EUV Lithography Research and Development Activities in Japan

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Outline

1. Introduction
2. Current R&D of EUV lithography at UoH
3. EUV lithography R&D at EIDEC
5. Capability of beyond EUVL (BEUVL)
6. Summary

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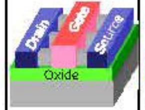
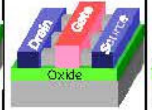
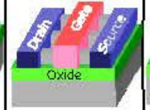
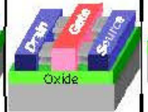
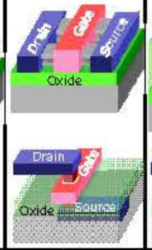
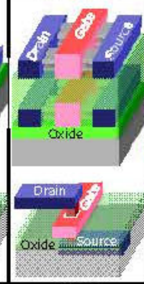
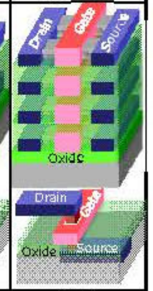
IRDS 2018 Device, PPA, and Ground Rules Roadmap for Logic Devices

Table MM01 - More Moore - Logic Core Device Technology Roadmap

YEAR OF PRODUCTION	2018	2020	2022	2025	2028	2031	2034
	G54M36	G48M30	G45M24	G42M21	G40M16	G40M16T2	G40M16T4
Logic industry "Node Range" Labeling (nm)	"7"	"5"	"3"	"2.1"	"1.5"	"1.0 eq"	"0.7 eq"
IDM-Foundry node labeling	i10-f7	i7-f5	i5-f3	i3-f2.1	i2.1-f1.5	i1.5e-f1.0e	i1.0e-f0.7e
Logic device structure options	FinFET	finFET	finFET LGAA	LGAA	LGAA VGAA	LGAA-3D VGAA	LGAA-3D VGAA
Mainstream device for logic	finFET	finFET	finFET	LGAA	LGAA	LGAA-3D	LGAA-3D
							
Vdd (V)	0.75	0.70	0.70	0.65	0.65	0.60	0.60
Gate length (nm)	20	18	16	14	12	12	12
Number of stacked tiers	1	1	1	1	1	2	4
Number of stacked devices	1	1	1	3	3	4	4
Digital block area scaling - node-to-node	-	0.60	0.75	0.82	0.79	0.57	0.50
Cell height limitation - HD	device	M0	M0	M0	M0	M0	M0
SoC area scalling (stacked) - node-to-node	-	0.70	0.79	0.84	0.83	0.60	0.60
CPU frequency (GHz)	2.90	3.13	3.27	3.64	4.02	3.46	3.30
Frequency scaling - node-to-node	-	0.08	0.04	0.11	0.10	-0.14	-0.05
CPU frequency at constant power density (GHz)	2.90	1.92	1.69	2.14	1.93	1.25	0.72
Power at iso frequency - node-to-node	-	-0.23	-0.14	-0.36	-0.20	-0.12	-0.14
Power density - relative	1.00	1.64	1.94	1.70	2.08	2.78	4.55
LOGIC TECHNOLOGY ANCHORS							
Patterning technology inflection for Mx interconnect	193i, EUV	193i, EUV DP	193i, EUV DP	193i, High-NA EUV	193i, High-NA EUV	193i, High-NA EUV	193i, High-NA EUV
Beyond-CMOS as complimentary to mainstream CMOS	-	-	-	2D Device, FeFET	2D Device, FeFET	2D Device, FeFET	2D Device, FeFET
Channel material technology inflection	Si	SiGe25%	SiGe50%	Ge, 2D Mat	Ge, 2D Mat	Ge, 2D Mat	Ge, 2D Mat
Process technology inflection	Conformal deposition	Conformal Doping, Contact	Channel, RMG	Stacked-device Non-Cu Mx	Stacked-device Non-Cu Mx	3DVLSI	3DVLSI
Stacking generation inflection	2D	2D	3D-stacking: W2W D2W	3D-stacking: W2W D2W	Fine-pitch + High-BW 3D stacking, P-over-N (CFET), VGAA use	3DVLSI: Mem-on-Logic, VGAA use	3DVLSI: Logic-on-Logic
LOGIC TECHNOLOGY INTEGRATION CAPACITY							
Number of tiers	1	1	1	1	1	2	4
SoC footprint area target (mm2)	80	80	80	80	80	80	80
NAND2-eq gate count (Mgates/mm2)	10	17	23	28	35	62	125

Acronyms used in the table (in order of appearance): FDSOI: Fully-Depleted Silicon-On-Insulator (FDSOI), LGAA: Lateral Gate-All-Around-Device (GAA), VGAA: Vertical GAA, 3DVLSI: Fine-pitch 3D logic sequential integration.

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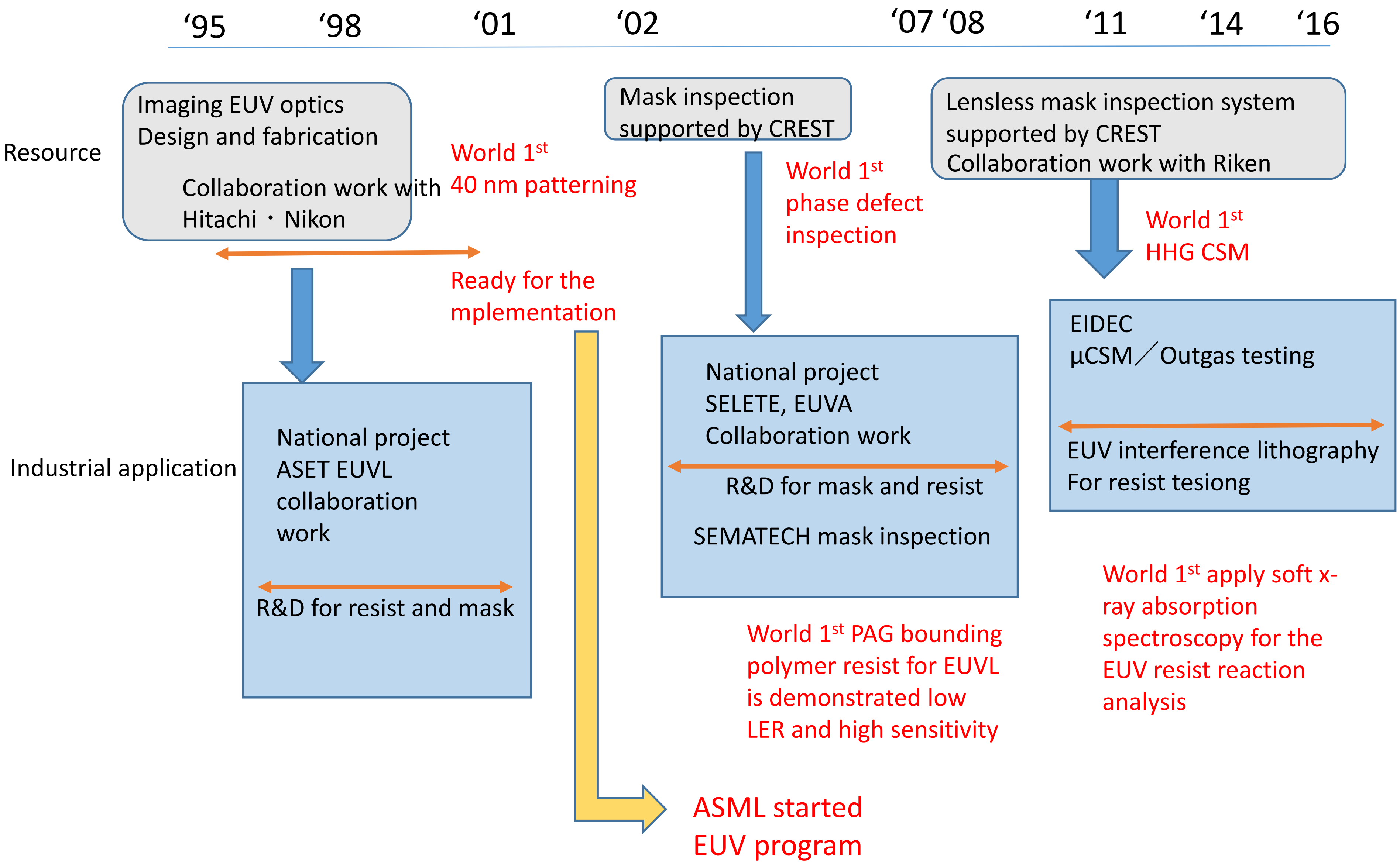
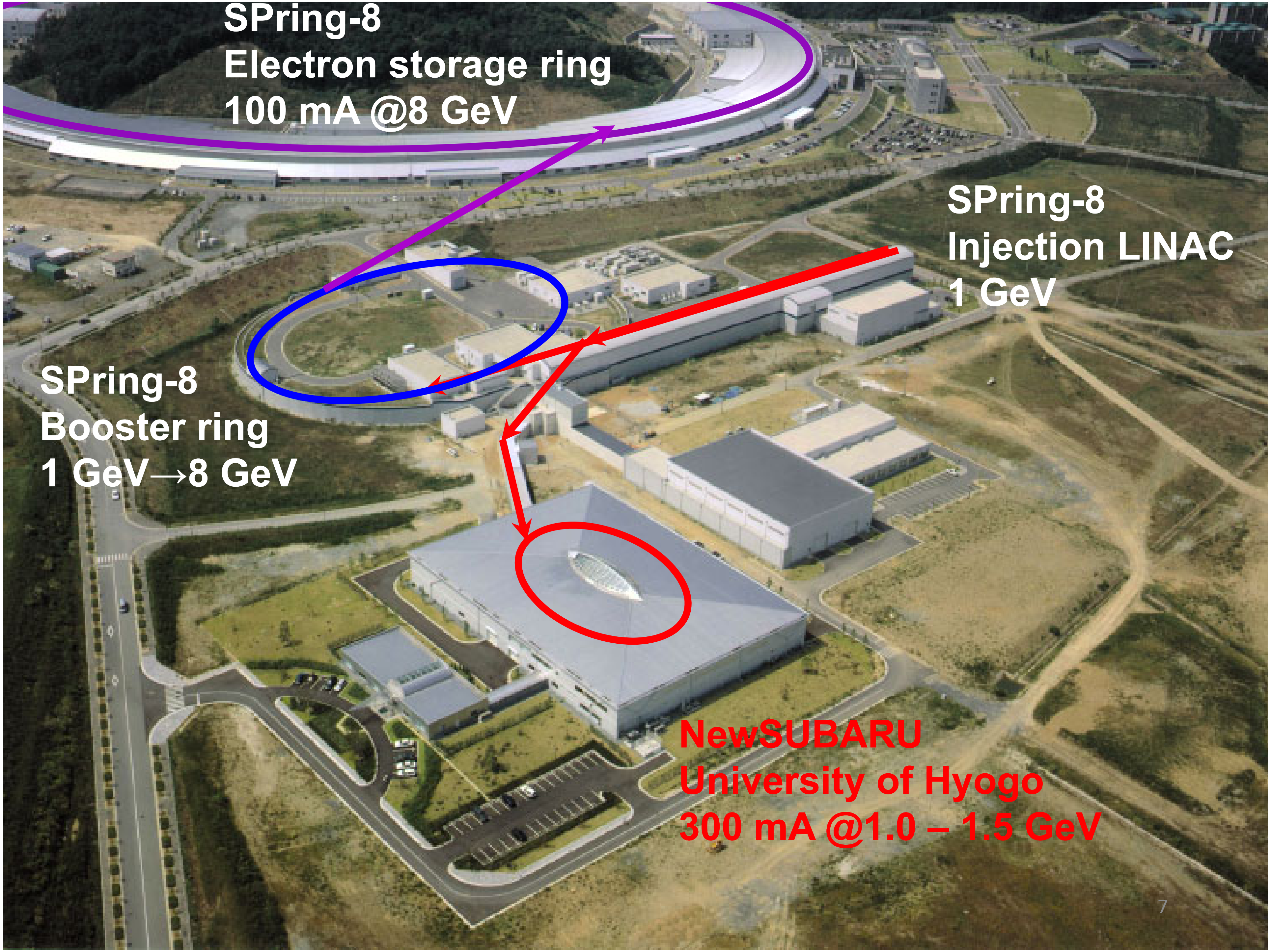
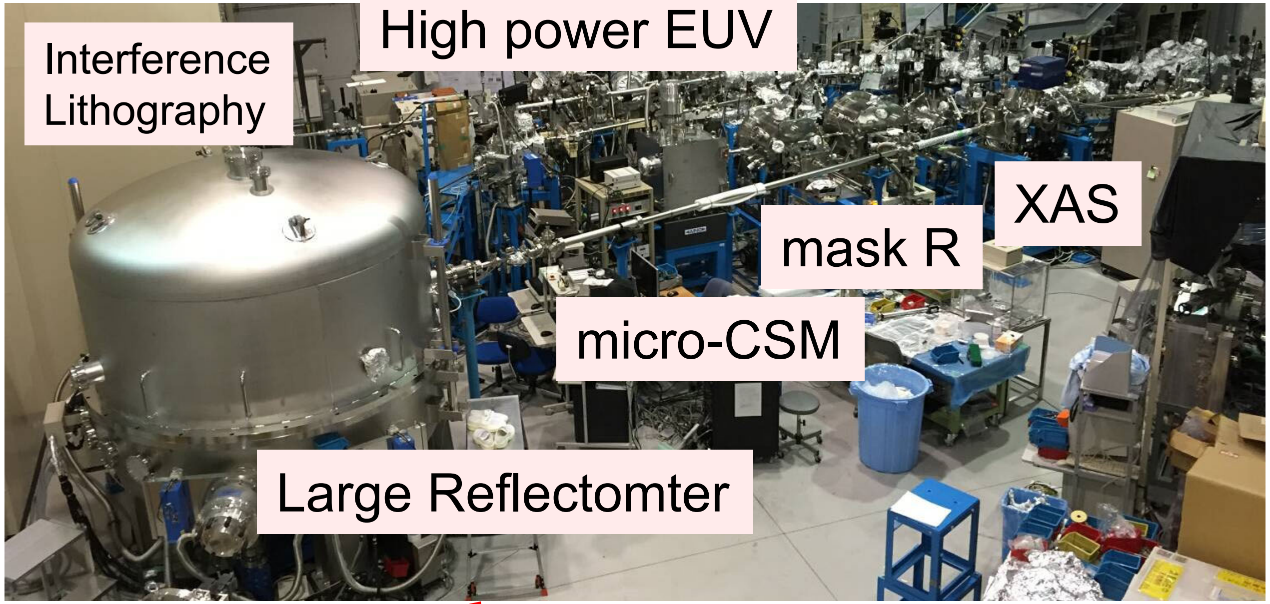
EUV Lithography R&D at University of Hyogo




SPring-8
Electron storage ring
100 mA @8 GeV
SPring-8
Injection LINAC
1 GeV
SPring-8
Booster ring
1 GeV→8 GeV
NewSUBARU
University of Hyogo
300 mA @1.0 – 1.5 GeV

Center for EUV Lithography

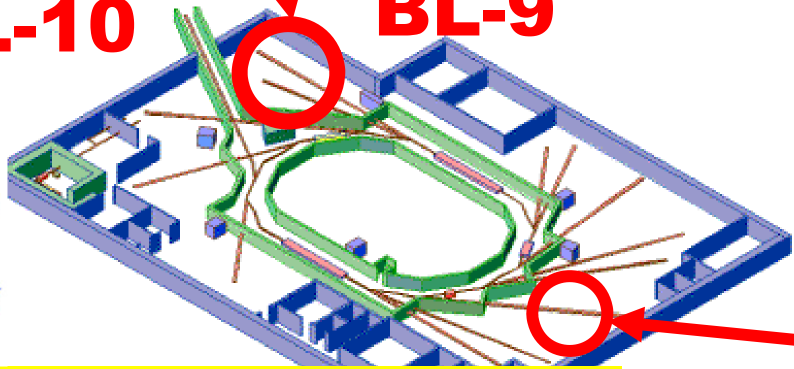
NewSUBARU Synchrotron Radiation Facility



in SPring-8 site

1) Resist
2) Mask
3) Large reflectometer of Collector mirror for EUV light source
4) Pellicle

Microscopes (EUVM)
Resist EUV Sensitivity



NewSUBARU

EUV & Soft X-ray

Three Beamlines for EUVL

Resist Evaluation Instruments at NewSUBARU Synchrotron Light Facility (Previous R&D)

Following instruments at three beamlines is for opened usage of the novel EUV resist material evaluation.

1) E_0 sensitivity measurement
2) Outgassing measurement
3) EUV Interference lithography
4) Carbon growth in-situ measurement by ellipsometry
5) Resist transmission measurement
6) Resist chemical reaction analysis by Soft X-ray Absorption Spectroscopy

Very few limitations to evaluate novel EUV resist materials using each above tools !!

Mask Evaluation Instruments at NewSUBARU Synchrotron Light Facility (Previous R&D)

Following instruments at three beamlines is for opened usage of EUV mask evaluation.

1) Multilayer sputtering tool
2) Reflectometer for Mo/Si multilayer, absorber
3) World largest reflectometer for collector mirror of EUV light source
4) EUV mask inspection tool by brightfield EUV microscope
5) EUV mask inspection tool by EUV coherent scattering microscope (CSM)

   Light source: SR, HHG laser (standalone)

6) EUV mask inspection tool by EUV micro CSM

Current R&D of EUV lithography at UoH

4-1) Analysis of the spatial distribution of functional material in resist functional groups, photosensitizers (acid generators), additives such as amines, and so on

4-2) Resist layer analysis using RSoXS

4-3) High aspect ratio pattering for the transmission grating and its diffraction efficiency analysis

4-4) Mo/Si ML reflectance affect in hydrogen gas environment

4-5) Out of band reflectance spectra of the Mo/Si ML and absorber

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Photon statistics - revisited

How Dose fluctuation turns into edge placement

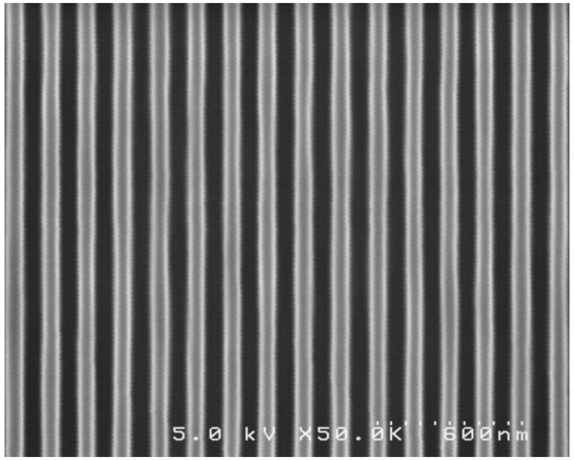
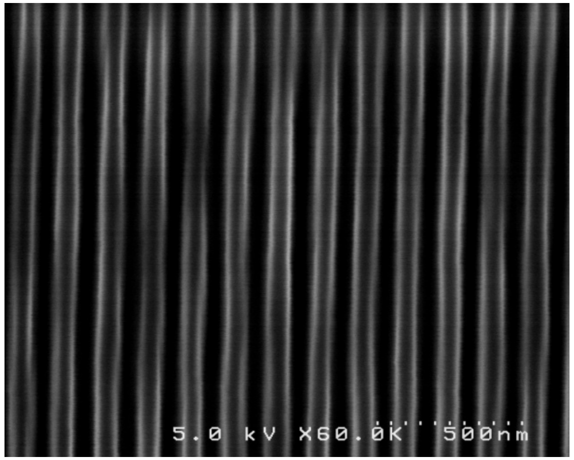
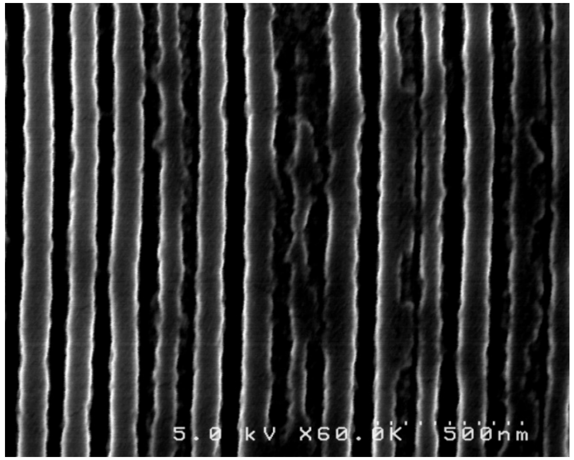
$$\frac{LCDU}{nm} \approx 0.75 \cdot \frac{1}{NILS} \cdot \sqrt{\frac{h\nu / eV}{Dose / (mJ / cm^2)}}$$

NILS = 2.5
$h\nu$ = 92 eV (13.5 nm)
Dose = 20 mJ/cm^2

→ *LCDU = 0.6 nm*

Comparison between PAG Bounded and Blended Resists (EB 30kV)

For the 75 nm L/S resist pattern

Bounded type	Blend type	Blend type
		
LER = 3.5 nm	LER = 7.5 nm	BAD LER

How to measure and analize?

・XAS using Cu *Kα* S(8 keV photon) cannot detect the chemical bonding of the elements such as C, N, O, F etc. of resist material.

・SXAS (soft x-ray absorption spectroscopy) is very powerful tool to distinguish the chemical bonding of C, N, O, F etc. in high contrast. (Resonance)

＋

・Soft X-ray Coherent scatterometry method is ver powerful tool to measure the structure of the chemical contents of resist material. (Scattering)

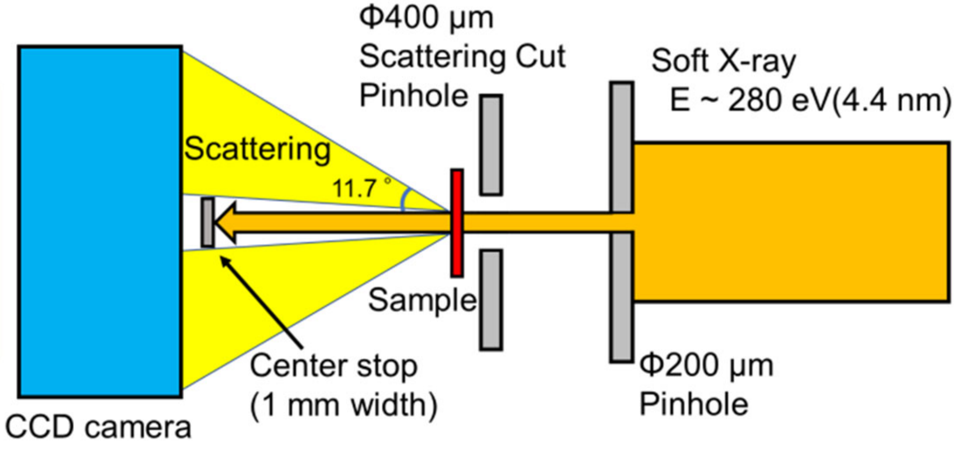
||

・Resonance Soft X-ray Scattering (RSoXS) is very powerful tool to measure the size of the structure of the chemical contents of resist material.

Experimental Setup

◆ RSoXS method

Scattering light from the sample is recorded by the CCD camera in vacuum.



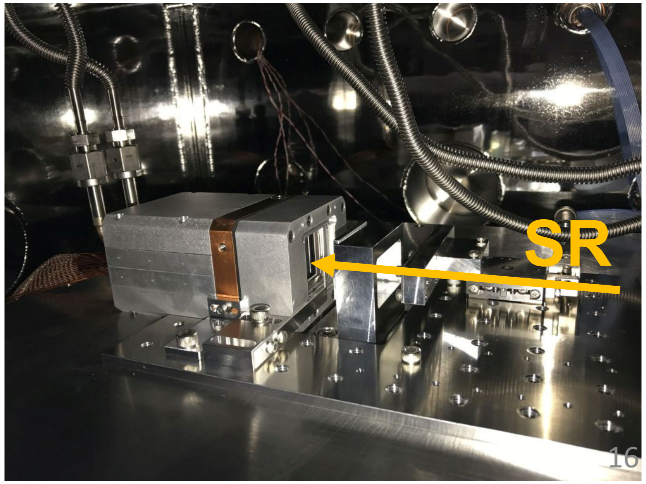
【BL-10 beamline】

- Light source : bending magnet
- Monochromator is provided upstream.
- Photon energy range : 60 – 1100 eV
- Energy resolution E/ΔE : 2500

The focal point is located 2.1 m upstream of this system.

【CCD camera】

The maximum acceptance angle : 24°
(corresponded to hp 11 nm at 280 eV)

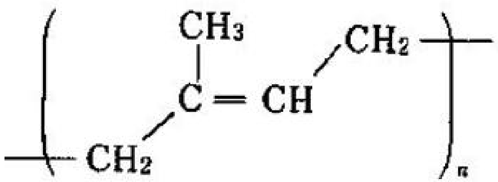


Measured DSA samples (1)

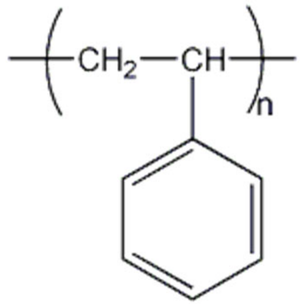
◆ Three polymers in triblock polymer

Triblock polymer consisting of polyisoprene, polystyrene, poly (2-vinylpyridine)

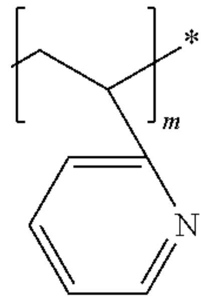
I : polyisoprene



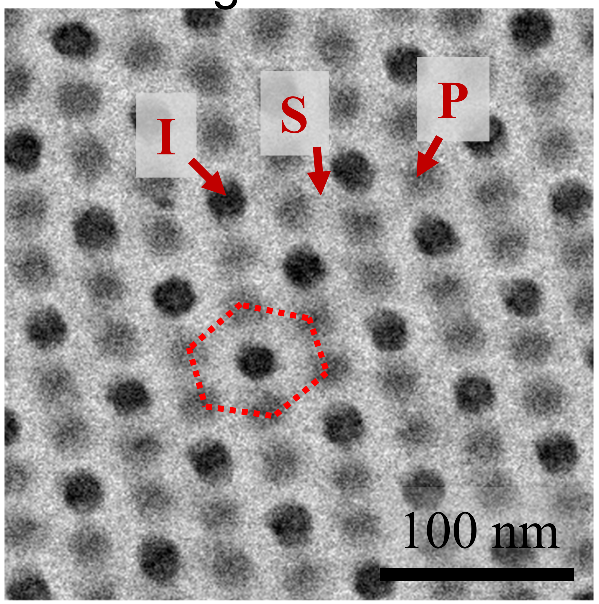
S : polystyrene



P : poly(2-vinylpyridine)

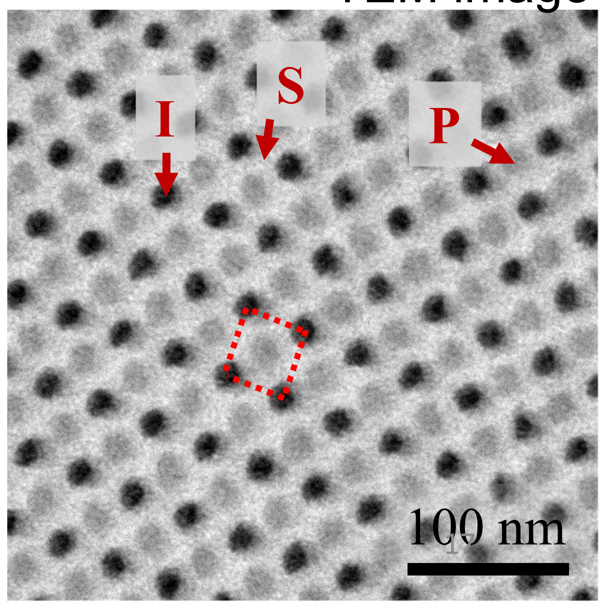


TEM image



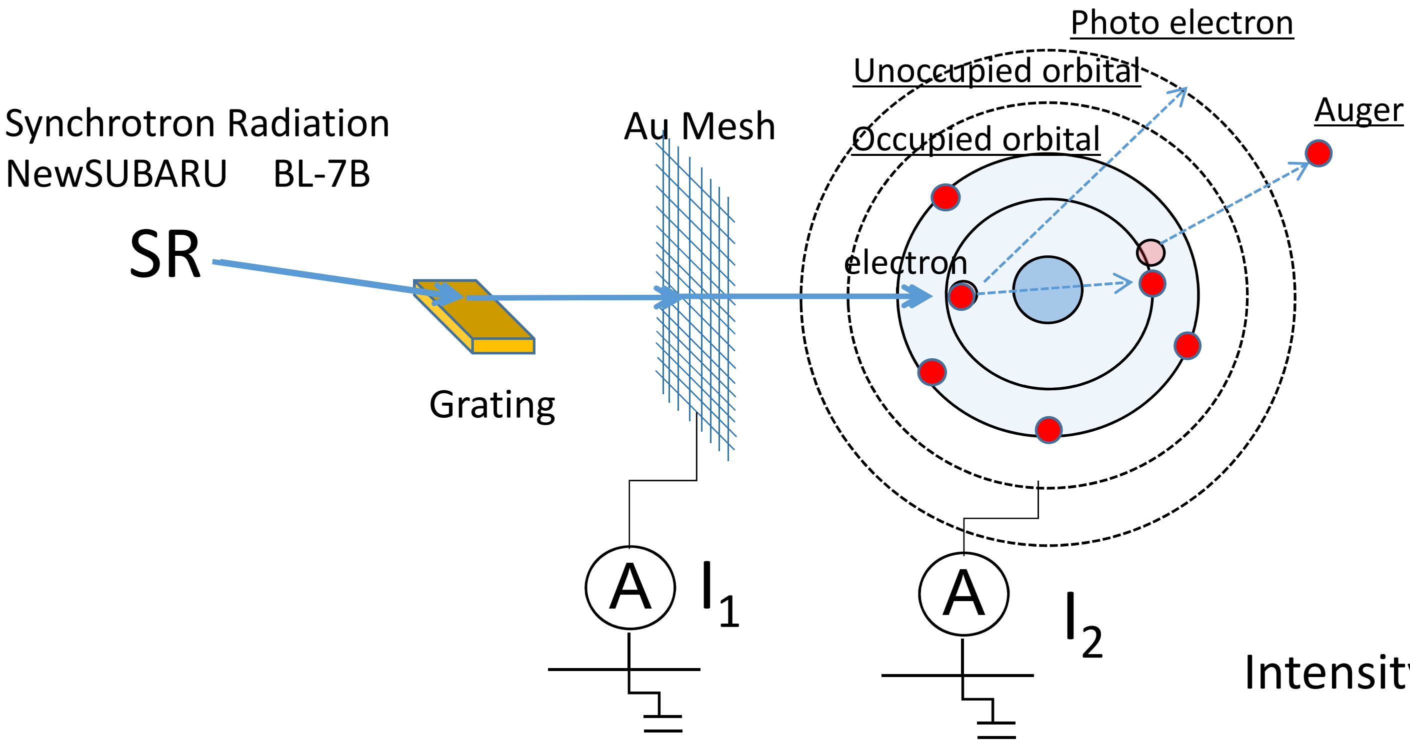
Hexagonal
Packed
Cylinders
(ISP:PSP=6:4)

TEM image



Tetragonal
Packed
Cylinders
(ISP 100%)

The soft x-ray absorption spectroscopy



Intensity = I_2 / I_1

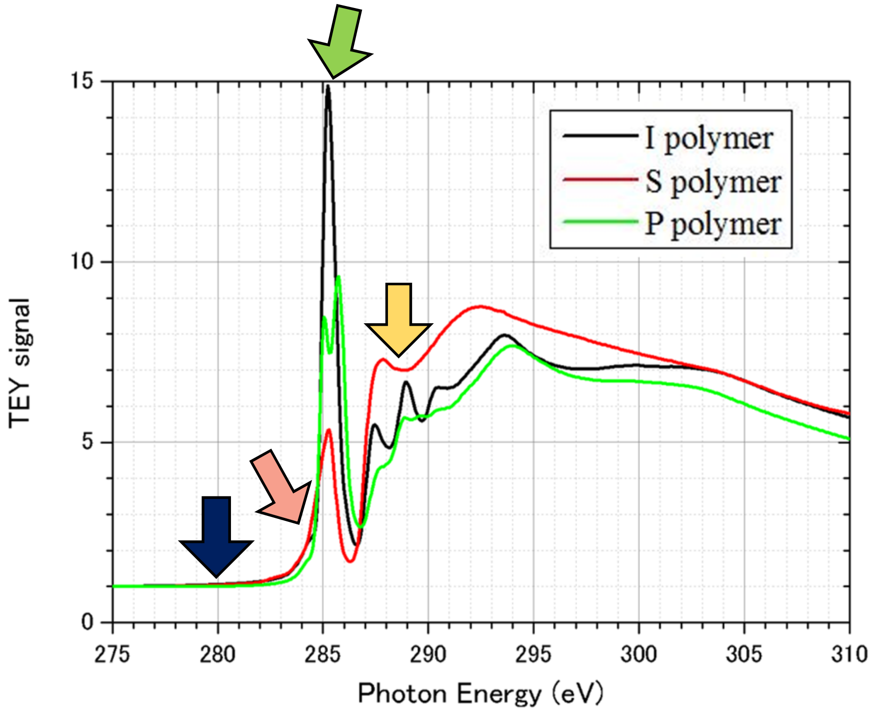
To measure the change of the chemical bonding, the specific energy of the incident energy required for the measurement.

For example,
Carbon 1s core
280~330 eV
Fluorine 1s core
690~730 eV

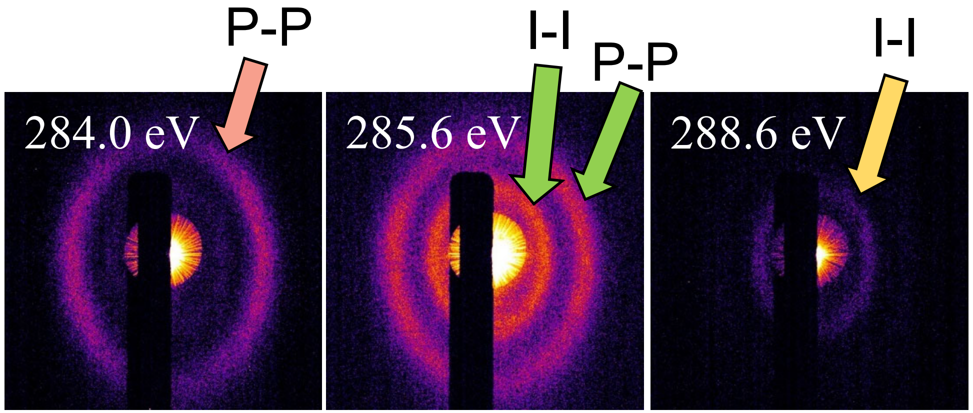
Powerful tool for evaluating the change of the chemical bonding

Results and Discussion

◆ Hexagonal packed cylinder



XAS results of the three polymers



In the RSoXS measurement, it is possible to distinguish the polymer types by changing the probe photon energy.

284.0 eV : P polymer had slightly small absorption. → Only P-P scattering

285.6 eV : Three polymers had different absorption. → Both I-I and P-P scatterings

288.6 eV : S polymer and P polymer had approximately same absorption.
→ Only I-I scattering

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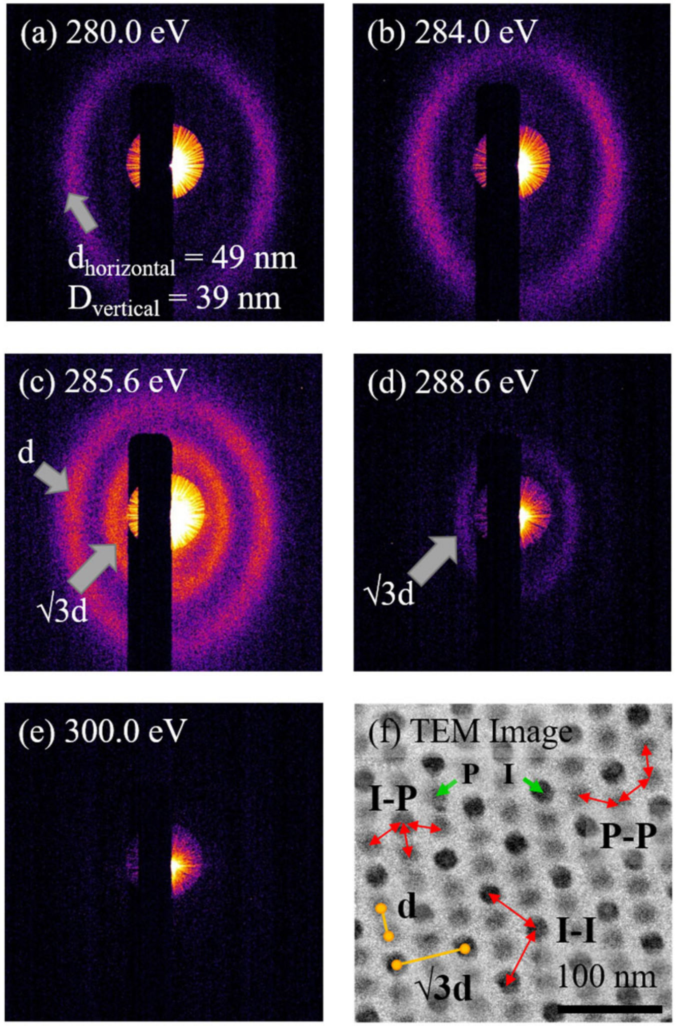


Scattering measurement results of hexagonal packed ISP triblock polymer

Two scattering signals with the ring-shape were recorded.

Ellipse shape (not circle shape)
→ The sample is streched along the horizontal direction.

Ring-shape
→ The domain size of this polymer is sufficiently smaller than the beam diameter of 100 μm.

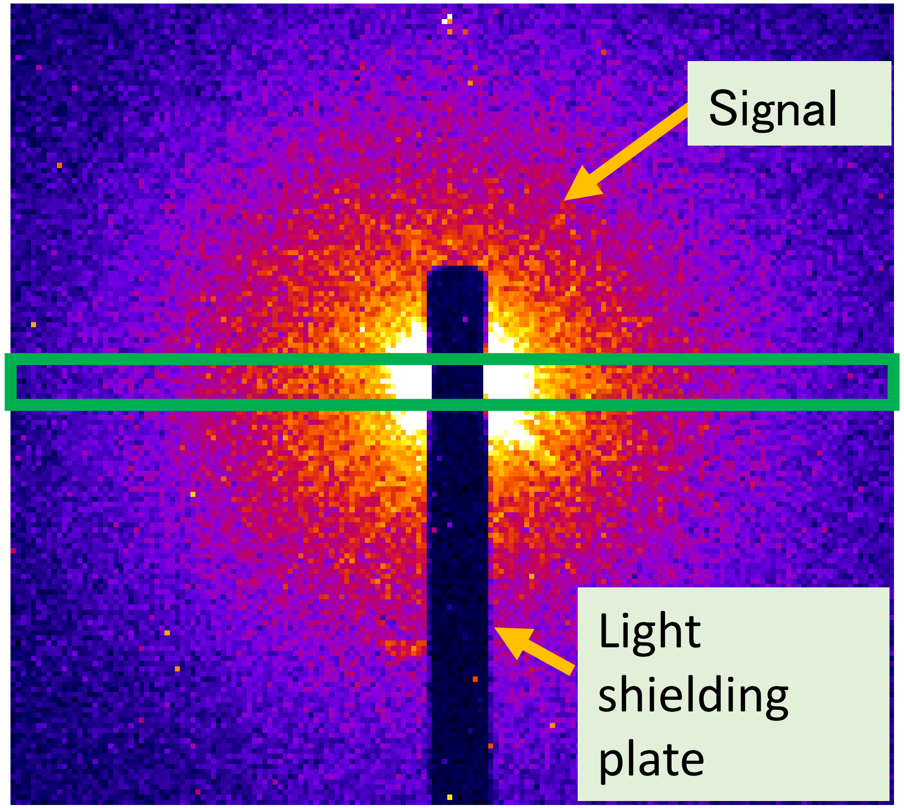
- The outer ring signals
→ were observed at 280.0, 284.0, 285.6 eV.
(a) (b) (c)

- The inner ring signals
→ were observed at 285.6, 288.6 eV.
(c) (d)

(c)285.6 eV : π* bonding of benzyl group

RSoXS method

CCD image



The scattering vector q can be calculated from the scattering intensity distribution obtained by CCD.

Scattering vector

$$q = \frac{4\pi}{\lambda} sin(\frac{\theta}{2})$$

λ = wavelength
ϑ = scattering angle

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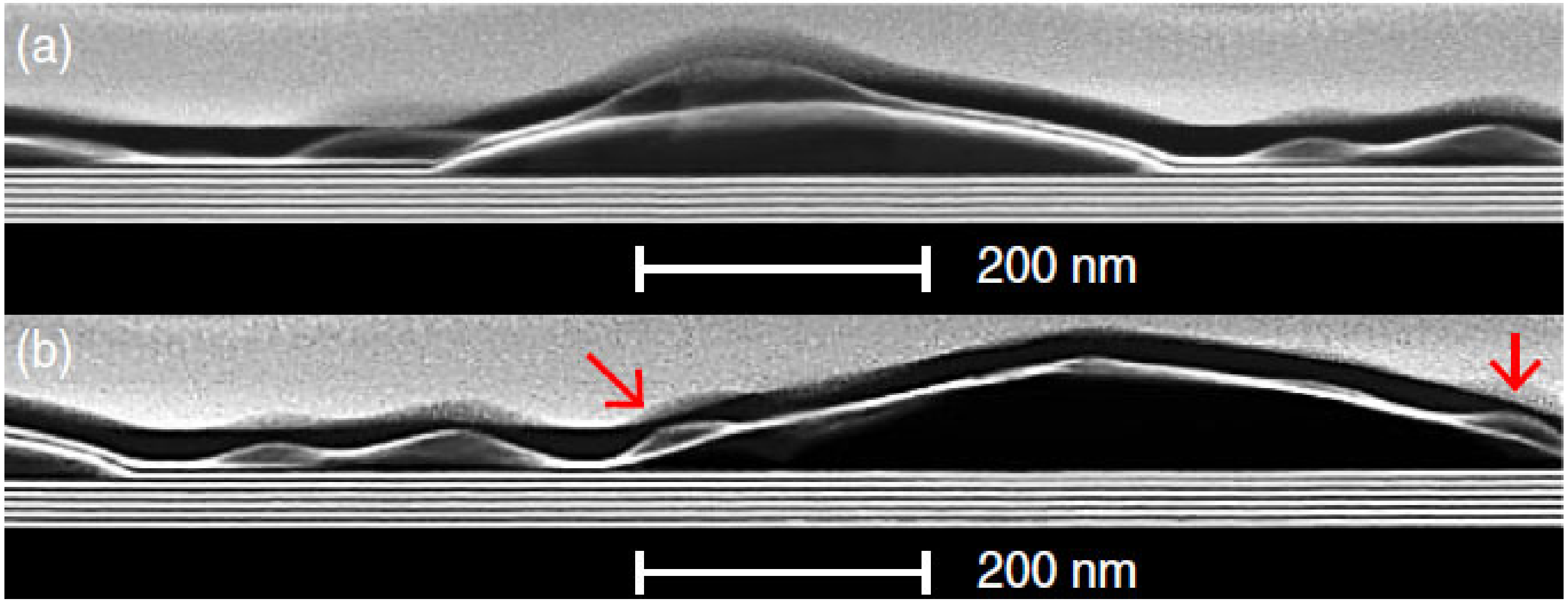
TEM Image of the Hydrogen Damage (Blister) of the Mo/Si Multilayer Film Surface



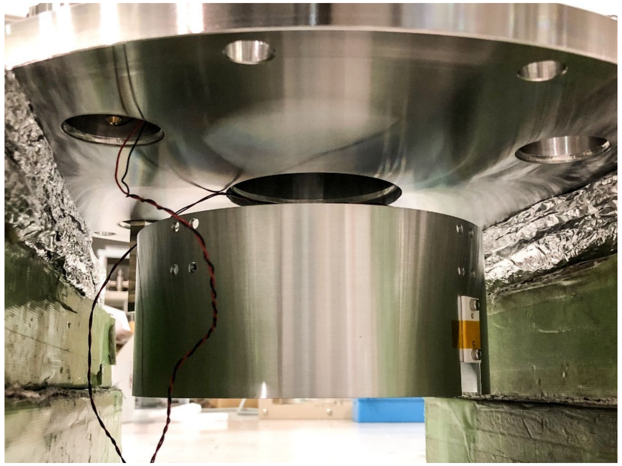
RAJM van den Bos et al., Proc. J. Phys. D, **50**,4(2017)

Table Comparison of the typical exposure condition between the HVM exposure tool and new H_2 exposure system.

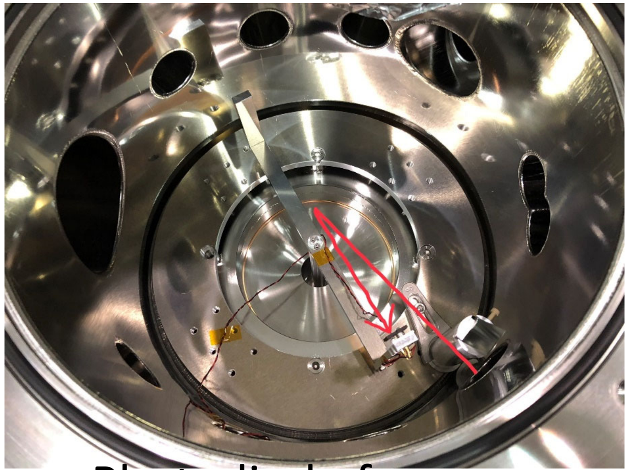
	The EUV expose tool	New H_2exp system
H_2 pressure	5 Pa	5 Pa
EUV power on the mask	5 W/cm^2	2.8 W/cm^2
EUV source power	250 W/cm^2	140 W/cm^2

Luigi Scaccabarozzi et al.,Proc.SPIE **8679**,867904(2013)

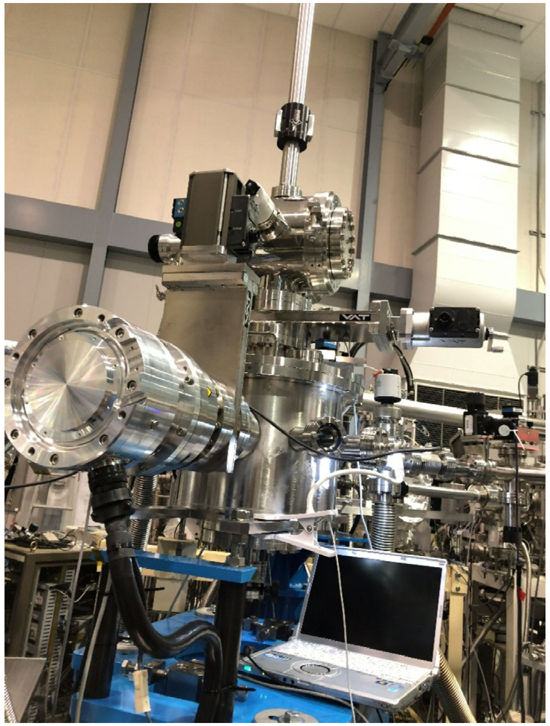
H_2 Exposure Chamber



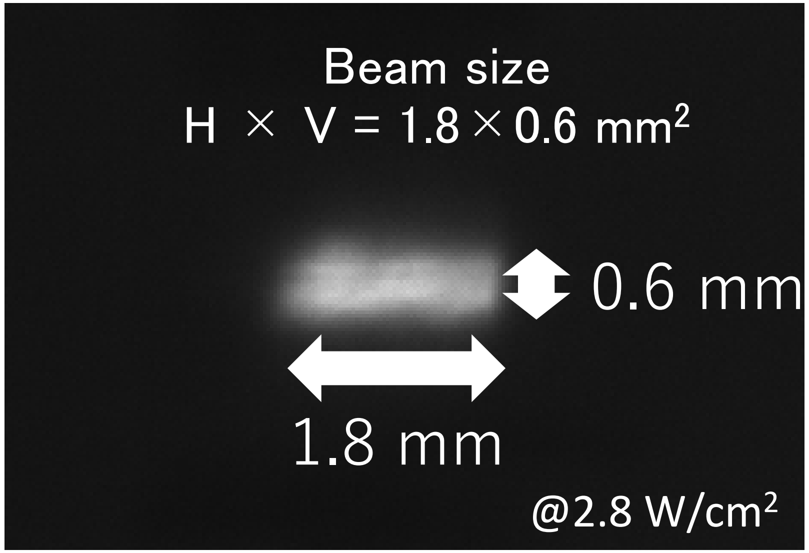
Direct beam photodiode and beam stop cylinder for reflected beam



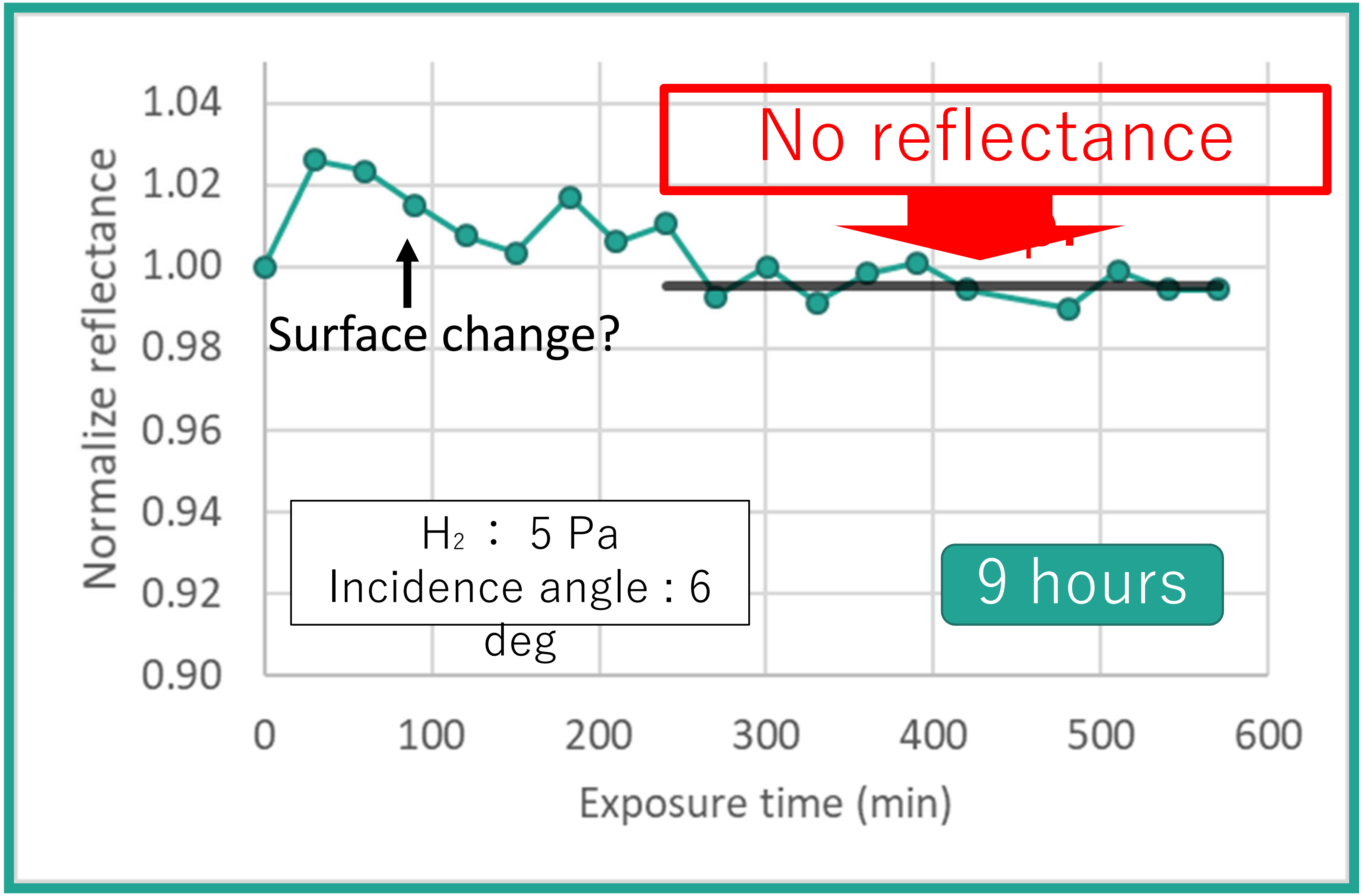
Photodiode for reflected beam measurement



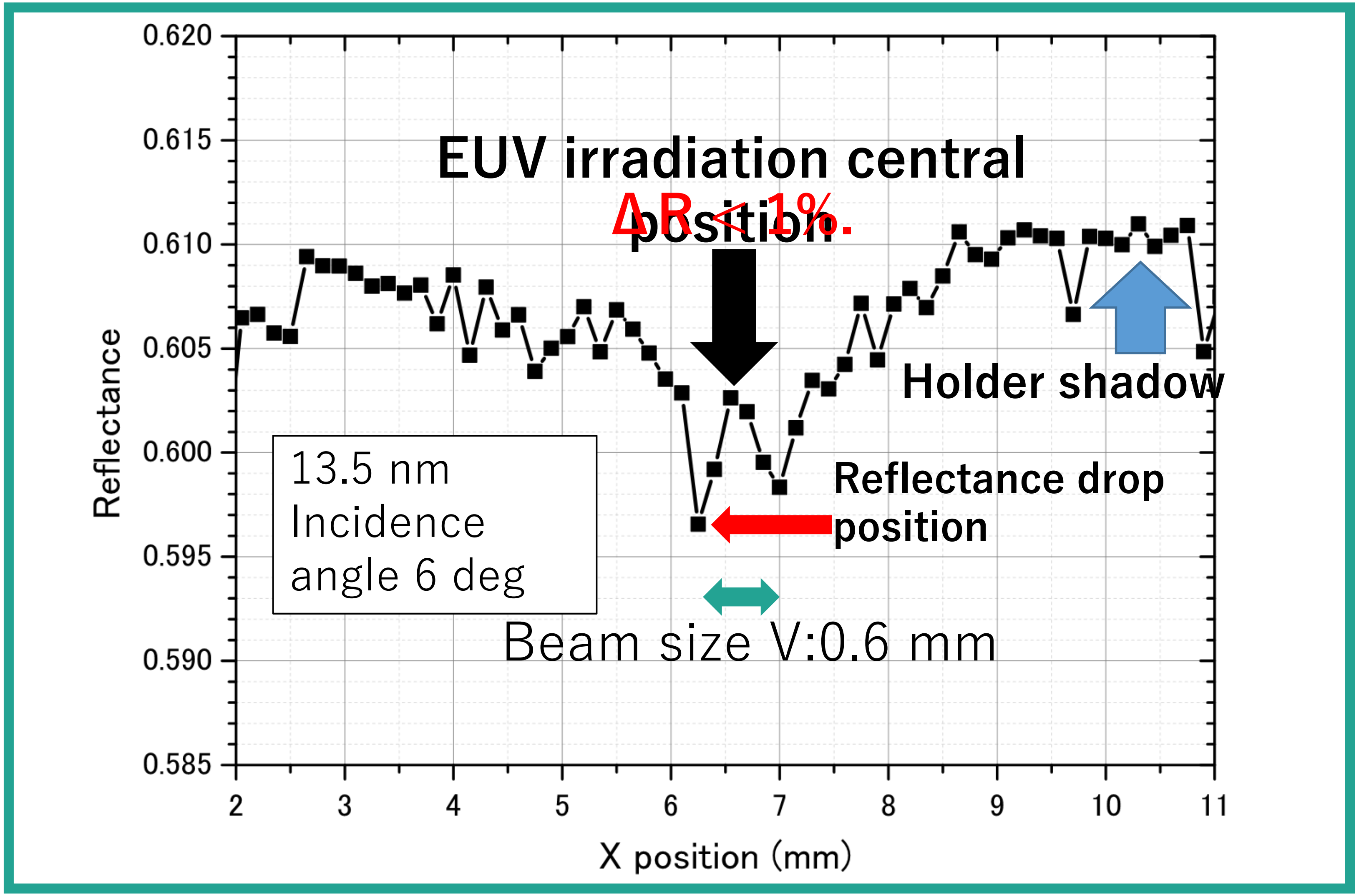
Perspective of the H_2exp chamber



Reflectometry Measurement Result during EUV Irradiation of the Mo/Si Multilayer



EUV Reflectance Distribution along Horizontal Direction



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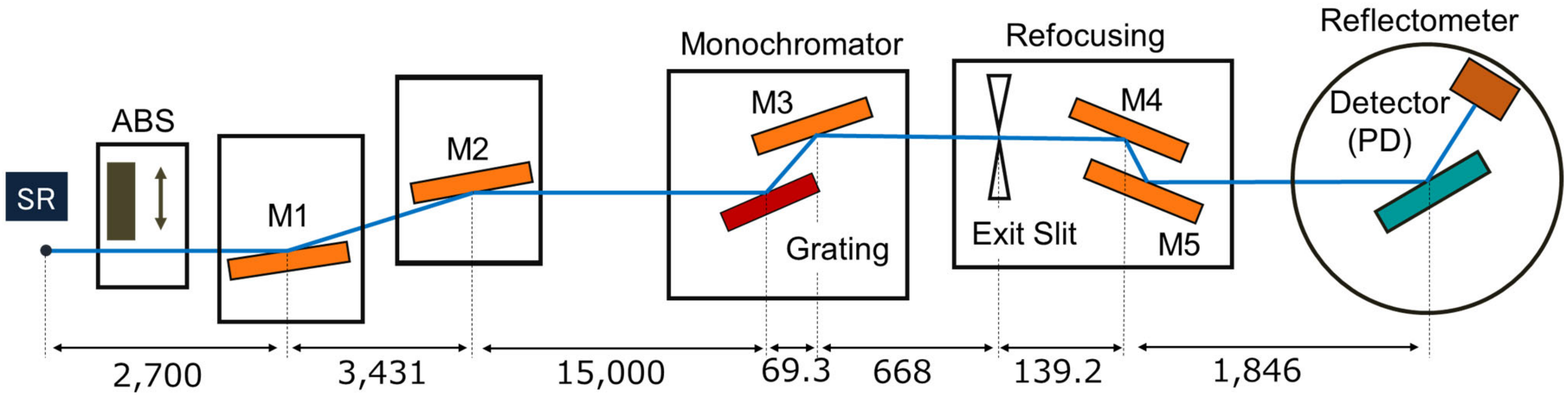
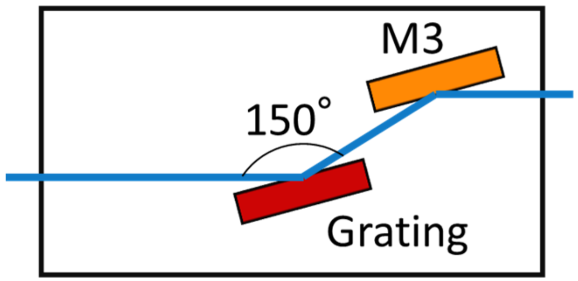
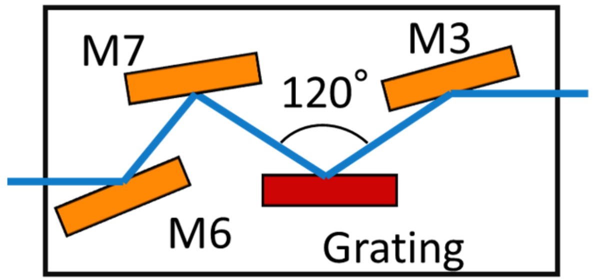
Development of an EUV and OoB Reflectometer



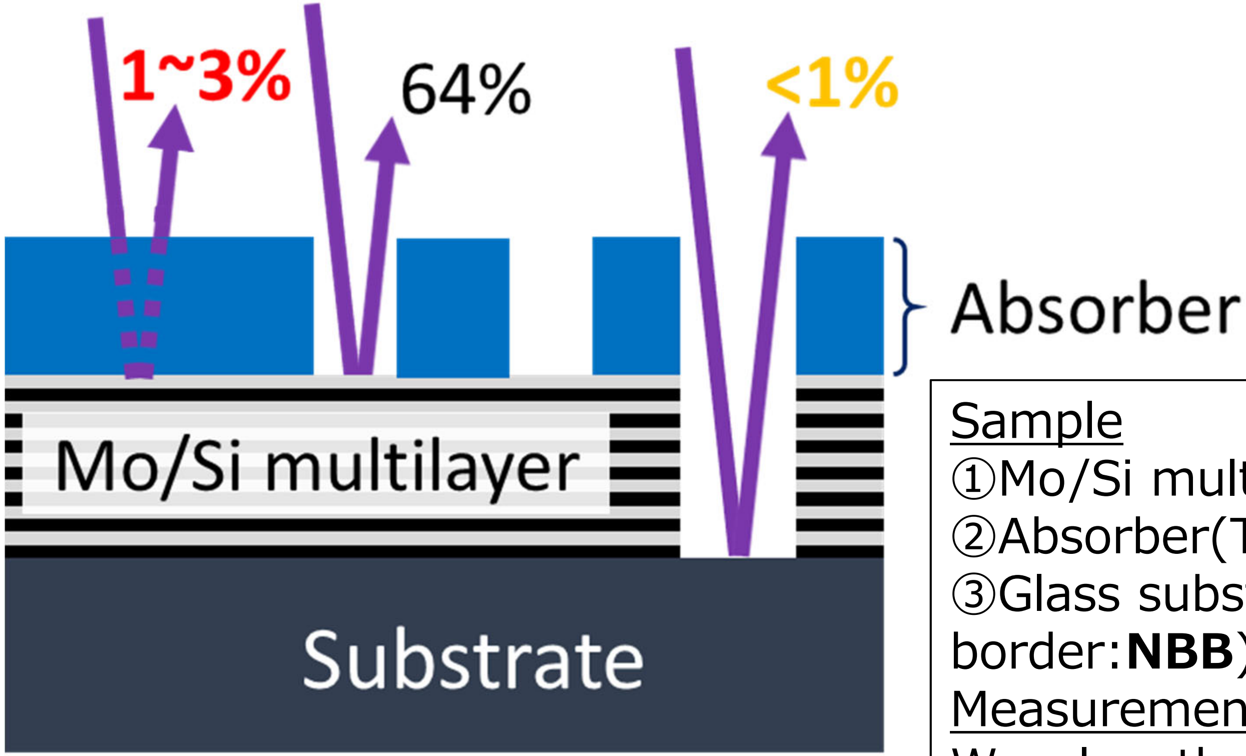
Deviation angle 150°(10~80 nm)

Deviation angle 120°(40~200 nm)





EUV Mask Reflectance Measurement

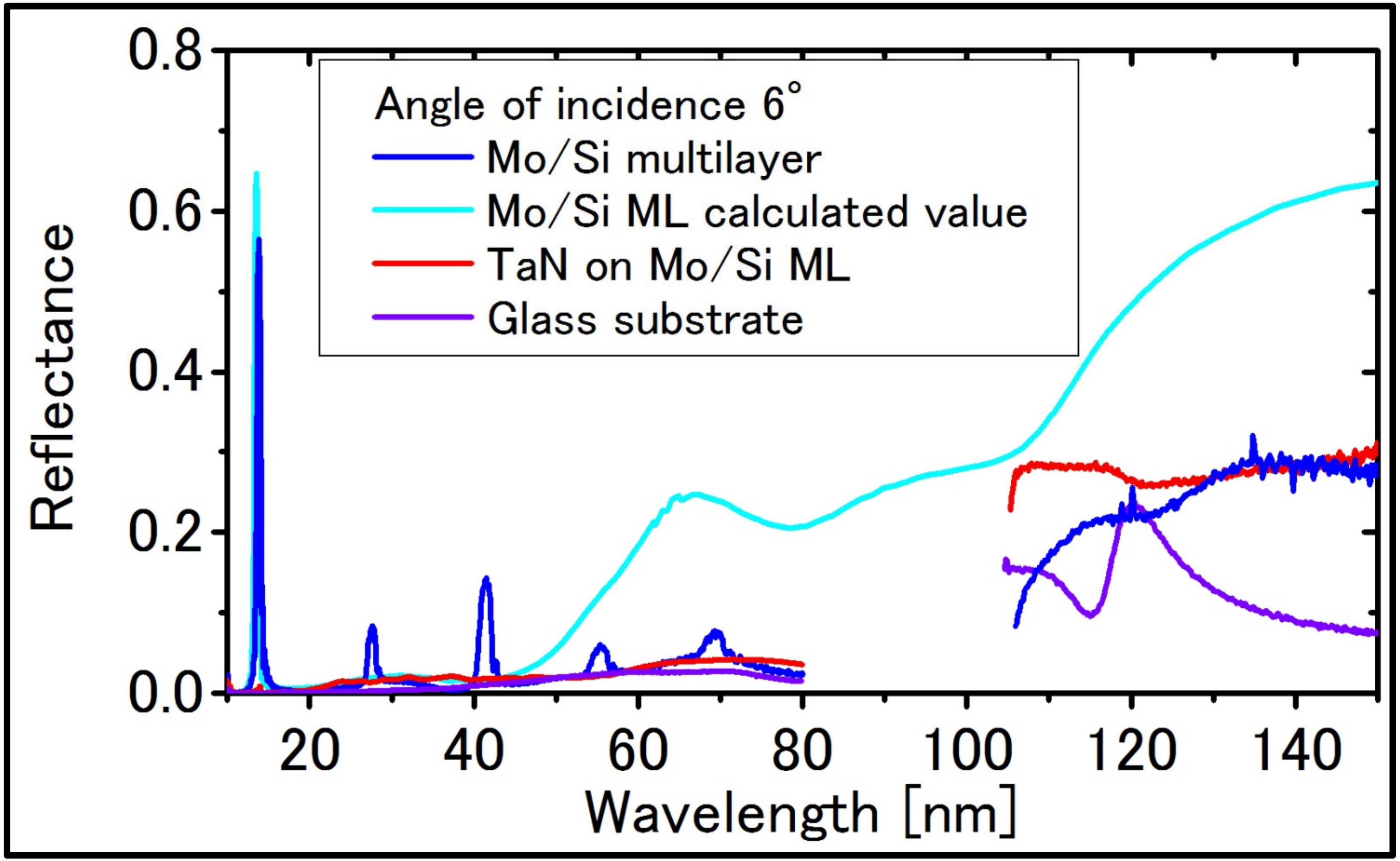


Schematic drawing of EUV mask and black border

<u>Sample</u>
①Mo/Si multilayer
②Absorber(TaN) on Mo/Si multilayer
③Glass substrate (Normal black border:**NBB**)
<u>Measurement condition</u>
Wavelength 10~80 nm, 105~150 nm
Incident angle 6° (Actual exposure angle)

- Black border(**BB**) does not reflect EUV at overlapped.
- BB is required at edge position of image field[1].
- In addition, BB should not reflect OoB[2].

Multilayer and Absorber Reflectance



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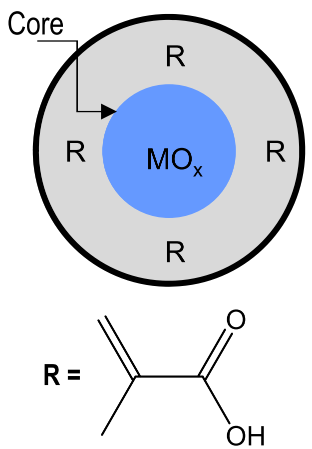
The Outline of NEDO Project @EIDEC

Preparing EUV resist

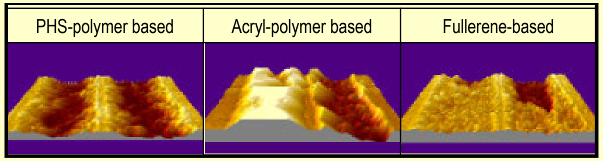


Shell: MAA

Metal resist

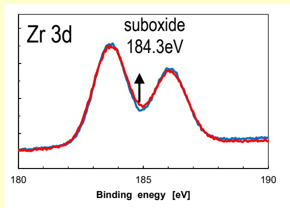
Verification of measurement technology and analysis of reaction mechanism

Resist dissolution process

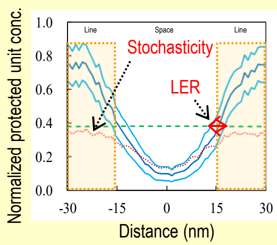


Analysis and Simulation

XPS analysis by NIMS

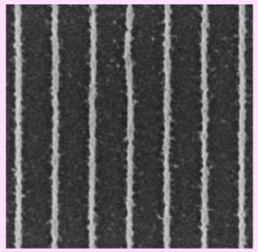


Simulation by Osaka Univ.



Pattern evaluation

HSFET（installed at AIST SCR）



17nm Line、$7 mJ/cm^2$、LWR=5.6nm

Feed back to EUV resist preparation

Correlation verification

Courtesy of EIDEC

Measurement technology verification by single nano-patterning material (resist)

1) Observation of resist dissolution process (High-speed AFM: HS-AFM)

2) Reaction analysis and simulation of metal resist

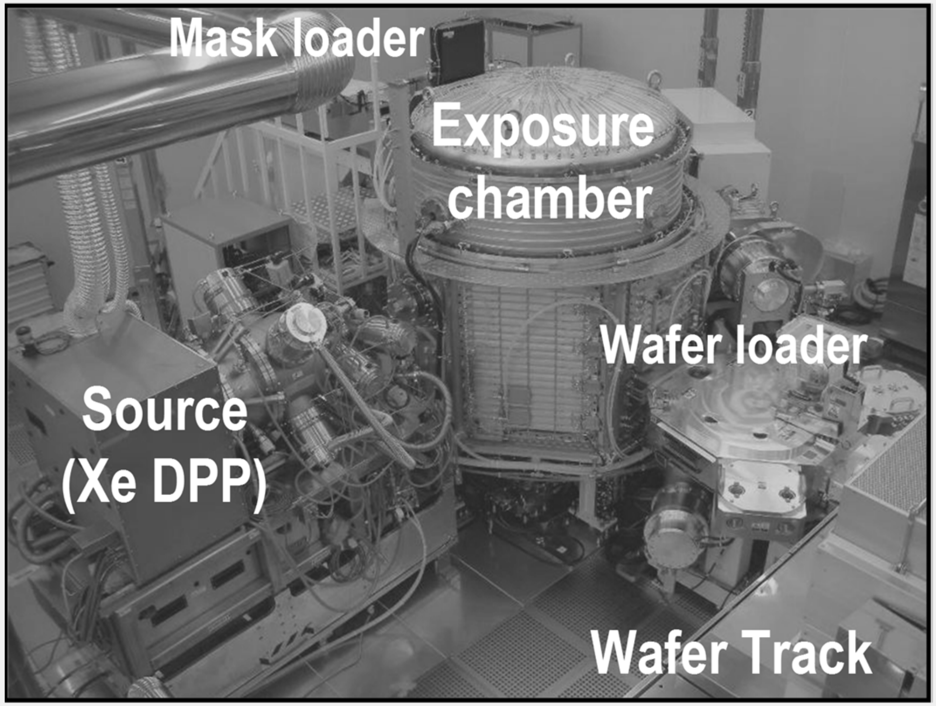
Measurement technology verification by single nano-patterning material (resist)

1) Observation of resist dissolution process
(High-speed AFM: HS-AFM)

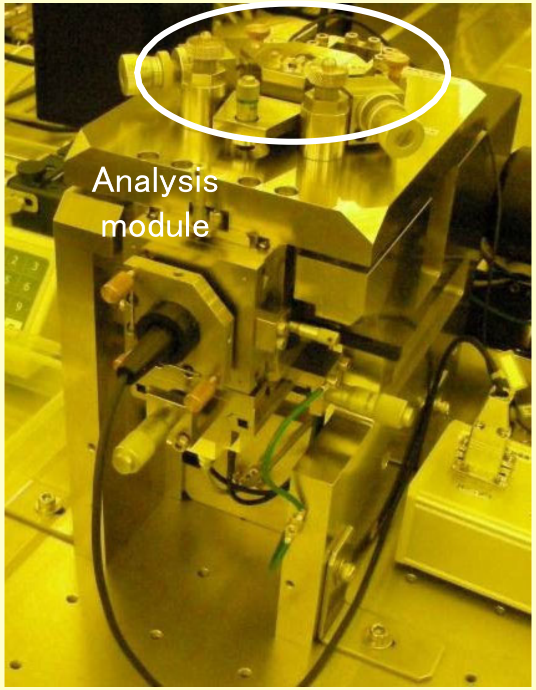
2) Reaction analysis and simulation of metal resist

Experiment method

Resist → Coat → PAB → EUV Exp. → PEB → Dev. → Rinse → Dry



EUV resist patterning exposure (HSFET)



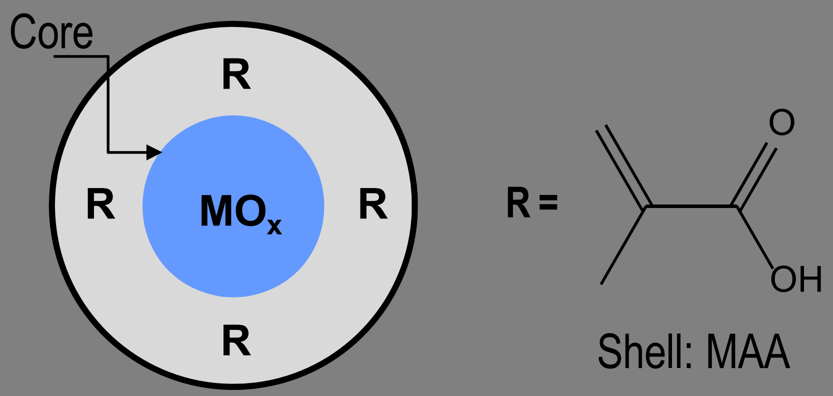
HS-AFM

Maximum : 20 images/s

Courtesy of EIDEC

Resist material / process

Material: Metal resist



Metal core : ZrOx, TiOx, HfOx
Shell molecule : methacrylic acid (MAA)

Process

① Film coat thickness : 30nm*
② PAB : 80ºC / 60s
③ Dev: nBA and Alt. developer / 30s

For EUVL patterning exposures

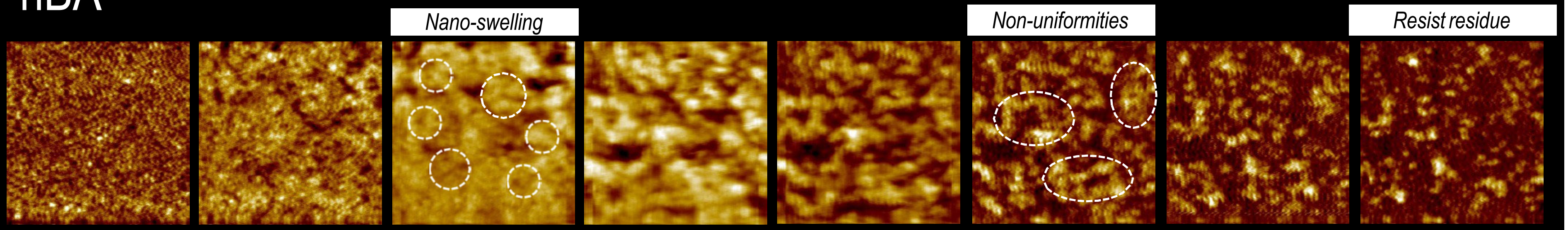
- Tool: HSFET (0.5NA)
- SEM: CG4000

- EUV metal resist materials were developed for fundamental research.
- Unexposed, this material is soluble in developer (negative tone).

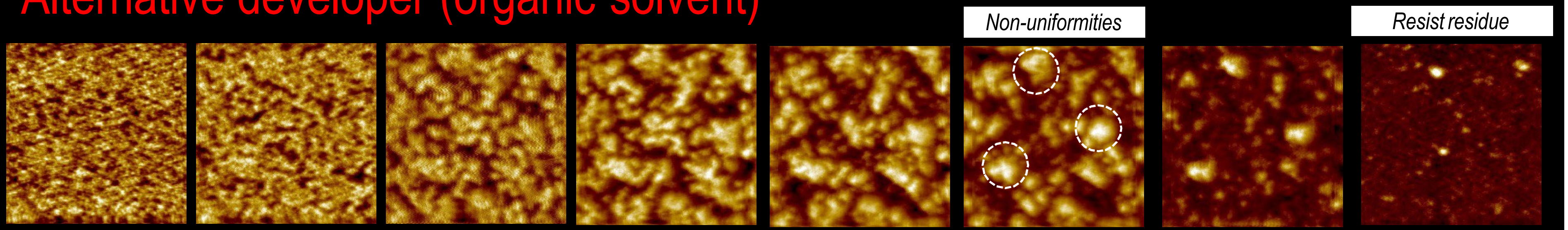
Courtesy of EIDEC

Developer dependence of metal resist dissolution behavior

nBA



Alternative developer (organic solvent)

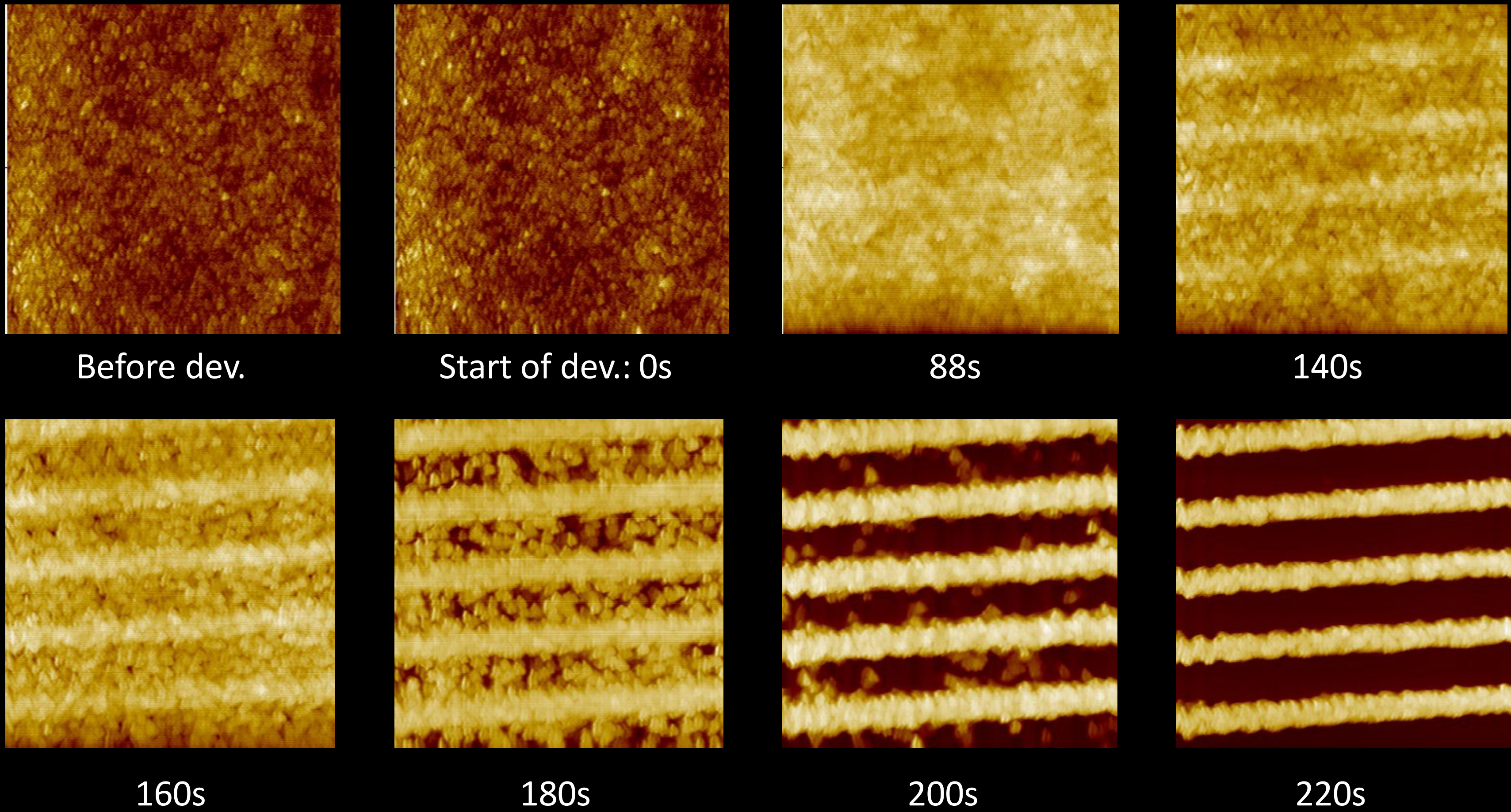


■ Using the alternate developer, resist residue can be reduced.

Courtesy of EIDEC

Dissolution and pattern formation process of silicon-based resist material

Developer: 2.38wt% TMAH



- The dissolution behavior of the new silicon resist material (negative type) is also made possible.
- It has been confirmed for the first time that the unexposed area (soluble area) of the space dissolves from the surface so that particles can be removed completely.

EIDEC

Courtesy of EIDEC

Measurement technology verification by single nano patterning material (resist)

1) Observation of resist dissolution process
(High-speed AFM: HS-AFM)

2) Reaction analysis and simulation of metal resist

Reaction analysis and simulation of metal resist

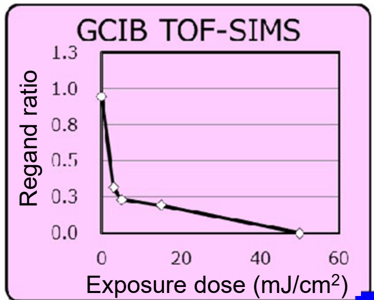
Method of reaction analysis and simulation

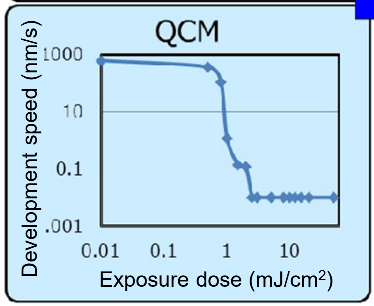
New

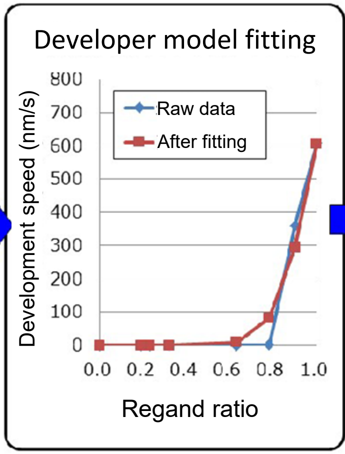
- GCIB TOF-SIMS: Regand ratio and dose
- QCM: Development speed and dose

→ Development model fitting → Derivation of developer parameters

Derivation of metal resist parameters in resist pattern simulation



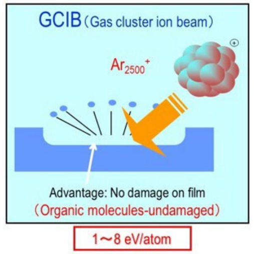


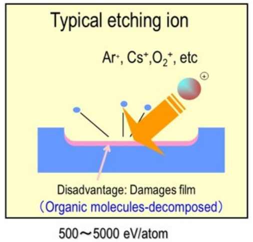


Parameter extraction of developer

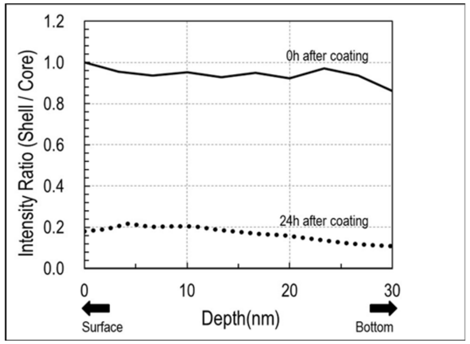
- Rmax = 607.0nm/s
- Rmin = 0.001nm/s
- n = 10.233
- Mth = 0

Advantages of GCIB TOF-SIMS





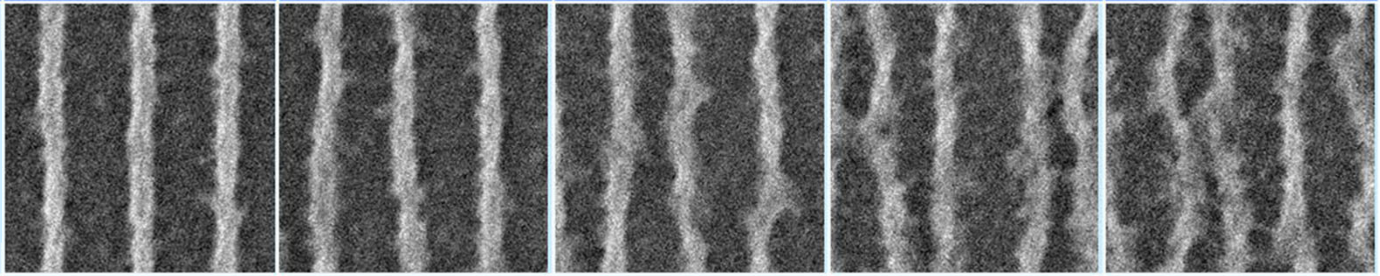
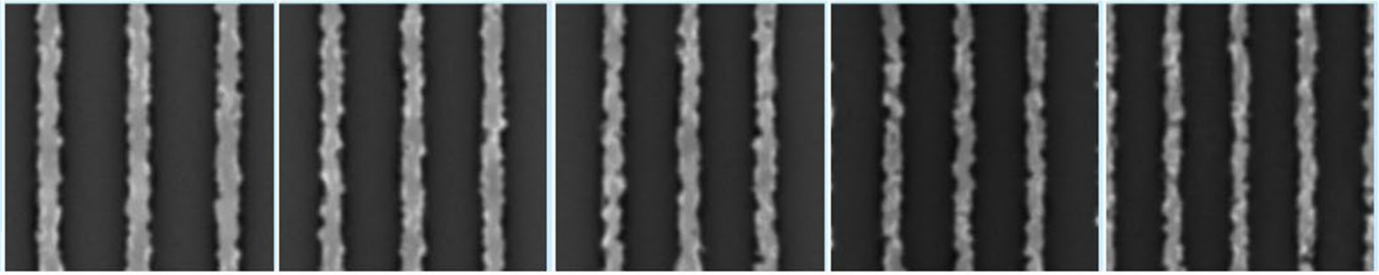
Distribution of metal core / ligand ratio in metal resist direction by GCIB TOF-SIMS



Establishment of development parameter derivation method using GCIB TOF-SIMS

Courtesy of EIDEC

Metal resist simulation (1)

Design size (nm)	20	18	17	16	15
SEM image Exposure tool: HSFET					
Simulation					

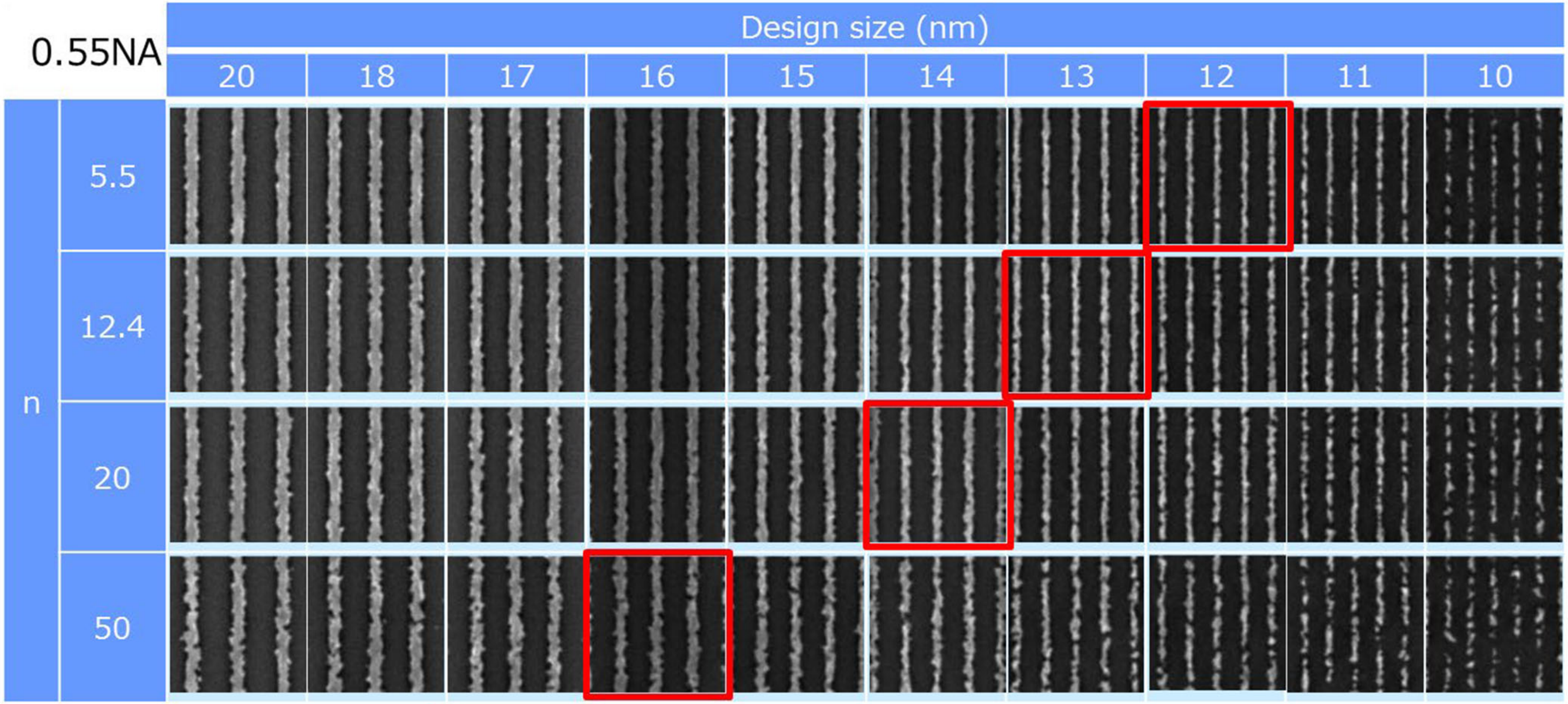
Development parameter

- R_{max}=128.7(nm/s)
- R_{min}=0.01(nm/s)
- M_{th}=0.001
- **n=12.43**

■ We established a lithography simulation of metal resist based on development parameters based on reaction analysis.
■ It has made it possible to make a phase-out of exposure results and simulation results.

Courtesy of EIDEC

Metal resist simulation (2)

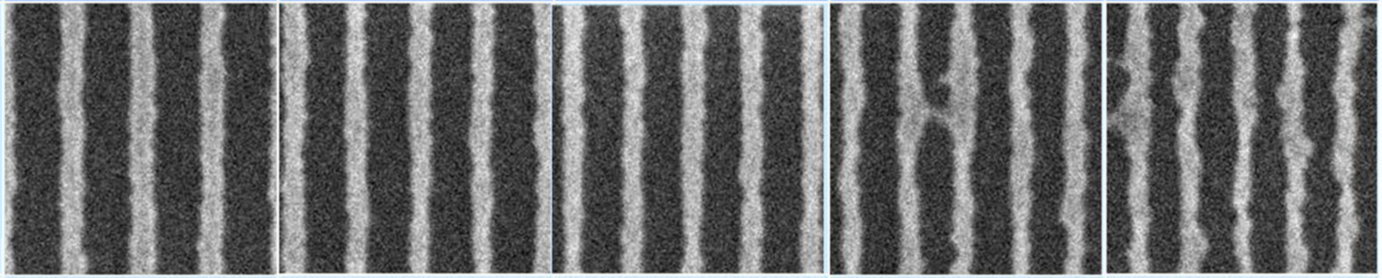
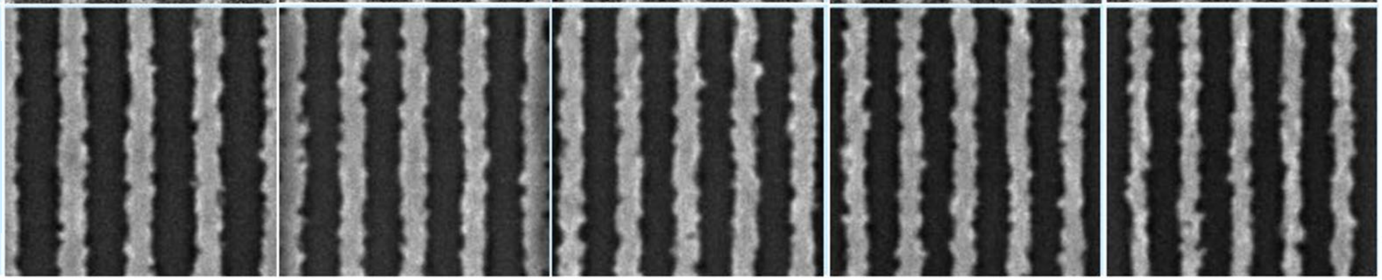


■ Furthermore, simulations were performed on the assumption of a 0.55 full-field scanner (ASML, Inc.) for next-generation EUV lithography.

■ The optimum dissolution contrast was also found to improve the lithography performance by optimization with n = 12.4 to 5.5 (limit resolution: 13 nm → 12 nm L / S).

Courtesy of EIDEC

Silicon containing resist simulation (1)

Design size (nm)	20	18	17	16	15
SEM image Exposure tool: HSFET					
Simulation					

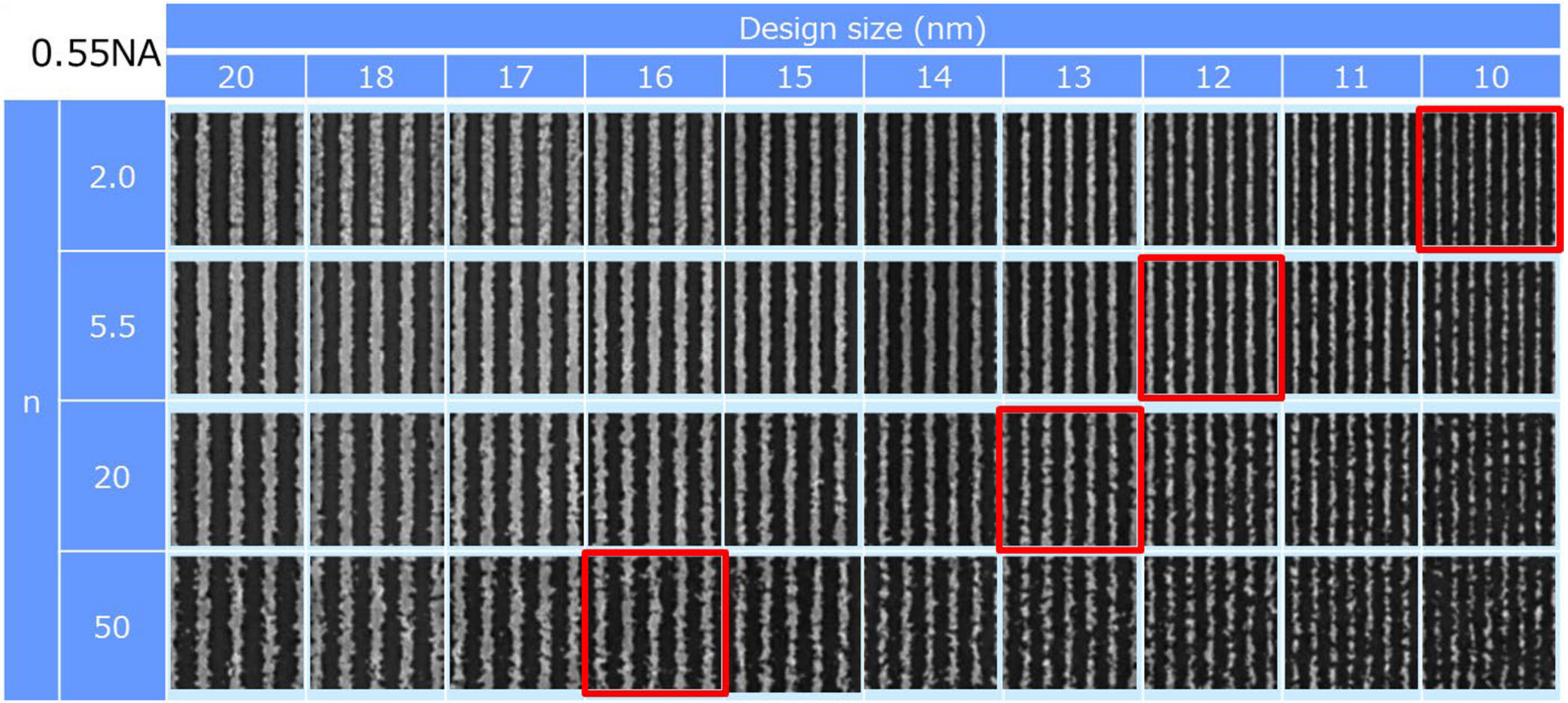
Development parameter

- Rmax=1.85(nm/s)
- Rmin=0.022(nm/s)
- Mth=0.00135
- **n=5.50**

It has become possible to simulate even silicon-based resist (negative type).

Courtesy of EIDEC

Silicon containing resist simulation (2)



Furthermore, simulation was performed assuming a 0.55 full-field scanner (ASML) of the next-generation EUV lithography, and optimization of n was found to improve the lithography performance (limit resolution: 12 nm @ n = 5.5 → 10 nm L / S @ n = 2.0).

Courtesy of EIDEC

Next-generation resist outgas measurement technology development

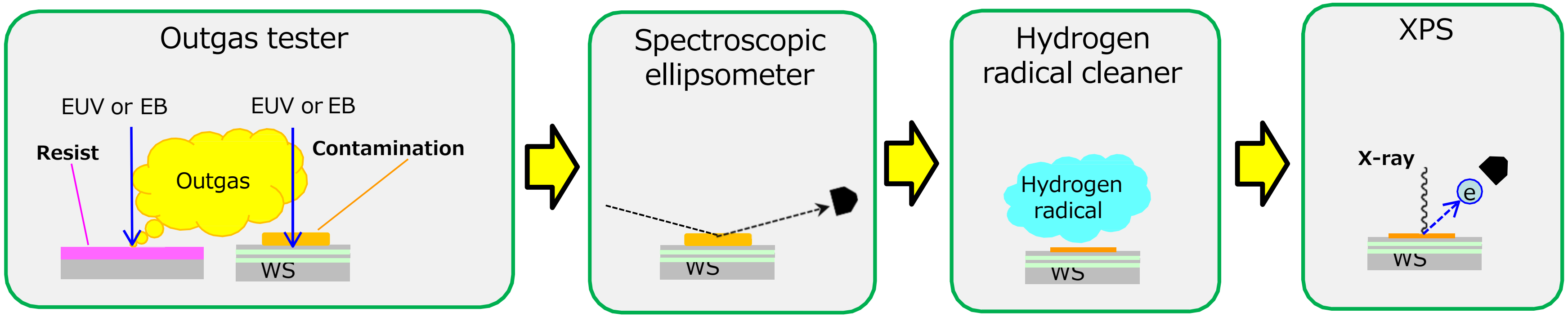
1) Outgas measurement result of metal resist

2) Issues and countermeasures for metal-based resist outgas measurement

Resist outgassing method and measuring equipment

Witness Sample (WS) Method

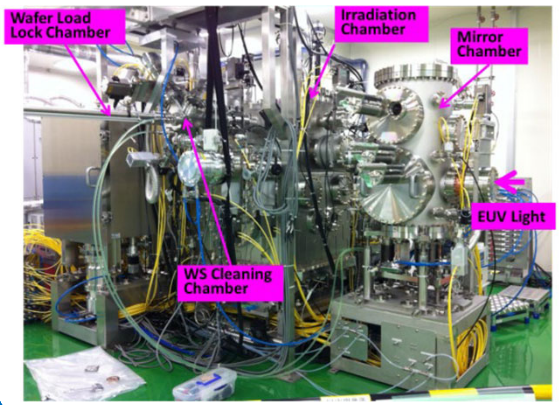
■ Measurement method that simulates contamination generation in the EUV exposure system



Contamination growth → Cleanable contamination → Hydrogen cleaning → Non-cleanable contamination

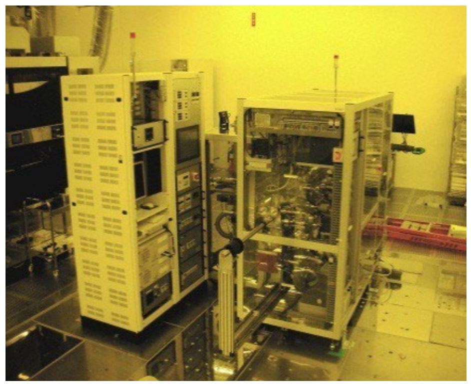
Witness Sample(WS)： A Ru-capped Si wafer that simulates an EUV mirror

EUV-based outgas tester
High Power EUV irradiation tool（HPEUV)



・Achieves 250W equivalent EUV intensity during mass production on the wafer surface
・Hydrogen introduced into the experimental chamber as well as the EUV exposure system
・Construct an outgas evaluation environment compatible with metal resists

EB-based outgas tester
EUVOM-9000



・Electron beam irradiation system outgas evaluation system
・Active in outgassing of chemically amplified resists

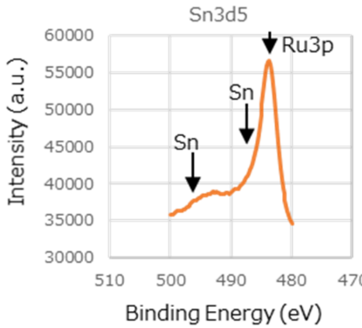
Courtesy of EIDEC

Outgassing evaluation results of metal-based model materials by HPEUV

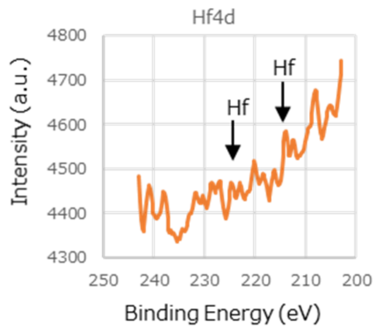
Non-cleanable contamination : XPS

EUVOM w/o H_2

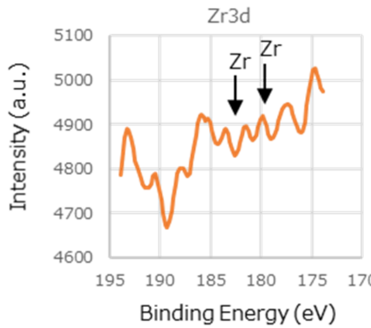
【SnO_2】



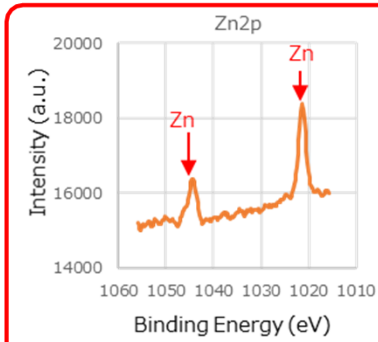
【HfO_2】



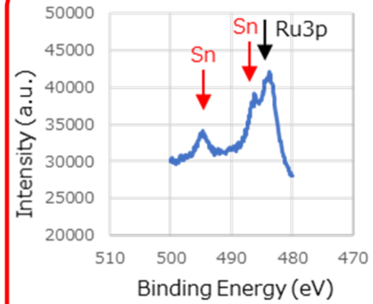
【ZrO_2】

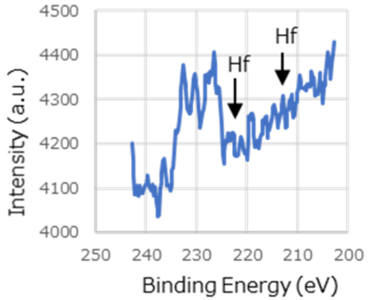


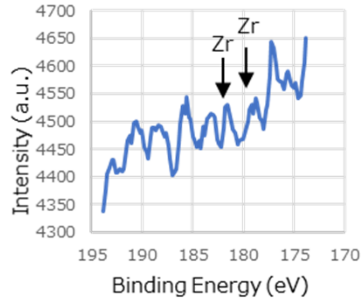
【Zn】

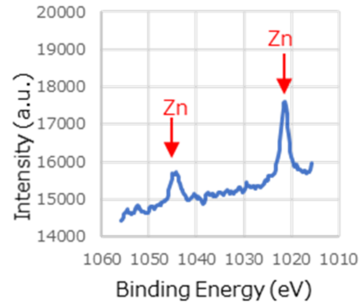


HPEUV w H_2

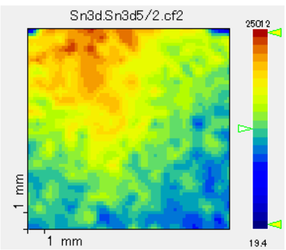








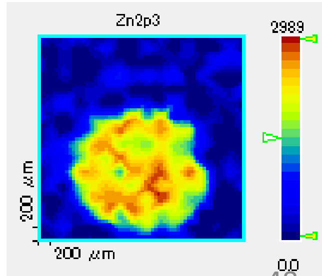
Sn contamination mapping @HPEUV



- No contamination detected in HfO_2 and ZrO_2
- Metal contamination is detected from Zn regardless of the presence of hydrogen atmosphere
- Metal contamination is detected from SnO_2 only under hydrogen atmosphere

For the first time, we have confirmed the occurrence of outgassing and contamination that only occurs under the hydrogen atmosphere typical of metal-based resists.

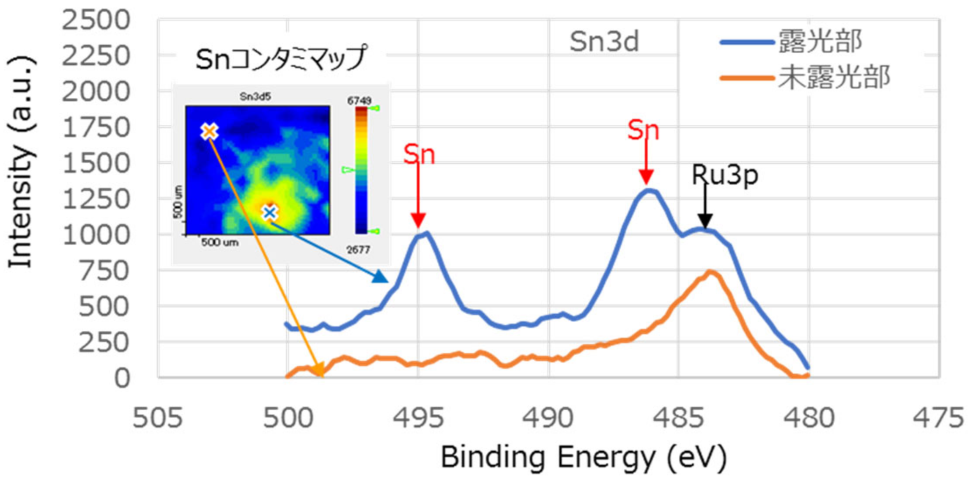
Zn contamination mapping @EUVOM



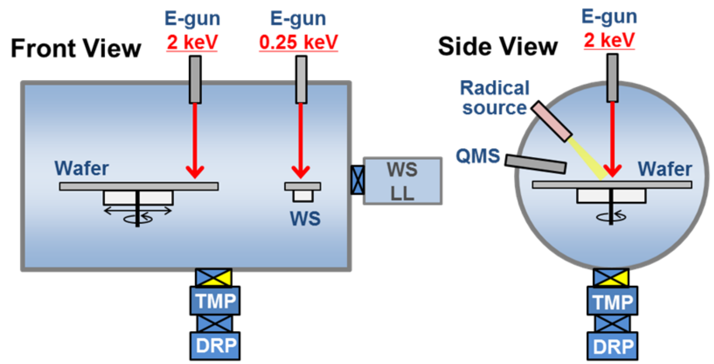
Courtesy of EIDEC

Evaluation result of SnO_2 by electron beam + hydrogen radical irradiation method

Non-cleanable contamination：XPS

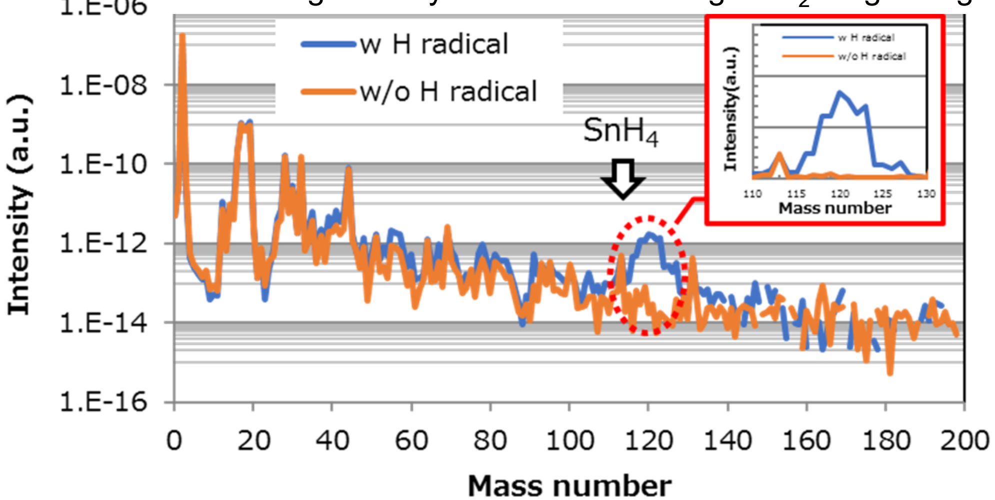


EUVOM-9000 with Hydrogen Radical Source

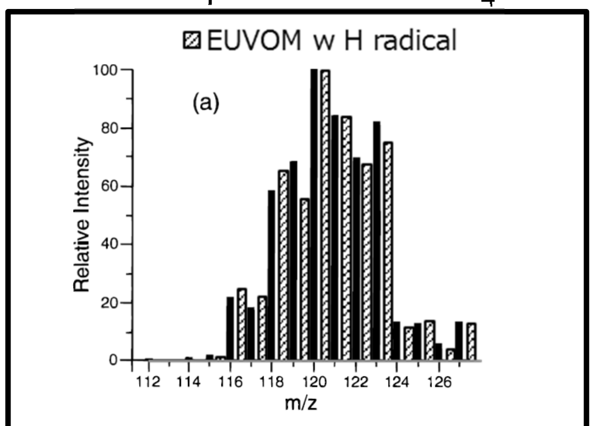


Detection of metal contamination from SnO_2 by electron beam + hydrogen radical irradiation method

Residual gas analysis when measuring SnO_2 outgassing



Mass spectrum of SnH_4



"Vacuum-Ultraviolet Photodecomposition of Stannane"
D. J. Aaserud and F. W. Lampe, J. Phys. Chem. 1996, 100, 10215

・The first confirmation of outgassing of metal hydride (SnH_4) by electron beam + hydrogen radical irradiation method
・Confirm the effectiveness of the same method in outgas measurement technology of metal resist

Courtesy of EIDEC

Outline

1. Introduction
2. Current R&D of EUV lithography at UoH
3. EUV lithography R&D at EIDEC
5. Capability of beyond EUVL (BEUVL)
6. Summary

Difficult Challenges 2019 Draft V2

Next Generation Technology	First Possible Use in Mfg.	22Feature Type	Device Type	Key Challenges	Required Date for Decision making
EUV Single Patterning	2018	22 to 24 nm hp CH/Cut Levels back end metals at 18nm hp LS	"7nm" Logic Node	-Pellicle -Actinic mask patterned mask inspection -Resist speed combined with LER and Stochastics -shot noise	Product Evaluation Completed
EUV Double Patterning	2022	12nm hp LS	"3nm" Logic Node	-Tolerance, EPE, and Overlay	2021
EUV high NA	2025	10.5nm hp LS	"2.1nm" Logic Node	-Stitching of two mask patterns -Shot noise	2024
EUV new wavelength	2028 ?	8nm hp LS ?	"1.5nm" Logic Node	-EUV source power -Resist material -Actinic blank and patterned mask inspection	2030
NanoImprint	2019	20 nm lines and spaces 20 to 30nm contact holes	3D Flash Memory	-Defectivity -Overlay -Master Template fabrication and inspection <20nm -Defect repair -Mass-production capacity	Product Evaluation Completed
DSA (for pitch multiplication)	2022	Contact hokes/cut levels for logic. Possibly nanowire patterning	"3nm" Logic Node	-Pattern Placement -Defectivity and defect inspection -Design -3D Metrology	2021

Work in Progress: Not for Distribution

Challenges for Beyond EUVL in shortening wavelength) (λ = 13.5 nm → 6.75 nm)

1) Imaging

- Flare level scales $\propto 1/\lambda^2$
- Bandwidth of a single mirror $\Delta\lambda/\lambda$(Mo/Si)=4% → $\Delta\lambda/\lambda$(La/B4C)<1%
- Bandwidth of the optical column $\Delta\lambda/\lambda$(Mo/Si)=2% → $\Delta\lambda/\lambda$(La/B4C)=0.6%

2) Multilayer for masks and optics

- Smaller layer thickness $\propto\lambda$
- Requirements to interlayer diffusion $\propto\lambda$
- Larger number of bi-layers per multilayer to increase the reflectivity.

3) Source

- New fuel is needed in LPP.
- EUV FEL is necessary.

4) Resist

- Resist sensitivity becomes 5-7 times lower

  Quantum efficiency of current EUV resist will decrease due to lower absorption of 6.7nm(186eV) photons vs 13.5nm(92eV) photons
- Potential shot noise increases

Mid-spatial frequency (MSFR) and flare level

- Flare reduces contrast and increases LWR

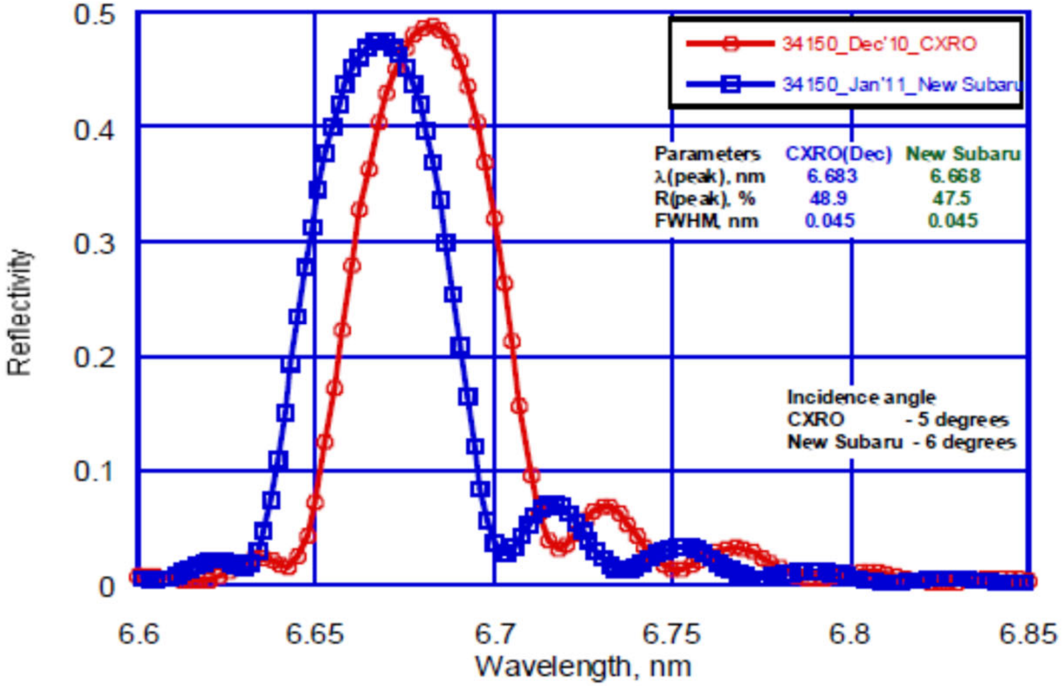
- MSFR is linked to surface roughness

- Flare scales with wavelength as $1/\lambda^2$
  13.5nm ==> 6.x nm
  flare increases 4x at the same MSFR

MSFR (nm)	Flare (%) @λ=13.5nm	Flare (%) @λ=6.7nm
0.2	16	65
0.14	8	32
0.12	6	23
0.1	4	16
0.05	1	4

Next Generation EUVL Optics for 6.X nm

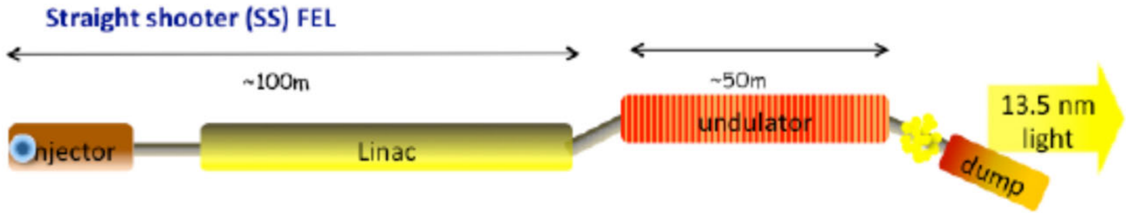
- Achieved the highest measured reflectivity to date, actively developing multilayers to their theoretical limit ~ 70%



Courtesy of Rigaku

FEL for EUV Light Source

Short term risk profile comparison



Leveraged on LCLS-II design and development, and X-FEL experience worldwide

Well developed modeling tools

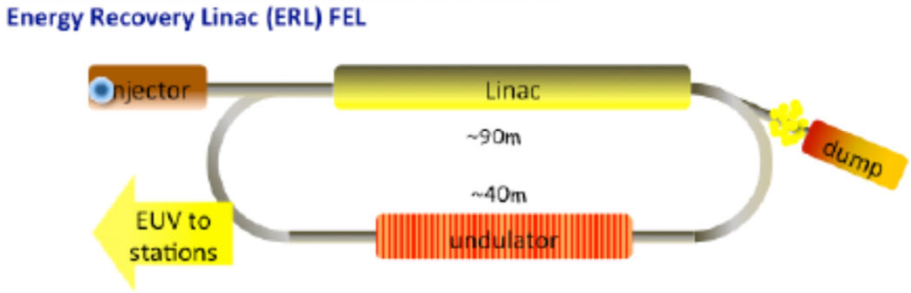
Massive practical experience with single pass X-FEL, large pool of experts and trained personnel

Smaller injected/recirculated current

Untested physics of high efficiency short wavelength FEL

Higher RF and beam dump costs

Modular design, enables future upgrades, also testing can be done in existing facilities



Leveraged on Jlab design and 10 kW IR ERL FEL (2001)

Closed system, has to be developed and tested in its entirety

High injected/recirculated current, machine protection is an issue

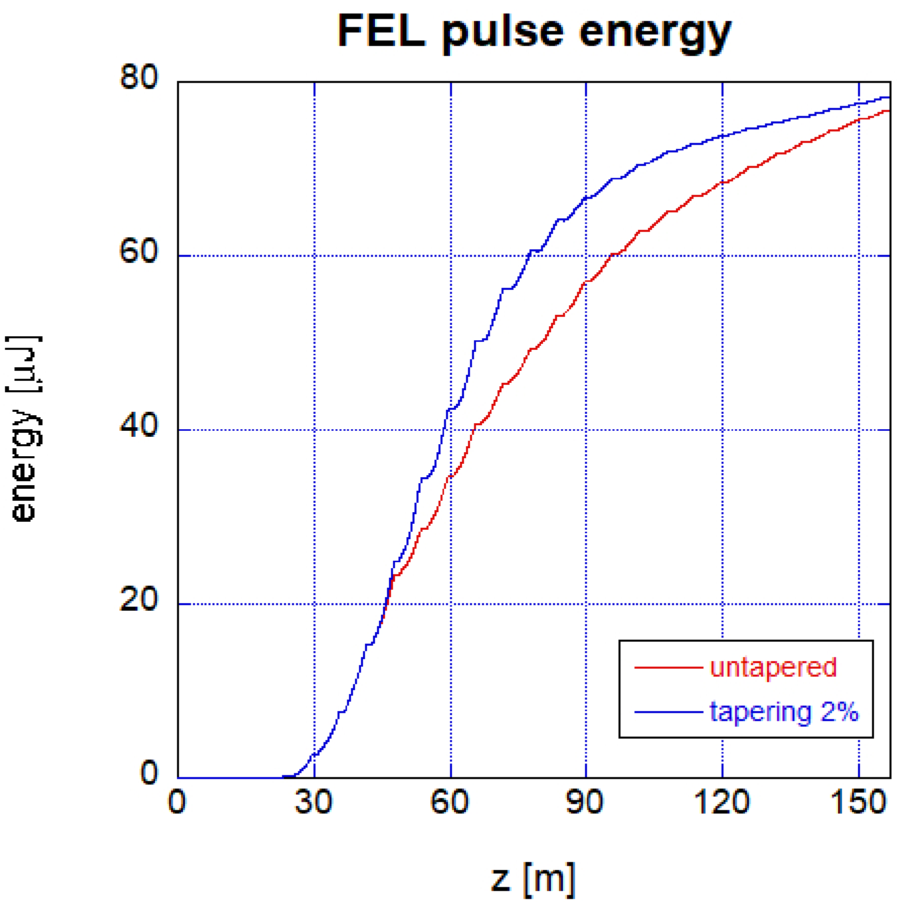
Untested physics of short wavelength ERL FEL

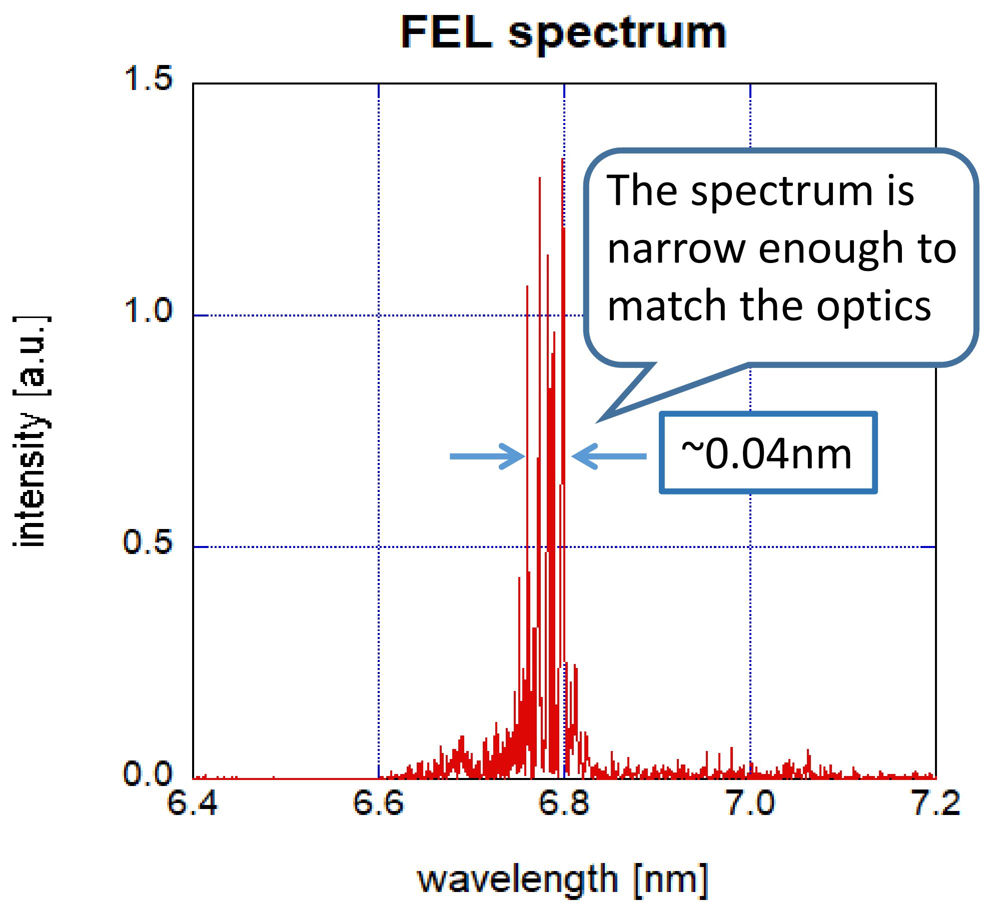
Very elegant solution to reducing the RF power and beam dump costs

Very few operating ERL facilities worldwide

Numerical tools require validation

Recent study about the power and spectrum at BEUV





FEL power with 2% tapering:
12.7/25.4 kW @ 9.75/19.5 mA (162.5/325 MHz)

$\Delta\lambda/\lambda = 6 \times 10^{-3}$

Accelerator Parameters: $E_{acc} = 1131$ MeV $(800 \times \sqrt{2})$,
The other conditions are almost same to these of EUV-FEL

BEUV

1) Lithography for 6.x nm wavelength has a potential to extend EUVL beyond 10 nm node

2) ML coatings

- Potential of for high reflectivity (up to 80%) for LaB_4C
- Currently demonstrated reflectivity is 44% thus better inter-layer diffusion control is required

3) EUV source

- Two types potential source fuels are investigated: Tb and Gd
- Considering resist sensitivity, EUV-FEL is necessary.

4) Optimization of EUV source spectrum with ML optics is required

5) Transmission of gases and contaminants for 6.x is significantly (up to 5x) better than for 13.5 nm

6) 6.x EUVL has a potential for a throughput comparable with 13.5 nm lithography at higher resolution

Summary

1. Semiconductor market was up 13.7% in 2018 to B$468.8.
2. The wavelength of 13.5 nm own to Mo/Si multilayer materials.
3. The early stage of X-ray projection lithography (present EUV lithography) is introduced.
4. The Resonant soft X-ray scattering method is very powerful method to evaluate the origin of resist stochastic and layer analysis in an EUV resist film.
5. The capability of beyond EUVL (BEUVL) is discussed.

Acknowledgements

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A part of the research results of UoH was supported by NEDO through EIDEC.

A part of the research results of UoH was supported by Kakenhi through MEXT.

Thank you for your kind attention!!