

2015 International Workshop on EUV and Soft X-Ray Sources (2015 Source Workshop)

November 9-11, 2015, Dublin, Ireland

Performance of One Hundred Watt Source and Construction of 250Watt HVM LPP-EUV Source (S12)

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- Prototype LPP Source System Development Update
 - » Proto Device #1
 - » Proto Device #2

- New Pilot System Development Update
- Summary



Power-Up Scenario and Key Technologies Update

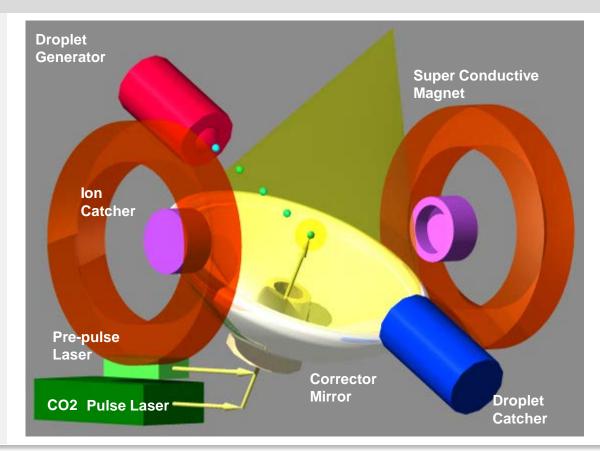
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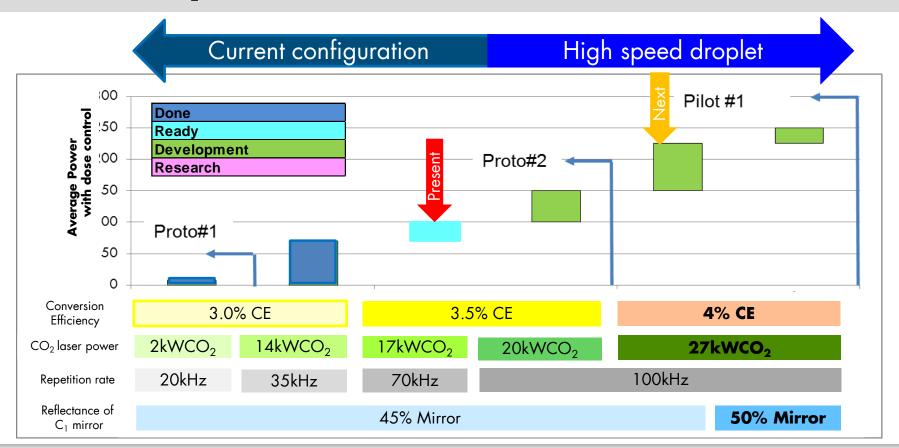
OUTLINE

Gigaphoton's LPP Light Source Concept

- High ionization rate and CE EUV tin (Sn) plasma generated by CO₂ and pre-pulse solid laser dual wavelength shooting
- Hybrid CO₂ laser system with short pulse high repetition rate oscillator and commercial cw-amplifiers
- Accurate shooting control with droplet and laser beam control
- Tin (Sn) debris mitigation with a super conductive magnetic field
- High efficient out of band light reduction with grating structured C1 mirror



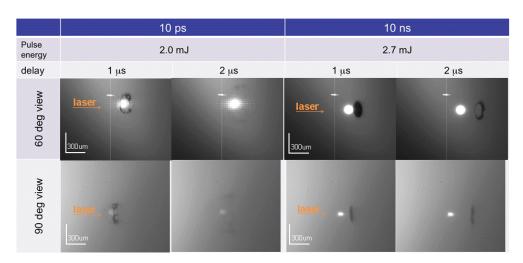
Power up scenario

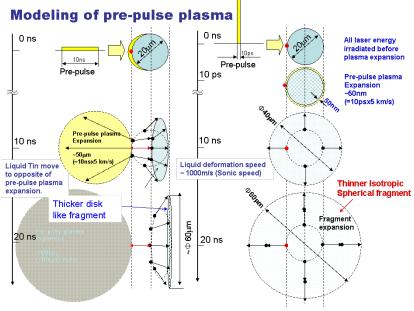


Pre-Pulse Technology (1)

Fragment distribution measurement

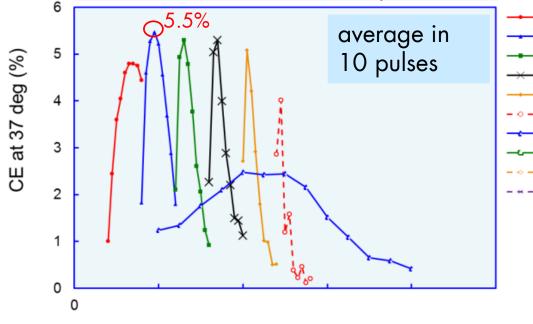
- The mist shape of a picosecond pre-pulse is different from the nanosecond
- Nano-cluster distribution could be a key factor for high CE





Pre-Pulse Technology (2)

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





PPL - CO2 delay

Pre-Pulse Technology (3)

EUV plasma parameters measurement by "Thomson Scattering" is ongoing in Kyushu University

A Collective Laser Thomson Scattering System for Diagnostics of Laser-Produced Plasmas for Extreme Ultraviolet Light Sources

Kentaro Tomita1, Kazuki Nakayama¹, Kazuya Inoue1, Atsushi Sunahara², and Kiichiro Uchino¹

¹Interdisciplinary Graduate School of Engineering and Sciences, Kyushu University, Kasuga, Fukuoka 816-8580, Japan ²Institute for Laser Technology, Suita, Osaka 565-0871, Japan

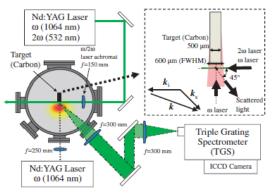
To develop a diagnostic system for laser-produced plasmas for extreme ultraviolet (EUV) light sources, collective laser Thomson scattering (LTS) was applied to laser-produced carbon plasmas to measure plasma parameters such as electron density (ne) and electron temperature (Te).

Plasmas having parameters necessary for an EUV lie source (ne = 10^{24} - 10^{25} m³, Te = 30-50 eV) we and these parameters were successfully evaluat diagnostic system with errors below 10%. From an LTS system for diagnostics of tin plasmas for real EUV light sources was designed.

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K. Tomita et al.



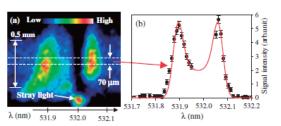
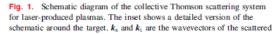
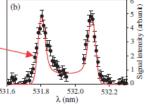


Fig. 2. (a) Two-dimensional Thomson scattering image. (b) LTS spectrum extracted from the center part of (a) and the curve fit based on the theoretical model.





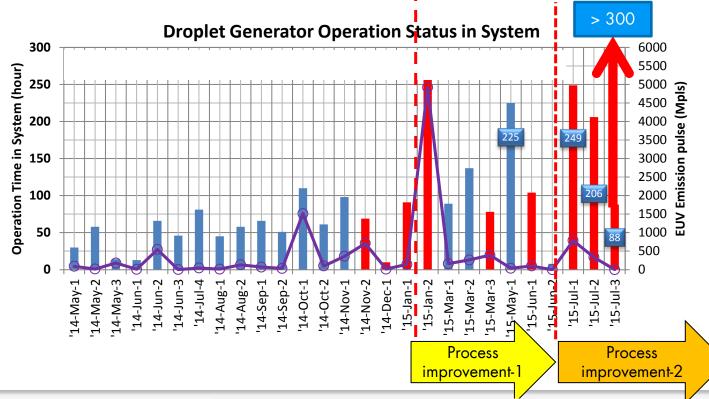


→Dr. K. Tomita will be report New data in EUV Source Workshop in Dublin Nov. 2015

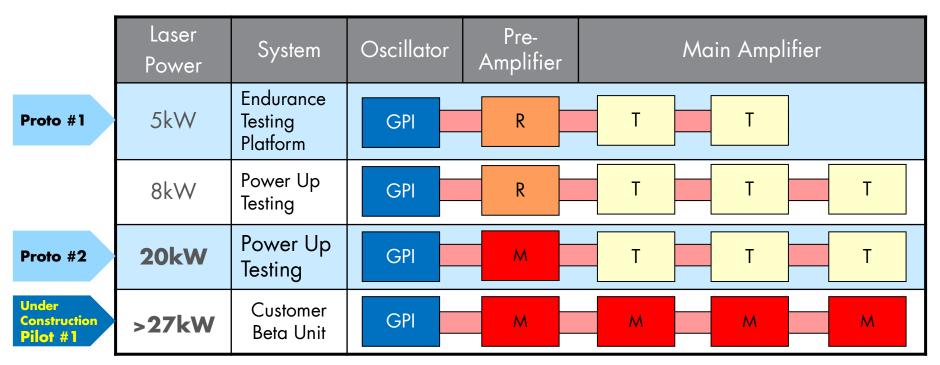
Fig. 3. (a) Two-dimensional Thomson scattering image when the additional laser was injected. (b) LTS spectrum extracted from the center part of (a) and the curve fit based on the theoretical model.

Droplet Generator technology (2)

Process improvement enables more than 200hrs droplet generation



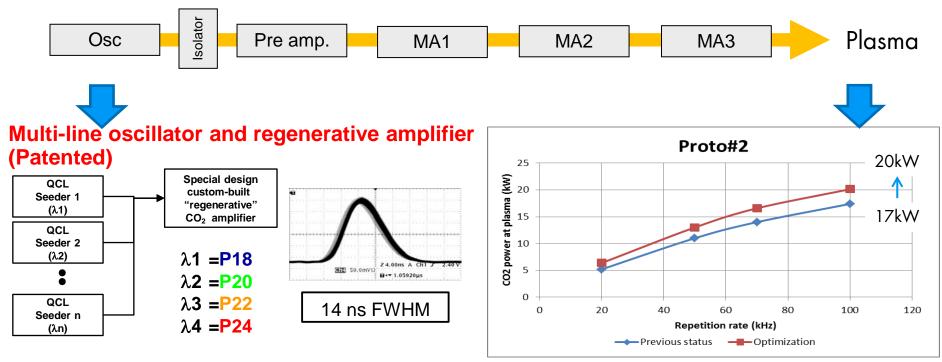
High Power CO₂ Laser Technology (1)



validated performances at system

High Power CO₂ Laser Technology (2)

Potential of 20kW CO2 power at plasma was confirmed in proto#2 system. This is close to 250W target in pilot#1 system, which is 23kW.



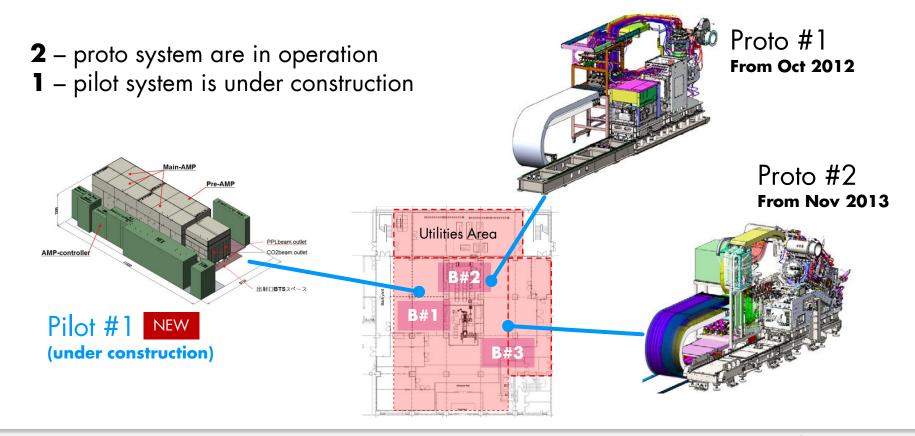
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Gigaphoton EUV Sources



Proto Systems in Operation

Target System Specification

Operational Specification		Proto #1	Proto #2	Pilot #1 (under construction)	
	EUV Power	25 W	> 100 W	250 W	
	CE	3%	3.5%	4%	
	Pulse rate	100 kHz	100 kHz	100 kHz	
Target Performance	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 5 kW		20 kW	27 kW	
	Pre-pulse laser	picosecond	picosecond	picosecond	
	Debris mitigation	validation of magnetic mitigation in system	10 days	> 3 month	

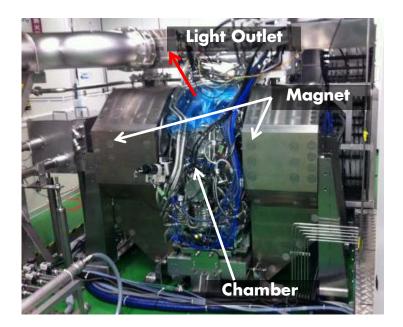
Gigaphoton's High Power EUV Light Source

Prototype high power EUV light source is in operation

Proto 1 Exposure & Mitigation test



Proto 2 High power Experiment



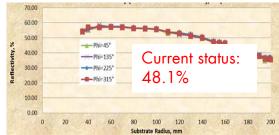
Collector Mirror Technology

Collector reflectivity is one of the key item for power improvement





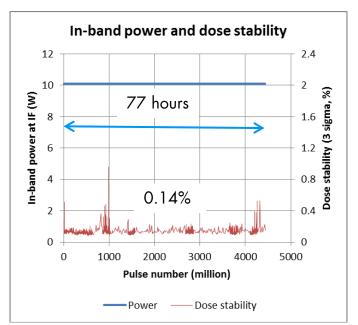




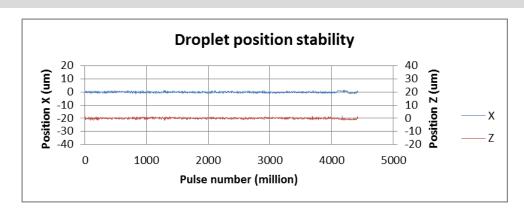
	Current	250W target
Collector type	V5	V5+
H2 Pressure	<20Pa	<20Pa
Collector Efficiency	>74%	>74%
Collector Reflectivity	>45%	>50%
Gas Transmittance	>95%	>95%
Plasma to clean	31.6%	35.1%

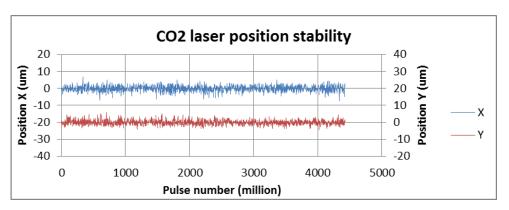
Long lifetime operation in Proto#1 system

77 hours operation with 25% dose margin



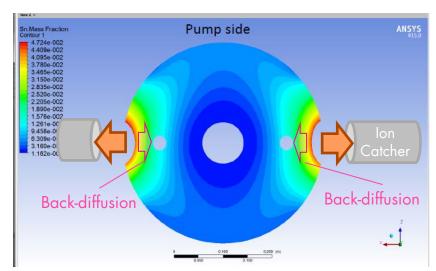
Dose control, 20kHz, 80% duty cycle



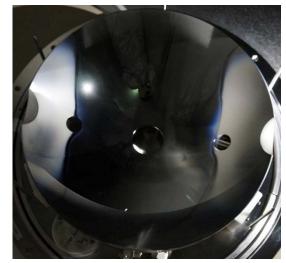


Tin Back-diffusion Issue from the Ion Catcher

- Issue: tin depositions on mirror caused by back-diffusion from the ion catcher
- Reduction of the back-diffusion from the ion catcher is key



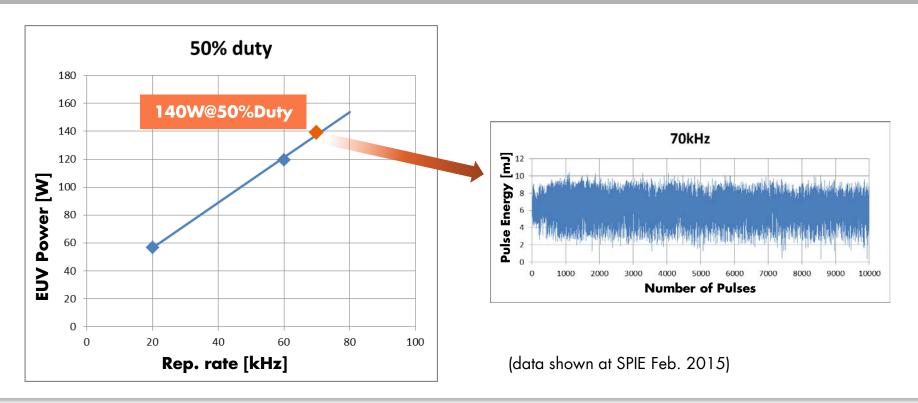
Tim Deposition Simulation



Actual Tin Deposited on Collector

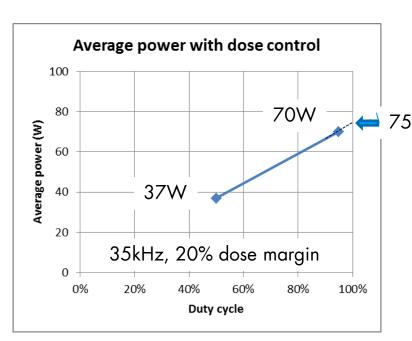
Proto #2: EUV Power Data (short term)

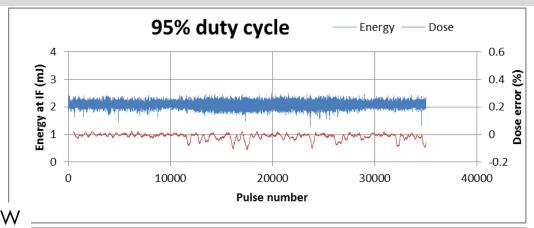
Champion Data: 140W EUV in burst power with 70kHz, 50% duty cycle

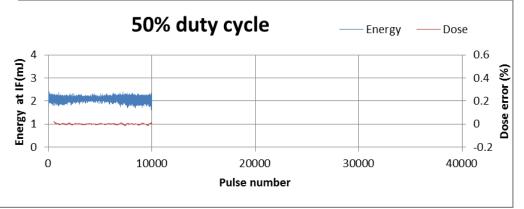


Proto#2: High Duty Cycle with Dose Control

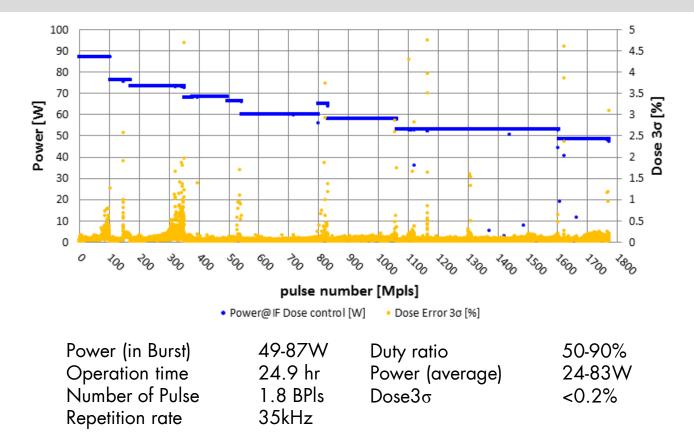
Dose control capability up to 95% duty cycle with 20% dose margin was confirmed in proto#2 system at 75W in burst level operation



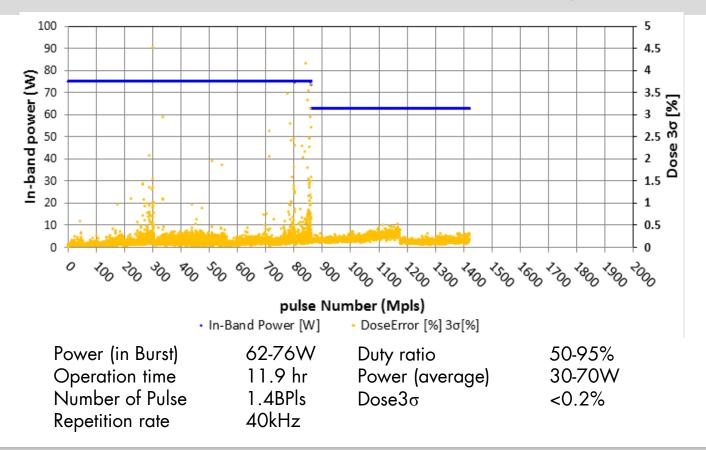




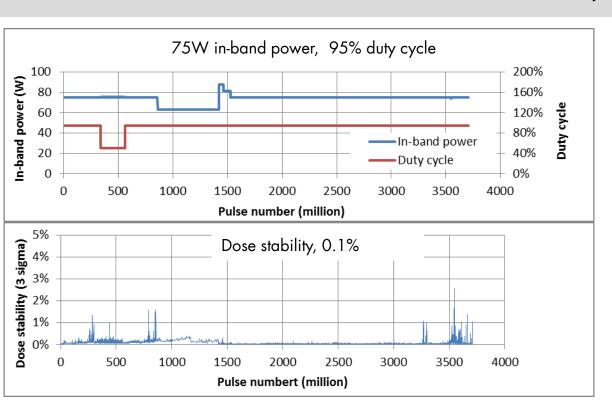
Proto #2: EUV Power Data (long term 1)



Proto #2: EUV Power Data (long term 2)



Proto #2: EUV Power Data (long term 3)



75 W
31 hr
3.7 BPls
40 kHz

Duty ratio	95%
Power (average)	72W
Dose3σ	<0.2%

22. Oct. 2015

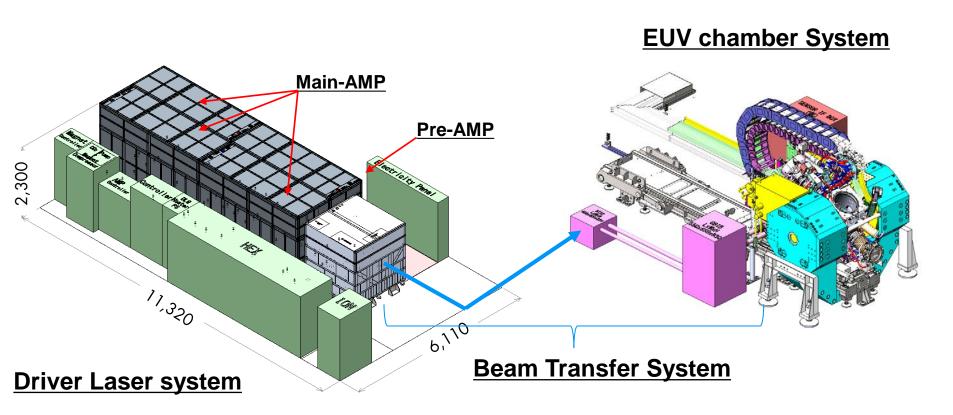
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Pilot #1: Configuration



Pilot construction status



Driver laser



Pre-AMP
OSC and PPL

Beam line

EUV chamber



Piping

<u> (essel</u>





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CONFIDENTIAL

CO2 power status in pilot system

100kHz	OSC	PA	MA#1	MA#2	MA#3	Plasma
Target	80W	5kW	12kW	20kW	27kW	23kW
Result	93W	Perfo	rmance will i	be verified b	efore the en	d of Q4
Proto#2	70W	4.8kW	9.1kW	16.5kW	23.7kW	(20kW)

System	Electrical power	Oscillator	Pre- amplifier	Main amplifier
Proto#2	1060kVA	G	M	T
Pilot#1	880kVA	G	M	M M M

Technology scenario

 31hours operation with 72W average power was confirmed. Next target is 100W by increasing repetition rate.

	Status			Target			
	Feb 2015	Apr 2014	Oct 2015	Dec 2015	Mar 2016	Jun 2016	Dec 2016
System	Proto#1	Proto#2	Proto#2	Proto#2	Proto#2	Pilot#1	Pilot#1
In band power	10W	74W	75W	120W	170W	250W	250W
Average power at IF dose control	8W	70W	72W	100W	150W	250W	250W
Operation time	77hour	0.5hour	31hour	>24hour	>1 week	>1 week	>1 month
Duty cycle	80%	95%	95%	>90%	>90%	100%	100%
Repetition rate	20kHz	35kHz	40kHz	>70kHz	100kHz	100kHz	100kHz
CO2 power at plasma	1.1kW	10kW	11.1kW	14kW	1 <i>7</i> kW	>23kW	>23kW
CE	3.2%	3.2%	3.4%	3.5%	3.5%	4.0%	4.0%
Power budget from plasma to IF	31.6%	31.6%	31.6%	31.6%	31.6%	35.1%	35.1%
Dose margin	25%	20%	40%	20%	20%	20%	20%
Availability based on 24x7	13.5%	5.3%	10%	>20%	>50%	>60%	>90%

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Summary

- Progress of Proto #1 unit
 - » Further improvement of "Magnetic debris mitigation"
 - » Simulation expect further improvement of back-diffusion
 - » Report new data: 77 hrs., 10W operation data without maintenance was reported.
 - » Magnetic mitigation capability is discussed by using Tin distribution simulation.
- Progress of Proto #2 unit
 - » Driver CO₂ laser system achieved 20 kW by multiline amplification with new pre-amplifier.
 - » Maximum power champion data: 140 W (CE 3.7%) in burst at 70 kHz, 50% duty.
 - » Report new data: 75W power in burst, 95 % duty under closed loop, 72W average was demonstrated during 31 hours.
 - » Next step is 100W average power operations during more than 24 hrs with higher availability.
- Pilot #1 is under construction
 - » Design of system is almost fixed most parts are already ordered
 - » Construction will finish in Q4, 2015. First data will be expected in Q1, 2016

Acknowledgements

Thanks for co-operation:

Mitsubishi electric CO₂ 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 CO₂ amplifier development. He will be missed very much.

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

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THANK YOU

