NIKON CORPORATION

Development of EUV lithography tool technologies in Nikon

Katsuhiko Murakami
Hiroshi Chiba, Masahiko Kanaoka, Kazushi Nomura, Katsura Otaki, Masayuki Shiraishi, Atsushi Yamada, Shinnichi Takahashi, Noriaki Kandaka, Atsushi Yamazaki, Takashi Yamaguchi, Tetsuya Oshino, Hiroyuki Kondo, Kazuya Ota

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Outline

- **Lithography roadmap & PO design update**
- **Progress of polishing technology**
  - EEM (Elastic Emission Machining)
- **Contamination control in EUV exposure tools**
  - Carbon contamination
  - Surface oxidation
  - Other
- **Particle behavior observed in EUV1**
- **Summary**

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Lithography roadmap

	NA \ HP	32nm	28nm	25nm	22nm	20nm	18nm	16nm	14nm	13nm	11nm	10nm	9nm	8nm
ArF 193nm DP	1.30	0.22	0.19	0.17	0.15	0.13	0.12	0.11	0.09	0.09	0.07	0.07	0.06	0.05
	1.35	0.22	0.20	0.17	0.15	0.14	0.13	0.11	0.10	0.09	0.08	0.07	0.06	0.06
EUV 13.5nm	0.25	0.59	0.52	0.46	0.41	0.37	0.33	0.30	0.26	0.24	0.20	0.19	0.17	0.15
	0.33	0.78	0.68	0.61	0.54	0.49	0.44	0.39	0.34	0.32	0.27	0.24	0.22	0.20
	0.35	0.83	0.73	0.65	0.57	0.52	0.47	0.41	0.36	0.34	0.29	0.26	0.23	0.21
	0.40	0.95	0.83	0.74	0.65	0.59	0.53	0.47	0.41	0.39	0.33	0.30	0.27	0.24
	0.45	1.07	0.93	0.83	0.73	0.67	0.60	0.53	0.47	0.43	0.37	0.33	0.30	0.27
	0.50	1.19	1.04	0.93	0.81	0.74	0.67	0.59	0.52	0.48	0.41	0.37	0.33	0.30

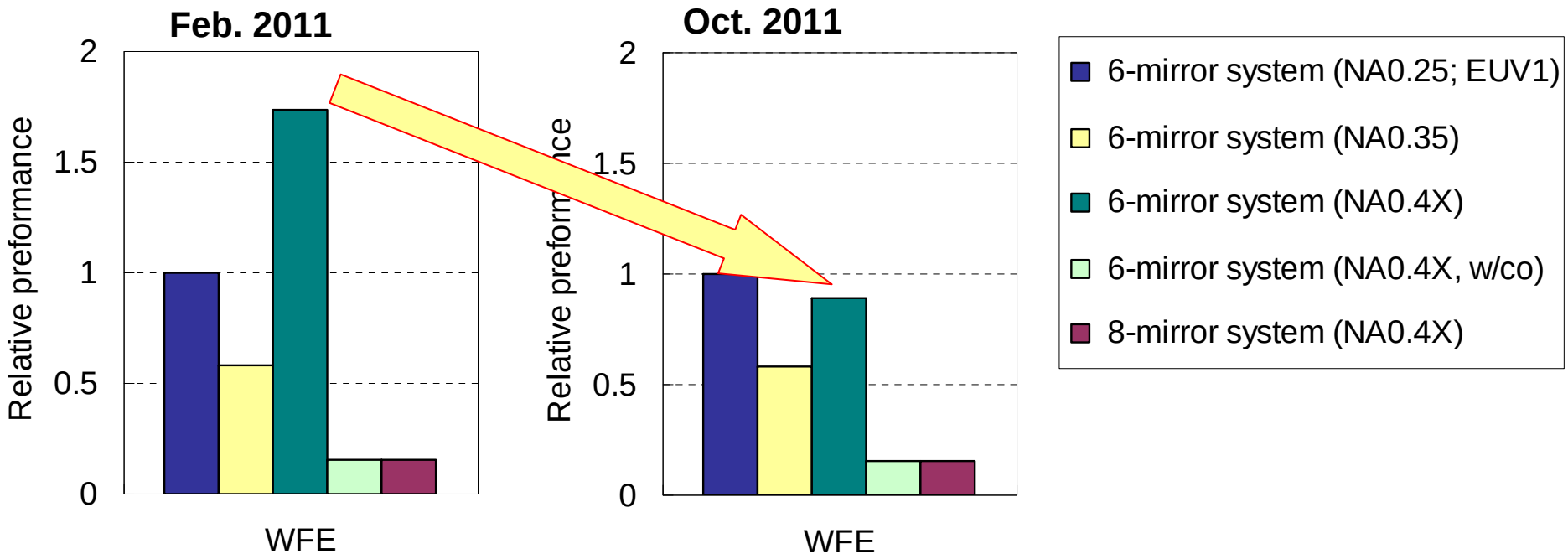
32nm hp - 22nm hp

16nm hp - 11nm hp

32nm hp – 22nm hp node: ArF immersion double patterning

16nm hp – 11nm hp node: EUV with NA>0.4

NA>0.4 optics design update



Wavefront error of NA0.4X 6-mirror system without central obscuration was much reduced.

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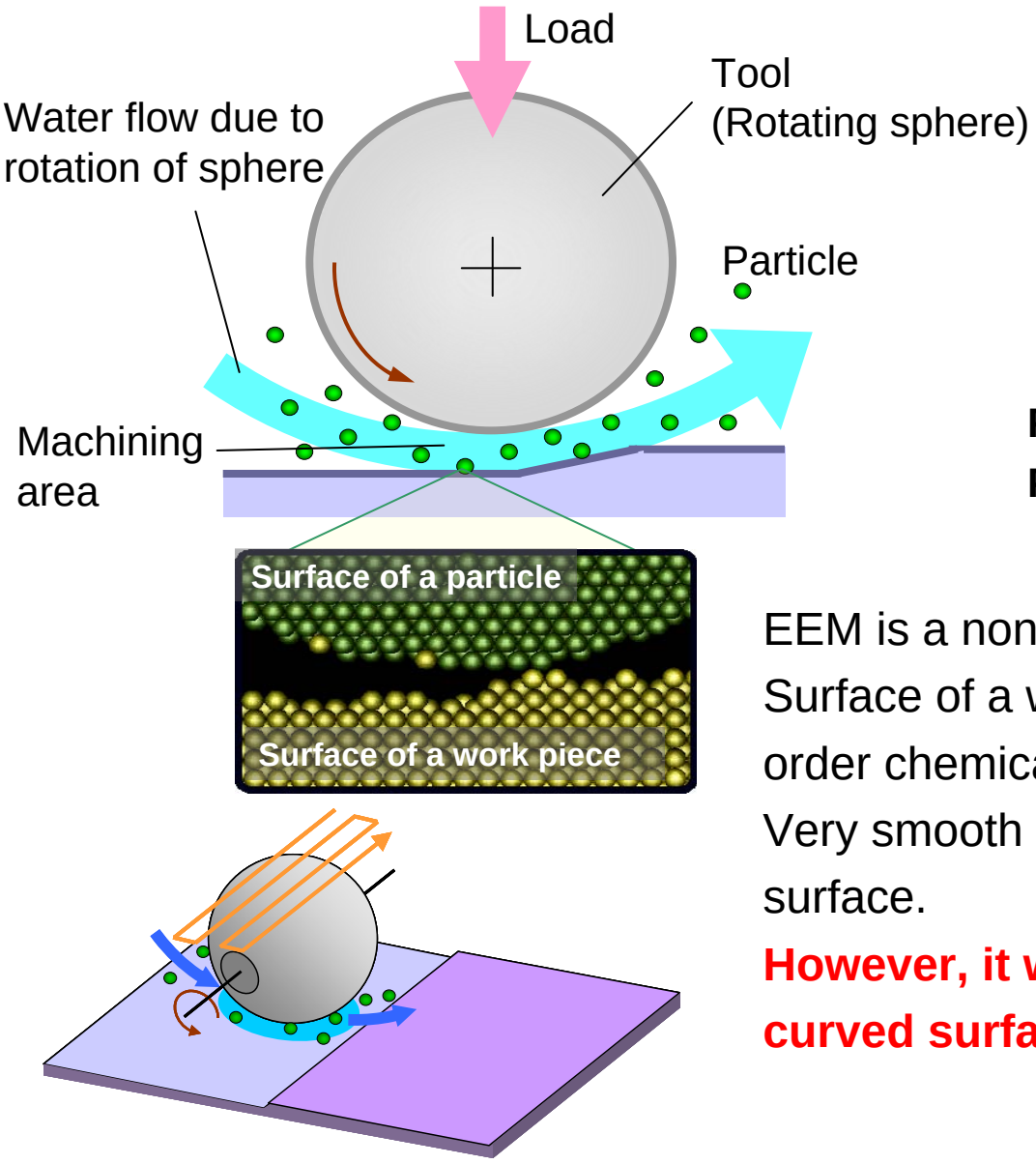
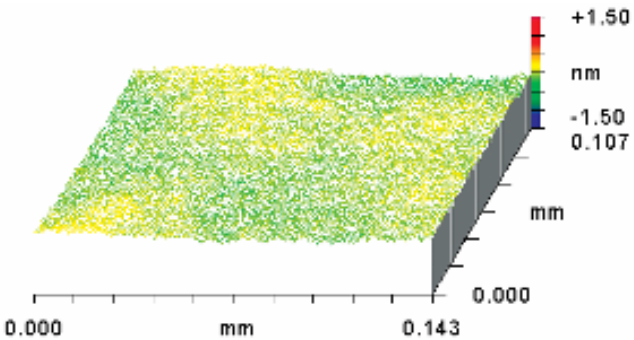
EEM (Elastic Emission Machining)





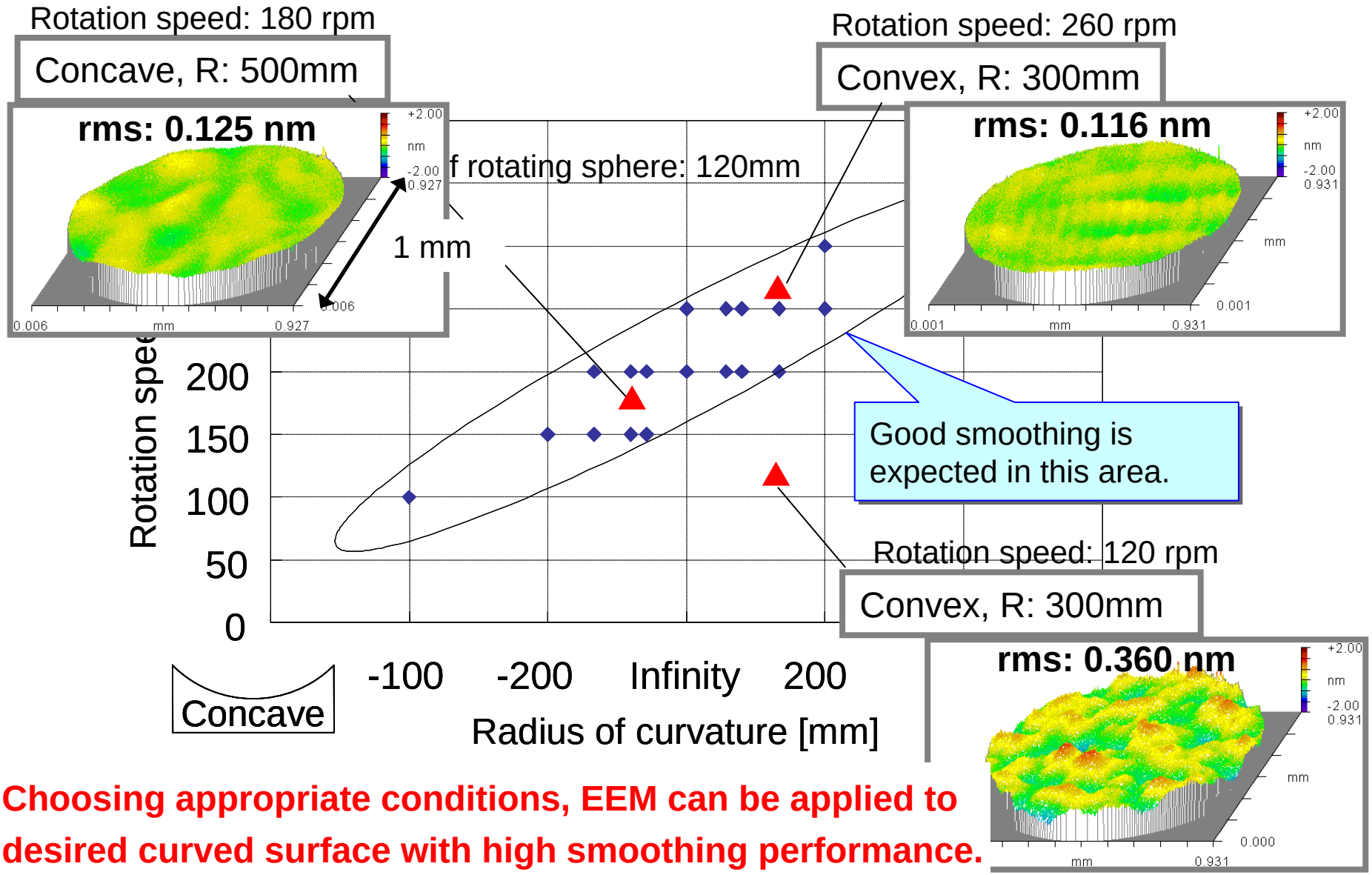
Flat surface polished using EEM

PV : 1.068 nm, rms: 0.085nm

EEM is a non-contact polishing method. Surface of a work piece is removed by atomic-order chemical reaction with surface of particles. Very smooth surface can be obtained in a flat surface.

However, it was difficult to apply EEM to curved surface.

Application of EEM to curved surface



Choosing appropriate conditions, EEM can be applied to desired curved surface with high smoothing performance.

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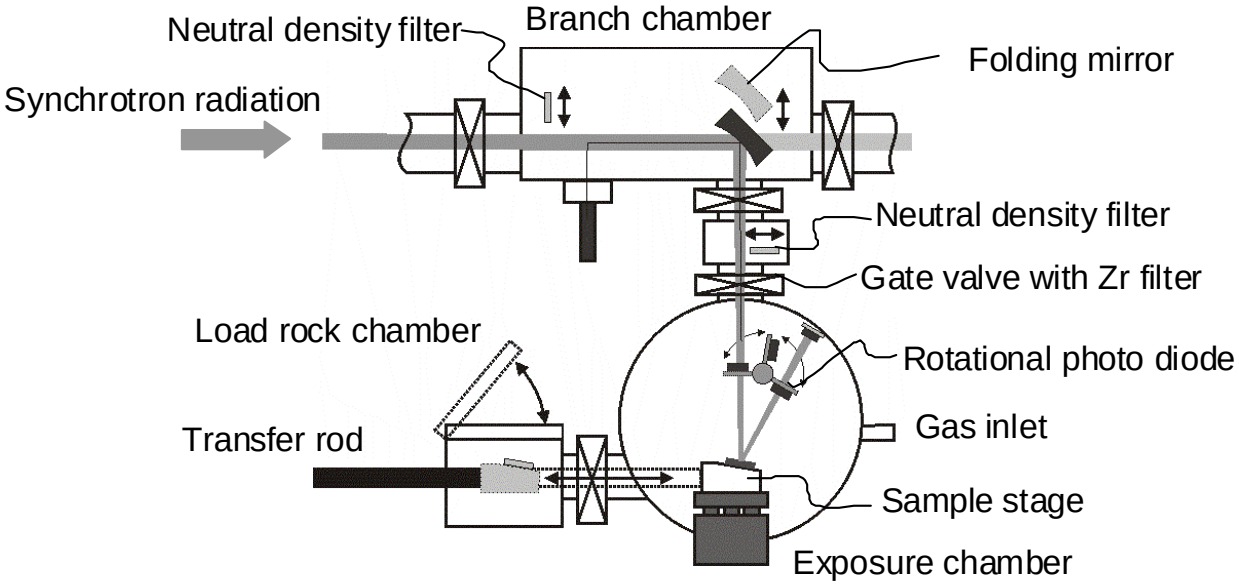
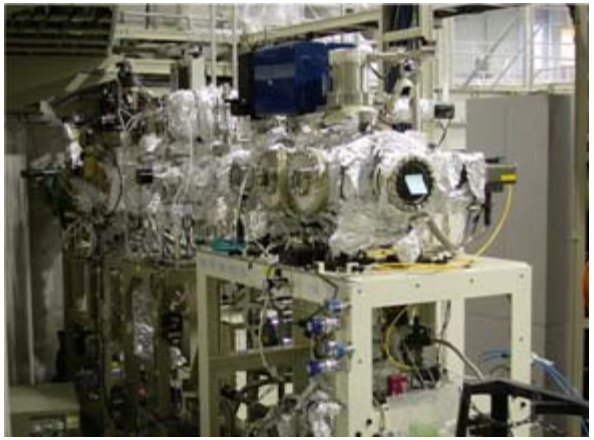
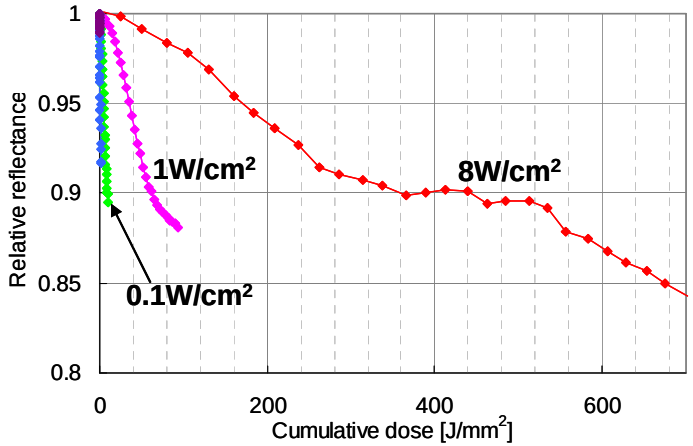
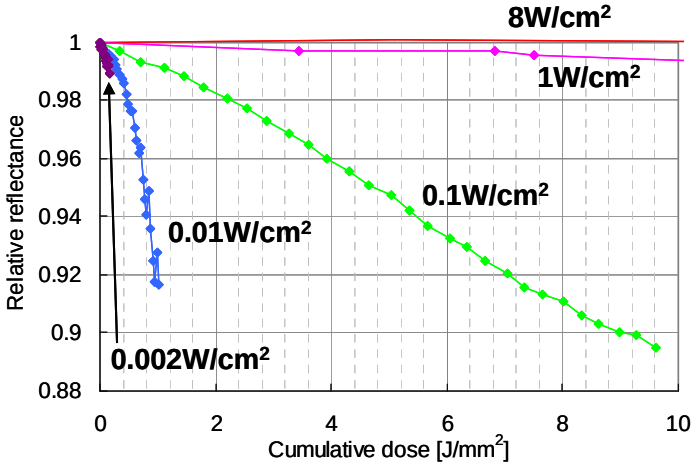
Contamination study using a synchrotron facility





BL 18 at SAGA LS SR facility





Contamination growth with perfluorohexane (C_6F_{14})

Contamination control in EUV exposure tools

Carbon contamination

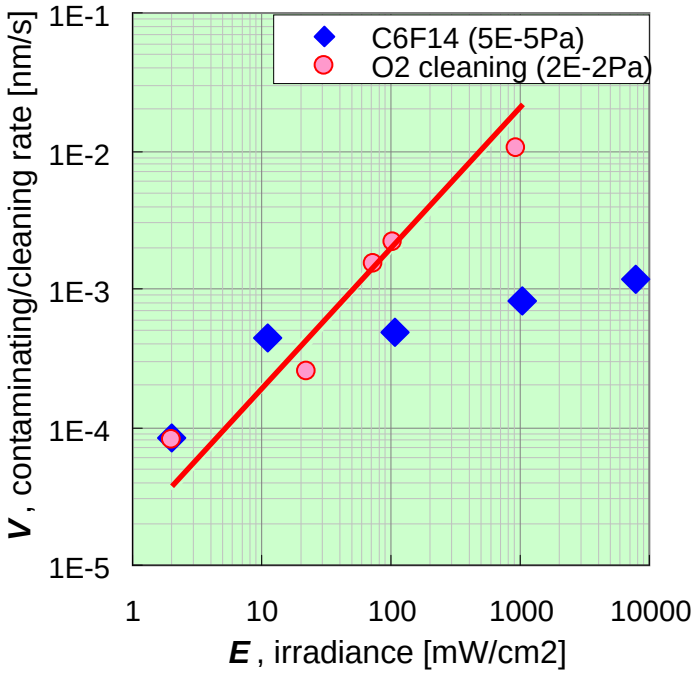
EUV + O_2 mitigation

on-body UV dry cleaning with reduced pressure

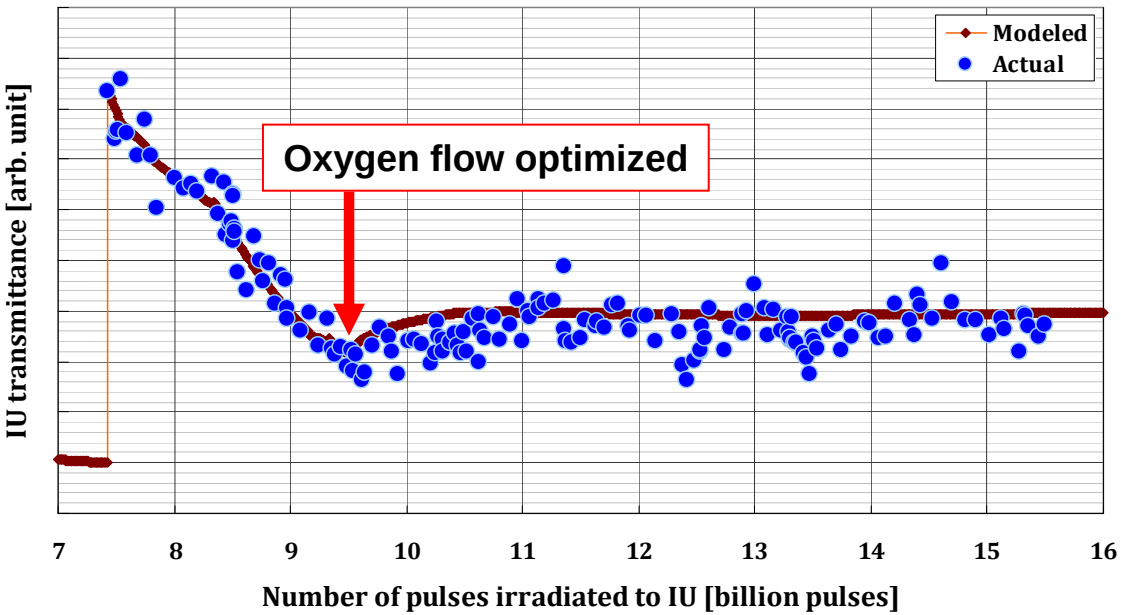
Surface oxidation

Other

EUV + O_2 mitigation



Contamination growth rate and O_2 cleaning rate



History of IU transmittance of EUV1

O_2 cleaning rate exceeds carbon contamination growth rate in appropriate condition.

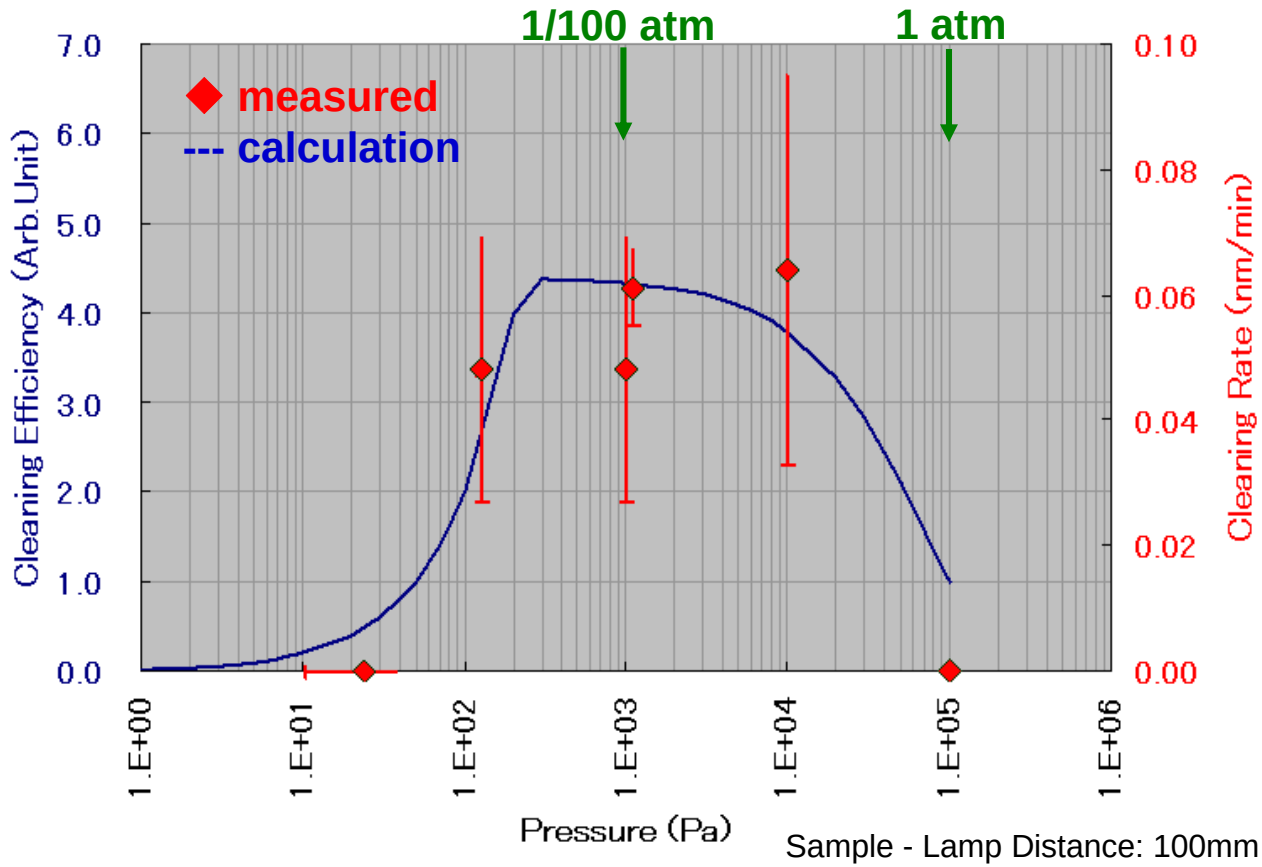
Degradation of IU (Illumination Unit) transmittance of EUV1 was stopped after optimization of O_2 flow rate.

EUV + O_2 mitigation is very effective to carbon contamination.

UV dry cleaning with reduced pressure

Before cleaning

After cleaning



Carbon contamination can be removed with UV dry cleaning using a low pressure mercury lamp. Cleaning rate increases with reduced pressure.

UV dry cleaning with reduced pressure was applied to EUV1 as on-body cleaning.

Contamination control in EUV exposure tools

Carbon contamination

EUV + O_2 mitigation

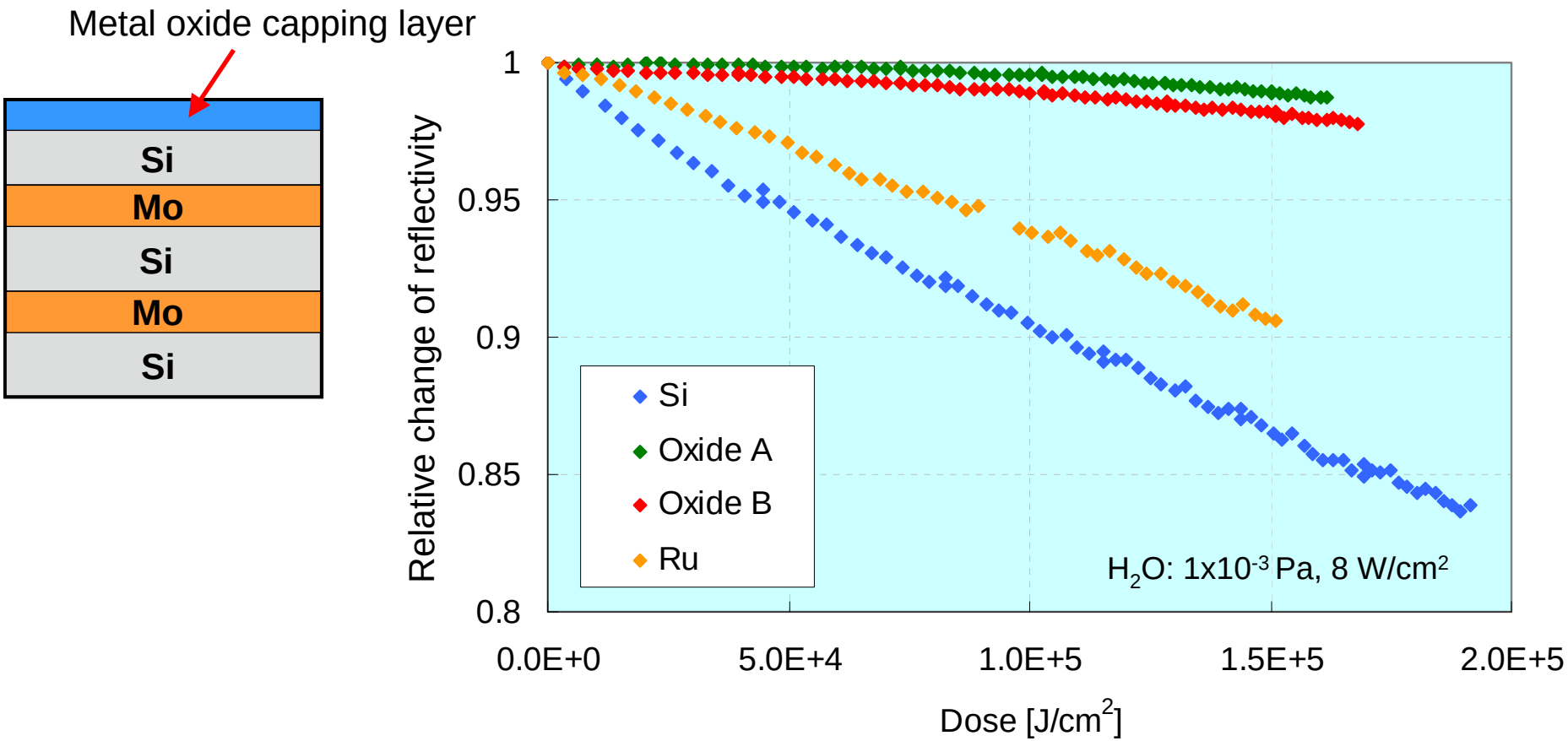
on-body UV dry cleaning with reduced pressure

Surface oxidation

Metal oxide capping layer

Other

Metal oxide capping layer



Reflectivity change of Mo/Si multilayers with several different capping layer materials during EUV exposure in water vapor was measured.

Metal oxide capping layers have much higher oxidation durability compared with conventional Ru capping layer.

Contamination control in EUV exposure tools

Carbon contamination

EUV + O_2 mitigation

on-body UV dry cleaning with reduced pressure

Surface oxidation

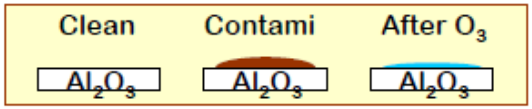
Metal oxide capping layer

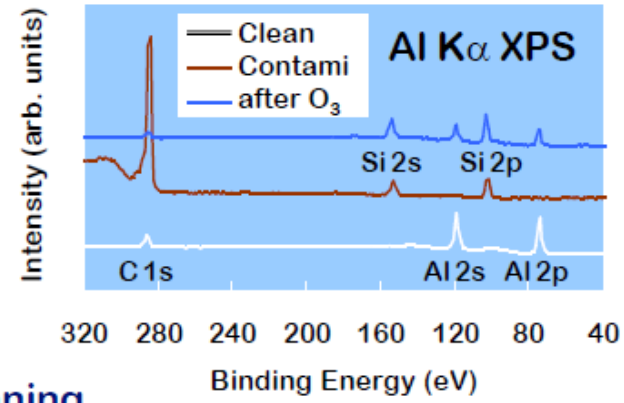
Other (Si containing carbon contamination)

Si containing carbon contamination

Where Does Si Come from ?

- Almost all carboneous contamination we investigated (SR, DPP, LPP) contains several parcents of Si species.
  - Other groups also reported Si in contaminations.
    - Intel MET
      N1 mirror: C : O : Si ~70 % : 20 % : 10 %
      G1, G2 mirror: C : O : Si ~ 85 % : 10 % : 5 %
      Manish Chandhok, IEUVI Optics Contamination / Lifetime TWG (1st Mar. 2007)
    - Albany MET
      G2: C : O : Si : P : N = 74 : 20 : 2 : 2 : 1
      Andrea Wüest et al., IEUVI Optics Contamination / Lifetime TWG (1st Nov. 2007)
- The origin of Si was unclear. No Si species has been detected by QMS or GC-M.
  - So we deposited contamination on sapphier (Al_2O_3) substrates.





- The result clearly shows that Si comes from vacuum.
  In addition, this Si species seem hard to remove by oxidative cleaning.

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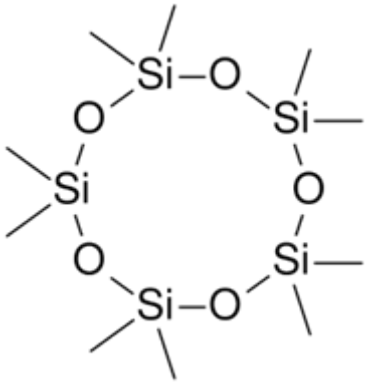
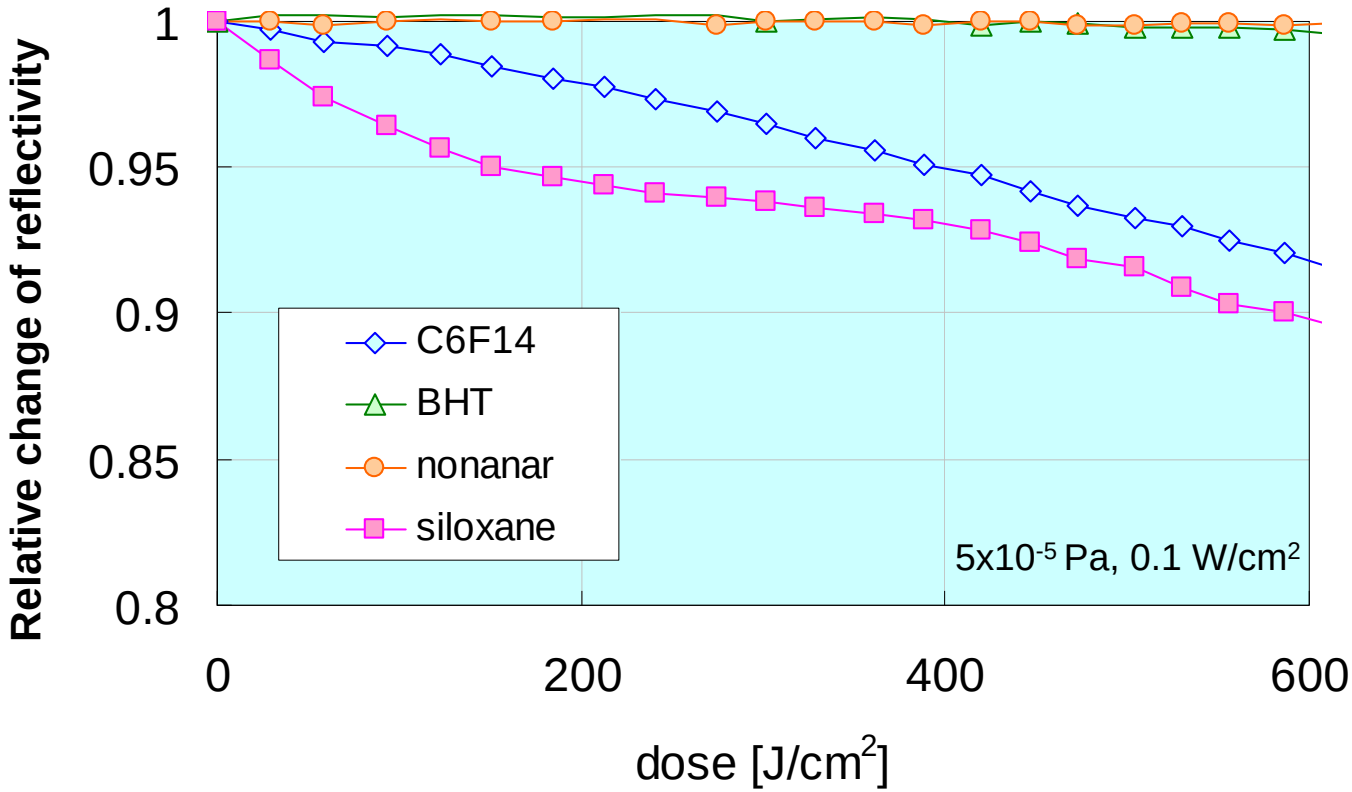
Contamination growth due to siloxane

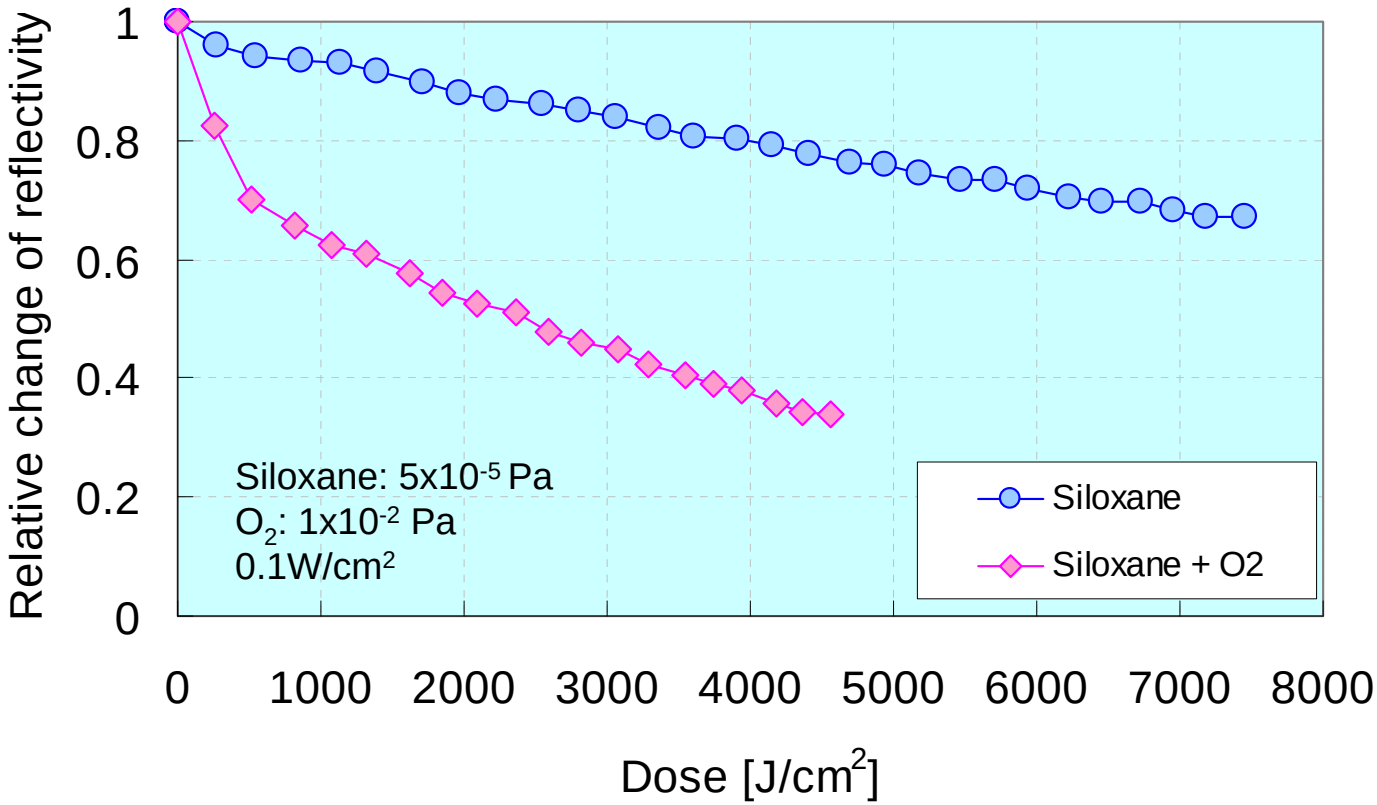


$C_{10}H_{30}O_5Si_5$
decamethyl
cyclopentasiloxane



We supposed that siloxane is a contributor of Si containing carbon contamination.
Slioxane is commonly observed organic compound which contains Si.
Contamination growth rate under EUV irradiation was measured.
Siloxane has the highest contamination growth rate of all materials that we had ever tested.

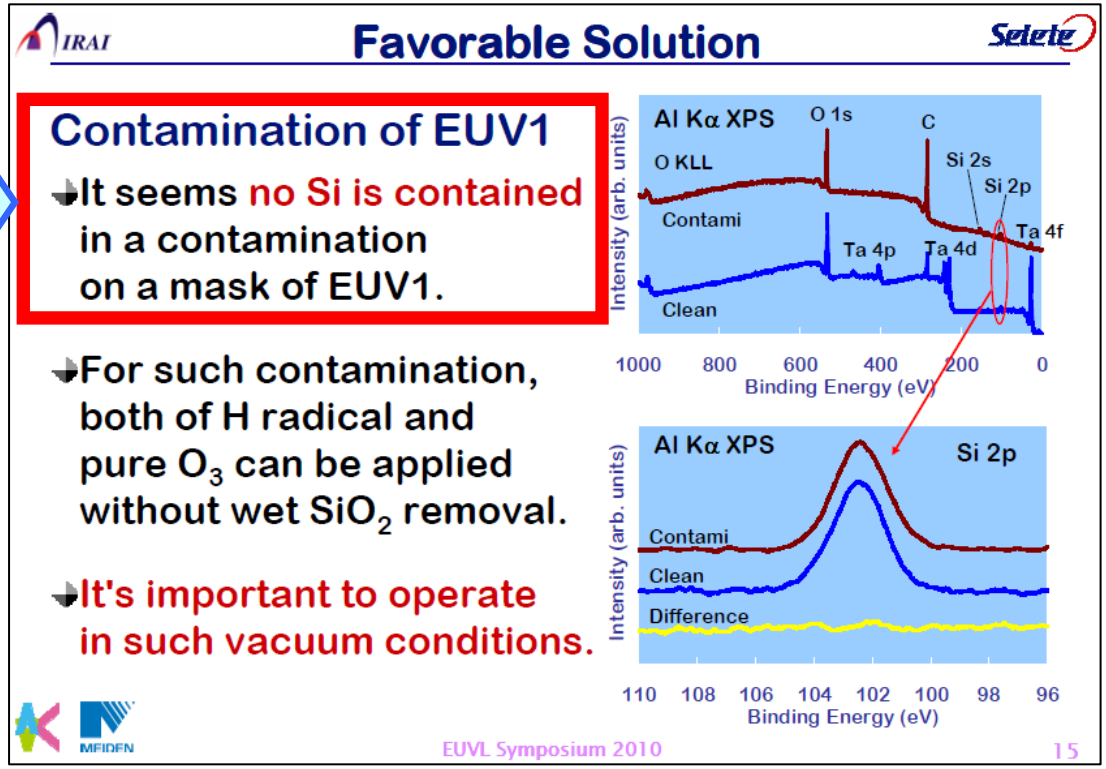
EUV + O_2 mitigation with siloxane



Contamination growth rate in siloxane vapor with and without O_2 was tested.

EUV + O_2 mitigation has the opposite effect on Si containing carbon contamination caused by siloxane.

Carbon contamination of EUV1



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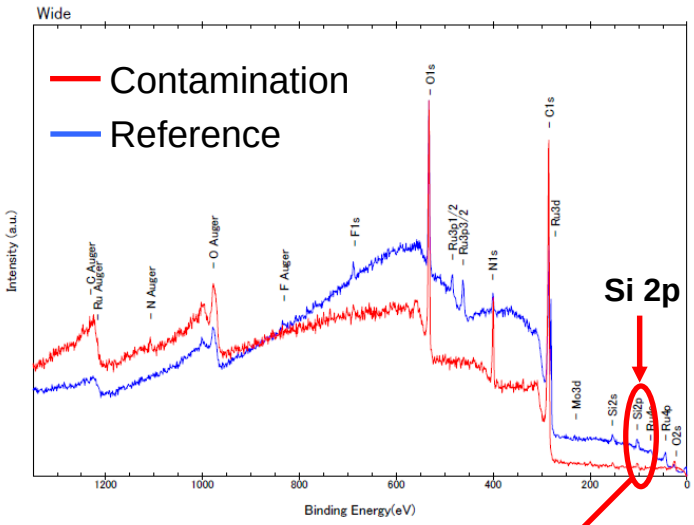

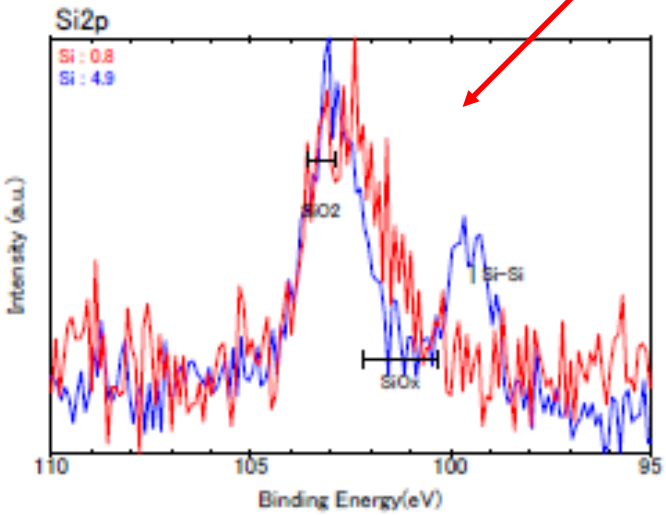

XPS analysis of contamination on illumination optics of EUV1

No Si was observed in carbon contamination in EUV1.

Si containing contamination can be prevented by clean vacuum eliminating Si containing compound.

Contamination control in EUV exposure tools

Carbon contamination

EUV + O_2 mitigation

on-body UV dry cleaning with reduced pressure

Surface oxidation

Metal oxide capping layer

Other (Si containing carbon contamination)

Elimination of Si containing compound (siloxane) from vacuum environment

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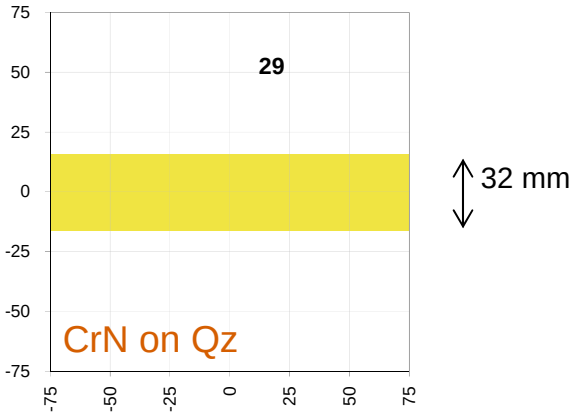
Particles observed on a reticle in EUV1

Courtesy of Selete

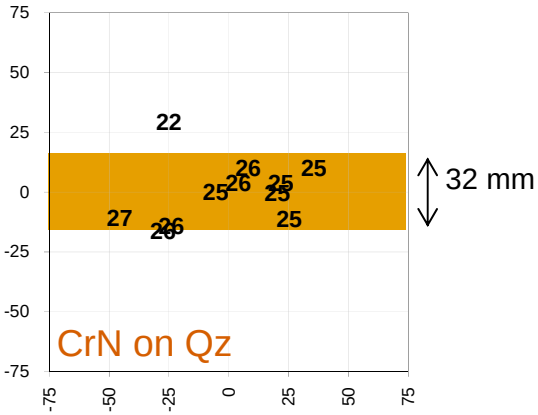
Dummy exposure testing

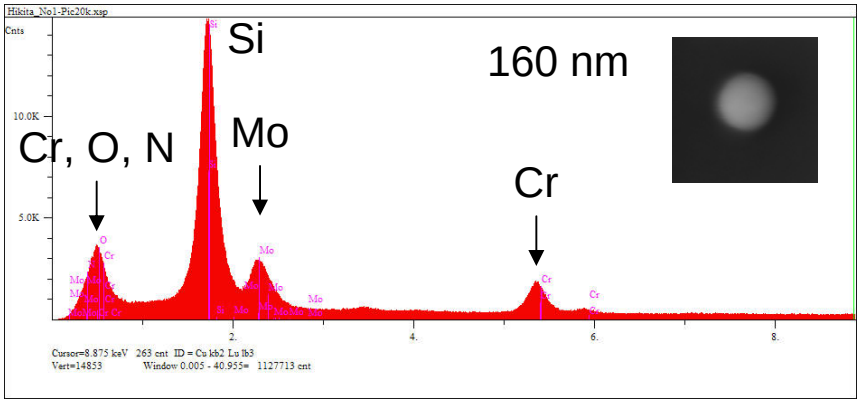
Handling, chucking,
30-minute scanning without EUV light.



Real exposure testing

Handling, chucking,
30-minute scanning exposure.





7 pix ≈ 83 nm PSL equivalent on CrN

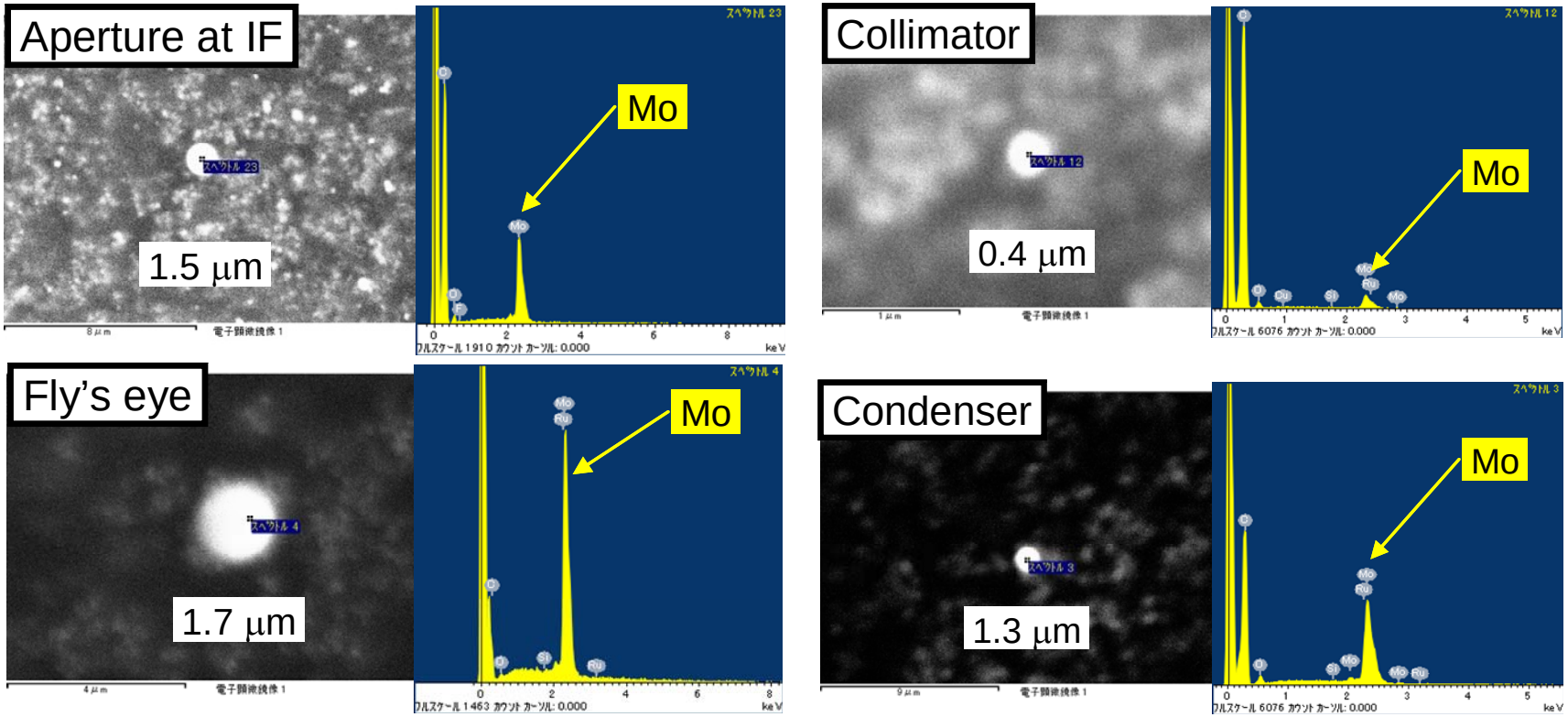
Particle adders on a reticle in EUV1 during exposure was examined.

Adders were observed only in the exposure area.

These adders contain Mo.

See "EUV1 Reticle Particle Contamination"
K. Ota, et al., at Poster Session

Particles observed on IU mirrors in EUV1



Similar particles as observed on a reticle were found on mirrors of illumination optics.

These particles traveled from upper part of IU onto the reticle plane.

Particles travel very long distance in vacuum.

See "EUV1 Reticle Particle Contamination"
K. Ota, et al., at Poster Session

Summary

Lithography roadmap & PO design update

✓Target of EUVL is 16-11nm hp node with NA>0.4.

✓WFE of 6-mirror PO with NA>0.4 was reduced.

Progress of polishing technology

✓EEM can be applied to desired curved surface.

Contamination control in EUV exposure tools

✓EUV + O_2 mitigation and on-body UV dry cleaning for carbon contamination.

✓Metal oxide capping layer prevents surface oxidation.

✓Si containing contamination can be prevented by clean vacuum environment.

Particle behavior

✓Particles travel very long distance in vacuum.

Acknowledgments

- EUVA
- NEDO
- METI
- Selete
- SAGA Light Source

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