2013 International Symposium on Extreme Ultraviolet Lithography

Toyama, Japan ● 6 - 10 October, 2013

High Ce and Magnetic Mitigation Technology for HVM EUV Source

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2013 International Symposium on Extreme Ultraviolet Lithography

Toyama, Japan, 6-10 Oct. 2013

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GIGAPHOTON

Agenda

- Introduction
  - EUV lithography and light source
  - Delay of EUV lithography on the ITRS Road Map
- LPP source technology
  - Concept of Gigaphoton LPP source
  - High CE Pre-pulse technology
  - High Power Laser
  - Extendibility to 1kW EUV power
- Update of LPP source development
  - High power EUV source systems
- Summary

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EUV Lithography and light source (1)

Finer patterning is realized by shorter wavelength

Resolution at projection optic system *R*

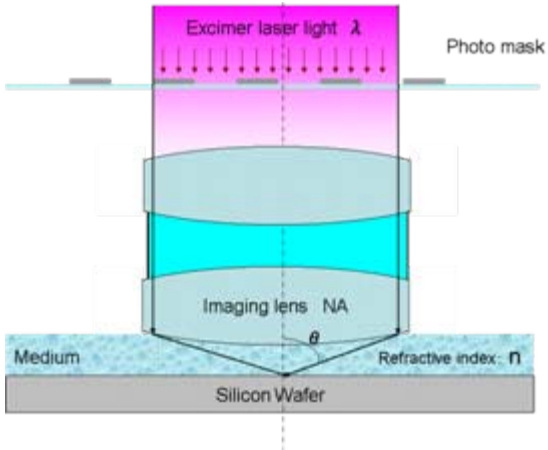
$$R = K_1 \frac{\lambda / n}{NA}$$

(*Rayleigh Formula*)

λ : Wavelength
NA : Numerical Aperture (NA=sin θ)
k_1 : Process factor
n : Refractive index

Shorter Wavelengths

	R (K1=0.4) nm	n	medium	λ /n *nm*	NA	Power
KrF dry	124	1	Air	248	0.8	40
ArF dry	103	1	Air	193	0.75	45
F_2 dry	84	1	N_2	157	0.75	–
ArF immersion	40	1.44	H_2O	134	1.35	90
EUV (λ =13.6nm)	**18**	**1**	**Vacuum**	**13.6**	**0.3**	**>250**
EUV (λ =13.6nm)	9	1	Vacuum	13.6	0.6	>500
EUV (λ = 7.6nm)	4.5	1	Vacuum	7.6	0.6	>1000

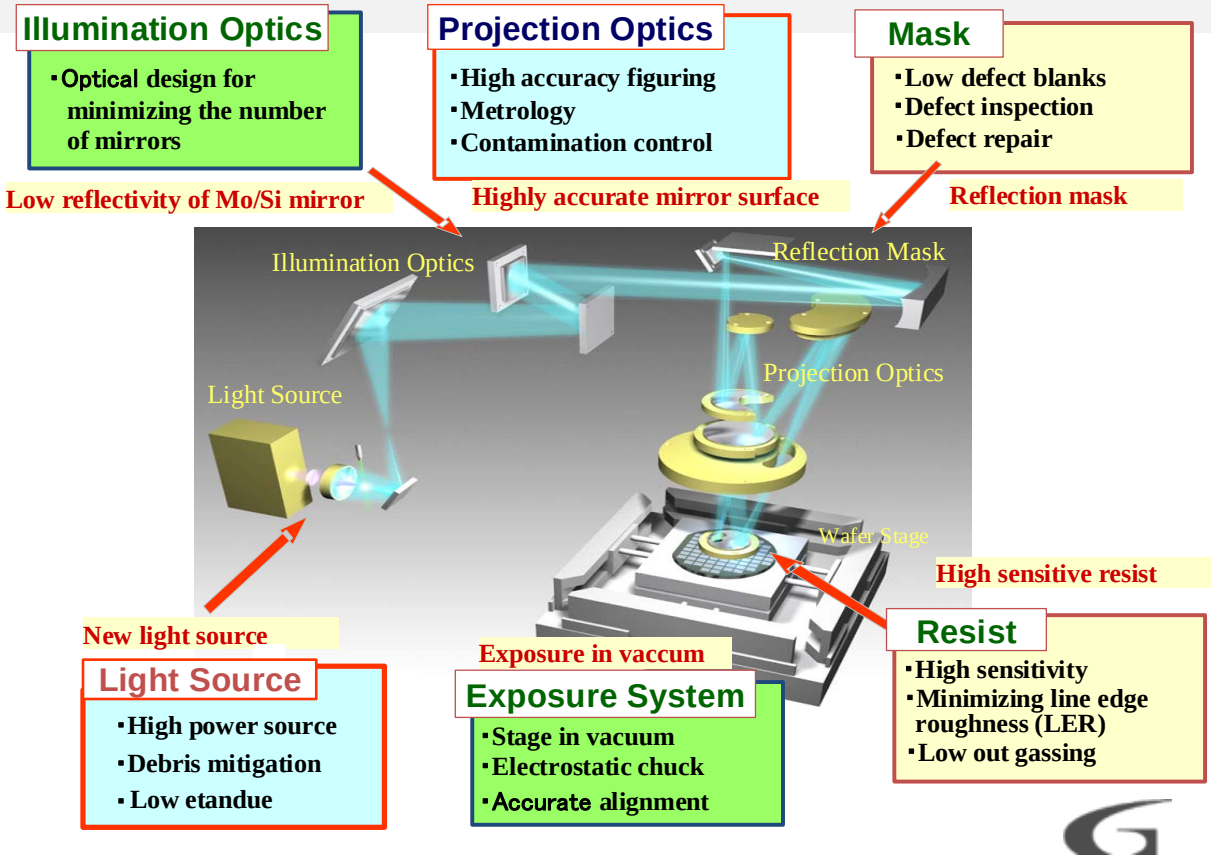


EUV Lithography and light source (2)

The EUV lithography exposure tool

- EUV lithography is operate in high vacuum circumstances.
  - At 13.5nm we can use 70% reflective optics Si/Mo multilayer refrector.
  - 13.5nm light can't transmits in air, water.
  - High cleanness is important.

- ***Light source is one of biggest issue to realize EUV HVM lithography at present***



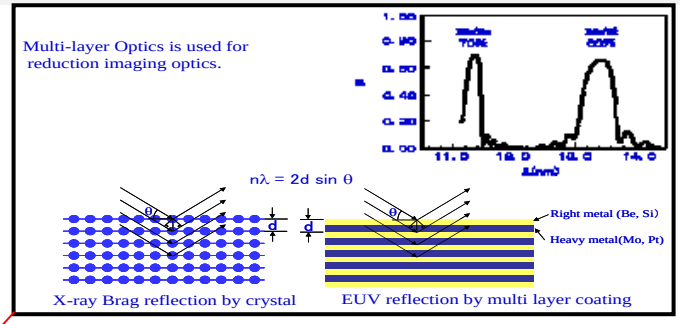
EUV Lithography and light source (3)

Light source issue in EUV lithography

EUV light transmittance is only 2% at 11 refection mirror system

High power light source for HVM exposure tools is the **KEY** Issue

Demand: >**250W** at 1st stage HVM



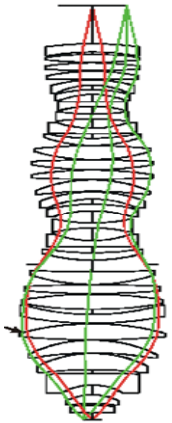
70% Reflection

SiO2,CaF2
>30 lenses and few mirrors

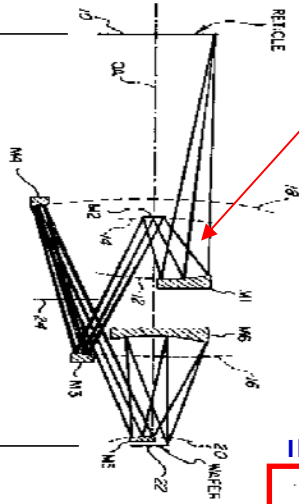
NA=0. 85—1. 35

Imaging (30)
$0.98^{30}=0.55$

Imaging (30)
+
Illumination (20)
$0.98^{50}=0.36$



Mask



Wafer

DUV

EUV

Mo/Si multilayer
6-8 mirrors

NA=0. 25—0. 35

Imaging (6)
$0.70^{6}=0.11$

Imaging (6)
+
Illumination + Mask (5)
$0.70^{11}=0.02$

Delay of EUV Lithography in the ITRS Roadmap

Figure LITH3A DRAM and MPU Potential Solutions

First Year of IC Production	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
DRAM ½ pitch (nm) (contacted)	36	32	28	25	23	20.0	17.9	15.9	14.2	12.6	11.3	10.0	8.9	8.0	7.1	6.3
MPU/ASIC Metal 1 1/2 pitch (nm)	38	32	27	24	21	18.9	16.9	15.0	13.4	11.9	10.6	9.5	8.4	7.5	7.5	7.5

45 193nm Imm

32 193 nm DP

193nm Extension

22 ~~EUV~~
~~193nm MP~~
~~ML2 (MPU)~~
~~Imprint (DRAM)~~

16 EUV
193nm MP
ML2
Imprint
DSA + litho platform

11 EUV / EUV + MP
EUV (6.Xnm)
ML2
Imprint
Litho + DSA
Innovation

MPU / DRAM time line

Narrow Options

Narrow Options

Narrow Options

32nm
Decided to use 193nm DP in 2009

22nm
EUV was #1 candidate, but...
Decided to use 193nm MP in 2012

16nm
Decision will likely happen in 2015
Will EUV finally succeed?
If not, 193nm MP is the backup plan

This legend indicates the time during which research, development and qualification/pre-production should be taking place for the solution.

Research Required
Development Underway
Qualification / Pre-Production
Continuous Improvement

ITRS International Technology Roadmap for Semiconductors

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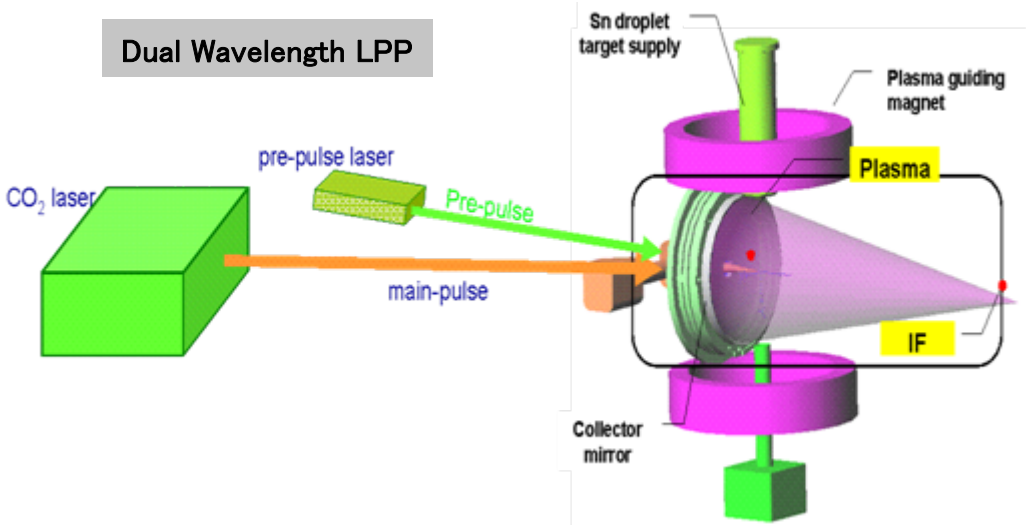
Concept of Gigaphoton LPP Light Source

1. Combined use of Sn droplets & pulsed CO_2 lasers
2. Stable 20mm droplet supply with Droplet Generator (DLG)
3. **Dual wavelength (pre-pulse & main pulse) LPP plasma**
4. Accurate shooting control with droplet and laser beam control
5. **Perfect ionization and magnetic plasma mitigation**

Dual Wavelength LPP

Magnetic Plasma Mitigation



Pre-pulse & Magnetic Mitigation Technology

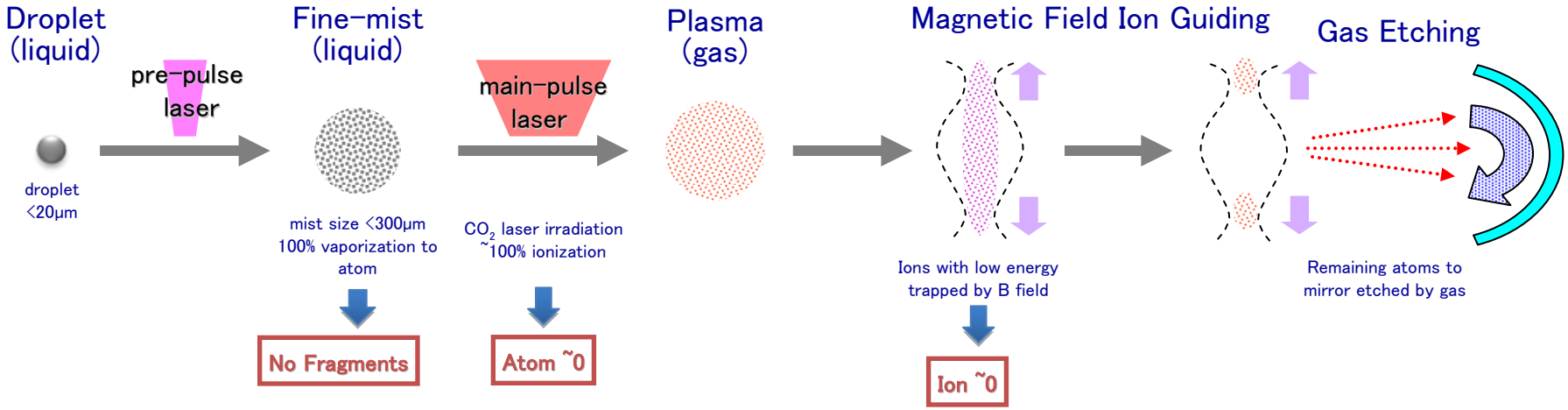
Ideal concept for High Power and Minimal Debris, suitable for HVM

Higher CE and Power

- Optimum wavelength to transform droplets into fine mist
- Higher CE achievement with ideal expansion of the fine mist

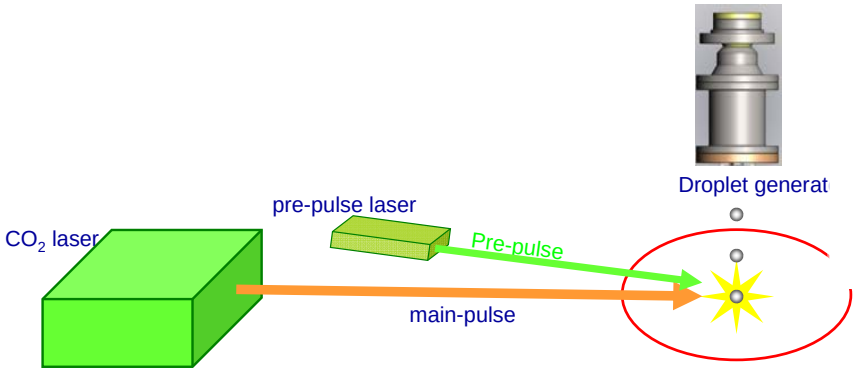
Long Life Chamber

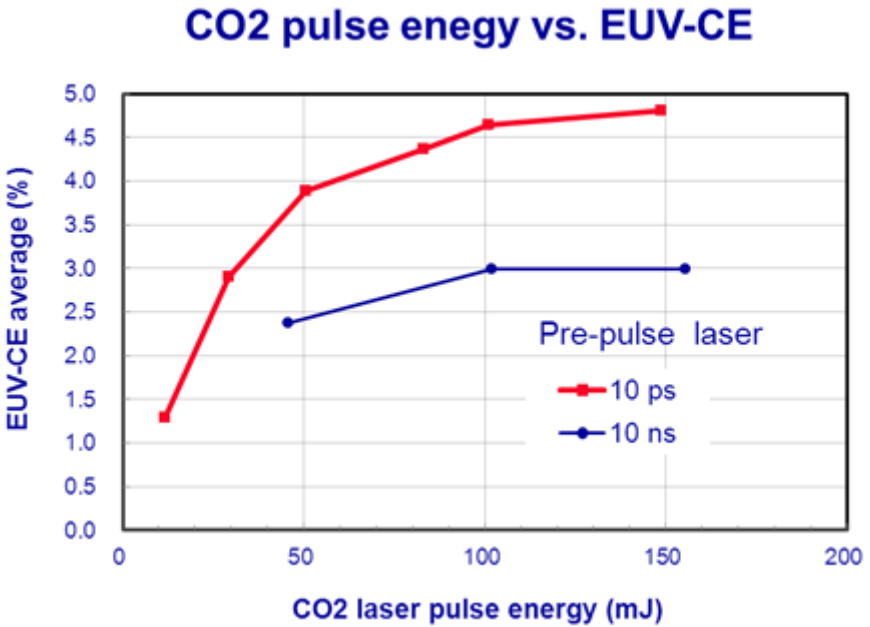
- Debris mitigation by magnetic field
- Ionized tin atoms are guided to tin catcher by magnetic field



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

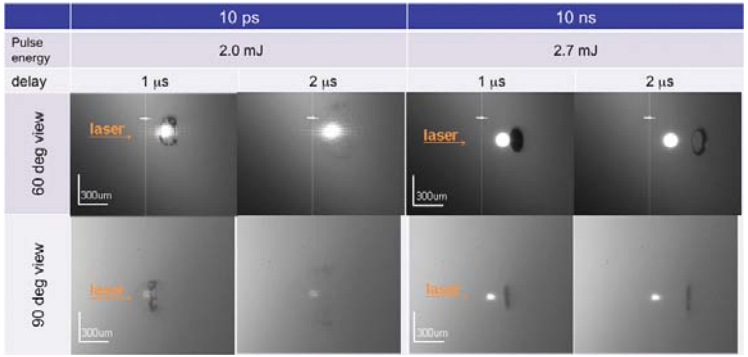


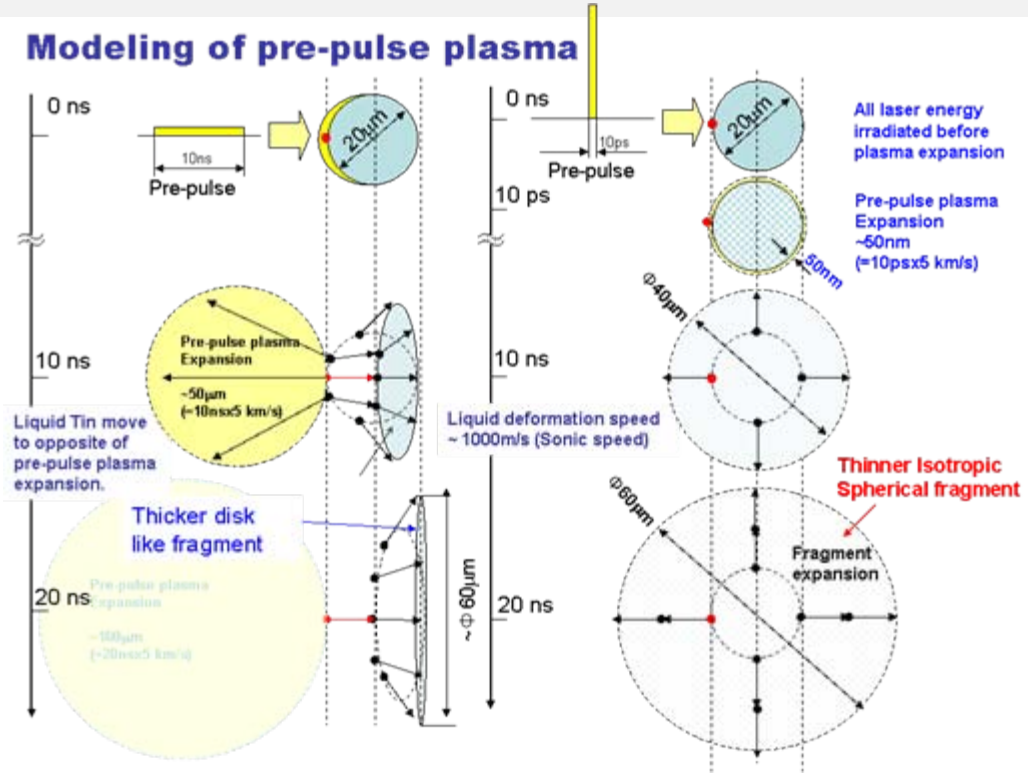


Pre-Pulse Technology (2)

Fragment distribution measurement

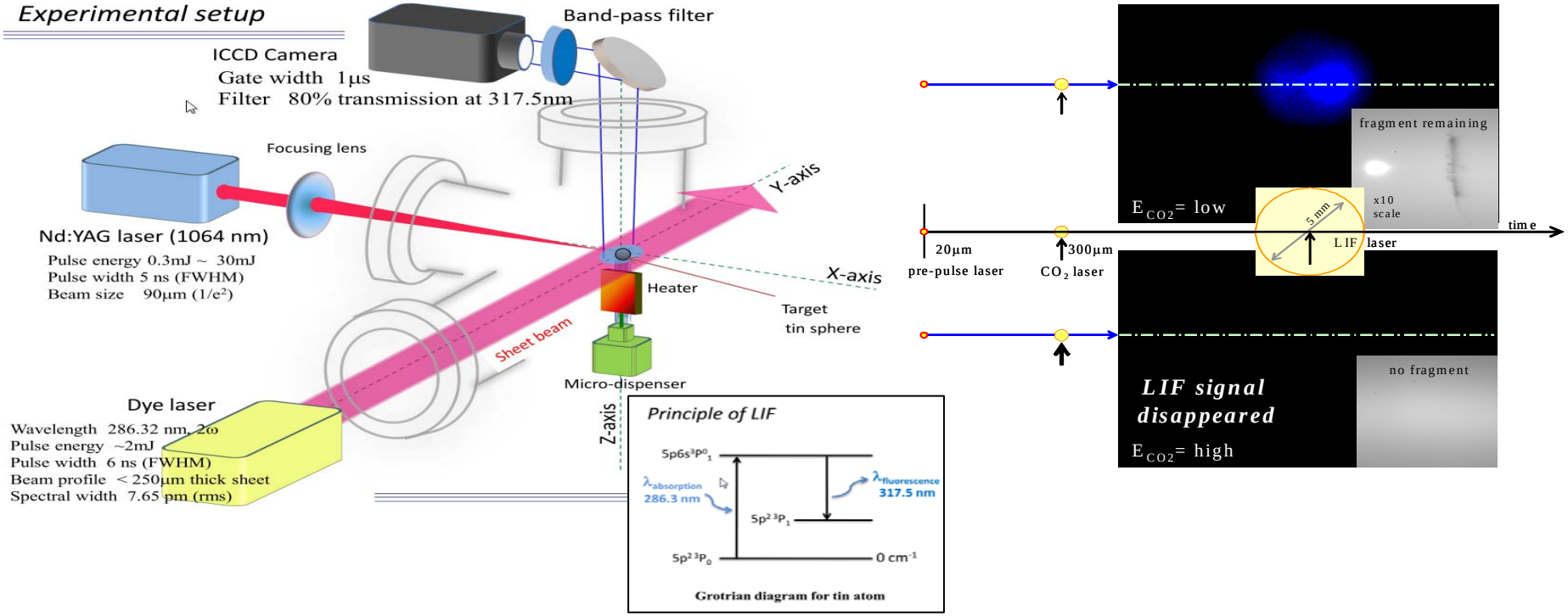
- The mist shape of a picosecond pre-pulse is different from the nanosecond pre-pulse (ps = dome vs. Ns=thin disk or ring)
- Fragment distribution could be a key factor for high CE





Pre-Pulse Technology (3)

Neutral atoms measurement: ionization ratio is investigated

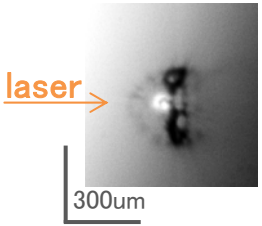


Pre-Pulse Technology(4)

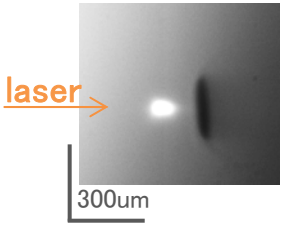
Experiment shows pico-second pre-pulse dramatically enhances ionization rate and CE

Sn Droplet Smash

psec — Dome like target

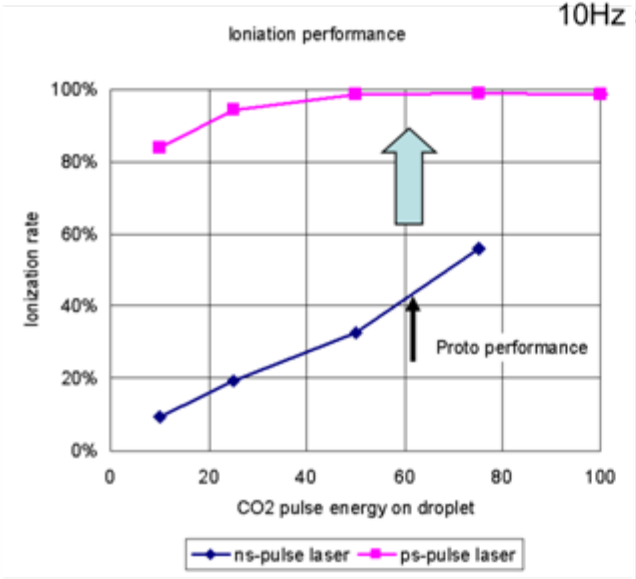


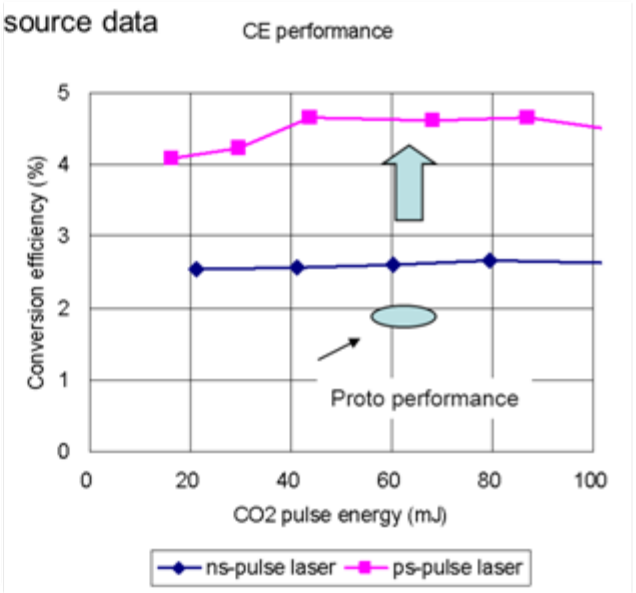
nsec — Flat disk like target



Data in 10Hz Experimental Device

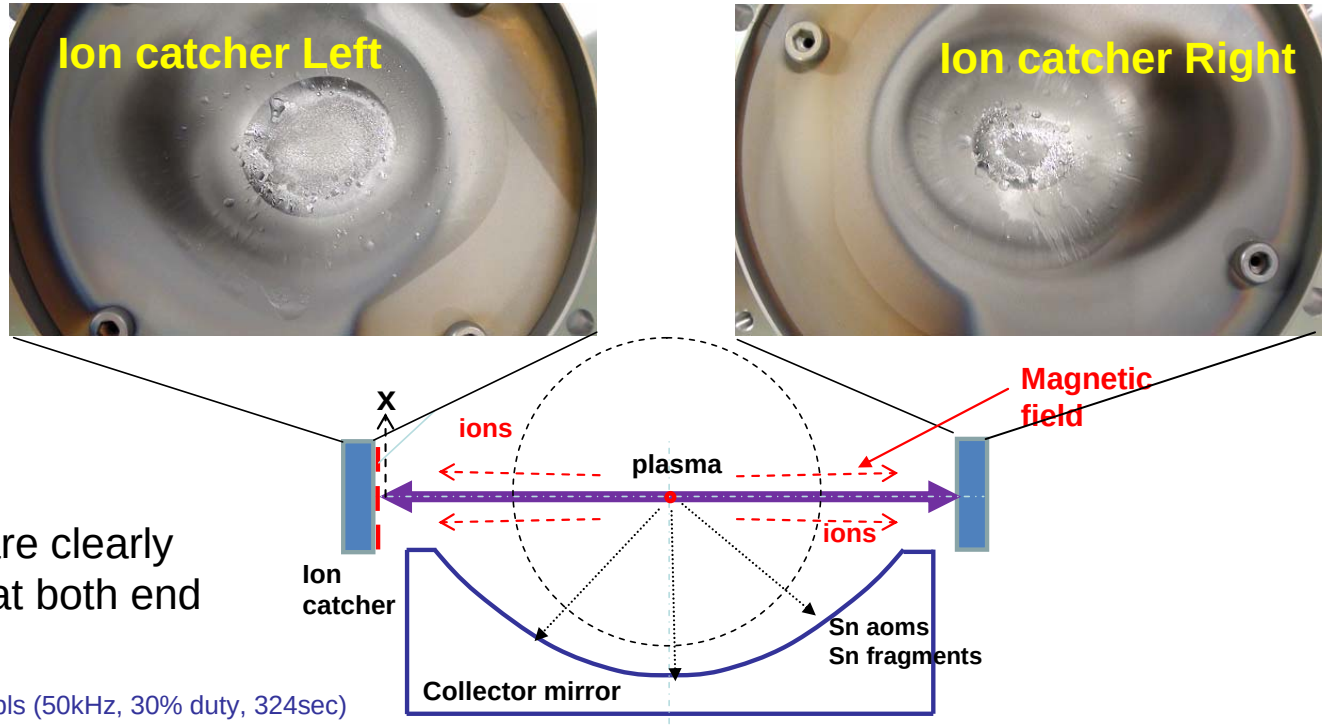
10Hz source data





Magnetic Mitigation Technology

Generated ion is corrected at Ion catcher



Magnetically guided ion are clearly corrected by ion catcher at both end of magnetic pole.

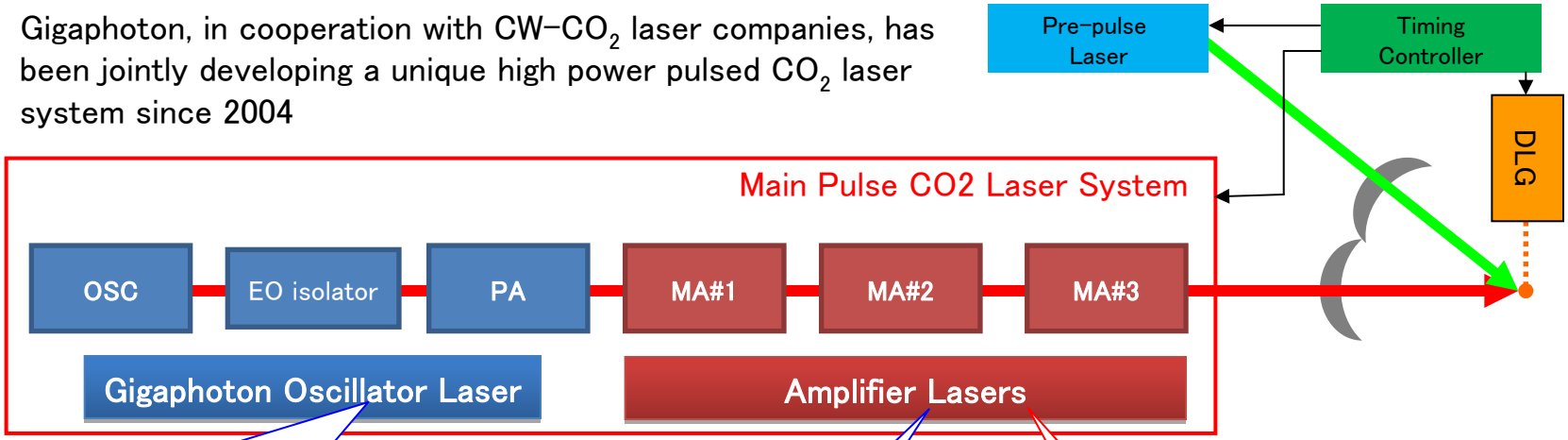
✓4.86Mpls (50kHz, 30% duty, 324sec)

✓Pre-pulse 3.1mJ, CO2 laser 54mJ, DL=ϕ30um,

High Power CO_2 Laser Technology (1)

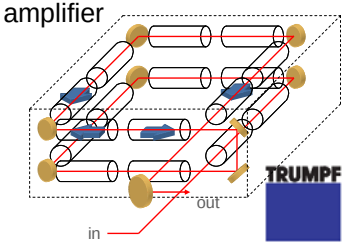
Driver Laser System

Gigaphoton, in cooperation with CW-CO_2 laser companies, has been jointly developing a unique high power pulsed CO_2 laser system since 2004

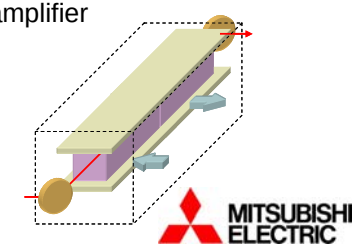


Reported by Dr. Krysztof M Nowak at P-SO-60

Fast axial flow CO2 laser amplifier



Transverse-flow CO2 laser amplifier



Rev A)
notice

High Power CO_2 Laser Technology (2)

Amplifier System A: experiment on present system using Trumpf amplifier laser

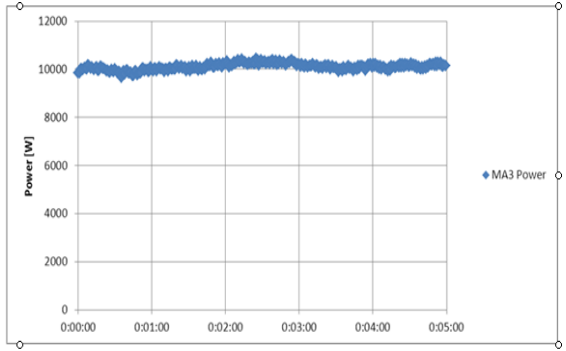
Performance data with 3x MA

−10kW performance was confirmed during hour level operation

- Pulsed CO2 laser system experiment with Gigaphoton oscillator laser and Trumpf amplifiers x3units laser system.

−Next challenge

- Confirm operation at target shooting
- Further power improvement



High Power CO_2 Laser Technology (3)

Amplifier System B: Laboratory level experiment with Mitsubishi electric amplifier laser

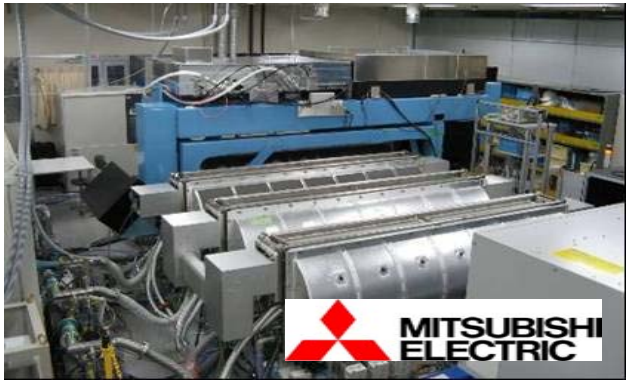
Performance data with 3x MA System-B

-20kW performance was confirmed at minute level

- Pulsed CO_2 laser system experiment with Gigaphoton oscillator laser and 4 Mitsubishi amplifier laser system

-Next challenge

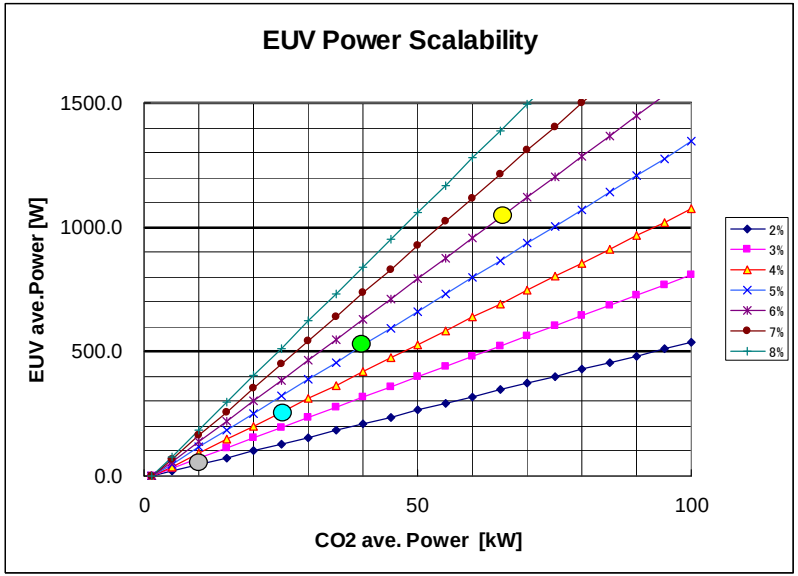
- Achieve 25kW level
- Field level integration
- Confirm operation while shooting at Sn target



*Detail data will be presented at **next presentation** by Y.Tanimoto-san, Mitsubishi electric*

Extendibility to 1kW EUV Power (1)

Feasibility study of EUV Output Power vs. CO2 Input Power



Feasibility study of extendibility to 1kW

- Conversion efficiency is Key. At least achievement of CE＞4% is essentially important. If not, CO2 laser will become ＞100kW.
- At least ＞50kW CO2 laser power must be realized. Even in best case of CE=8%.
- I believe; 1000W EUV source is feasible in future, from the technical data (experiment of CE and CO2 laser) and technical expectation at present.

Extendibility to 1kW EUV Power (2)

Possible scale up scenario of 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
CE	4%	5%	6%
Pulse rate	100 kHz	100kHz	100kHz
Pre-pulse laser	Pico-s	Pico-s	Pico-s
CO2 laser power	25kW	40kW	65kW
# of main amps	3	5	8

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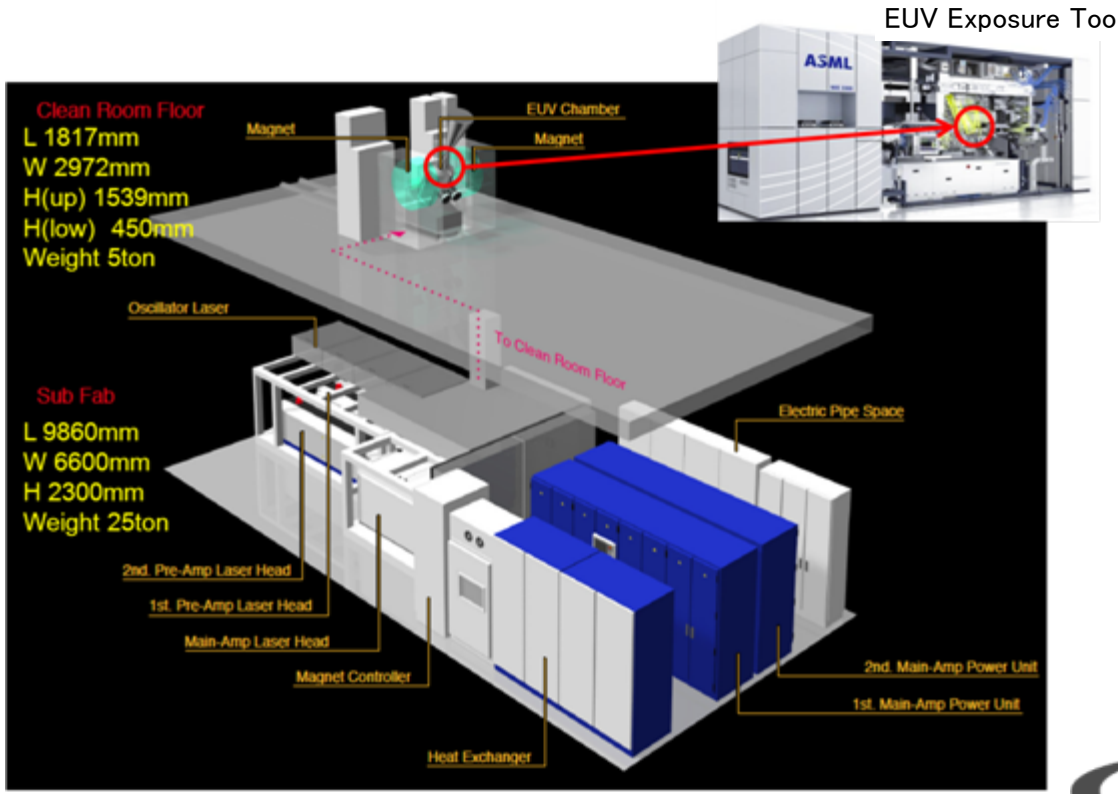
High Power EUV Source Systems (1)

Layout of 250W EUV light source

First HVM EUV Source

- We are developing 250W EUV source.
- Target timing 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)



High Power EUV Source Systems (2)

System Specification (Target)

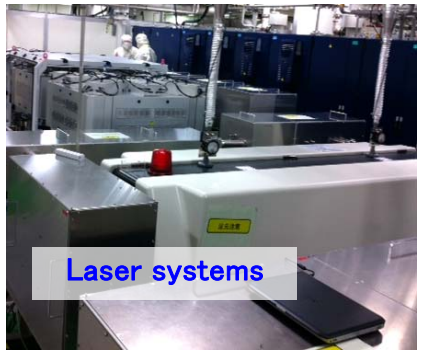
Operational Specification (target)		#1 in PROTO-2	#2 in PROTO-2	PILOT HVM Source
Performance	EUVPower	25W	> 50W	250W
	CE	3 %	4%	4%
	Pulse rate	100kHz	100kHz	100 kHz
	Output angle	horizontal	62 degrees upper (matched to NXE)	62 degrees upper (matched to NXE)
	Availability	1week (operation time)	1week (operation time)	> 75%
Technology	Dloplet generator	20 – 25 μm	20 μm	< 20 μm
	CO2 laser	> 8kW	> 12kW	25kW
	Pre-pulse laser	picosecond	picosecond	picosecond
	Debris mitigation	Validation of magnetic mitigation in system	10days	15days

Light source data is corrected

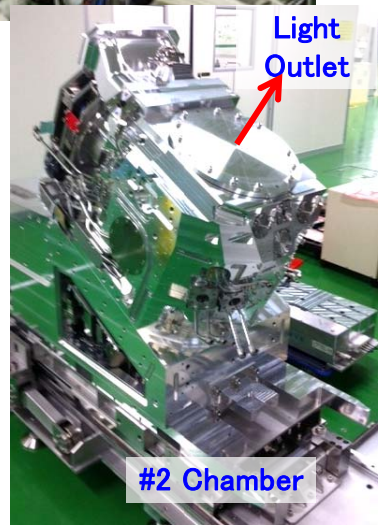
High Power EUV Source Systems (3)

Status of proto light sources, #1 and #2

- System #1 : For EUV irradiation experiment (Operational)
  - The whole system (lasers and chambers) is working now
  - There are some issues and improvement activity is in progress



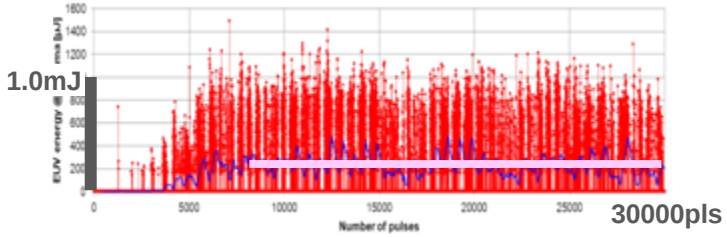
- System #2 :For high power development (Under construction)
  - The design and procurement was finished
  - The assembly will be finish soon
  - After the initial adjustment, the first EUV emission will be in this Q4



High Power EUV Source Systems (4)

In-burst Power performance improvement at proto #1

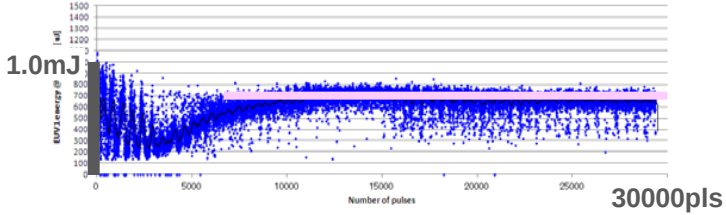
Nov. 2012



4.3W*, 100kHz
*:EUV Clean power @I/F

Shooting control and stabilization A

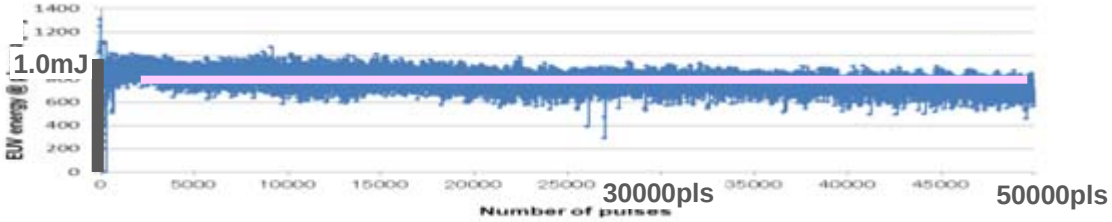
Mar. 2012



6.5W*, 50kHz
*:EUV Clean power @I/F

Shooting control and stabilization B
Improve pre-pulse laser

Aug. 2013



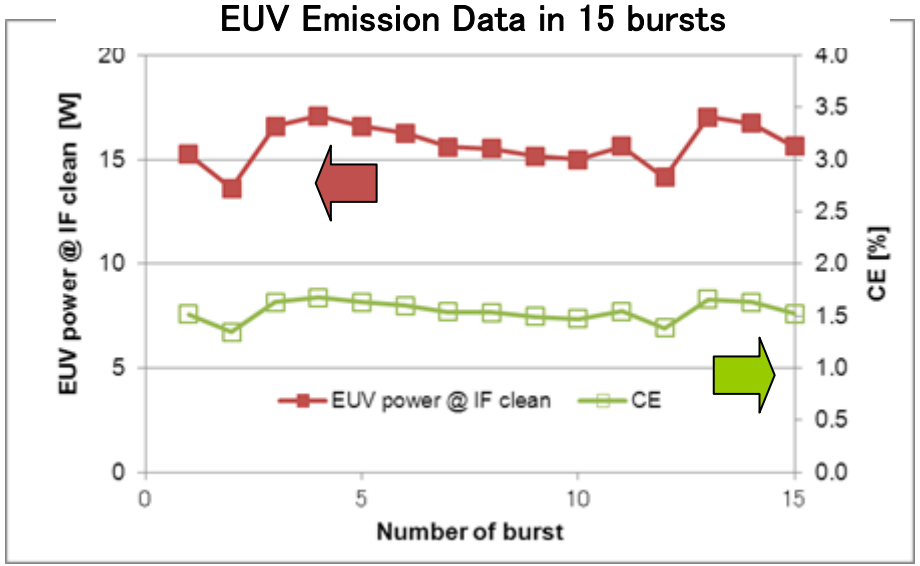
15W*, 100kHz
ON/OFF=0.5s/0.5s
Duty=50%, CE=1.5%
*:EUV Clean power @I/F

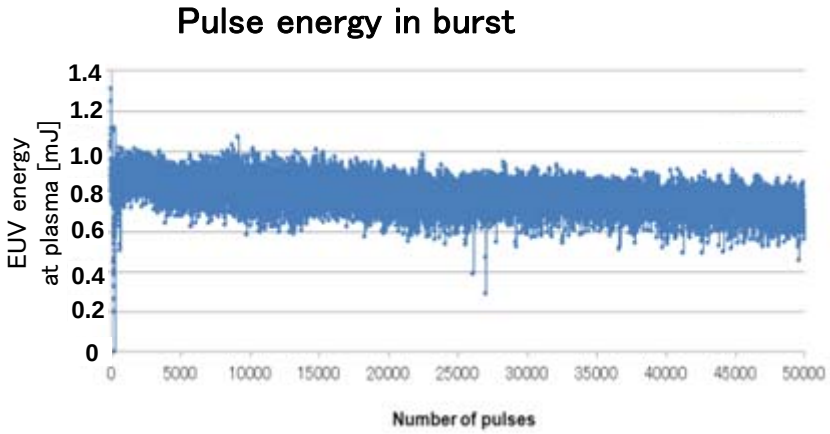
High Power EUV Source Systems (5)

Latest update on power and conversion efficiency (CE)

＊ EUV Clean power at I/F[W]

- 15W* (100kHz) EUV power in burst (50% duty) was achieved.
- CE is **1.5%**. Now we are **improving CE >2.5%** by optimizing shooting conditions.
- Higher CE gives high ionization rate to activate magnet mitigation properly.





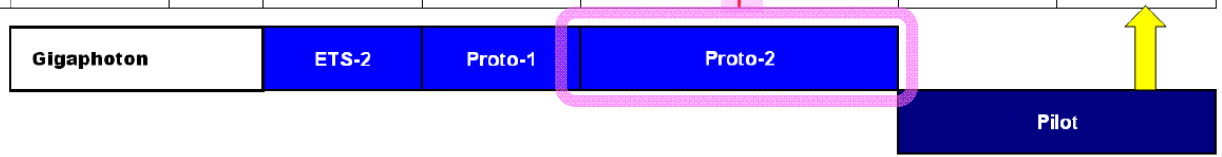
50000pls(0.5sec)ON−0.5secOFF, 50%Duty

High Power EUV Source Systems (6)

Roadmap of EUV light source development

Gigaphoton will release a PILOT source in 2015.
Preceding the PILOT source are two PROTO-2 machines which are currently under development.

	Year	Spec	2010	2011	2012	2013	2014	2015
Dec.2009 Roadmap	Pre-mass Production (ASML)	35nm 100WPH	NXE-3100					
	Source	100W	(100W)					
	Mass Production (ASML)	22nm 200WPH			NXE-3300B	NXE-3300C	NXE-3300D	
	Source	250W		(50W)	(250W)	(350W)	(500W)	
Dec.2012 Roadmap	Pre-mass Production (ASML)	35nm 100WPH	NXE-3100		7 Unit 10WPH	Delayed 3 years		
	Source	100W	CYMER (100W)		Achivement: 9-13W			
	Mass Production (ASML)	22nm 200WPH				NXE-3300B		
	Source	250W				40-60W	(125W)	(250W)



1st PROTO-2 system on operation

2nd PROTO-2 system will be used for higher power development.
(Under construction)

Agenda

- Introduction
  - EUV lithography and light source
  - Delay of EUV lithography on the ITRS Road Map
- LPP source technology
  - Concept of Gigaphoton LPP source
  - High CE Pre-pulse technology
  - High Power Laser
  - Extendibility to 1kW EUV power
- Update of LPP source development
  - High power EUV source systems
- Summary

Summary (1)

- Mass production EUV market is delayed 3 years, because of light source power issue.
  - Bottle neck is power of EUV light source.

- Extendibility of LPP-EUV source power is discussed
  - High CE technology
    - We found CE 4.7% average with pico-second pre-pulse.
    - Demonstrated remarkable reduction of mist after the pico-second pre-pulse.
  - High power CO2 driver laser technology
    - For >500W EUV source, New 40kW CO2 laser amplifier development project started co-operation with Mitsubishi electric.
    - Target is 25kW until Q1 2013.6　20kW@S/L output is observed after 4-amplifier
  - 1000W EUV source feasibility
    - Possible scenario is reported

Summary (2)

- Gigaphoton LPP source:
  - We developing Proto-2nd phase machine to demonstrate key technologies.
    - Droplet generator is improved dramatically, stable operation >100h is demonstrated.
    - CO2 laser achieved 10kW operation with 75% duty.
    - EUV light emission 15 W (@I/F Clean power in 50% duty burst 100kHz) is achieved.
  - Proto-2 target is 25W level one week operation demonstration by Q4 2013.
  - Our shipment target of Pilot is 2015.

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THANK YOU

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