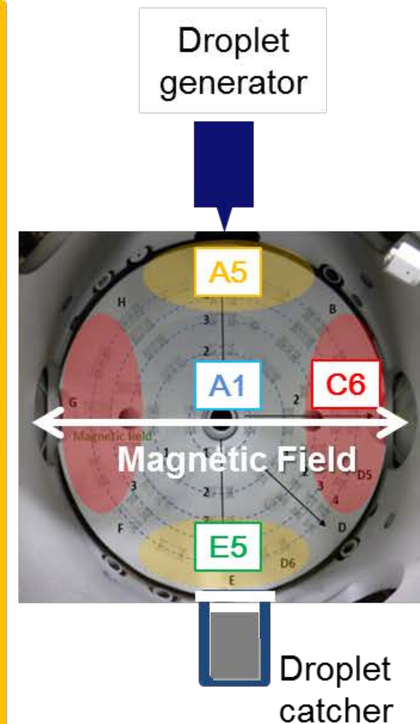
Debris Mitigation Technology (4)

Debris mitigation: SEM image

	2014 Jan	2014 Apr	2014 Jun	2014 Jul.
A1 sample Center of collector mirror SEM x10,000 Center	0.1nm/Mpls	0.075nm/Mpls	0.003nm/Mpls	0.002nm/Mpls
E5 sample SEM x1,000 Lower	8.7nm/Mpls	1.1nm/Mpls	0.62nm/Mpls	0.67nm/Mpls
A5 sample SEM x1,000 Upper	4.1nm/Mpls	0.16nm/Mpls	0.012nm/Mpls	0.008nm/Mpls
C6 sample SEM x1,000 Ion catcher side	25.1nm/Mpls	18.8nm/Mpls	25.9nm/Mpls	9.9nm/Mpls



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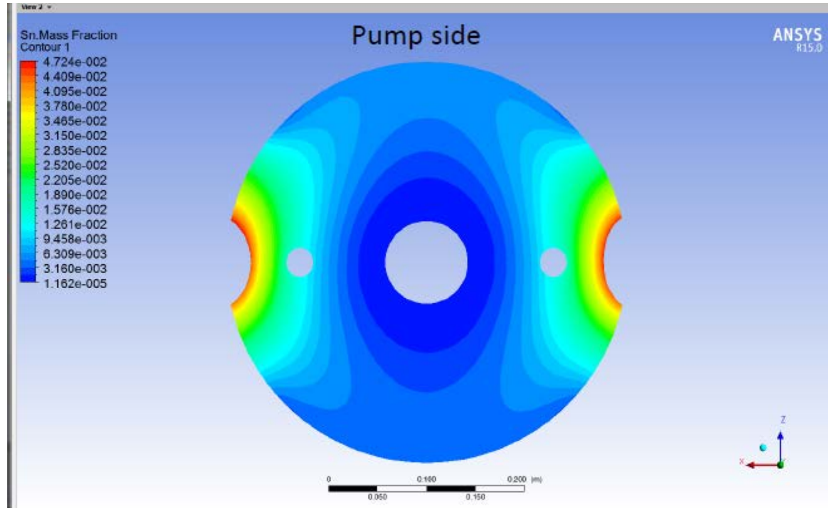
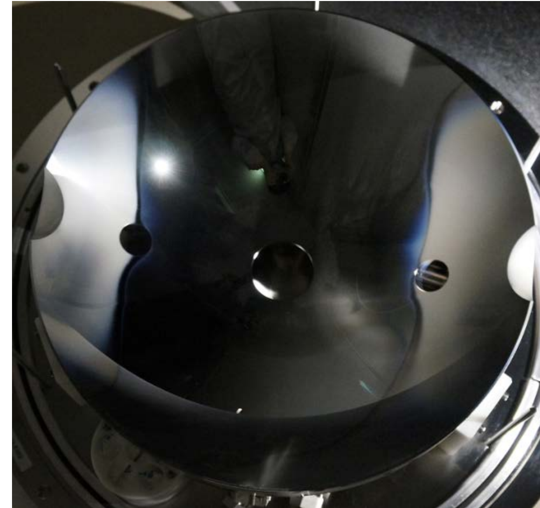
Debris Mitigation Technology (5)

Analysis: Tin Ion Catcher

- Tin depositions re-introduced from the ion catcher accumulates on the collector mirror
- We are improving the tin ion catcher mechanism to address this issue



Tim Deposition Simulation



Actual Tin Deposited on Collector

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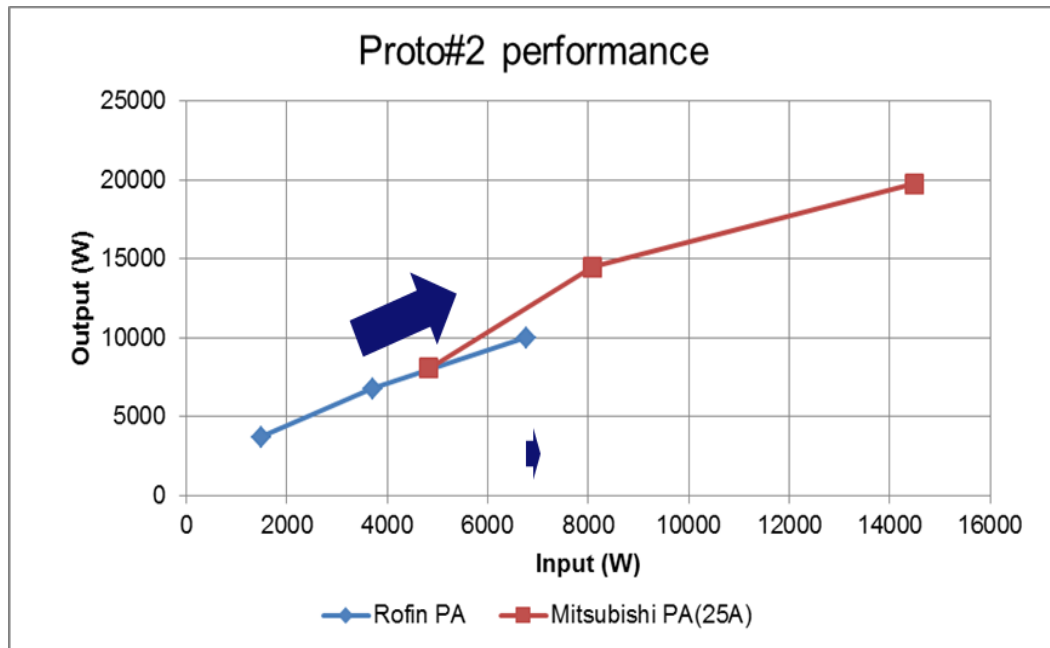
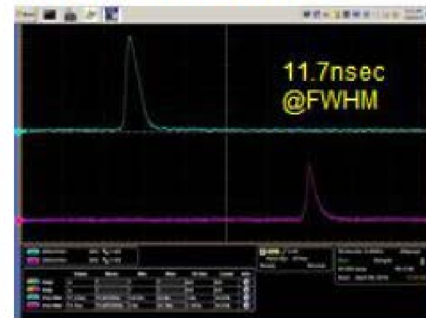
CO_2 laser driver Technology (2)

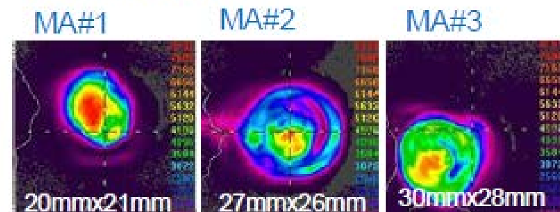
CO_2 laser driver system test result



Pulse waveform



Beam Profile



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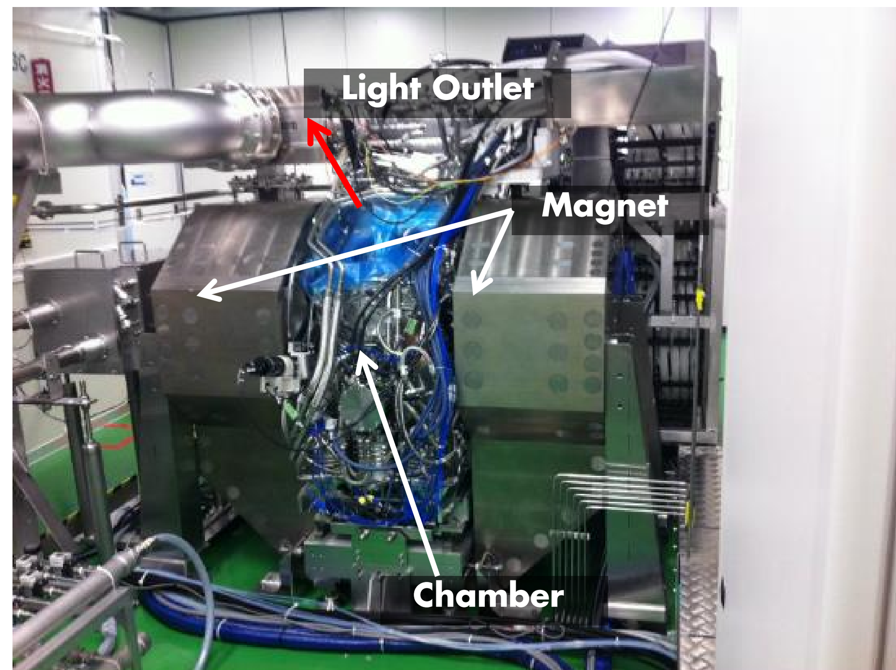
High Power EUV Light Source of Gigaphoton

- Proto type of high power EUV light sources are in operation

Proto 1 Exposure & Mitigation test

Proto 2 High power Experiment



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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
	CO_2 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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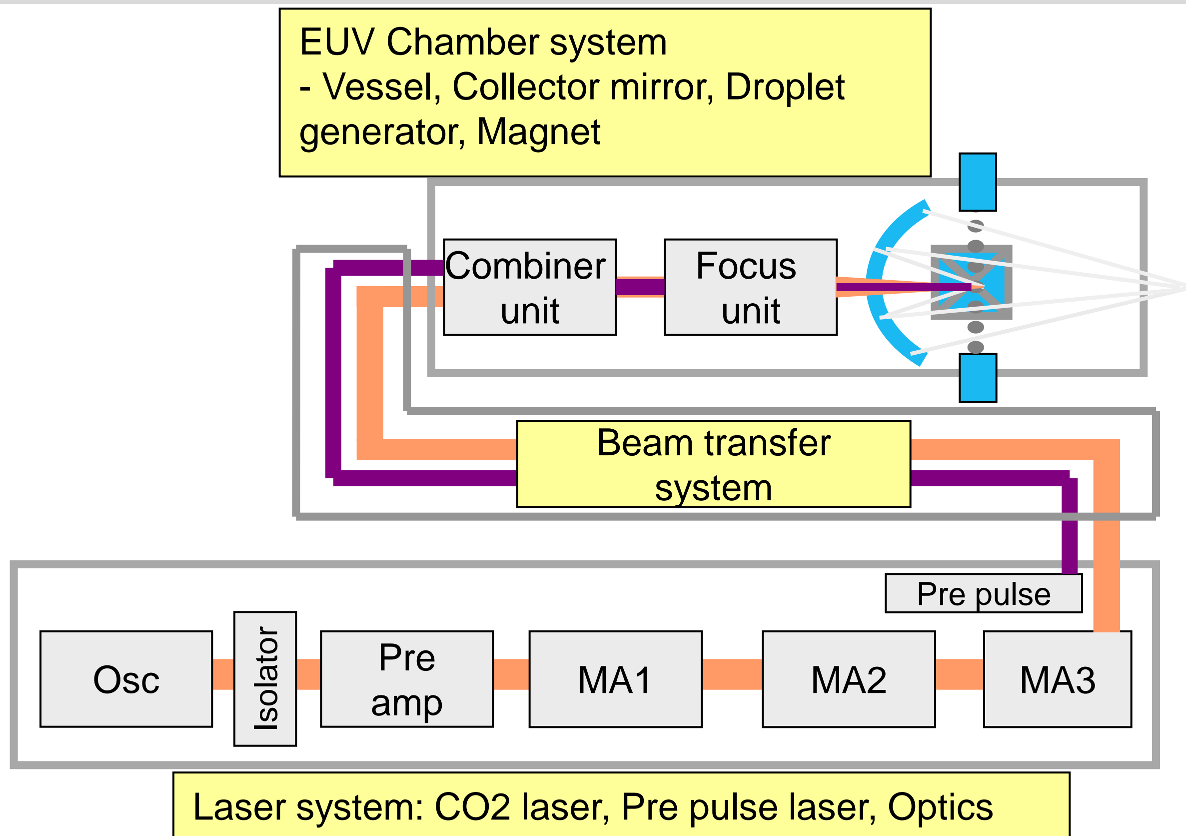
Driver Laser System Configuration

- Proto#1
  - » 5kW CO2 power at 100kHz by 2 MA CO2 laser system.
- Proto#2
  - » 17kW CO2 power at 100kHz by 3 MA CO2 laser system.
  - » Target is > 100W EUV clean power.
- Pilot#1 (Designing)
  - » 25kW CO2 power at 100kHz by using Mitsubishi amplifier system.
  - » Target is 250W EUV clean power



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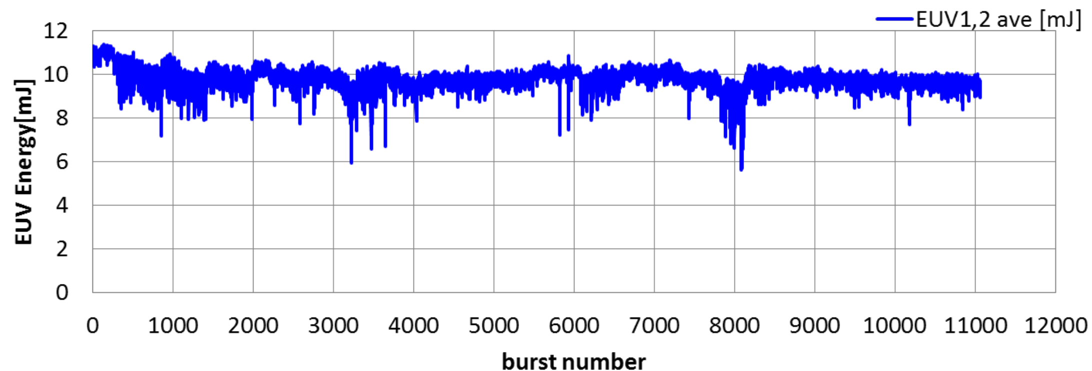
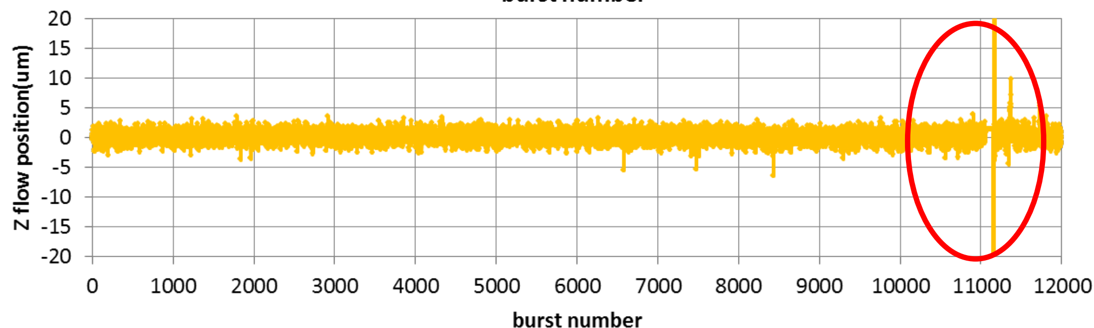
20kHz, 50% D/C: EUV power operation data

- 42W in burst, 21W average (42W x 50%) output power for 3hours (110Mpls)
  - » 20KHz 50% duty (10000pls/0.5ms OFF)





Rep.rate	20kHz
EUV energy (ave.)	9.79mJ
IF power @ clean	42W
CO_2 energy(ave.)	273mJ
CE	3.6%
EUV stability (3s)	14%
Pulse number	110Mpls
DLG	CJ1551-3
Droplet.diameter	25um
Droplet.spacing	500um
DL catcher	Type C
Ion catcher	Type D (L=200)

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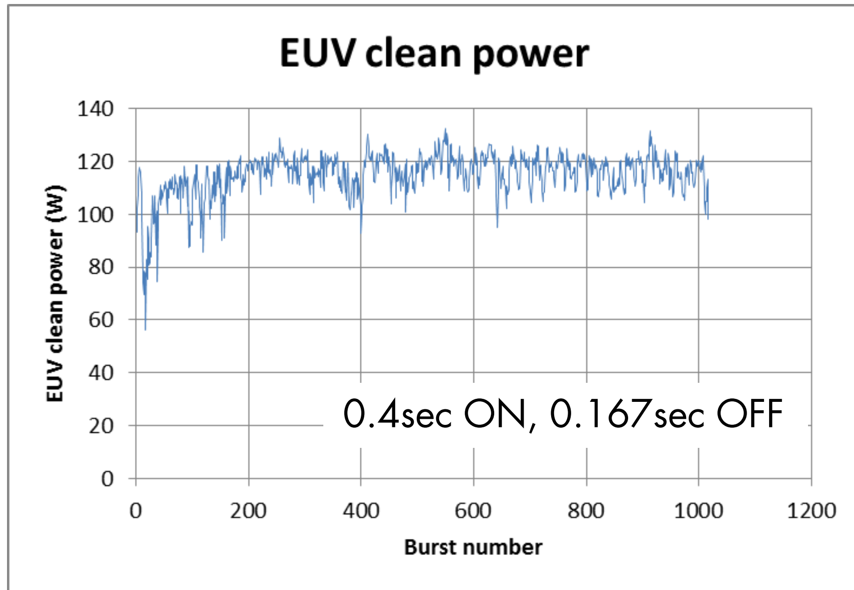
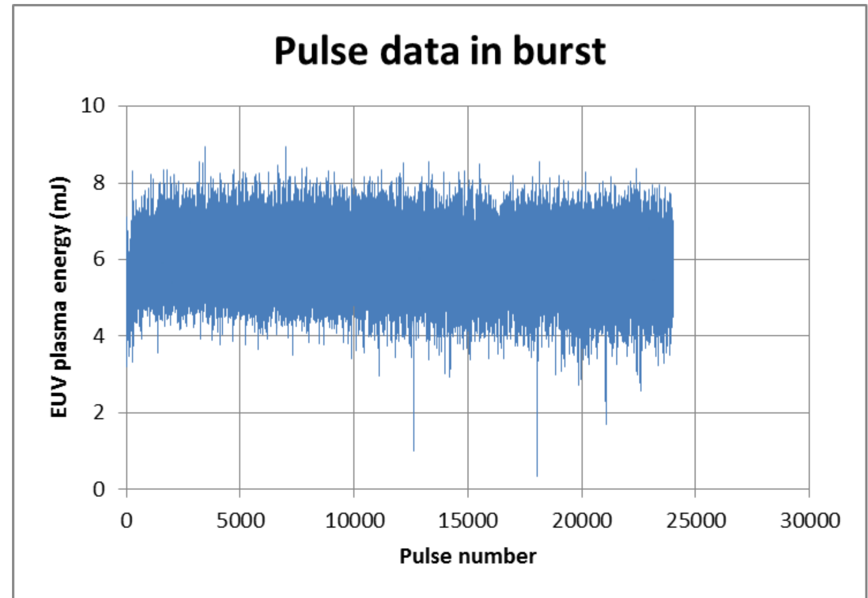
60kHz, 70% D/C: EUV power operation data

- 118W output with 3.7%CE, 60kHz, 70% duty cycle (Clean power in burst)
- 83W (=118W x 70%) output in average power.





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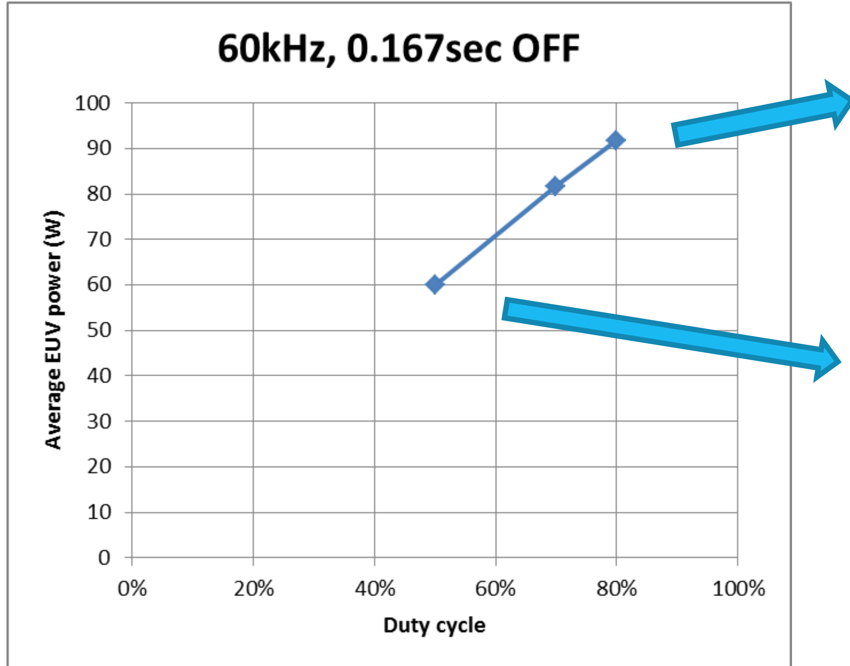
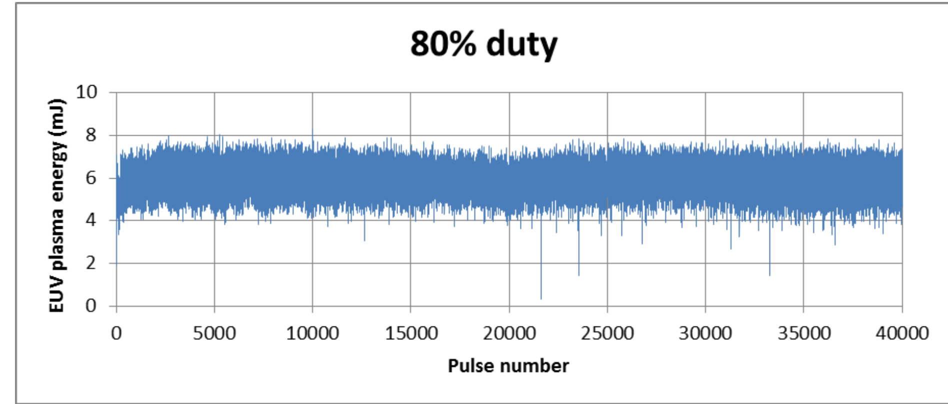
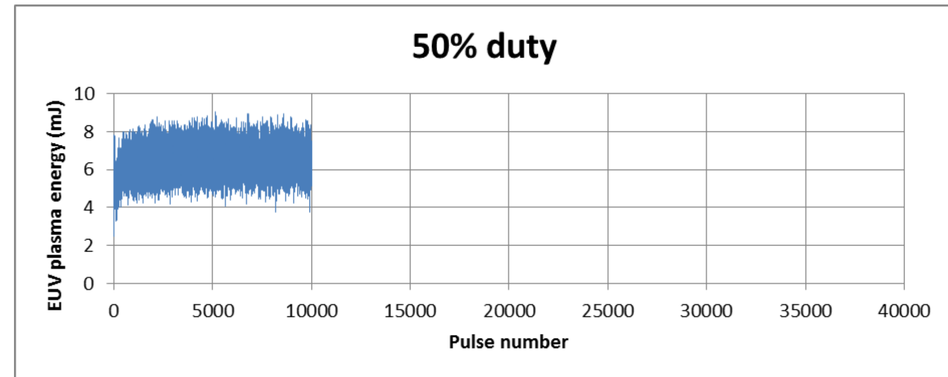
Potential of higher duty cycle operation







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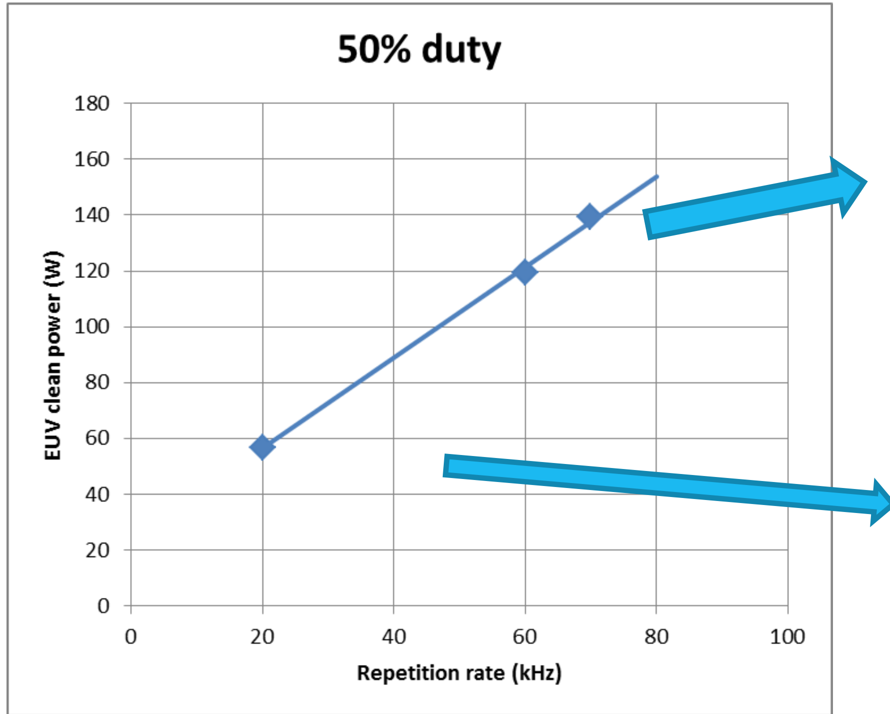
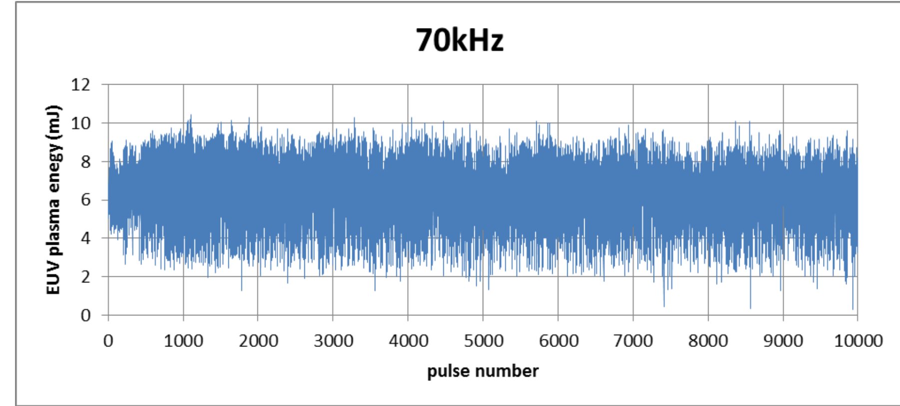
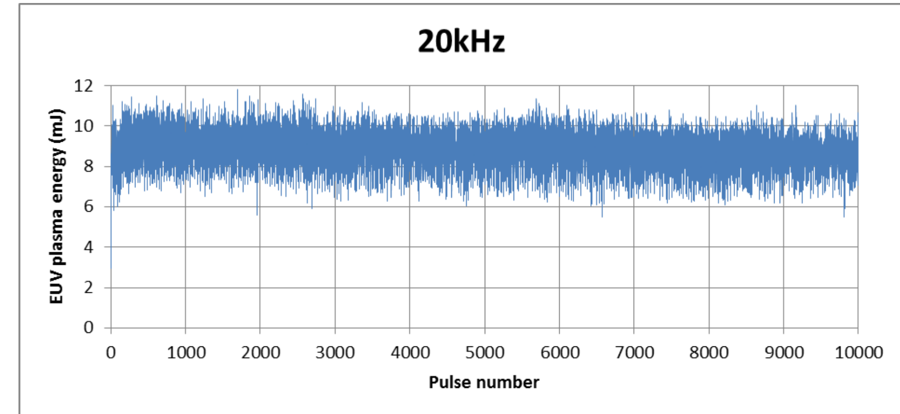
Potential of higher repetition rate operation







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EUV average power improvement and potential

Note: C1 mirror was changed to V5 from V3.

		2014 May Proto#2	2014 Jun Proto#2	2014 Sep Proto#2	2014 Oct Proto#2	Potential performance
EUV performance	EUV average power	3W	46W	**21W**	**83W**	(112W)
	EUV clean power	60W	92W	**42W**	**118W**	(140W)
	Duty cycle	5%	50%	50%	**70%**	80%
	Repetition rate	50kHz	50kHz	20kHz	**60kHz**	70kHz
	CE	3.7%	4.2%	3.6%	**3.7%**	3.7%
	Operation time	-	-	**3hour**	10min	
System parameter	Collector	V3	V3	V3	V5	V5
	Efficiency from plasma to clean	21.6%	21.6%	21.6%	31.6%	31.6%
	H2	7Pa	7Pa	7Pa	11Pa	11Pa
	CO2 power	7.6kW	10kW	5.4kW	10.2kW	10.2kW

Remark: EUV average power = EUV clean power x duty cycle , open loop F/B
Out of band DUV filter condition was revised sinse Oct.2014 data

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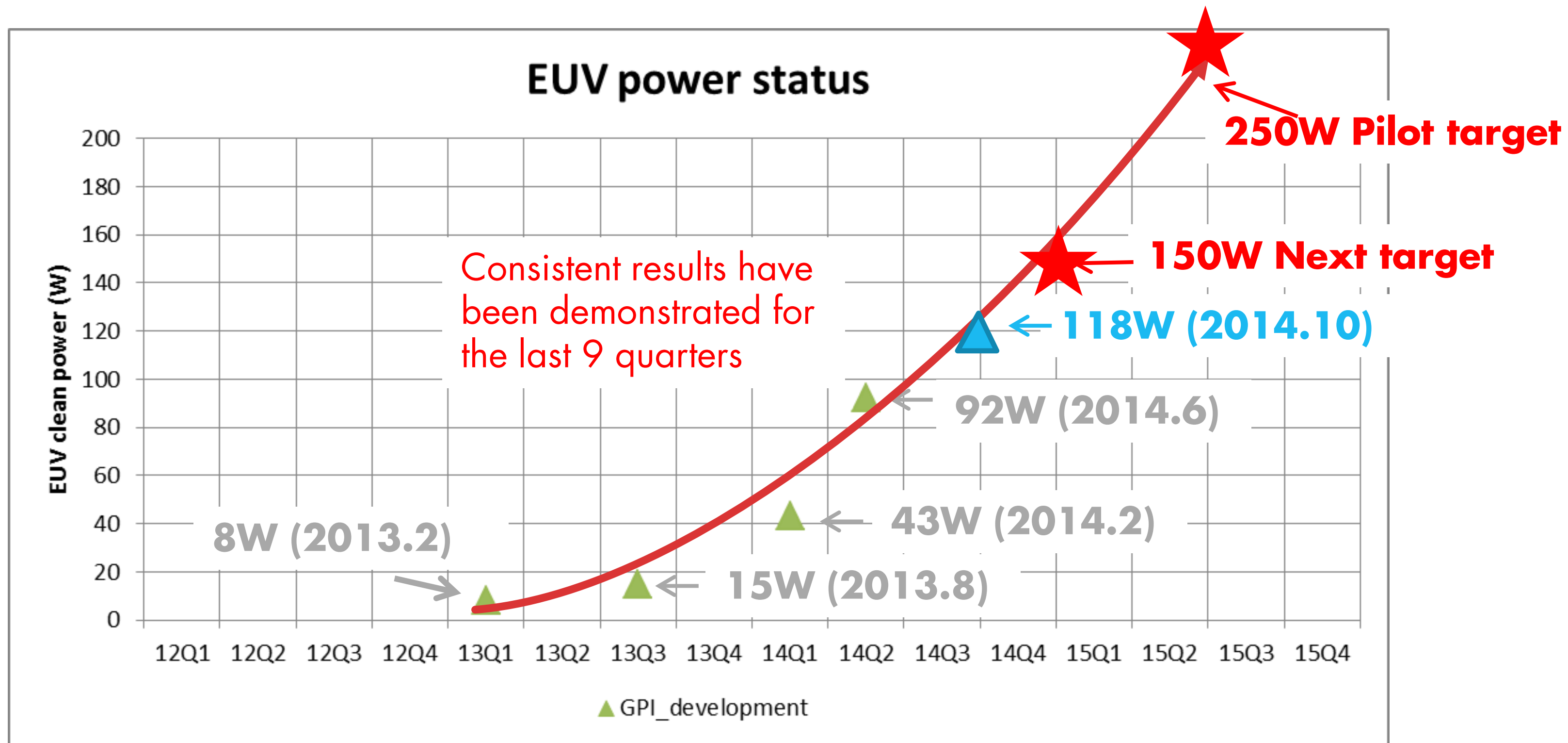
EUV Power achievement and Target



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Power-up Scenario of Driver Laser System

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

	Target at Plasma	System	Oscillator	Pre-Amplifier	Main Amplifier		
Current Proto #1	5kW	Endurance Testing Platform	GPI	R	T	T	
	8kW	Power Up Testing	GPI	R	T	T	T
Current Proto #2	14kW	Power Up Testing	GPI	M	T	T	T
Pilot #1	>20kW	Customer Beta Unit	GPI	M	M	M	M

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Power-up Scenario of HVM Sources

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

				Next Target	Pilot #1
EUV clean power	25W	43W	**118W**	**150W**	**250W**
Target	2013, Q4	2014, Q1	**2014,Q3**	**2014,Q4**	**2015,Q2**
CO_2 power at plasma	5kW	8kW	**10.2kW**	**>14kW**	**> 20kW**
CE	2.5%	3%	**3.7%**	**>4.2%**	**> 4.5%**
Plasma to IF clean	21.7%	21.7%	**31.6%**	**31.6%**	**35.1%**
CO_2 laser	2 main amp. system: Proto#1	3 main amp. system: Proto#2	**Mitsubishi pre. amp.: Proto#2**	**Mitsubishi pre. amp :Proto#2**	**Mitsubishi main amp. system**
Collector mirror	Normal Type	Normal Type	**Grating Type**	**Grating Type**	**Grating Type**

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Summary

- Progress of component technology;
  - » Improvement of debris mitigation is reported; 4 hrs. continuous operation, deposition sampled at mirror center area was less than 0.006nm/MPls.
  - » Improvement data of IR reduction corrector mirror is reported
  - » Driver CO2 laser power at plasma point is improved from 10kW to 17kW

- Verified high output EUV light on Proto#2 unit
  - » New Data: 118W (CE3.7%) x 70%duty, 83W average power x10min
  - » and 42Wx3hours, clean output at IF under 50%Duty* were reported.
  - » Next step is to enable higher duty cycle and higher repetition rate operations. Potential data is reported.
- Design of the development pilot#1 is reported.

* Percentage of EUV emission during operation

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** The authors would like to express their deepest condolences to the family of Dr. Yoichi Tanino who suddenly passed away on February 1st, 2014. We are all indebted to his incredible achievements in CO_2 amplifier development. He will be missed very much.*

Collector mirror suppliers – especially **Rigaku** for providing us with useful data

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WASEDA University

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Thank You

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