The role of ambient hydrocarbon species to reduce oxidation in Ru capping layers for EUVL optics mirrors

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Experiment @ NewSUBARU

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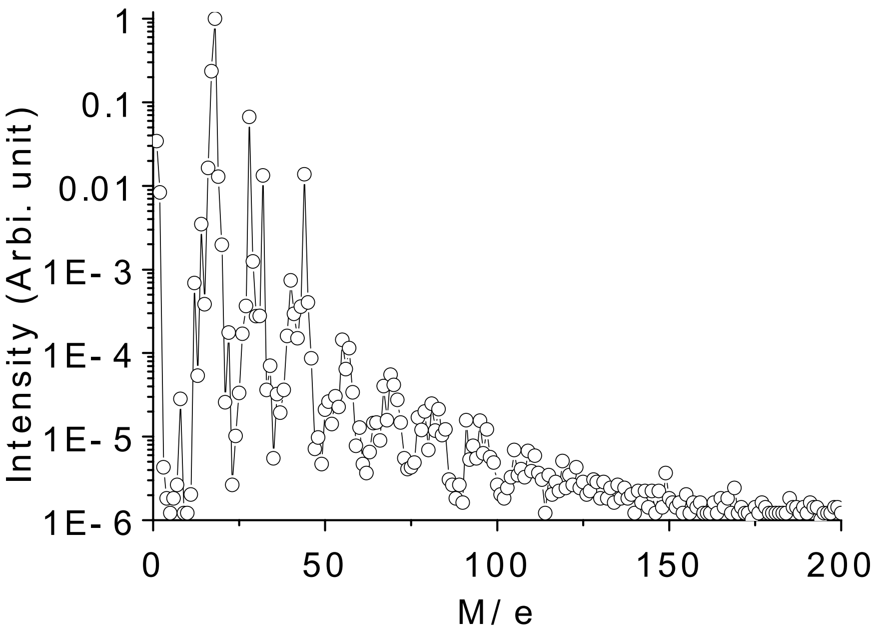
EUV irradiation experiment

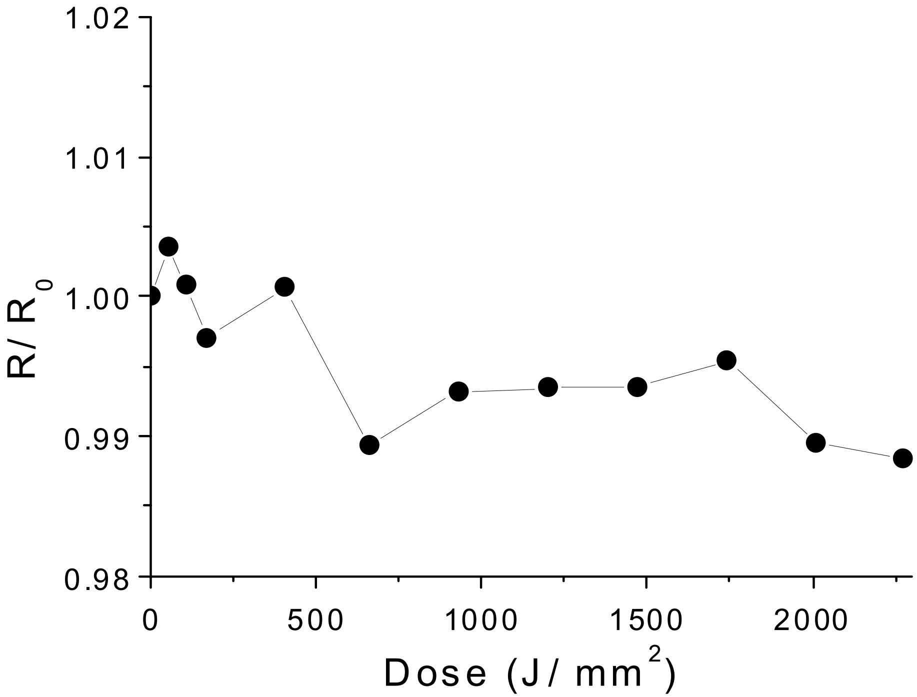


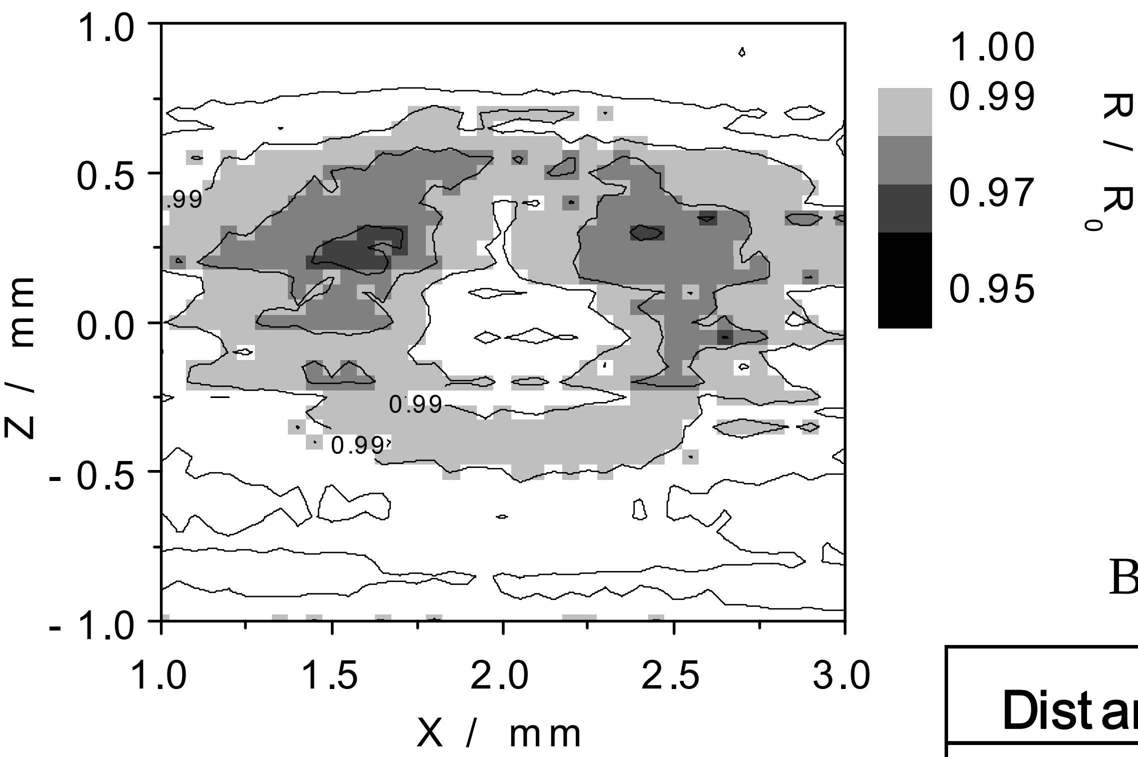
Average power: 140 mW/mm²

2250J/mm² corresponds to 3500hrs operation in the highest tool irradiation condition.

O ring system
Total pressure: 6.6×10^{-5}Pa
(Base pressure)

CH_x : 1.5×10^{-4} @ M/e=55
compared with M/e=18

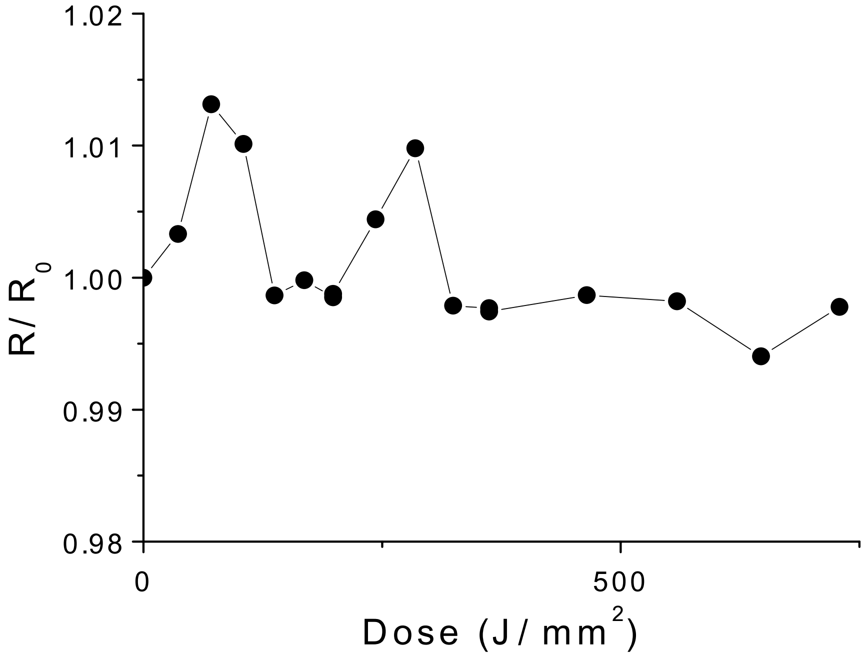




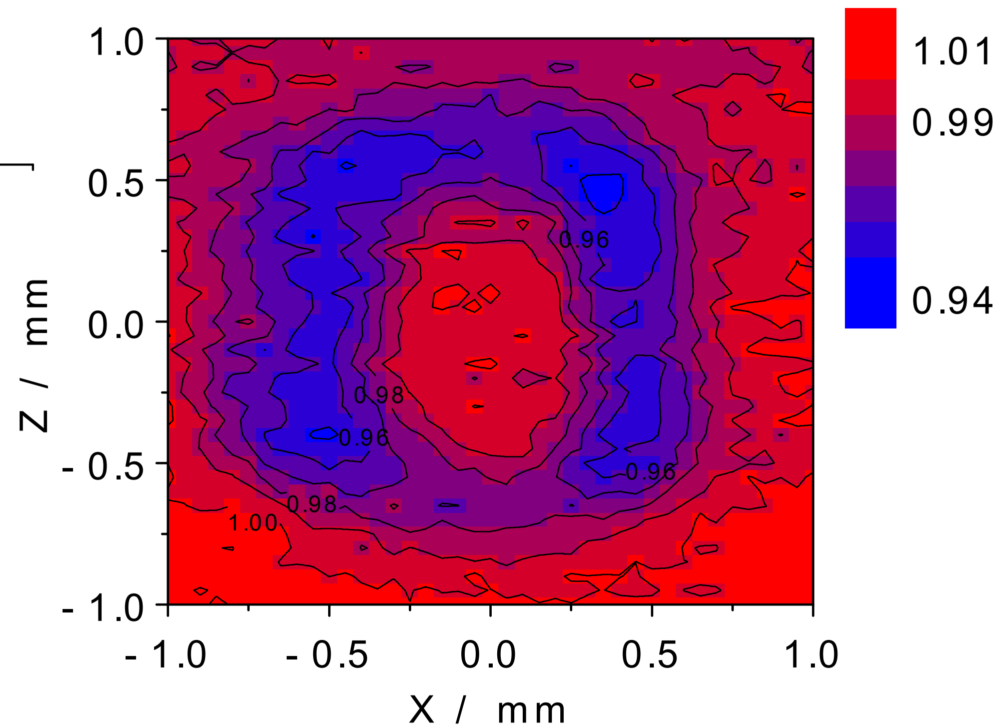
Distribution of EUV reflectivity
(Base pressure)

Beam intensity distribution

Distance (μ m)	Intensity
0 (Center)	1
200	0.4
400	0.04
600	0.004



Peripheral degradation is a little faster.

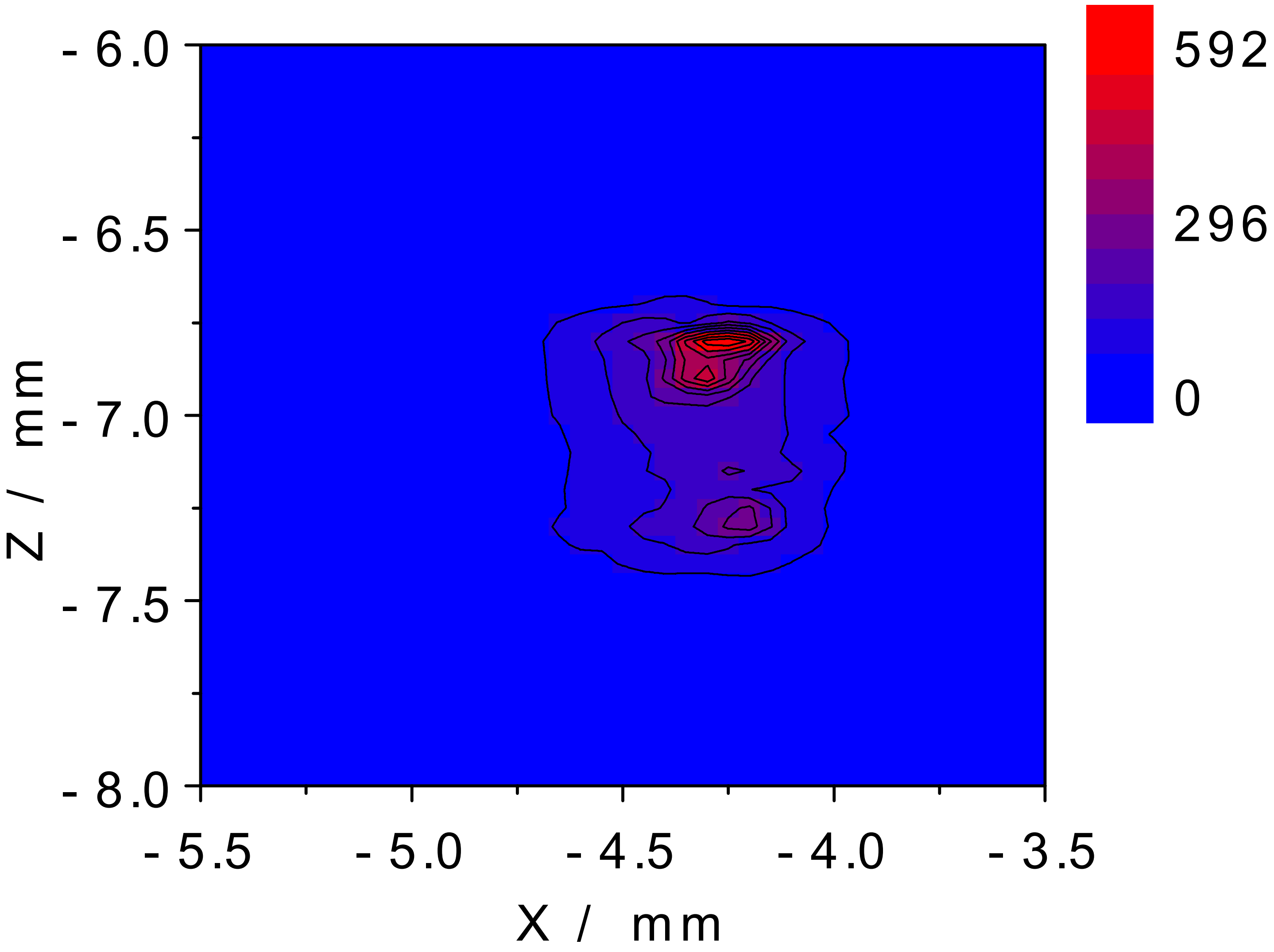


H_2O: introduced up to 1.3x10^{-2} Pa.

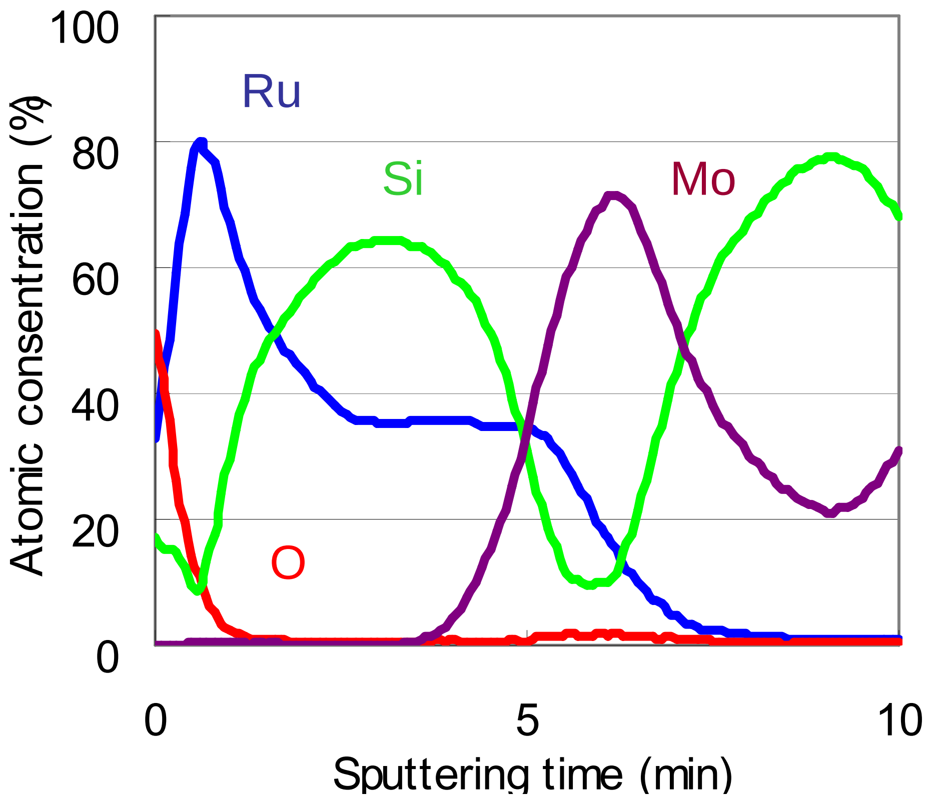
CH_x: increased to 2.2x10^{-5} @ M/e=55 compared with M/e=18

Average power: 80 mW/mm^2

Beam profile

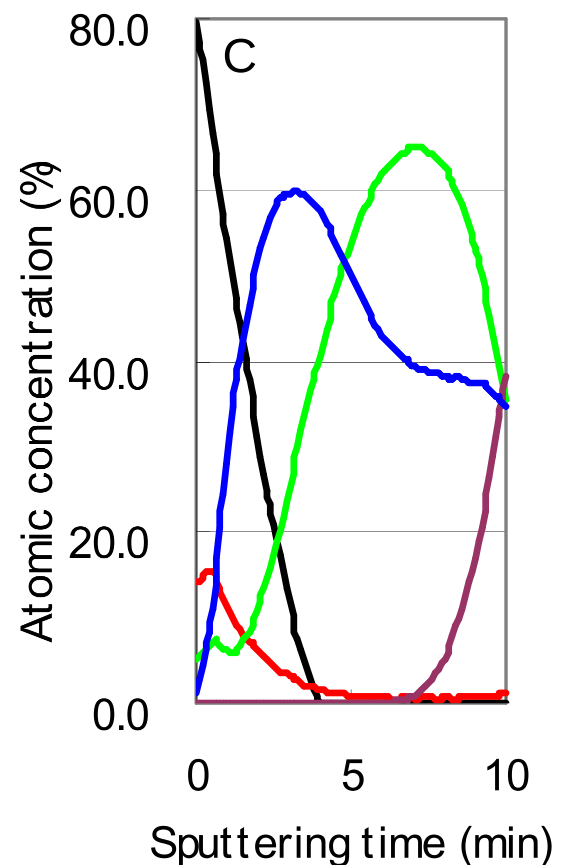


AES/sputter analysis

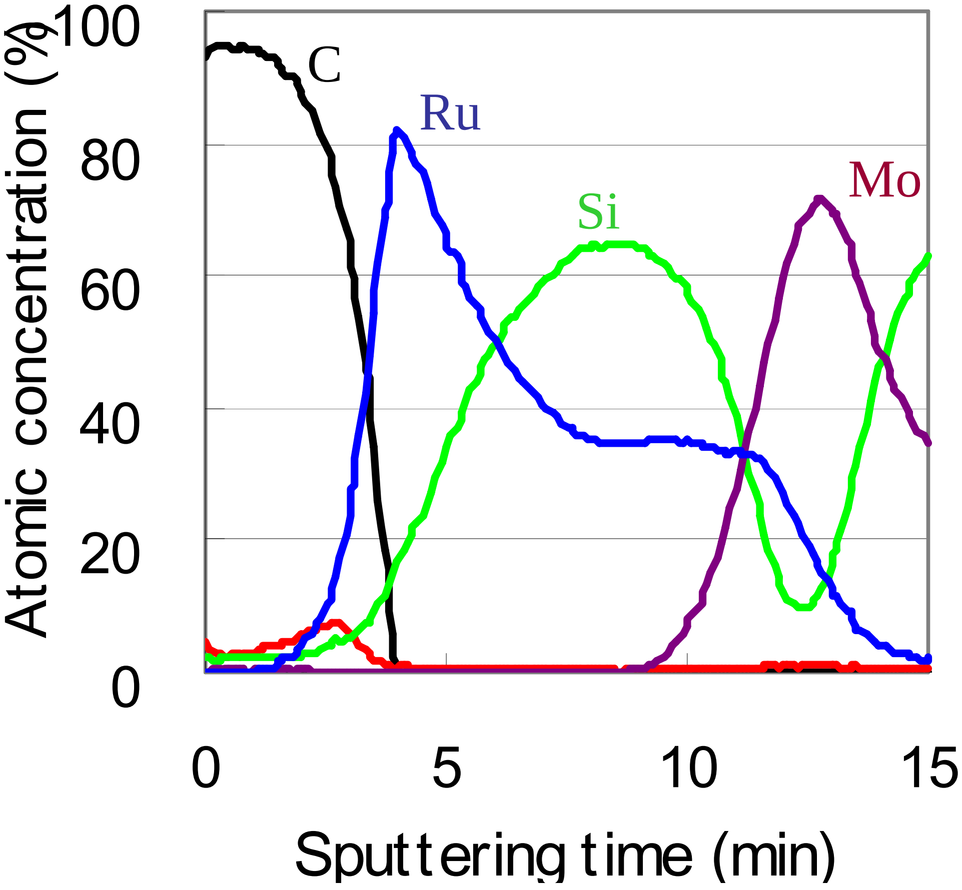


Irradiation center
(Base pressure)

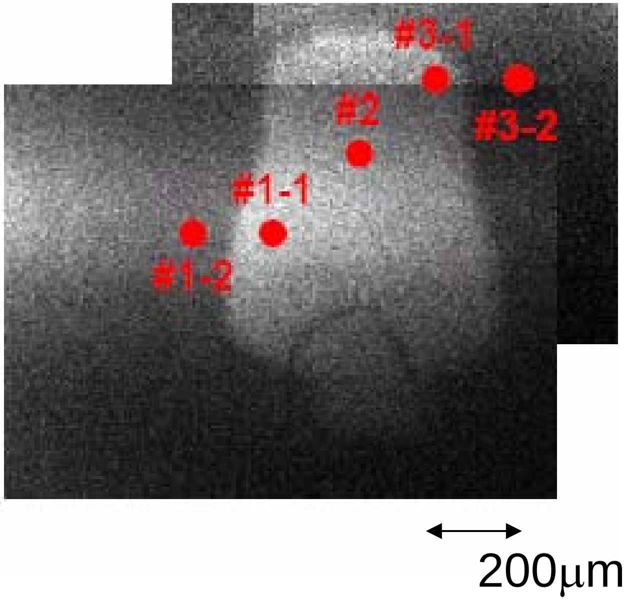
Near the boundary where reflectivity was kept (H_2O: 1.3x10^{-2} Pa)



Outside the boundary where reflectivity dropped (H_2O: 1.3x10^{-2} Pa)



XPS Analysis



H_2O: introduced to 1.3×10^{-2} Pa

Almost the same results were obtained with base pressure.

Unit：atom%

	C	O	Si	Ru
Center (#2)	11	55	12	21
Boundary inside (#1-1)	21	49	10	19
Boundary outside (#1-2)	73	18	3	5
Reference	15	45	13	27

Exposure tool conditions

Pulse frequency (f) of EUV source: 10-100kHz
Pulse length (t): 10ns @ LPP, 100ns @ DPP
Duty ratio (t*f): 10^{-3} - 10^{-4}

SR(NewSUBARU) : 500MHz, Duty ratio≈1/60
Incident power @ same average: EUV source≈SRx(17-170)

Irradiation conditions of 6 mirror system (from S. Bajt)

P=DA/t

D: Resist sensitivity,

A: Wafer exposure area,

t: Exposure time.

D=5mJ/cm^2, A=707cm^2, t=36s (corresponding to 100/hr)
Based on a common tool model, real exposure time may be ≈ 9s.
The rest is consumed for alignment, stage overhead and etc.

Irradiation power on exposure tools (S. Bajt*) and translation to SR irradiation conditions.

mW/mm^2

	M1	M2	M3	M4	M5	M6
Average*	**0.18**	**0.087**	**0.11**	**0.01**	**0.075**	**0.003**
Incident**	**0.72**	**0.35**	**0.44**	**0.04**	**0.3**	**0.012**
SR average***	**12-120**	**6-60**	**7.5-75**	**0.7-7**	**5-50**	**0.2-2**

** x4

*** x(17-170)

Discussion

Adsorption of residual gas species:

$$d\sigma_i/dt = S_i\Gamma_i - \sigma_i/\tau_i - \eta_i P \quad (1)$$

σ_i: surface areal density of residual gas molecules (/cm^2)

S: sticking probability

Γ: arriving rate of residual gas molecules (/cm^2.s)

$$\Gamma = n_i v_{thi}/4$$

τ: mean residence time (s)

η: photon-induced desorption coefficient (molecules/photon)

P: EUV photon flux (/cm^2.s)

Since we obtained similar results when we introduced H_2O by 200times as well as hydrocarbons by 30 times, the ratio of adsorbed species appears to play a main role.

To physically understand what is happening, we describe

Carbon deposition: $C_{cd}P^{m}\sigma_{CH\,x}$

Carbon removal: $C_{cr}P^{n}\sigma_{H_2O}$

where C is each rate coefficient. The boundary we saw in experiment may given by:

Carbon deposition = Carbon removal

The fact is that carbon removal happens in larger P. Some nonlinear term has to be introduced.

As for temperature, since the thermal conductivity of Si substrate is so good, the distribution is flat near the boundary. Thermal recombination may have acted a certain role.

Summary

1. When hydrocarbons exist, Ru capping layer suffers slight oxidation and carbon deposition depending on EUV intensity.

2. Arriving rate of H_2O and CH_x species appears to play a major role, determining the ratio of adsorbed species on the surface.

3. Since surface reaction is power dependent, acceleration may be possible by a factor of duty ratio which is 17-170 in applying SR.

4. Assuming LPP, 10kHz, the tool highest condition corresponds to 120mW/mm^2 in SR being close to the present experiment.

5. The fact that reflectivity was kept over 99% in 3500 tool hours is significant. An issue is how we can keep this in wide range of irradiation.