One Hundred Watt Class EUV Source Development for HVM Lithography

2014 EUVSource Workshop @ UCD, Dublin Ireland

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DOC#

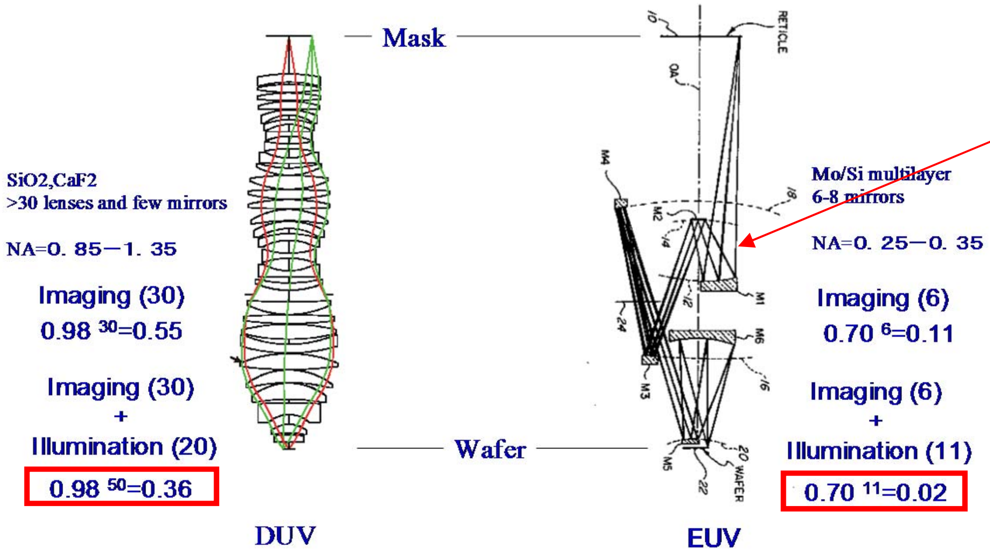
GIGAPHOTON

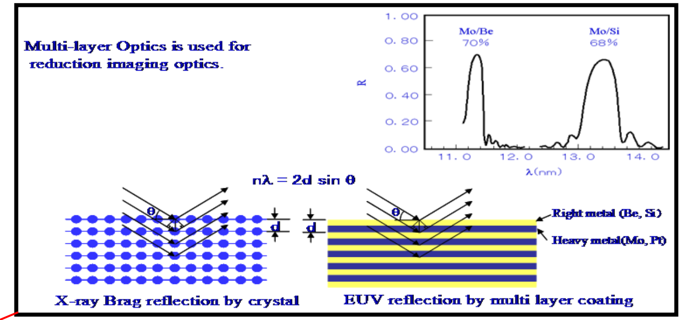
AGENDA

- Introduction
- LPP Light Source Concept and Component technology
  - » Droplet Technology
  - » Pre-pulse Technology
  - » Driver CO_2 laser
  - » Debris Mitigation Technology
  - » Collector Mirror and IR Reduction Technology
- Gigaphoton's High Power LPP Light Source System Development
  - » Output Power Update
  - » Potential performance
- Power-up Scenarios of HVM EUV Light Sources
  - » Construction of Pilot #1
- Summary

Technical Barrier of EUV Lithography

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



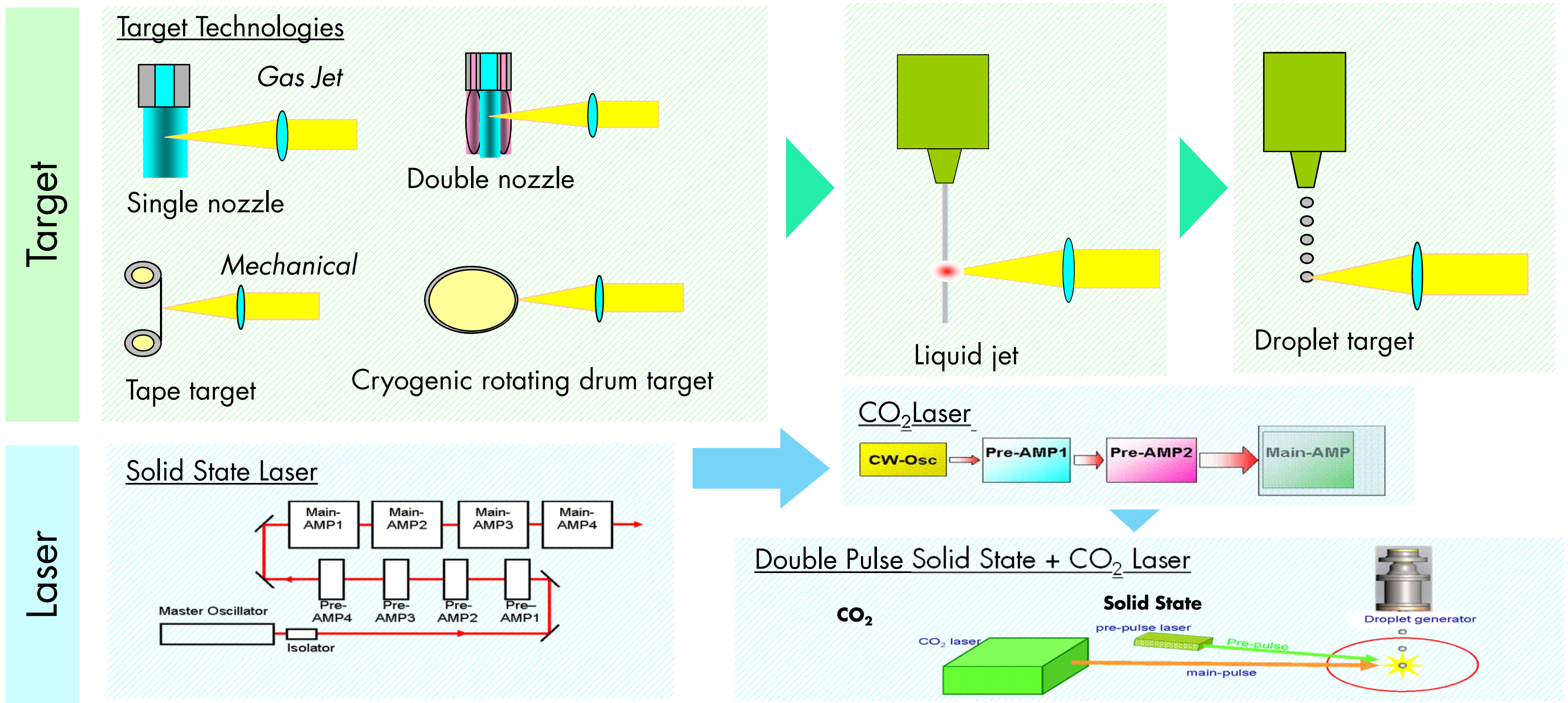


70% reflection

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

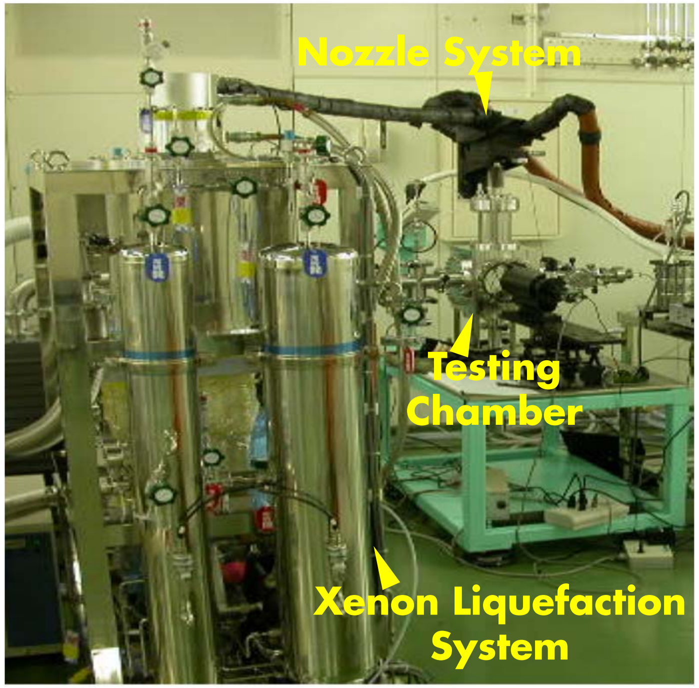
Demand is > 250W at first stage HVM

History of LPP Source Development (1)

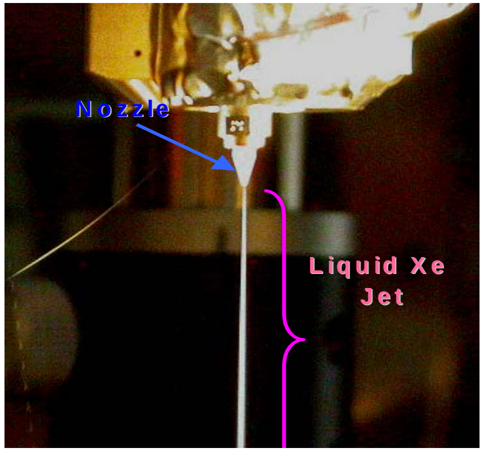


History of LPP Source Development (2)

Liquid Xe jet target experiment with YAG laser driver (2004)



Liquid Xenon Jet System



Xe Jet

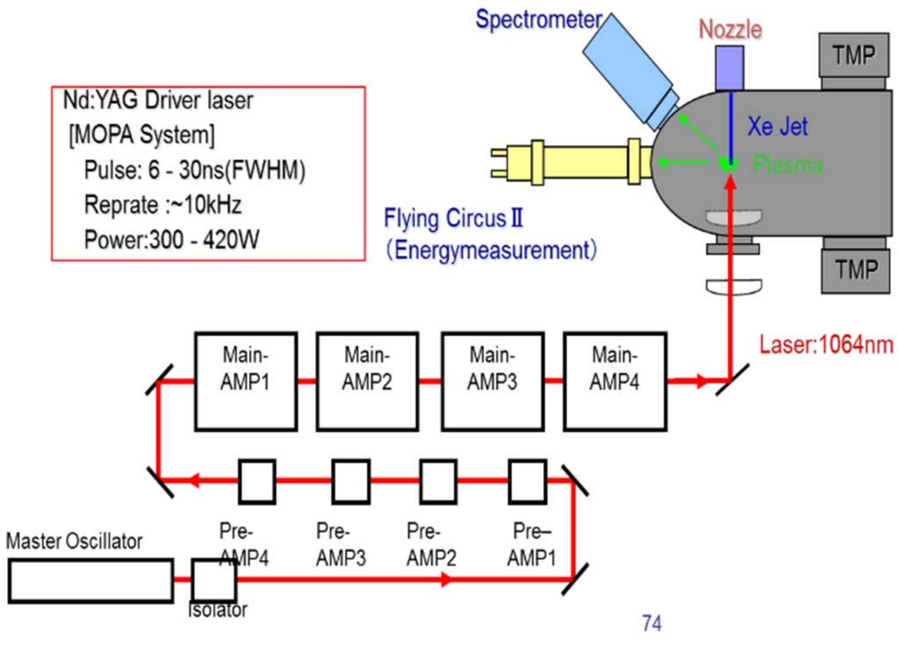
Velocity : 30 m/s
Stability σ : 10μm@10mm

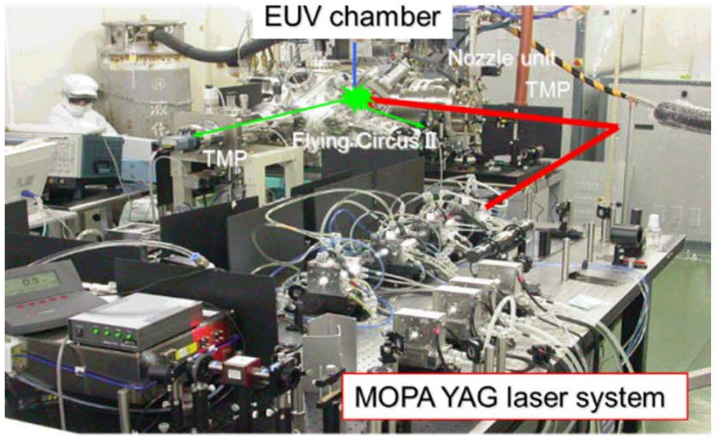
Xe Jet and Plasma

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

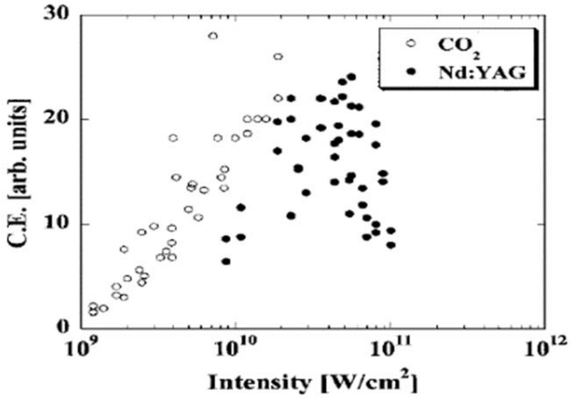
History of LPP Source Development (3)

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

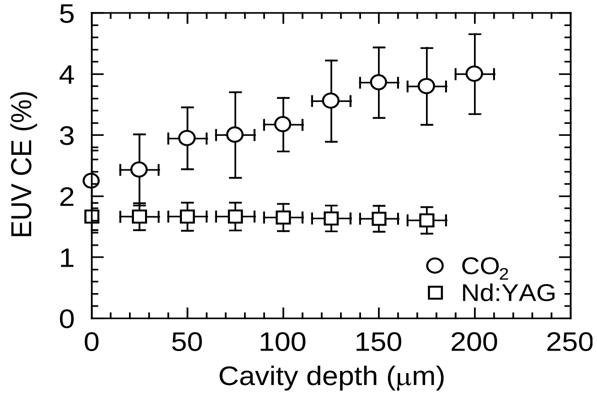




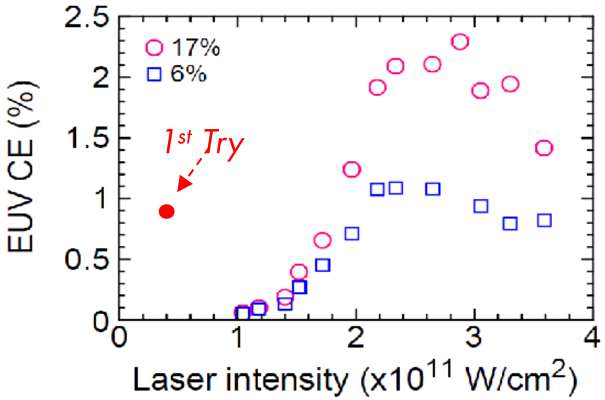
History of LPP Source Development (4)



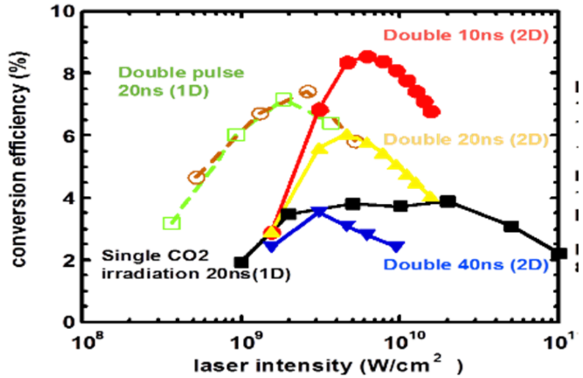
Kyusyu Univ. / H. Tanaka et al. / Appl. Phys. Lett. 87,041503 (2005)



EUV conversion efficiency (solid target) demonstrated in EUVA (2005)



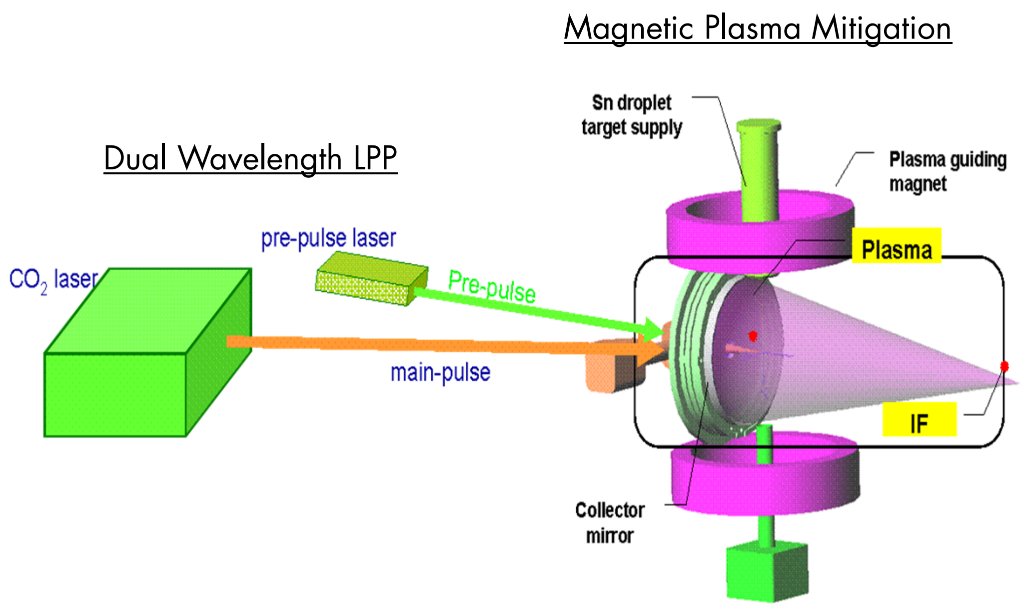
Miyazaki Univ. / T. Higashiguchi et al. / SPIE Microlithography 2006, 6151-146 (2006)



EUV conversion efficiency simulation by Osaka Univ. team (2006)

Gigaphoton's LPP Light Source Concept (2006)

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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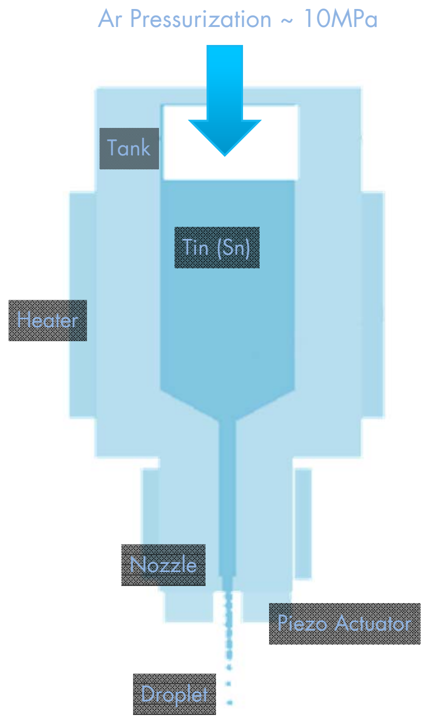
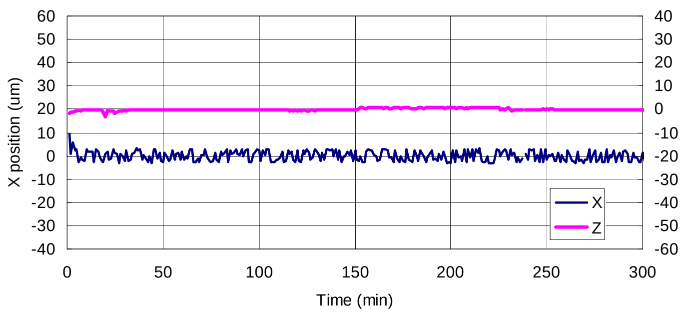
Droplet Technology (1)

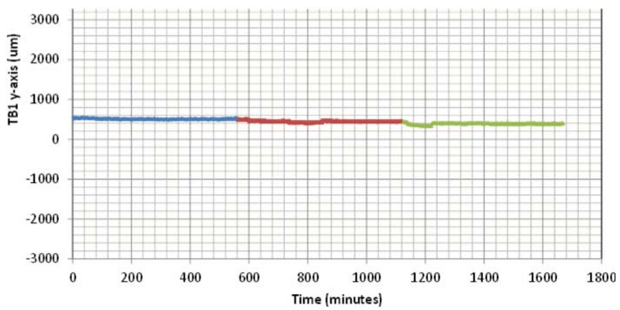
- The Droplet Generator is one of the key technologies for achieving HVM level EUV light sources
- Requirement for droplet generator
  - » Size of droplet is 20μm
    - Smaller droplet is better
      - – Debris mitigation
      - – Longer lifetime of droplet generator
    - Technical barrier is higher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

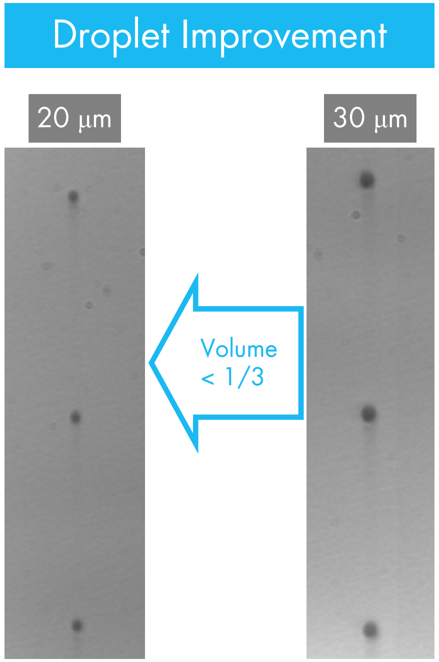


Droplet Technology (2)

- 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

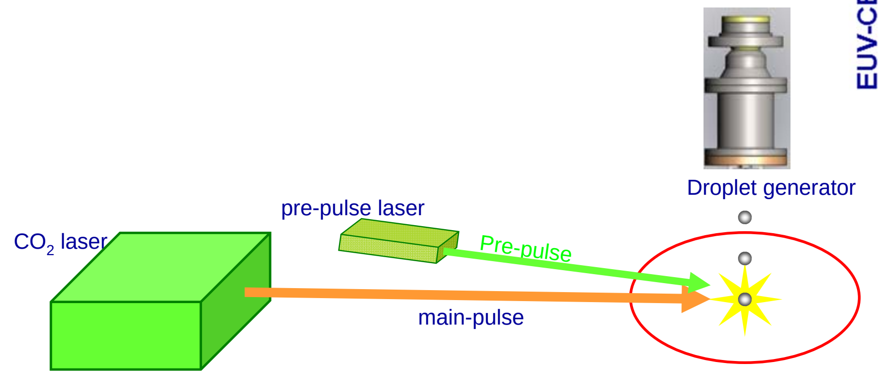


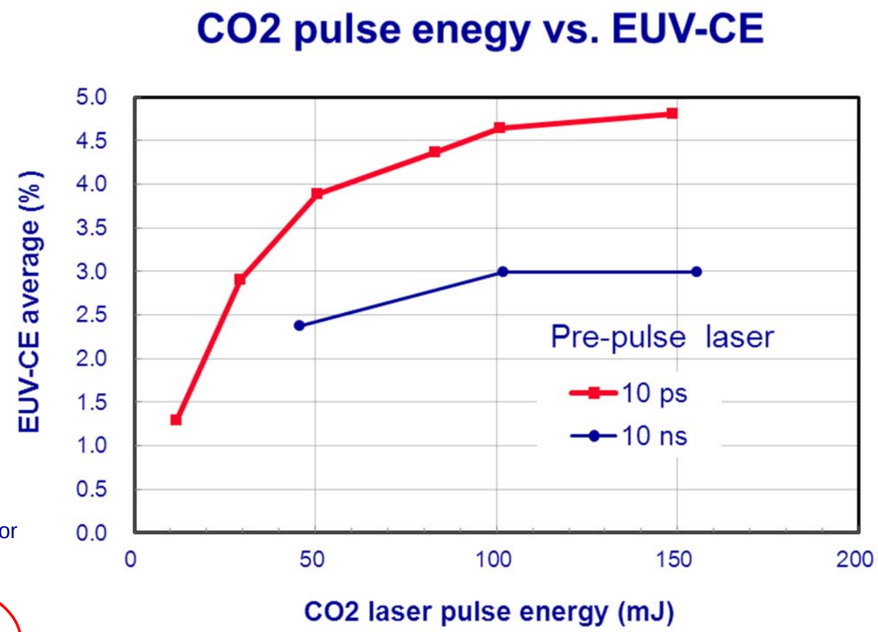




Pre-Pulse Technology (1)

- 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.**

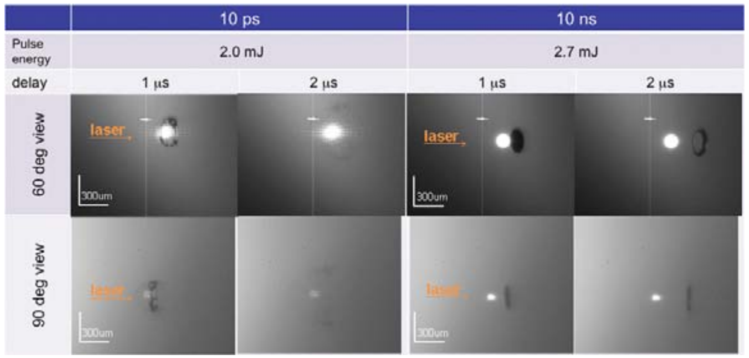


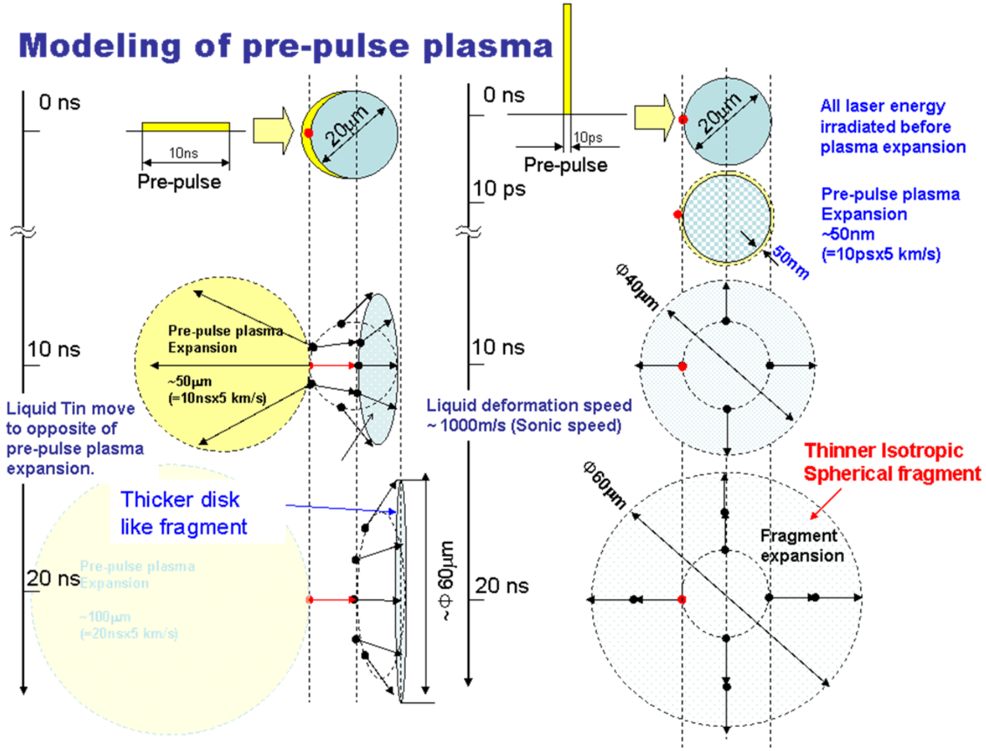


Pre-Pulse Technology (2)

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



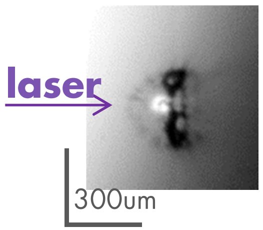


Pre-Pulse Technology (3)

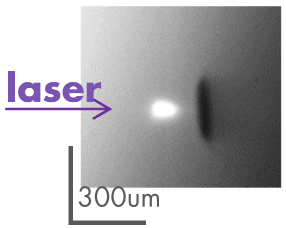
Experiment shows picosecond pre-pulse dramatically enhances ionization rate and CE

Sn Droplet Smash

psec Dome like target

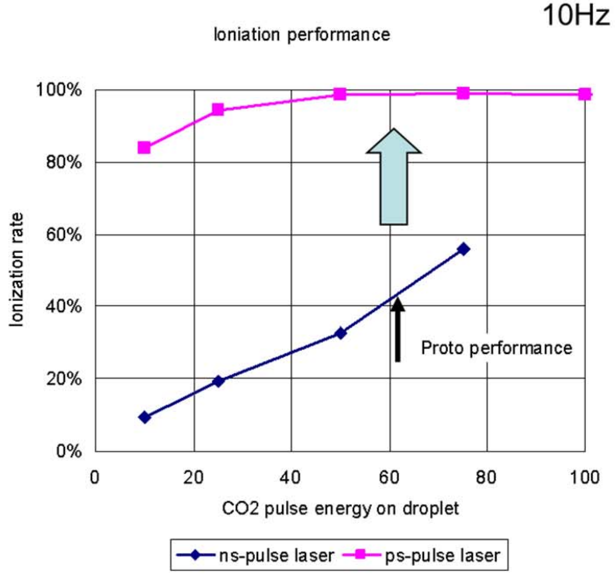


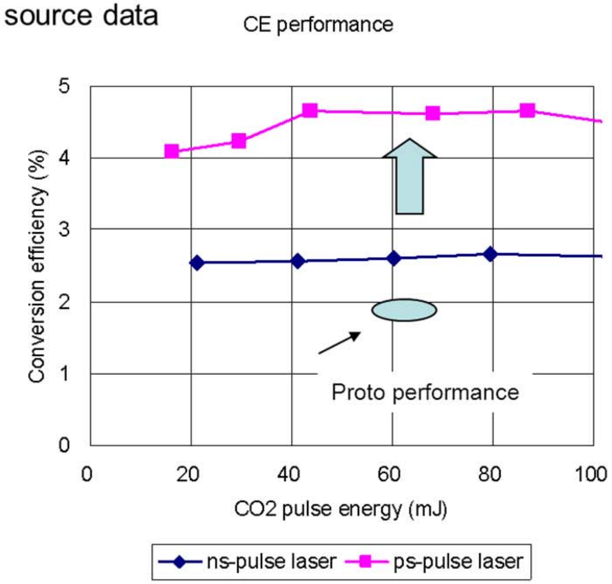
nsec Flat disk like target



Data in 10 Hz Experimental Device

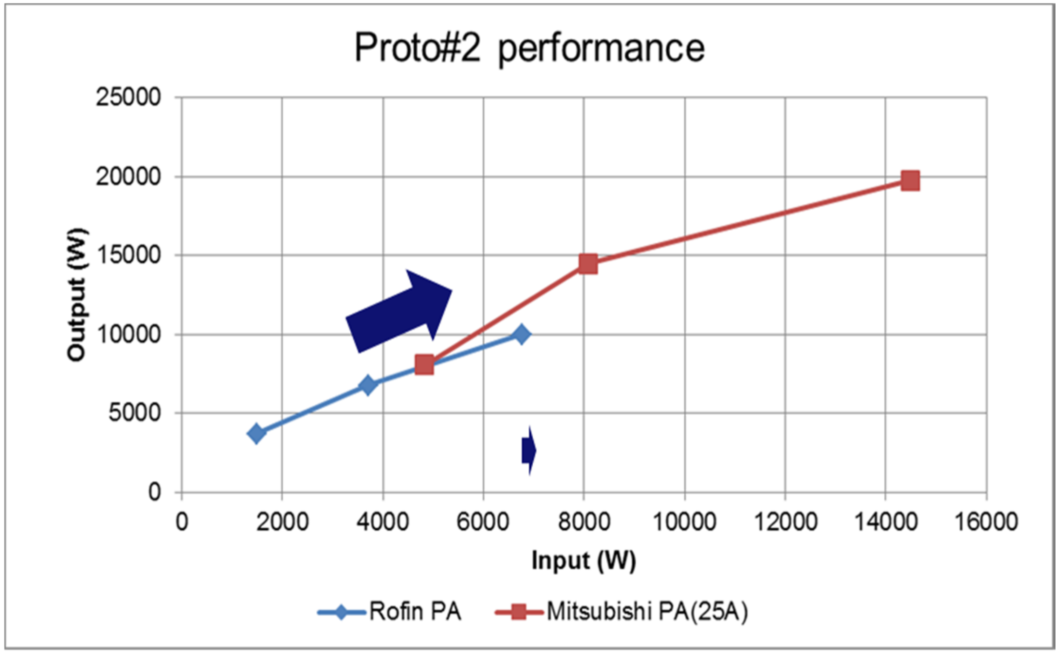
10Hz source data



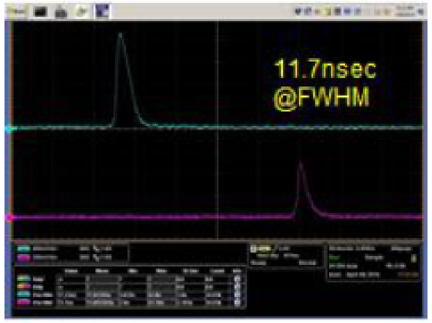


CO_2 laser driver Technology (2)

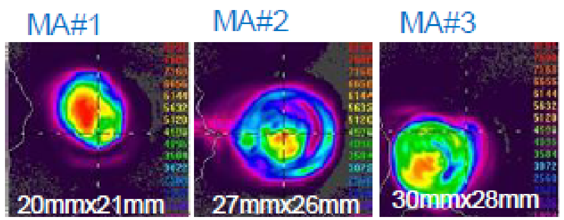
CO_2 laser driver system test result



Pulse waveform

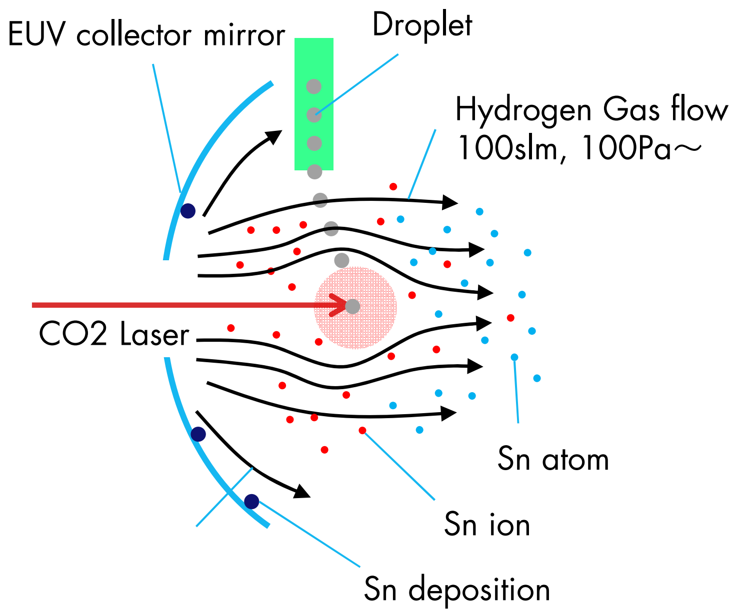


Beam Profile



Debris Mitigation Technology (1)

Gas mitigation method



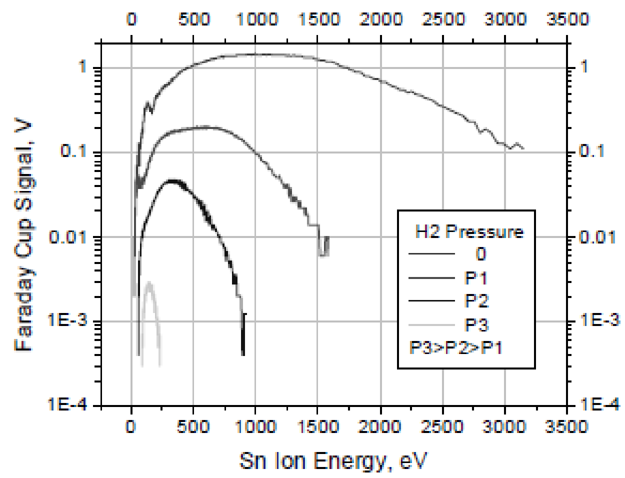
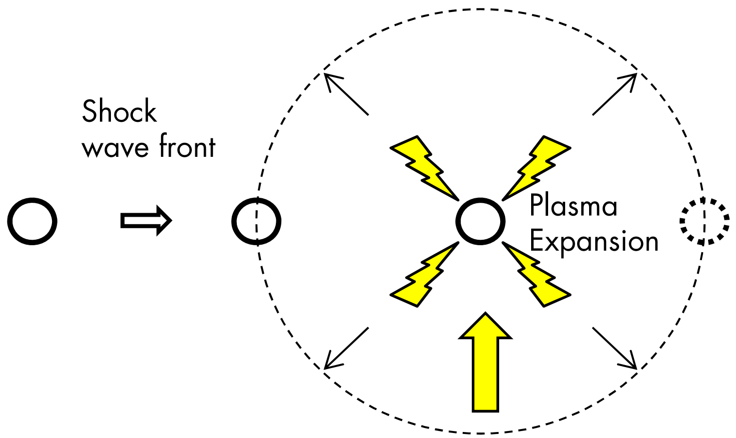


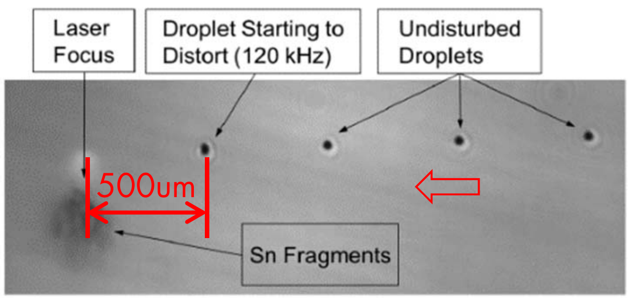
Figure 10: Hydrogen buffer gas pressure vs. ion energy and flux at the location of the collector surface

Proc. of SPIE Vol. 7636 763639 (2010)

Debris Mitigation Technology (2)

- Issue with previous gas mitigation techniques





100Pa
Droplet
30um

Proc. of SPIE Vol. 8322 83222N (2012)

The Vicious Circle of
Mitigation and Output Power

Higher Power

↓

Stronger shock wave

Gigaphoton has broken this vicious circle by developing the **Magnetic Debris Mitigation** system

↓

Increase Hydrogen pressure to compensate

Debris Mitigation Technology (3)

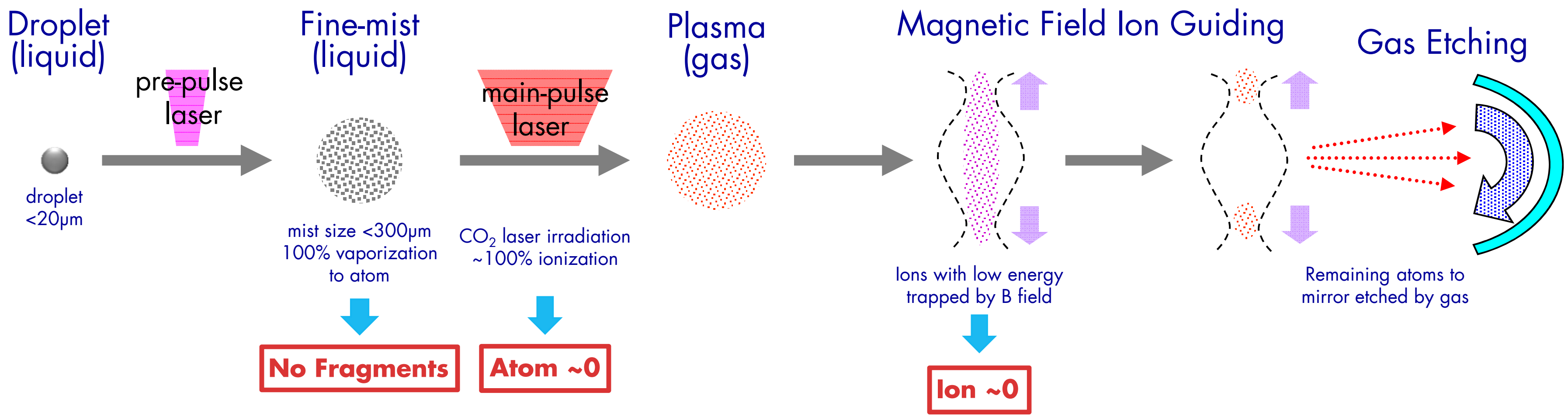
Gigaphoton's Magnetic Debris Mitigation concept

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

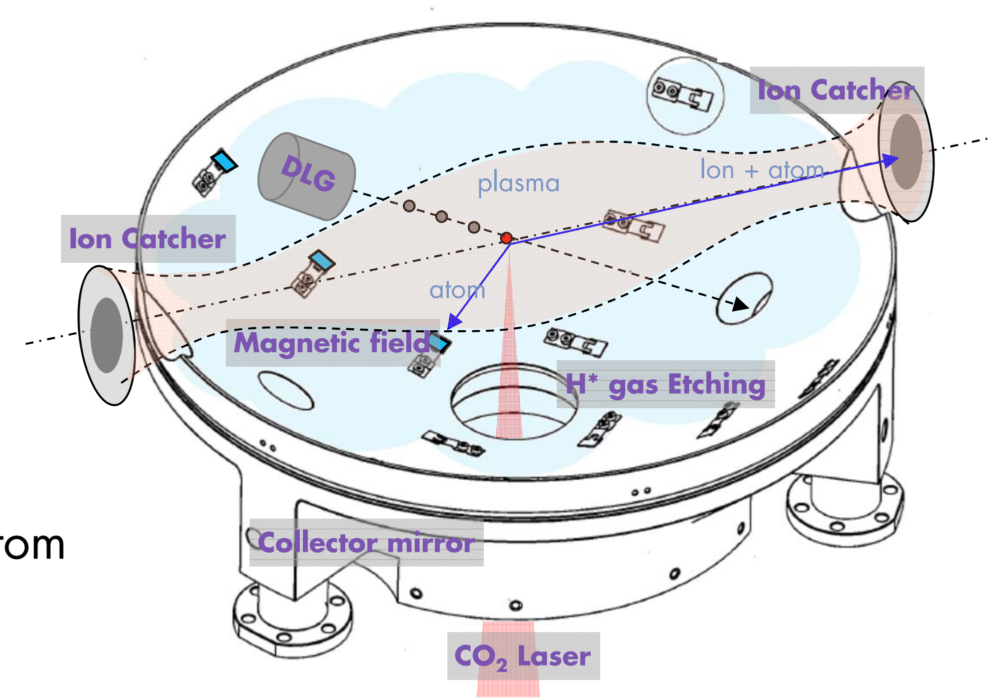
- Debris mitigation by magnetic field
- Ionized tin atoms are guided to tin catcher by magnetic field



Debris Mitigation Technology (4)

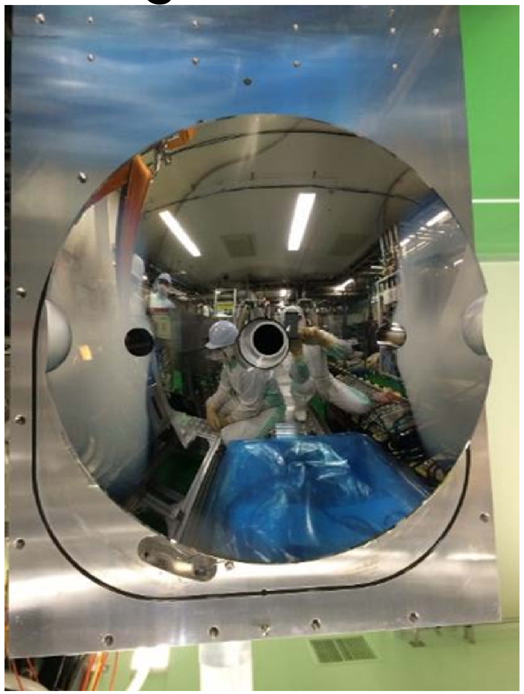
Gigaphoton's unique magnetic field + gas etching technology

- 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

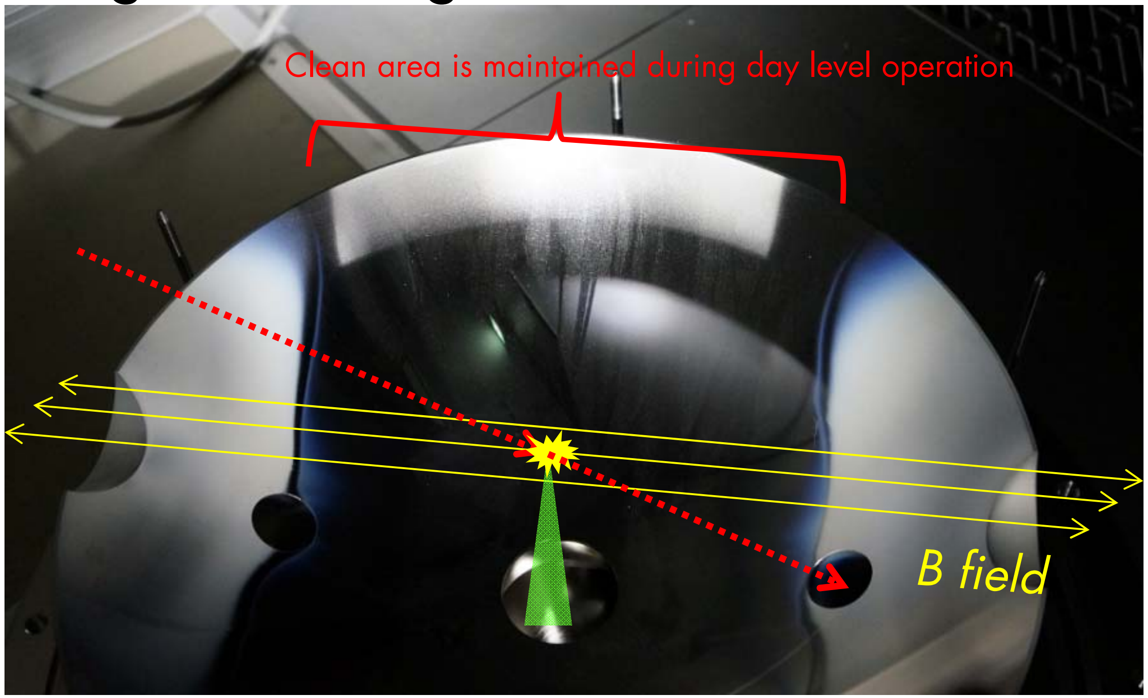


Debris Mitigation Technology (5)

EUV Light Source for Debris Mitigation Testing



Mounting the collector mirror

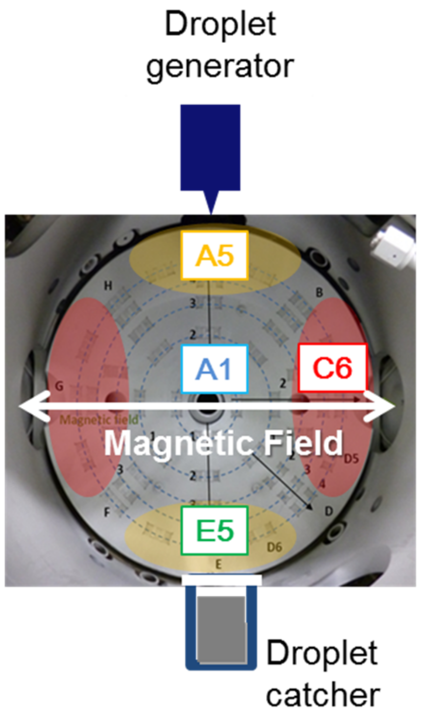


After 27Mpulse/3days with P(I/F)=10W@20kHz

Debris Mitigation Technology (6)

Debris mitigation: SEM image

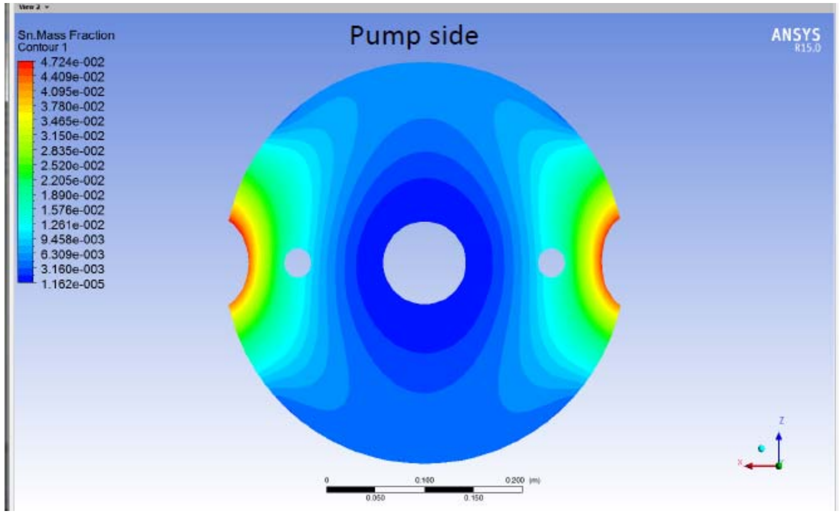
	2014 Jan	2014 Apr	**2014 Jun**	**2014 Jul.**
A1 sample Center of collector mirror SEM x10,000 Center	0.1nm/Mpls	0.075nm/Mpls	0.003nm/Mpls	0.002nm/Mpls
E5 sample SEM x1,000 Lower	8.7nm/Mpls	1.1nm/Mpls	0.62nm/Mpls	0.67nm/Mpls
A5 sample SEM x1,000 Upper	4.1nm/Mpls	0.16nm/Mpls	0.012nm/Mpls	0.008nm/Mpls
C6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



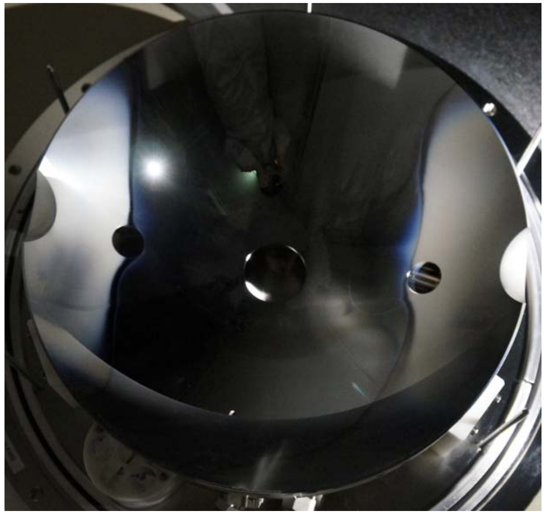
Debris Mitigation Technology (7)

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



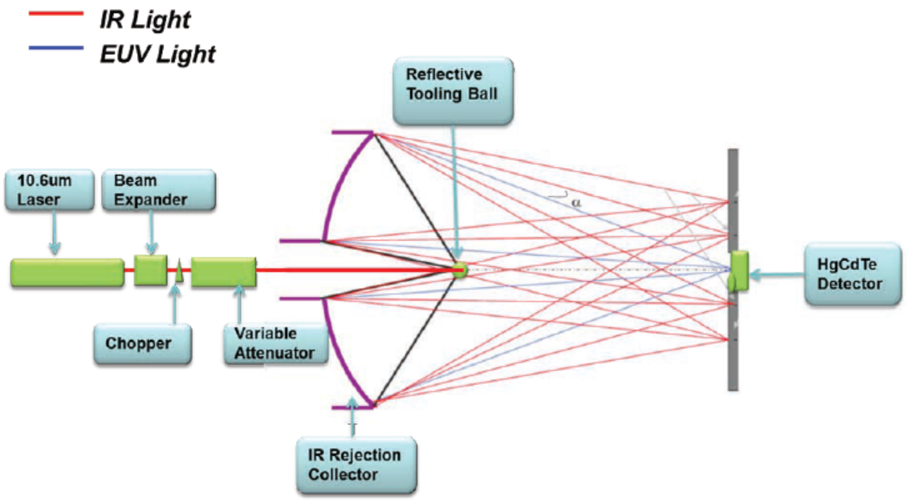
Actual Tin Deposited on Collector

Collector Mirror Technology (1)

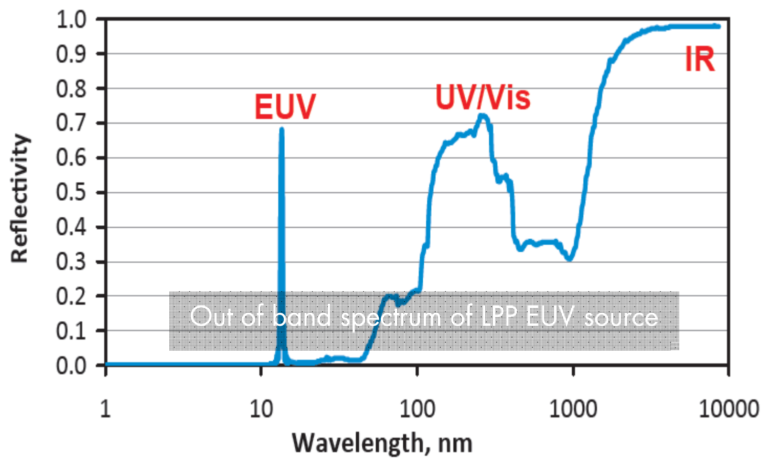
Collector Mirror progress

IR Reduction Technology is Advancing

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



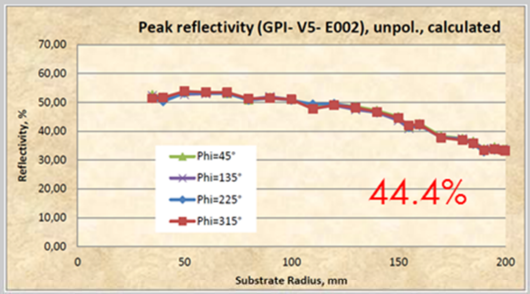
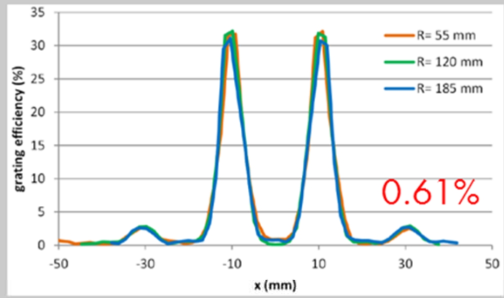
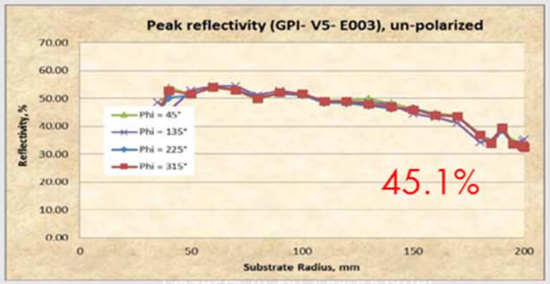
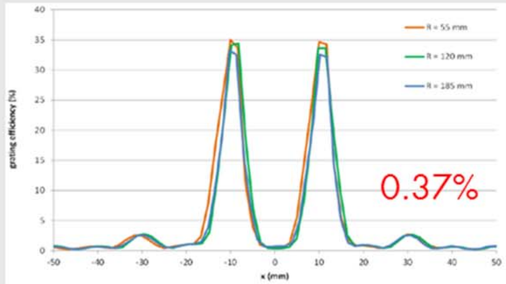
Gigaphoton's Patent Pending IR Reduction Technology



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%.

	Appearance	EUV Reflectivity	IR Reflectivity
V5-E002		 44.4%	 0.61%
V5-E003		 45.1%	 0.37%

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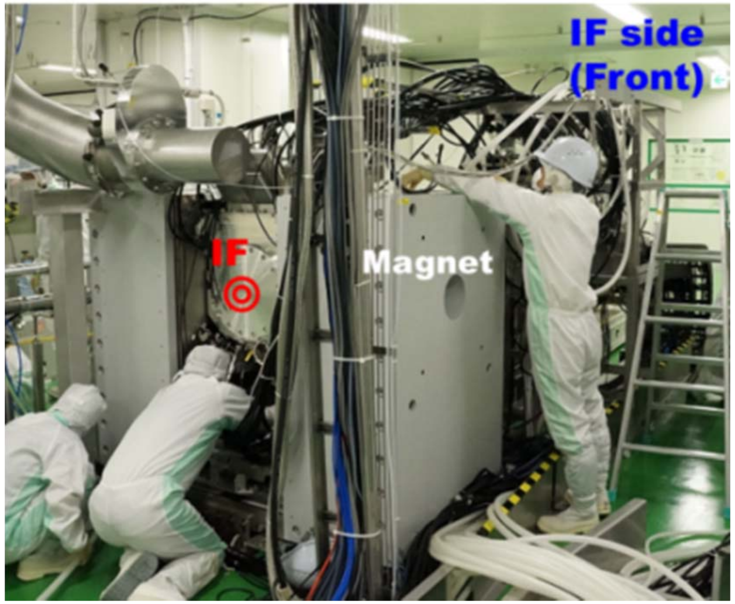
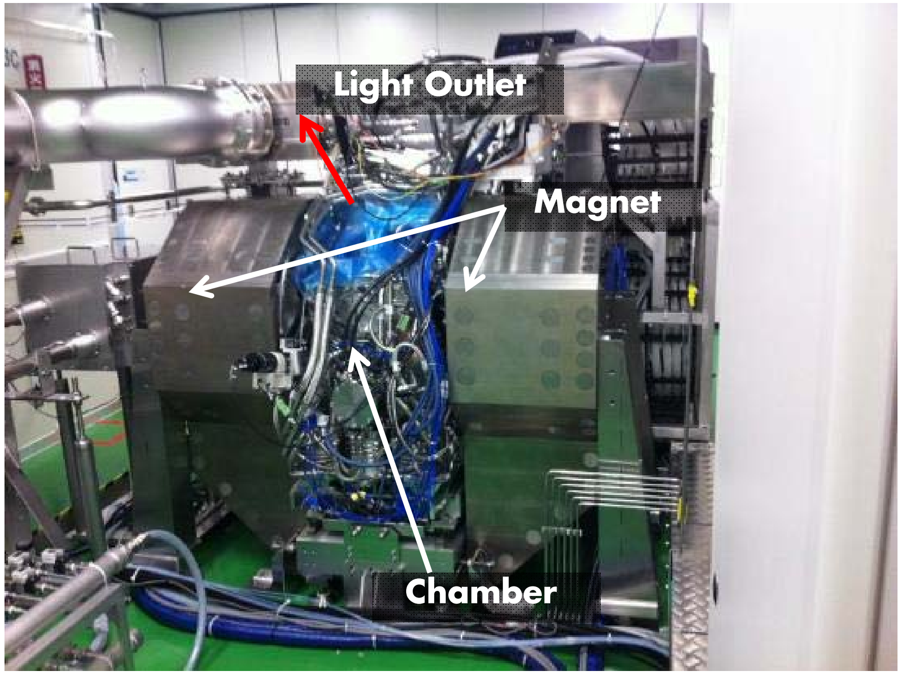
High Power EUV Light Source of Gigaphoton

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

Proto 1 Exposure & Mitigation test



Proto 2 High power Experiment



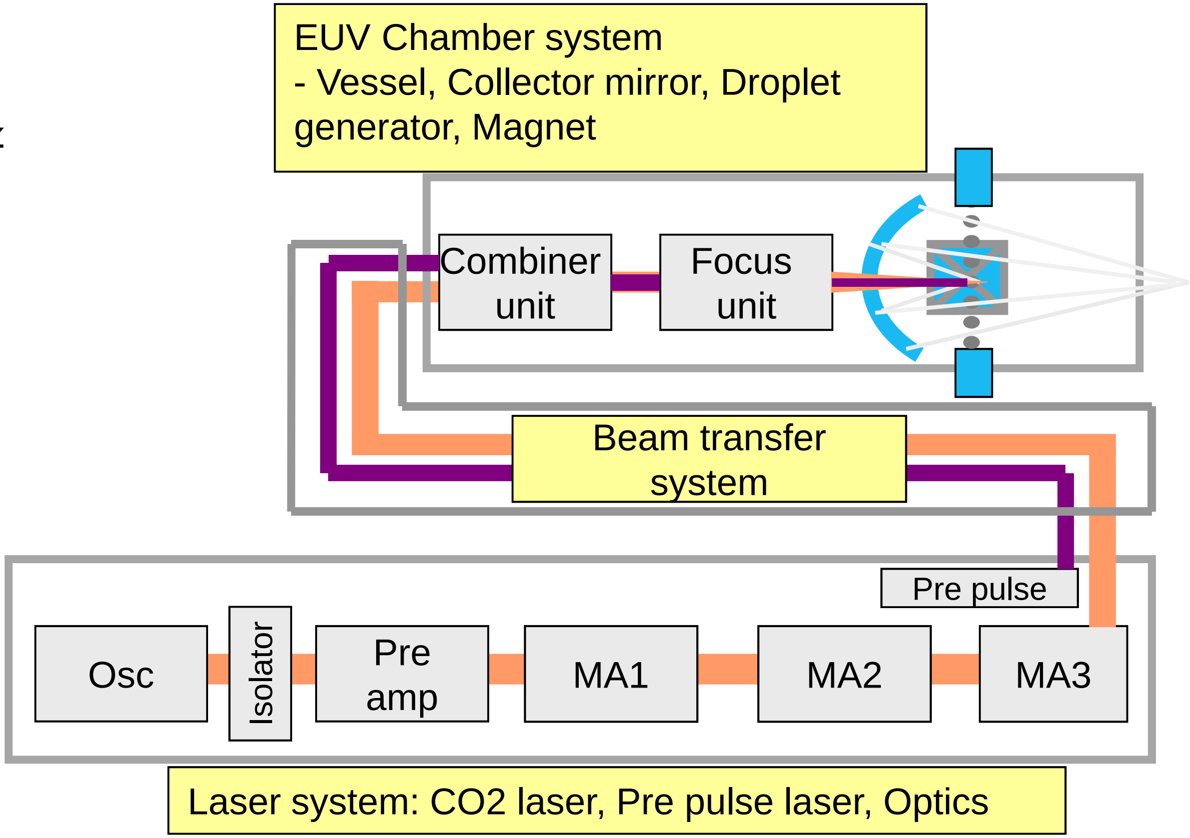
Proto Systems in Operation

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

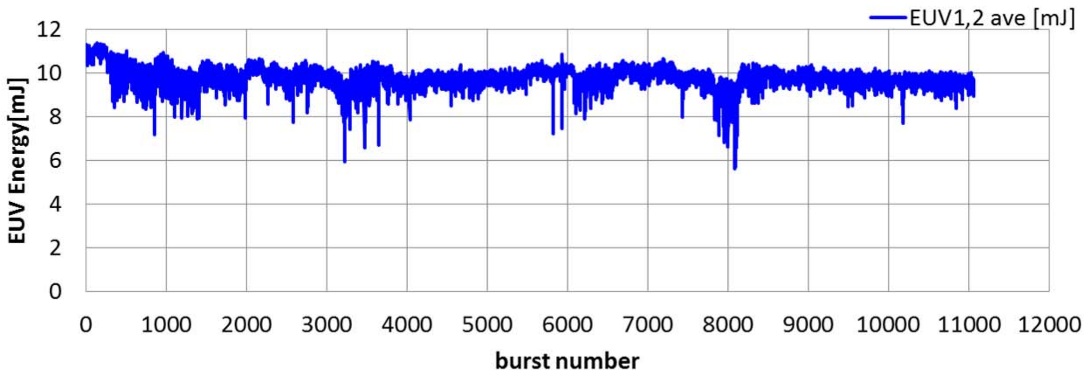
Driver Laser System Configuration

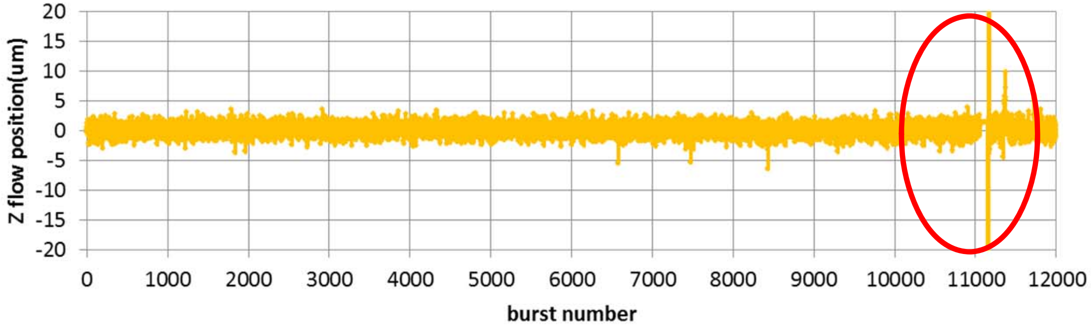
- Proto#1
  - » 5kW CO_2 power at 100kHz by 2 MA CO_2 laser system.
- Proto#2
  - » **17kW CO_2 power at 100kHz by 3 MA CO_2 laser + Mitsubishi pre-Amplifier system.**
- Pilot#1 (Designing)
  - » 25kW CO_2 power at 100kHz by using Mitsubishi amplifier system.



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)

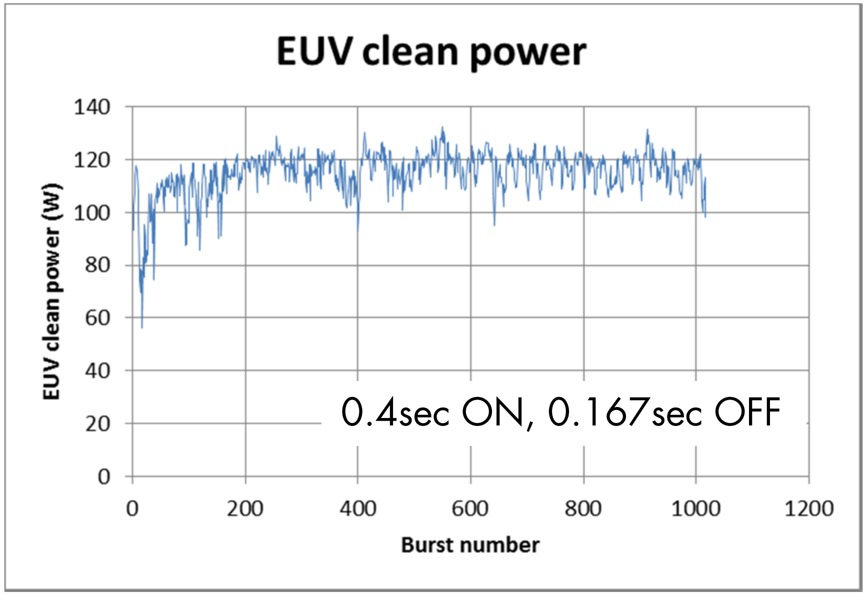


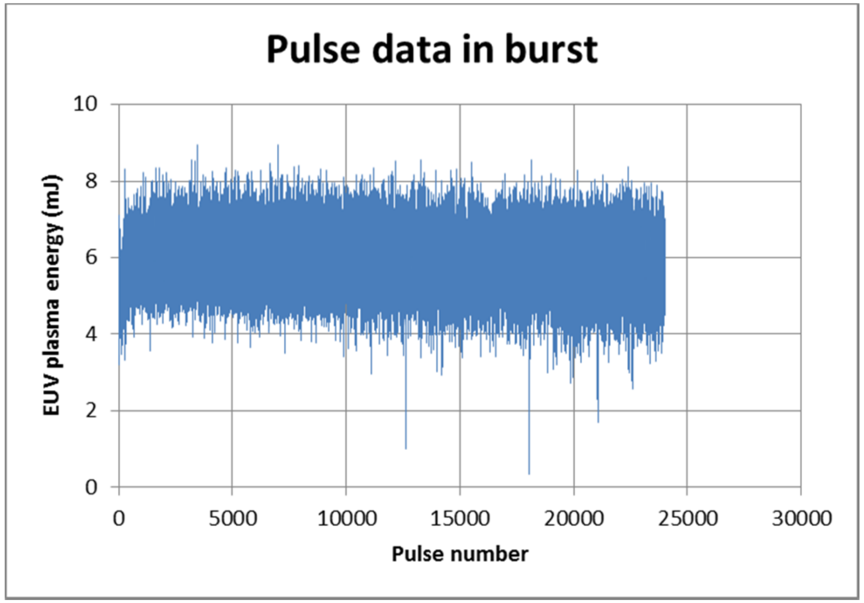


Rep.rate	20kHz
EUV energy (ave.)	9.79mJ
IF power @ clean	42W
CO2 energy(ave.)	273mJ
CE	3.6%
EUV stability (3s)	14%
Pulse number	110Mpls
DLG	CJ1551-3
Droplet.diameter	25um
Droplet.spacing	500um
DL catcher	Type C
Ion catcher	Type D (L=200)

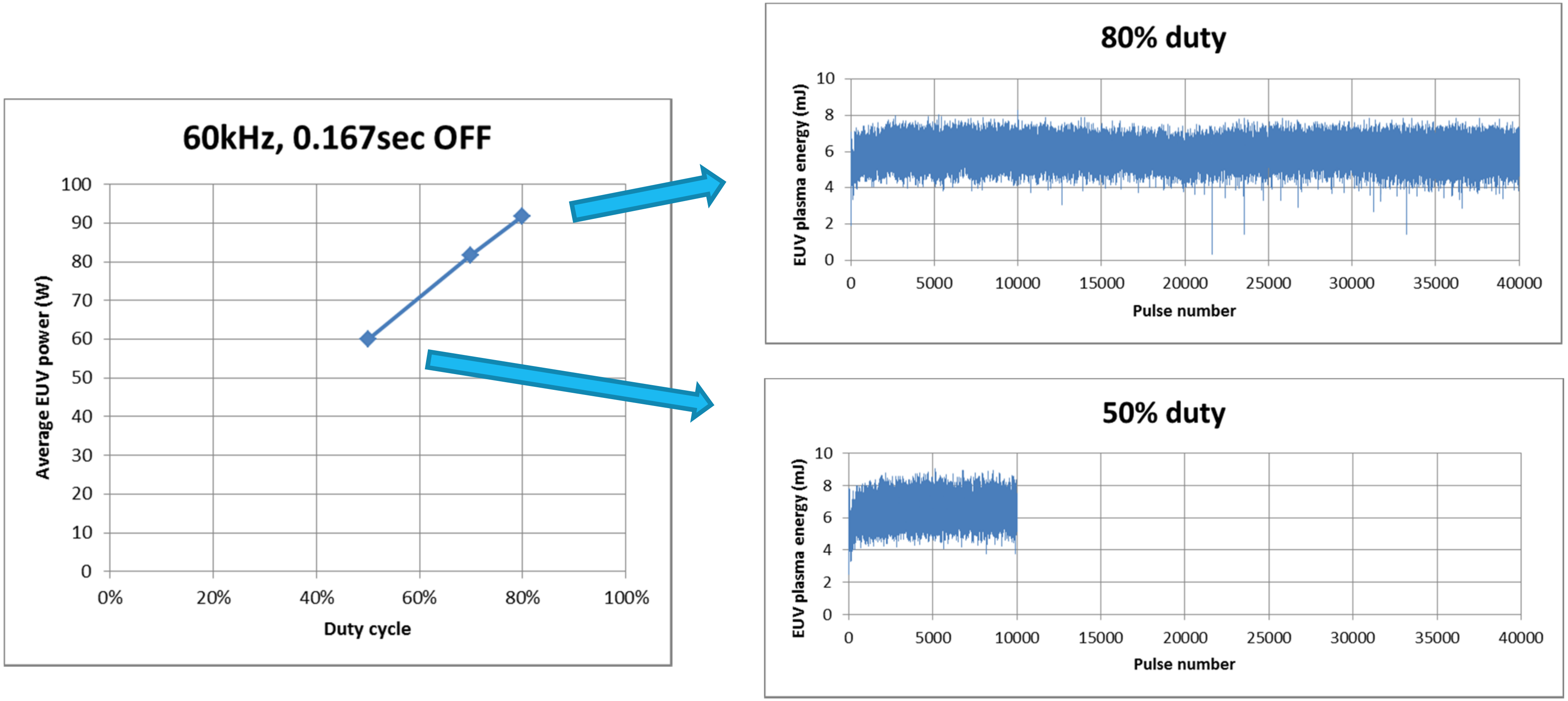
60kHz, 70% D/C: EUV power operation data

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

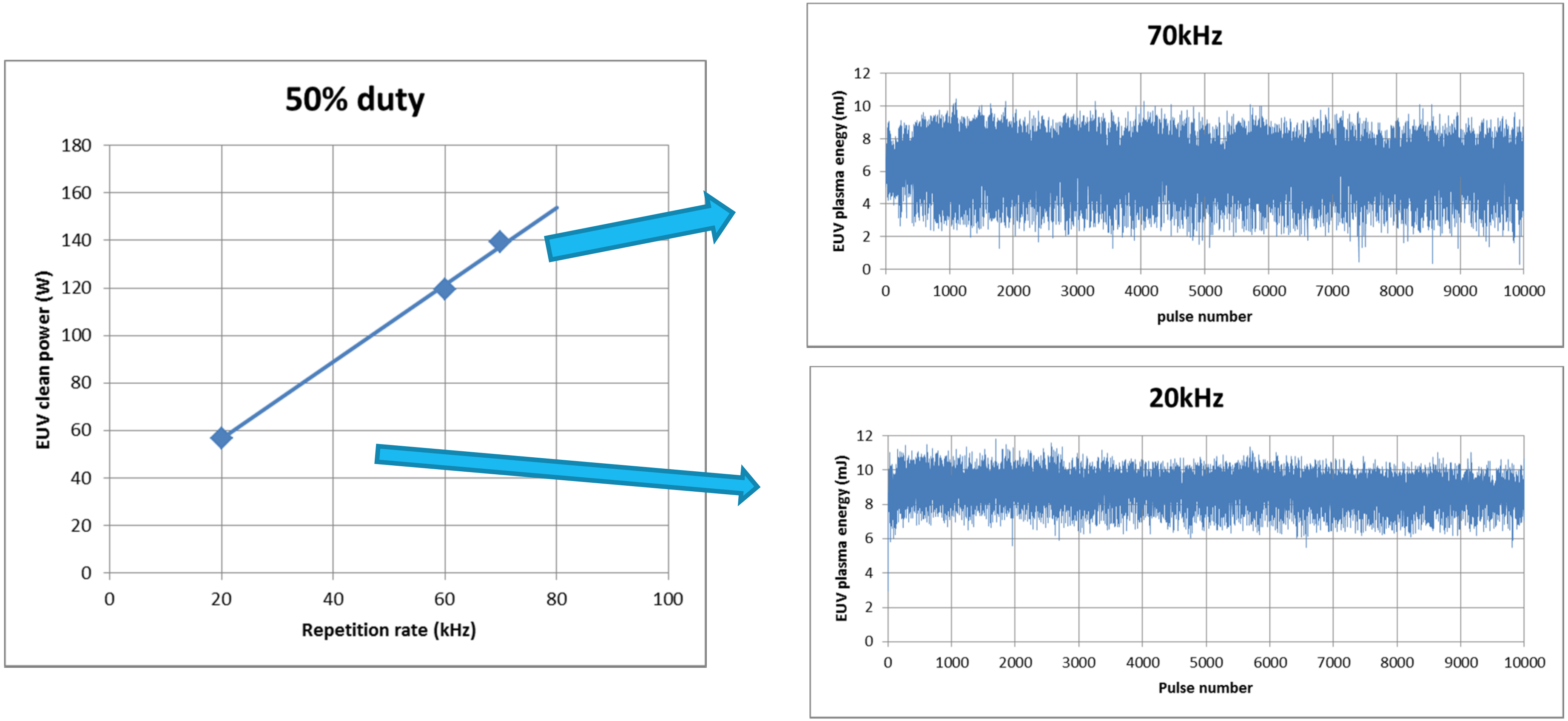




Potential: Higher Duty Cycle Operation



Potential: Higher Repetition Rate Operation



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	12.0kW

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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  - » Collector Mirror and IR Reduction Technology
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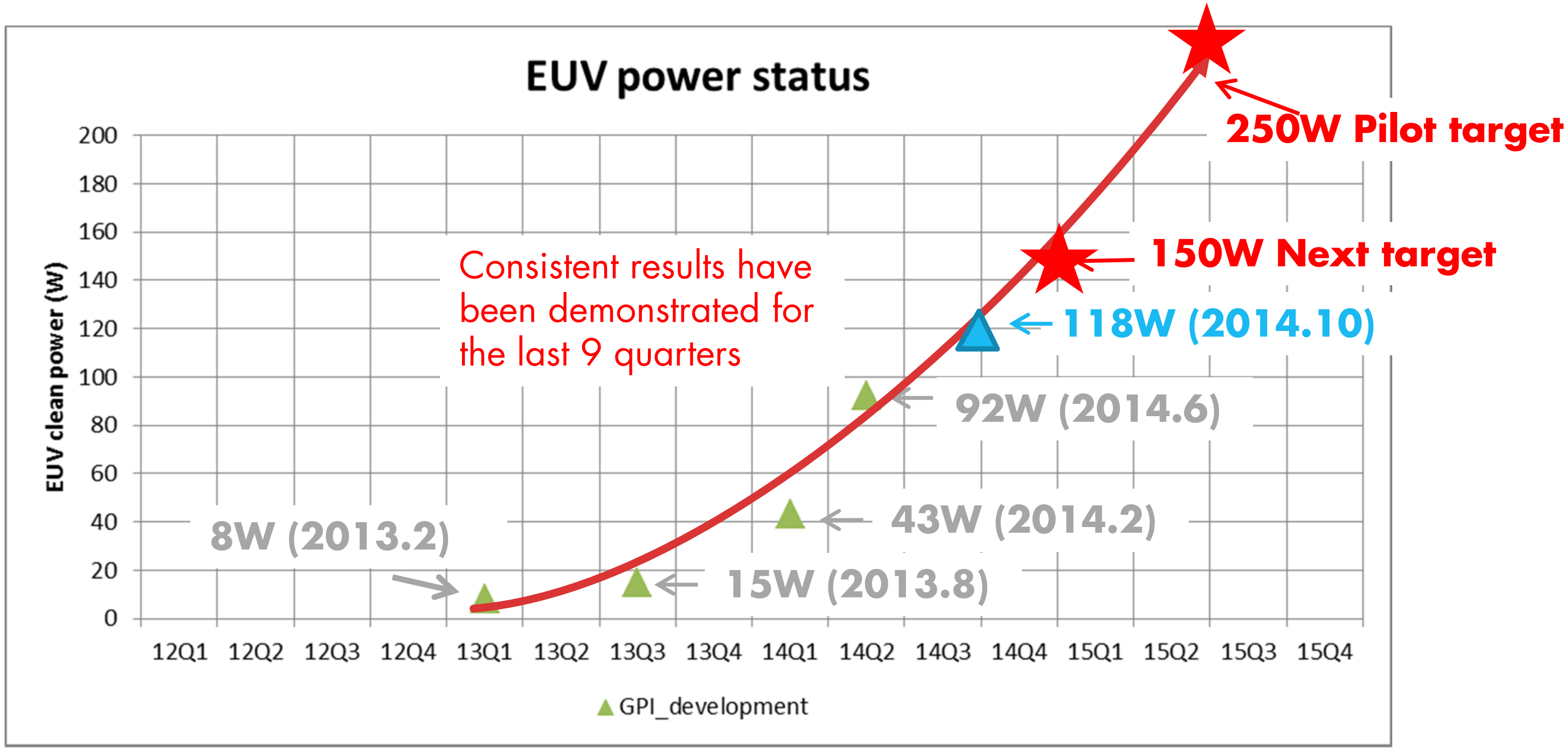
  - » Construction of Pilot #1
- Summary

EUV Power achievement and Target



Power-up Scenario of Driver Laser System (1)

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

Validated performances at system

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

Acknowledgements

Thanks for your co-operation:

Mitsubishi electric CO_2 laser amp. develop. team: *Dr. Yoichi Tanino**, Dr. Junichi Nishimae, Dr. Shuichi Fujikawa and others.

** 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

Dr. Akira Endo :**HiLase Project** (Prague) and Prof. Masakazu Washio and others in **Waseda University**

Dr. Kentaro Tomita, Prof. Kiichiro Uchino and others in **Kyushu University**

Dr. Jun Sunahara, Dr. Katsunori Nishihara, Prof. Hiroaki Nishimura, and others in **Osaka University**

Thanks for you funding:

EUV source development funding is partially support by **NEDO in JAPAN**

Thanks to my colleagues:

EUV development team of Gigaphoton; Hiroaki Nakarai, Tamotsu Abe, Takeshi Ohta, Krzysztof M Nowak, Yasufumi Kawasuji, Hiroshi Tanaka, Yukio Watanabe, Tsukasa Hori, Takeshi Kodama, Yutaka Shiraishi, Tatsuya Yanagida,Tsuyoshi Yamada, Taku Yamazaki, Takashi Saitou and other engineers.