Scalability of CO_2 amplifiers to generate stable > 500W extreme ultraviolet (EUV) beams

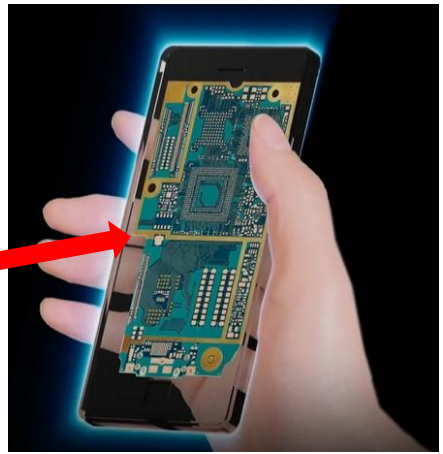
Koji Yasui[1], Ph.D
Naoyuki Nakamura[2], Jun-ichi Nishimae[2]
Masashi Naruse[3], Kazuo Sugihara[3], Masato Matsubara[3]

[1]Mitsubishi Electric Corporation, Head quarter, Tokyo, Japan
[2]Mitsubishi Electric Corporation, Advanced technology R&D center, Hyogo, Japan
[3]Mitsubishi Electric Corporation, Nagoya works, Nagoya, Japan

Introduction

1. We are supplying advanced machines for fast-growing market such as smart phones.

2. Today IoT/AI market is emerging and we are preparing for the new demands.



Contents

1. Why we need EUVL for IoT/AI era

1. Why we need EUVL for IoT/AI era

We need low-cost high-end devices for our machines

Smart Ecosystem

Physical

CPS AI

Comparable with today's super computer

Comparable with today's human brains

CPS:Cyber Physical System, AI：Artificial Intelligence

1. Why we need EUVL for IoT/AI era

JAPANESE-GERMAN CENTER BERLIN [JDZB]
MERCATOR INSTITUTE FOR CHINA STUDIES [MERICS]
in cooperation with
COLOGNE INSTITUTE FOR ECONOMIC RESEARCH [IW]
FUJITSU RESEARCH INSTITUTE [FRI]

TENTATIVE PROGRAMME

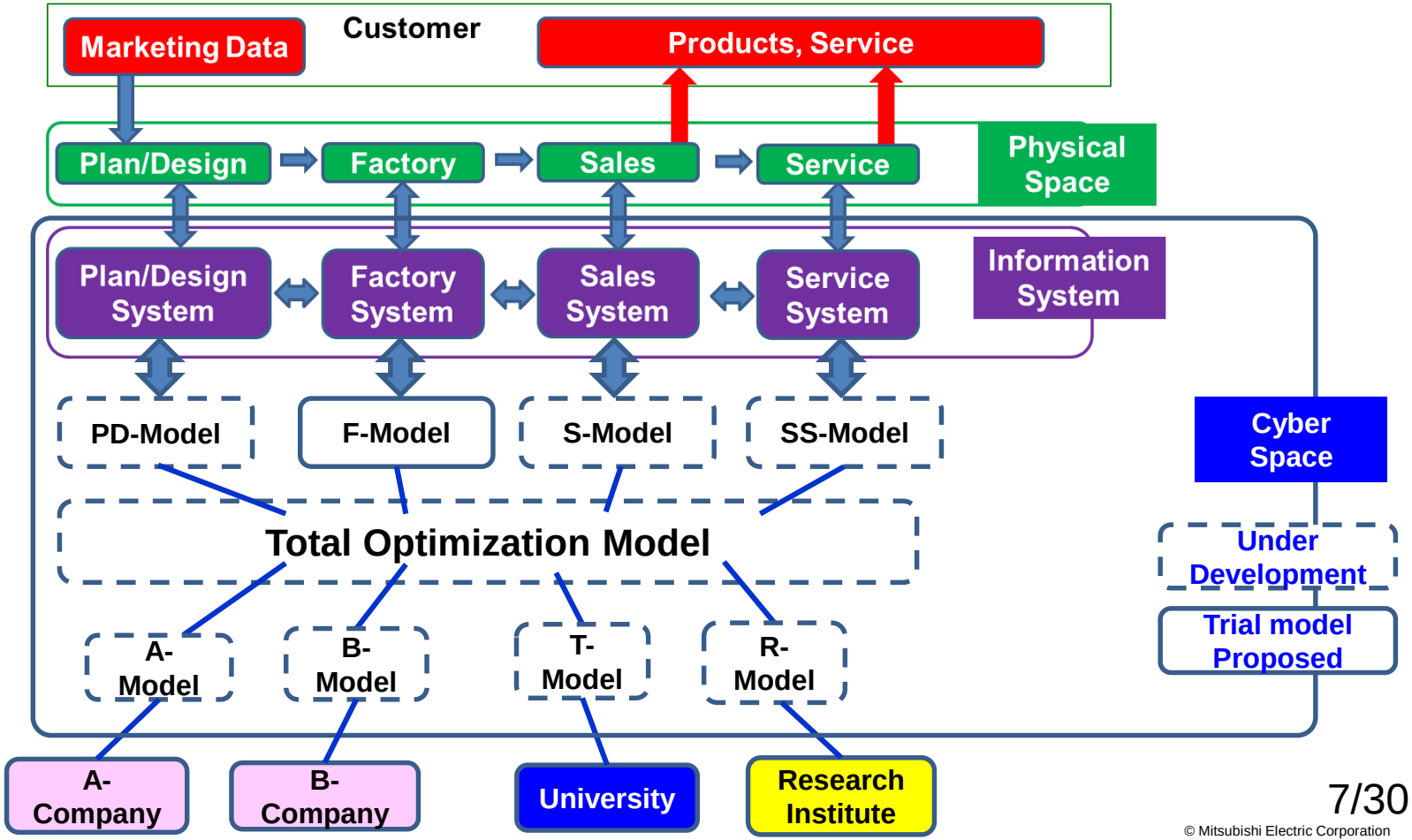
for the experts' symposium
The Future of Manufacturing:
Industry 4.0 in China, Germany and Japan

on Monday, June 12, 2017
at the JDZB, Saargemuender Str. 2, 14195 Berlin

http://www.jdzb.de/en/events/single-view/id/1632/

1. Why we need EUVL for IoT/AI era

Middle Goal



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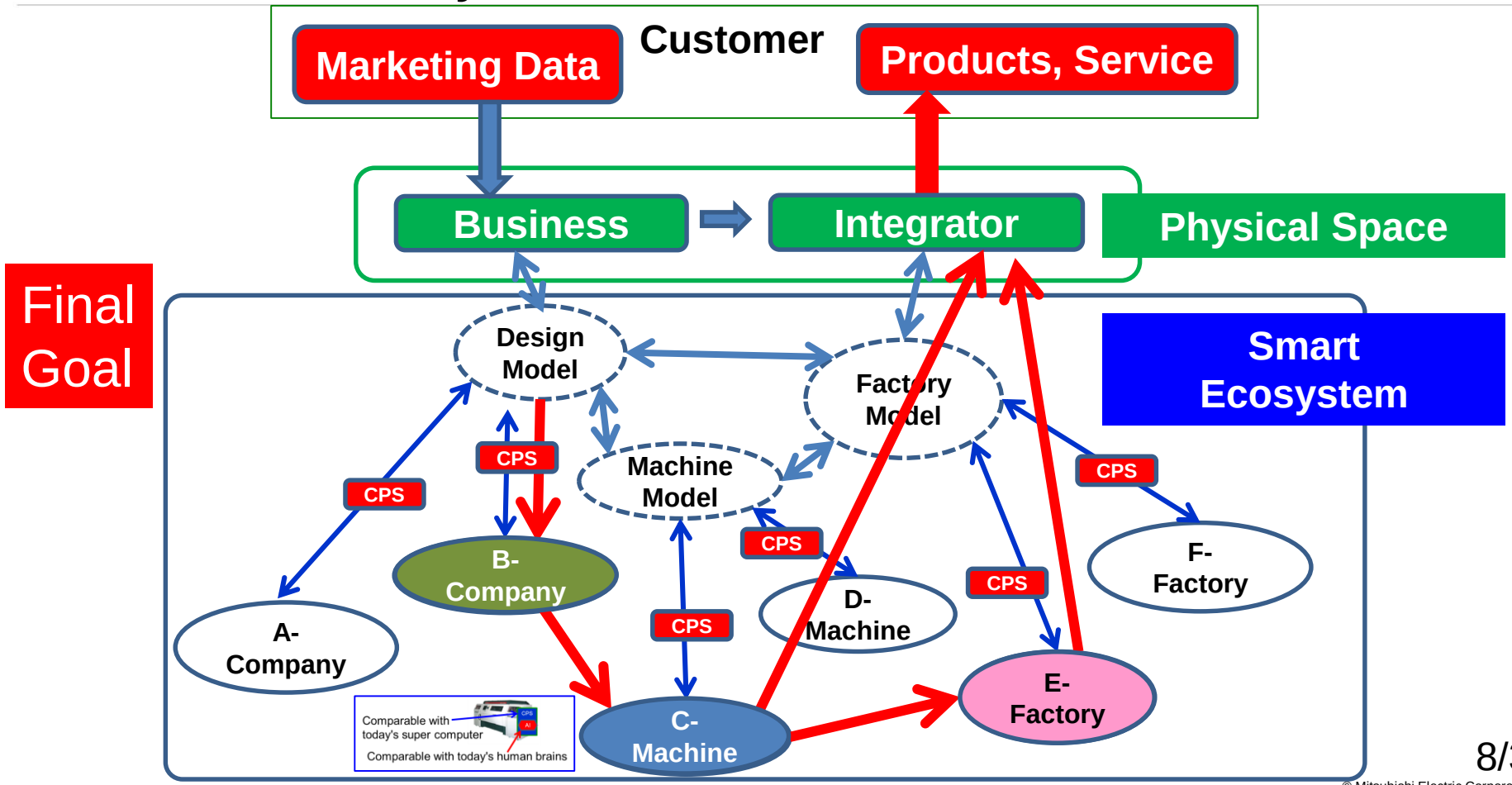
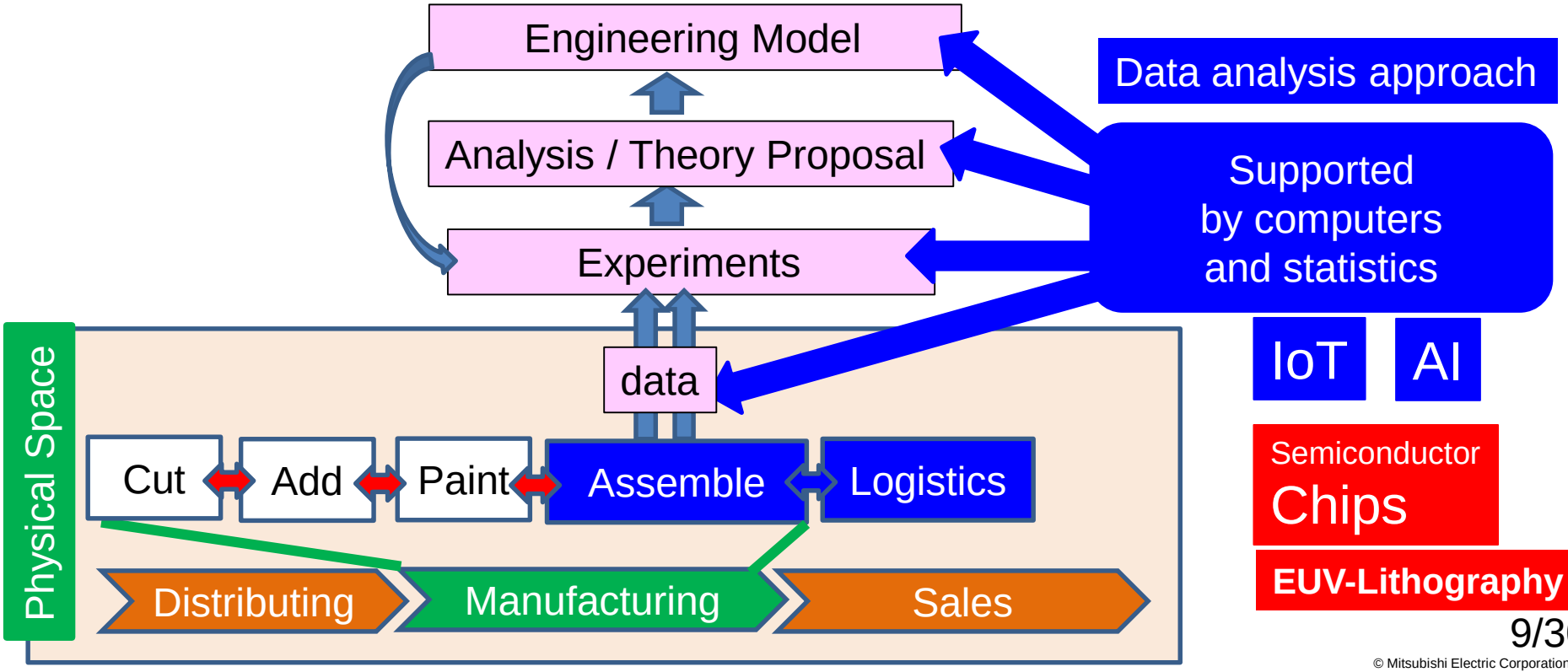


1. Why we need EUVL for IoT/AI era

Modeling requires advanced theories and calculation powers

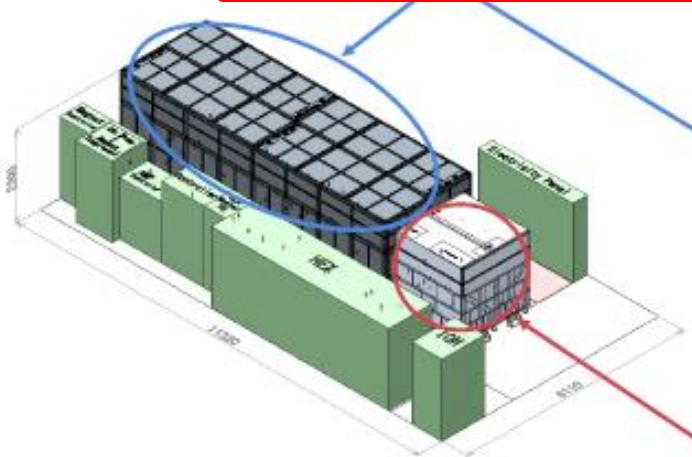


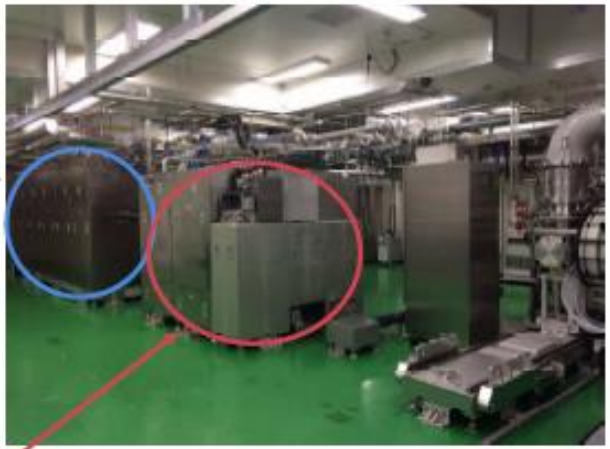
2. Our progress for EUVL success

2. Our progress for EUVL success

Pilot System Driver Laser and PPL System

4 x CO_2 Laser Amplifier Modules





Oscillator/PPL Module

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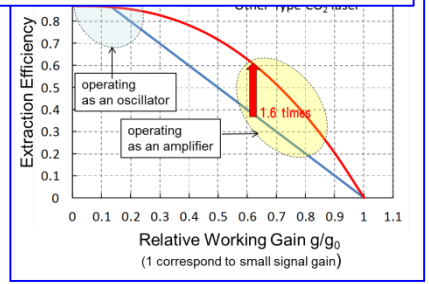
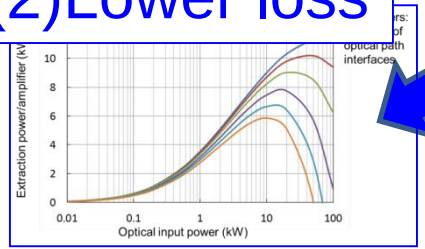
2. Our progress for EUVL success

Technological Advantages

(1)Higher gain

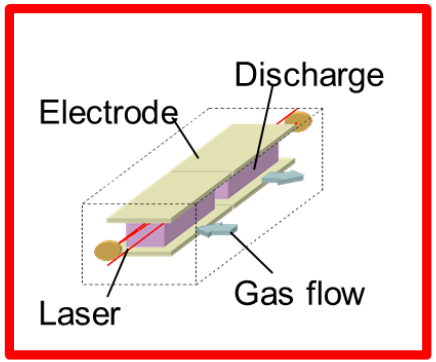


(2)Lower loss



(3)Better beam shapes

Today



1. Transverse-gas-flow

User Advantages

Today

(1)High power >25kW with better efficiency

(2)Stable operations

Today

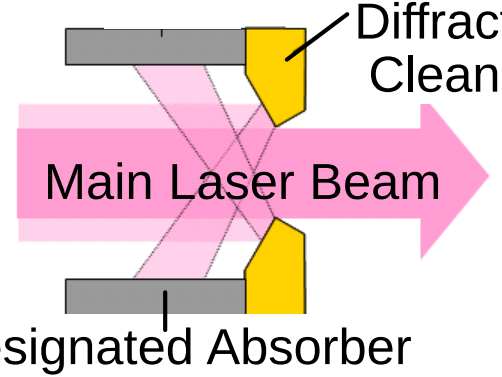
(3)High EUV power with better efficiency

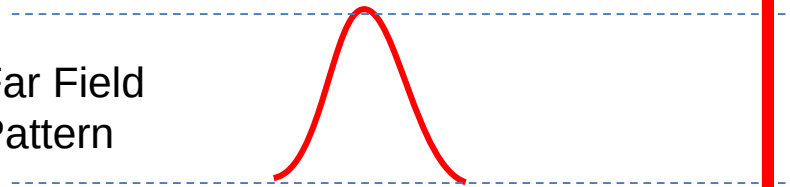
Also presented by Gigaphoton Inc.

2. Our roll for EUVL success

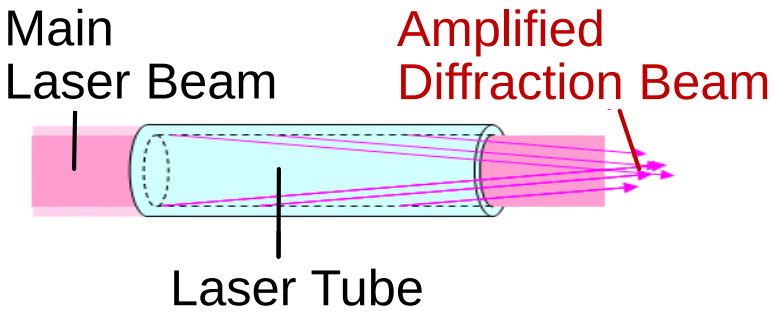
Better beam shapes improved for fine metal cutting applications are also effective for efficient EUV generation

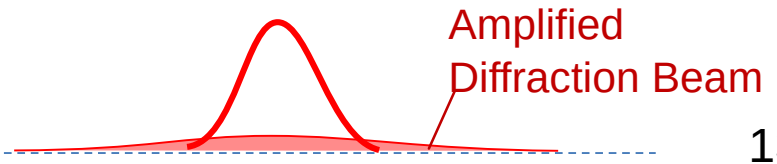
Transverse-gas-flow CO_2 laser





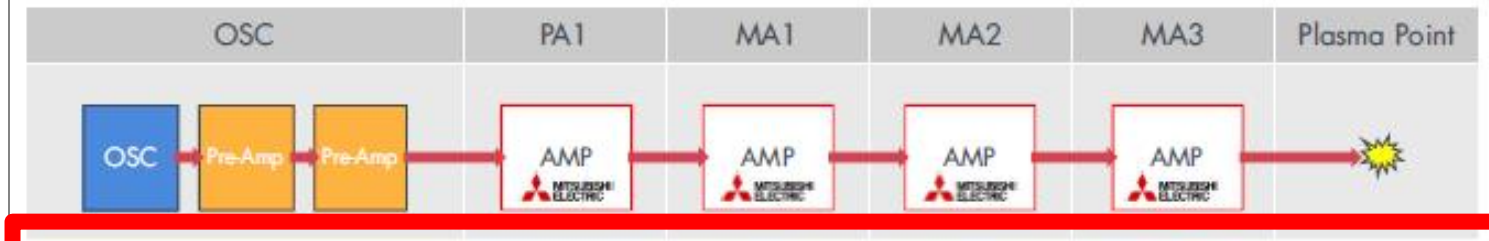
Fast-axial-flow CO_2 laser



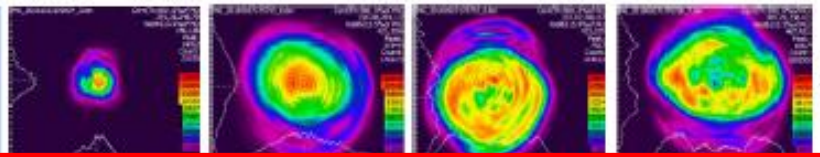


2. Our roll for EUVL success

Pilot System Driver Laser and PPL System Improvements

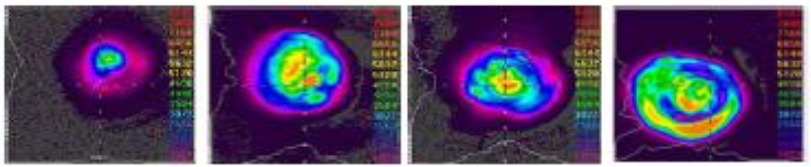


Pilot#1 uses Mitsubishi lasers for all amplifiers



greatly improved uniformity

Proto#2 uses TRUMPF lasers for the three main amplifiers



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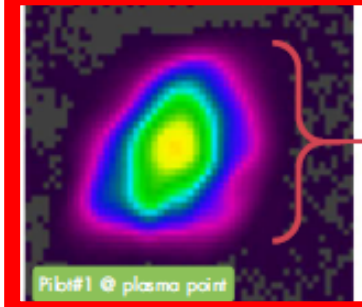
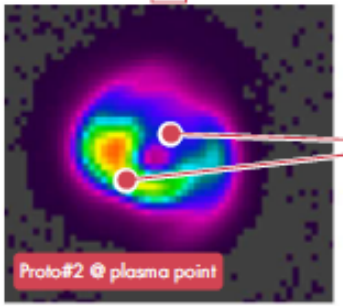
2. Our roll for EUVL success

Pilot System Driver Laser and PPL System

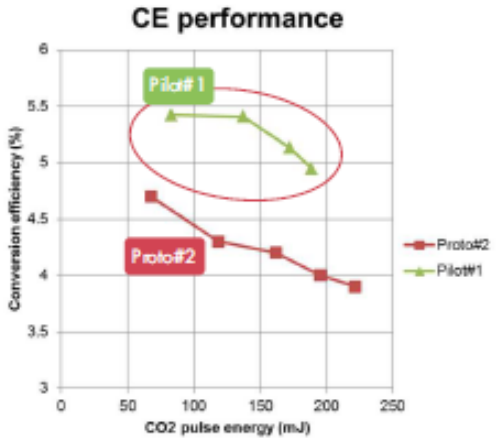
>5% CE was achieved due to the greatly improved CO_2 beam profile



Greatly improved evenness in beam profile allows for more uniform and efficient ionization of droplets – thus resulting in higher CE



Previous CO_2 beam profile was very uneven and hence less efficient by comparison



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2. Our progress for EUVL success

Technological Advantages

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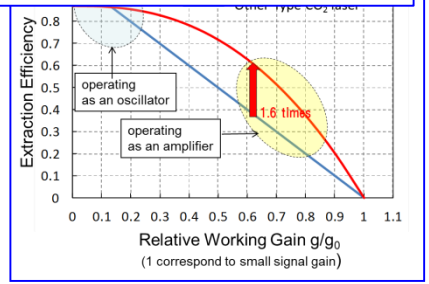
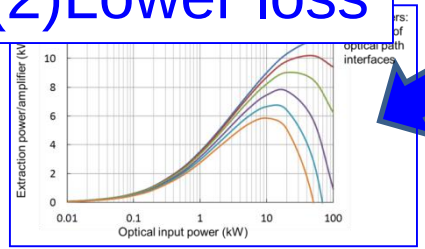
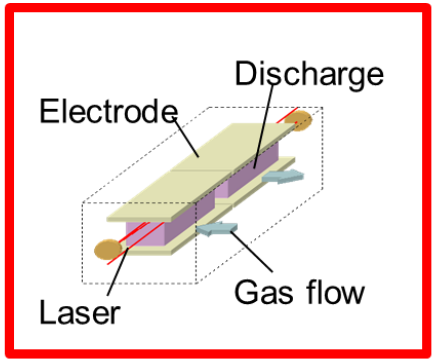


(2)Lower loss



(3)Better beam shapes

Today



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Also presented by Gigaphoton Inc.

3. Toward > 500W EUV beams

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High Power EUV Source for High NA EUV exposure tool

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	[illegible]0	139.2	162.4	185.6
150	15		73.7	110.6	147.4	[illegible]3	221.1	258.0	294.8
200	20		101.0	151.[illegible]	202.0	[illegible]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.[illegible]	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.[illegible]	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

Lithography	R(nm)*	NA	λ/n (nm)	Power (W)
KrF dry	102	0.85	248	40
ArF dry	73	0.93	193	45
F_2 dry	69	0.80	157	-
ArF immersion	50	1.35	134	90
EUV	14	0.33	13.5	>250
EUV (High NA)	7	0.6	13.5	>500

	HVM1	HVM2	HVM3
EUV Power	250W	300W	500W
Pulse Rate	100kHz	100kHz	100kHz
CE	4.5%	5%	5%
CO_2 Laser Power	25kW	25kW	40kW

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3. Toward > 500W EUV beams

Next Generation High Power EUV Source Development

in cooperation with MITSUBISHI ELECTRIC

	OSC	PA1	MA1	MA2	MA3	Plasma Point
	OSC → Pre-Amp → Pre-Amp	AMP	AMP	AMP	AMP	
For 250W EUV	100W	5kW	10kW	20kW	30kW	25kW
For 500W EUV	100W	**10kW**	**20kW**	**30kW**	**50kW**	**40kW**

Basic Experiment in 2013

1st Amplifier installation in 2015

Amplifier system installation in 2016

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3. Toward > 500W EUV beams

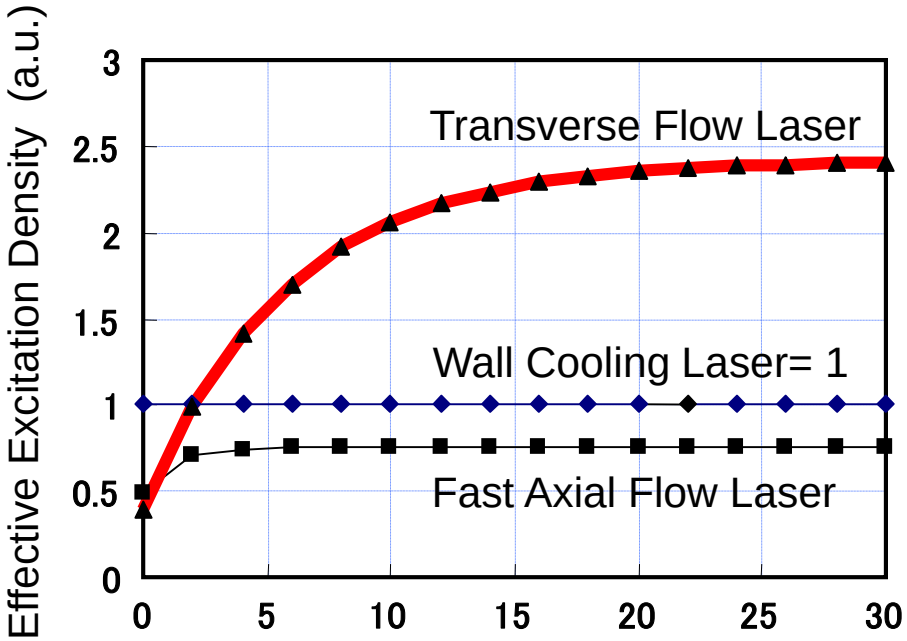
Possible technological bottlenecks toward higher power generation and prospects.

1. Beam shape degradation → Within our estimation **OK**

2. Higher electric powers

3. Toward > 500W EUV beams

Theoretical calculation to explain electrical input power reduction of > 50% compared with other CO_2 lasers



$$\frac{\frac{v}{\lambda}\left\{1+\frac{\lambda}{v}(W-l)-e^{-\frac{l\lambda}{v}}\left(1-e^{-\frac{(1+M)(r-l)\lambda}{v}}\right)-\frac{e^{-\frac{(1+M)(r-l)\lambda}{v}}}{1+M}\left(M+e^{\frac{(1+M)(W-l)\lambda}{v}}\right)\right\}}{(r-l)}$$

$$\frac{(1+M)W+\frac{v}{\lambda}e^{-\frac{(1+M)L\lambda}{v}}\left(1-e^{\frac{(1+M)W\lambda}{v}}\right)}{(1+M)L}$$

3. Toward > 500W EUV beams

Possible technological bottlenecks toward higher power generation and prospects.

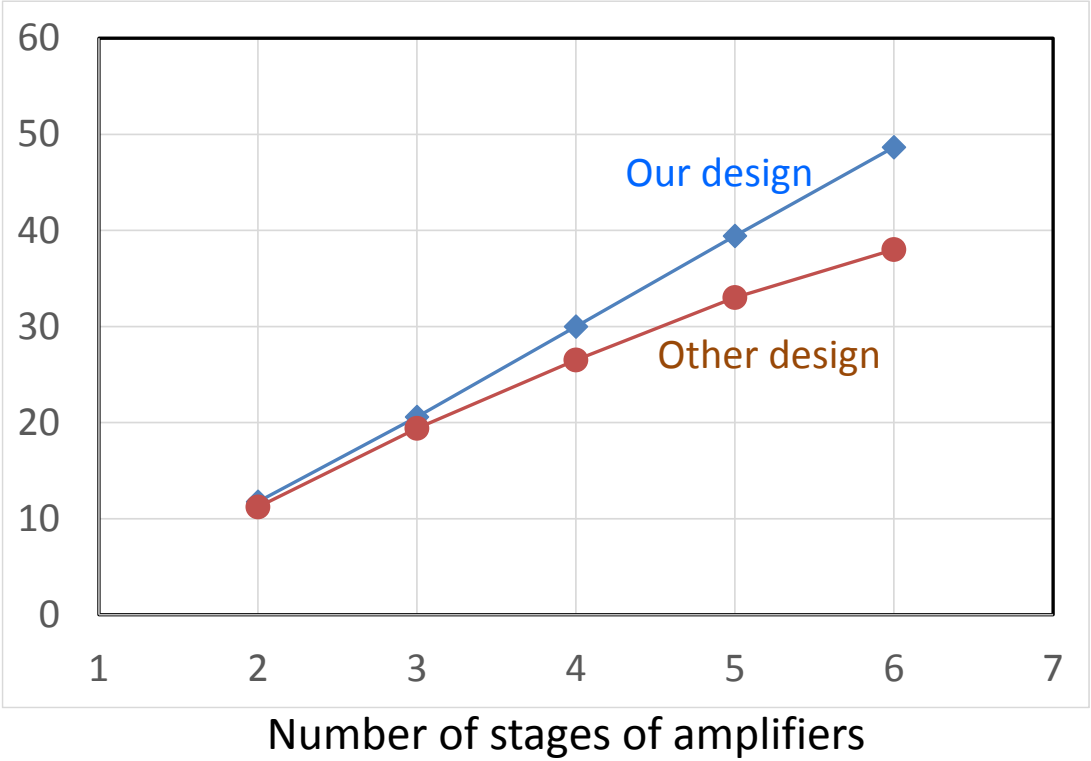
1. Beam shape degradation → Within our estimation **OK**

2. Higher electric powers → Within conventional powers even at 40kW **OK**

3. Extraction degradation

3. Toward > 500W EUV beams

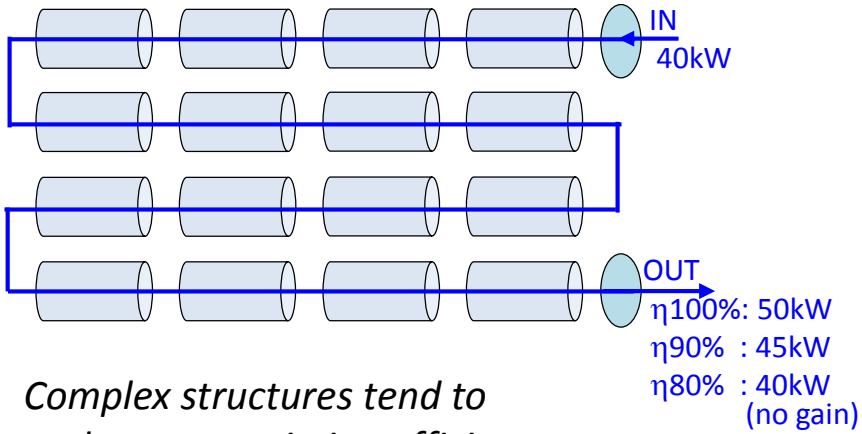
Scalable amplification system by increasing the number of stages of amplifiers can be easily configured



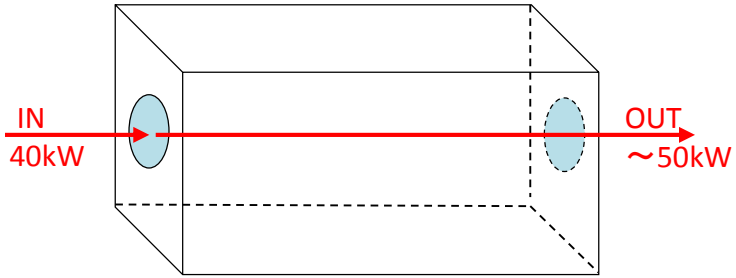
3. Toward > 500W EUV beams

Higher optical transmission efficiency is the essential property for high-power amplifiers

High-power amplifier
(assuming power extraction ability of 10kW)



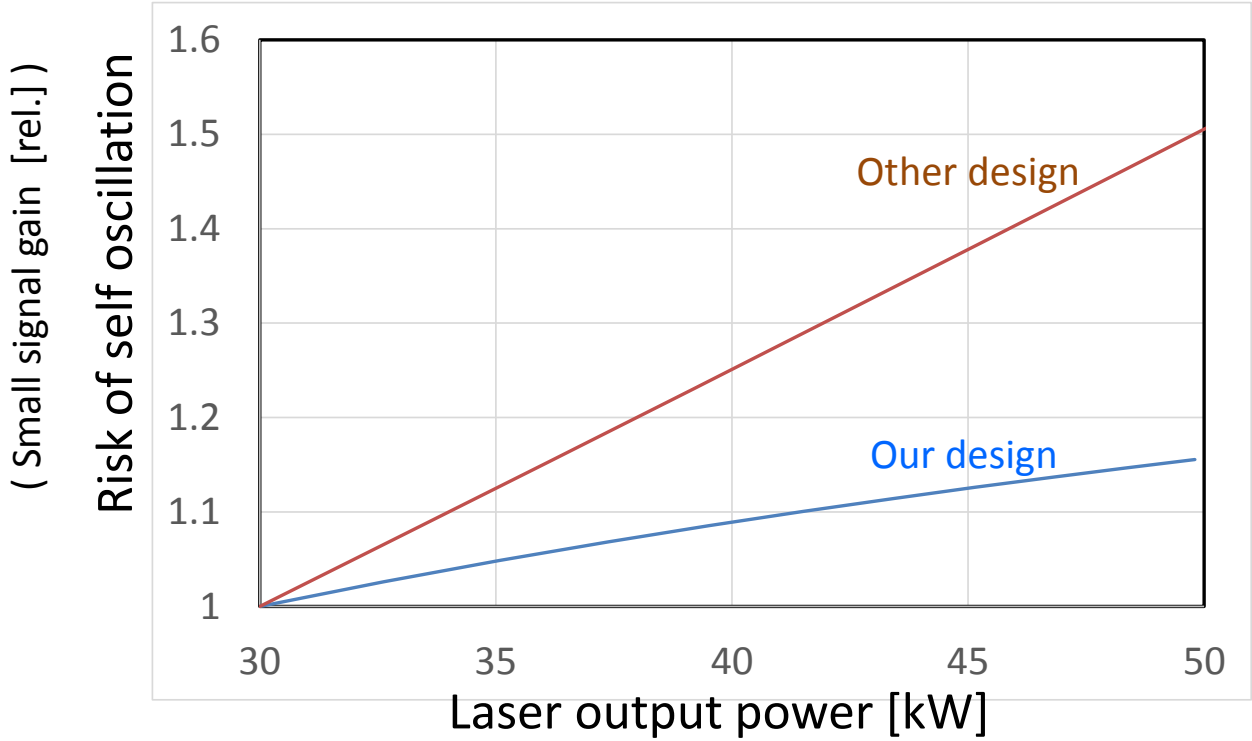
Complex structures tend to reduce transmission efficiency



The ultimately simple structure of our amplifier allows for the highest transmission efficiency and lead to scalable amplifier system

3. Toward > 500W EUV beams

The output power can be increased without significantly increasing the risk of self-oscillation



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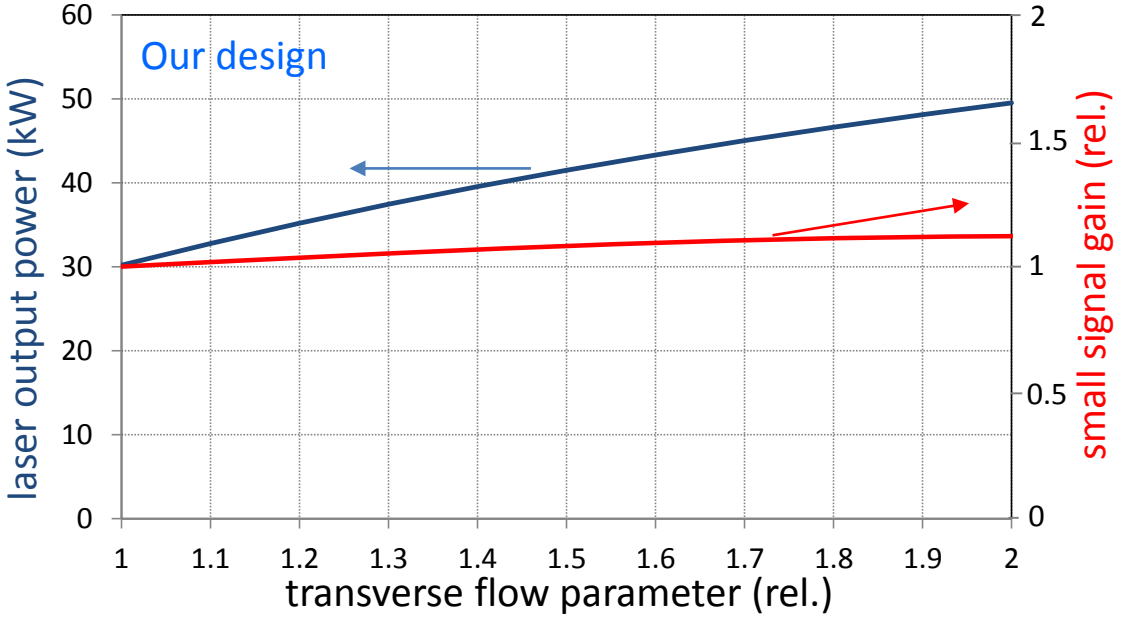

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1. Beam shape degradation → Within our estimation **OK**

2. Higher electric powers → Within conventional powers even at 40kW **OK**

3. Extraction degradation → Within our estimation **OK**

Summary

1. Scalability of CO_2 amplifiers to generate > 500W EUV beams that are required in the near future for high-volume-manufacturing of IoT/AI devices are discussed.

2. We consider that with the emerging application fields related to IoT/AI technology, EUV lithography has become essential technology.

3. We have shown that CO_2 amplifiers with transverse-gas-flow configuration could solve technological bottlenecks to enhance the EUV powers more than 500W.

One appendix

Digital pre-pulsing technology based on controllable digital picosecond lasers are also going to be proposed in the near future for better EUV efficiency.

Acknowledgements

- The experiments were performed by research members of Mitsubishi Electric corp. and Gigaphoton Inc.

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- A part of this work was supported by The New Energy and Industrial Technology Development Organization (NEDO, Japan)

NEDO

Thank you very much for your attention