Thermo-mechanical characteristics of EUV pellicle with particle contamination

HANYANG UNIVERSITY

Ha Neul Kim[1], Yong Ju Jang[2], Seong Ju Wi[1], and Jinho Ahn[1, 2*]

[1]Division of Materials Science and Engineering, [2]Division of Nanoscale Semiconductor Engineering,
Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea

INTRODUCTION

❑ Durability and reliability of EUV pellicle for EUVL HVM application

- Since cooling mechanism through heat conduction and convection is extremely limited, thermal properties of EUV pellicle has been a main issue with regard to a durability and reliability
- Localized heating of EUV pellicle w/ a microparticle can be occurred due to near-unity absorbance of the microparticle
- EUV pellicle should not be destroyed even after exposure to the contaminant, but there has been no report on the durability and reliability of the pellicle after contamination

	Item	Requirement
Pellicle material requirements	EUV transmittance	≥ 88% single pass
	EUV transmittance non-uniformity	≤ 0.4% half-range
	EUV reflectance	≤ 0.04%
	EUV power capability	≥ 300W @IF
	# of exposed wafers	10,000 wafers
	Particle printability lower limit	> 15 μm
Pellicle + frame requirements	Stand-off distance during expower	2.5 mm
	Max lateral acceleration	250 m/s^2
	Max vertical acceleration	400 m/s^2
	Max film deflection @2 Pa	0.7 mm
	Max added weight to reticle	15 gram

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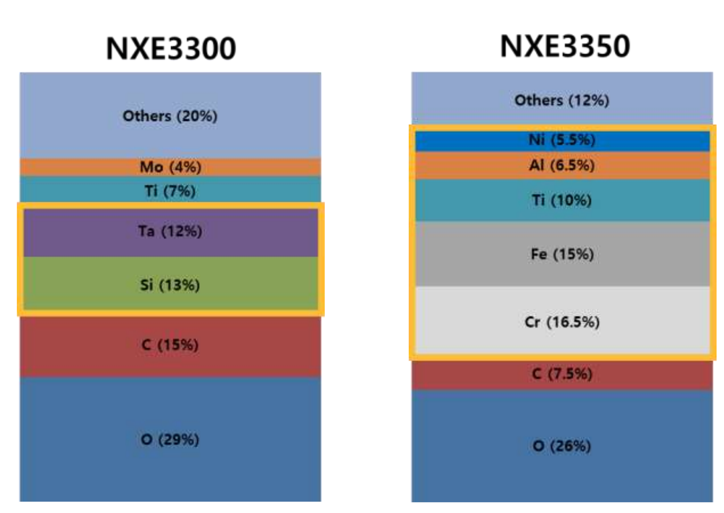
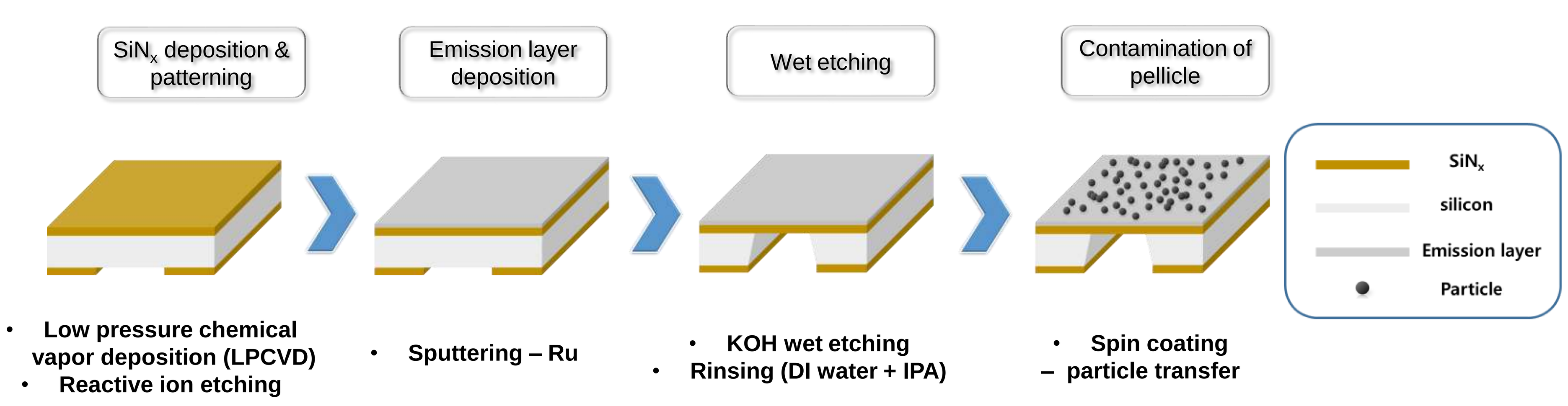
<EUV pellicle requirement>



<Contaminants in EUV scanner system>

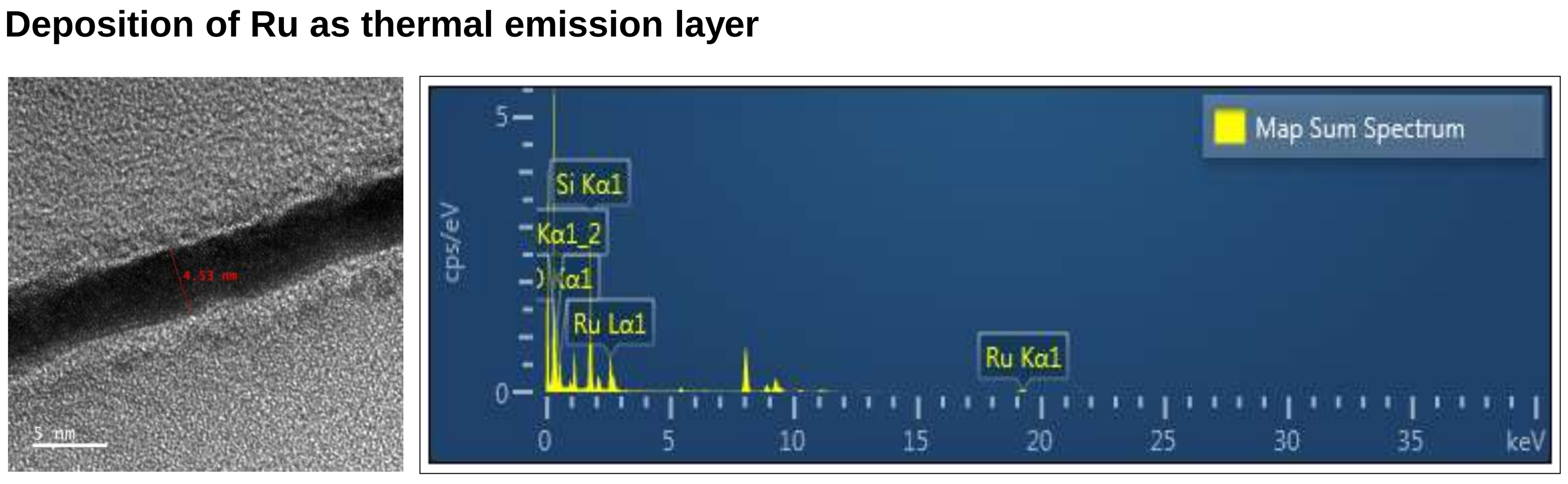
EXPERIMENT

❑ EUV pellicle fabrication and contamination



- SiN_x based pellicle composite was selected to evaluate effect of particle adders on pellicle during heat load test
- Particles were dispersed in IPA, and transferred to the EUV pellicle surface through spin coating
- 3 types of particles that mainly appear during EUV scanner system were used for contamination
  - ➢ Carbon, Ti, and Fe sphere particles (Average diameter ~ 10 μm)

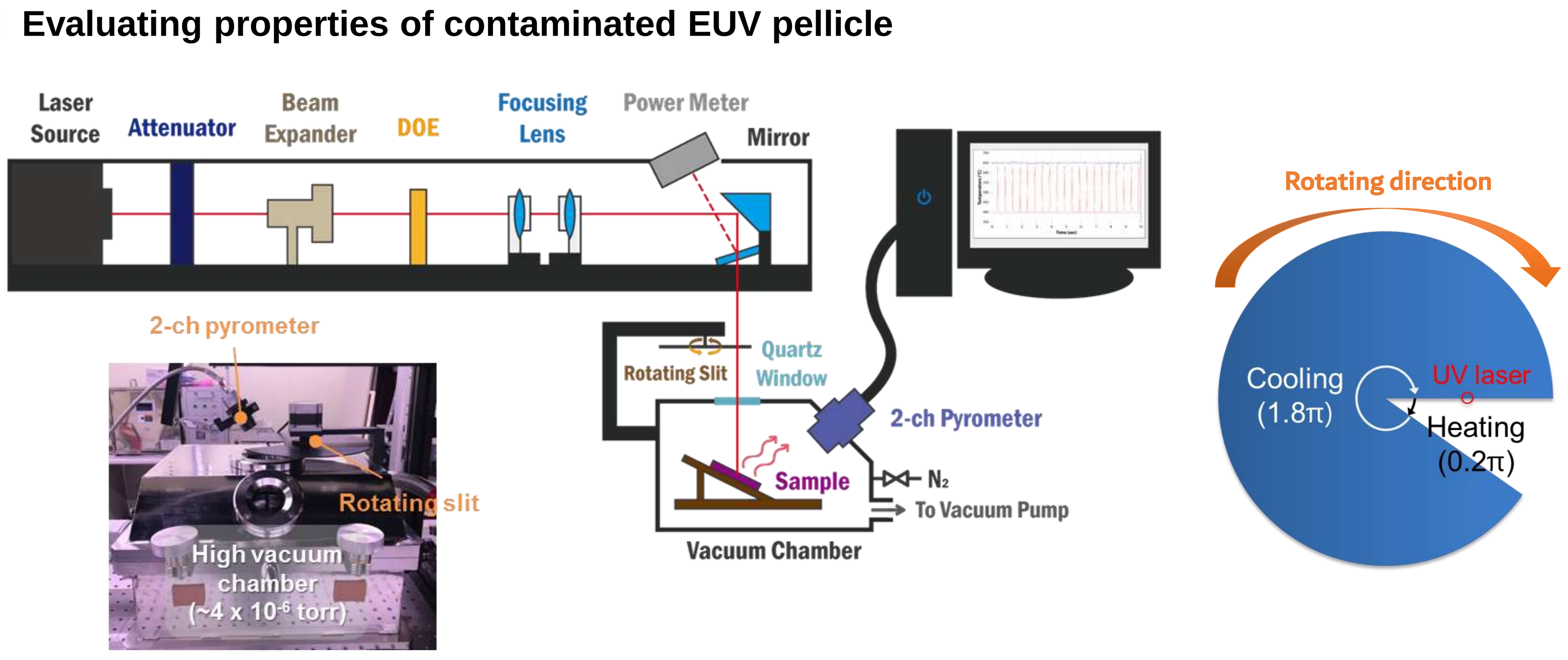
❑ Deposition of Ru as thermal emission layer



<Verifying thickness and composition of Ru layer by TEM and EDAX >

- Ru layer was deposited by DC/RF magnetron sputter under 100 W power, $<10^{-6}$ torr vacuum condition
- Thickness and composition of Ru layer were investigated by TEM and EDAX
  - ➢ Continuous thin film was formed when Ru thickness ≥ 4 nm

❑ Evaluating properties of contaminated EUV pellicle



<Overview and schematic of heat load test equipment with 355 nm UV laser>

$$\frac{P_{UV}}{D_{UV}} * A_{UV} = I_{abs}$$

I : absorbed heat load @ pellicle [W/cm²]
P : source power [W], D : beam size [cm²]
A : absorbance of pellicle membrane

Parameter	Value
Beam diameter	0.6 cm
Heating/cooling time	0.1 / 0.9 sec
Vacuum	〈 6×10^{-6} torr

<Heat load test condition>

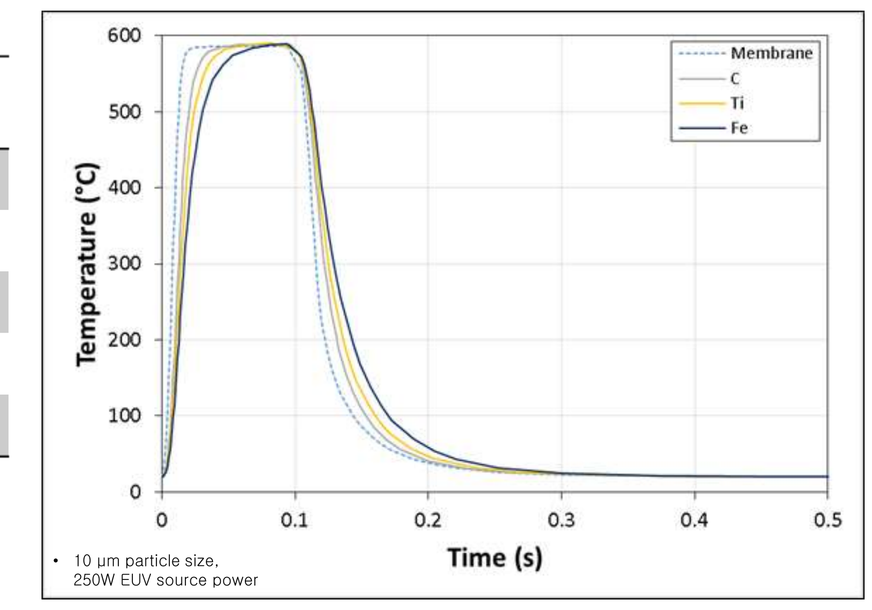
- Heat load of pellicle in EUV scanner can be emulated by UV laser considering absorbance of membrane, high vacuum chamber and rotating slit
- Thermo-mechanical characteristics of pellicle were evaluated by heat load test equipment with 1:9 on/off ratio using 355 nm UV laser

RESULTS & DISCUSSION – Finite element method simulation

❑ Simulation condition

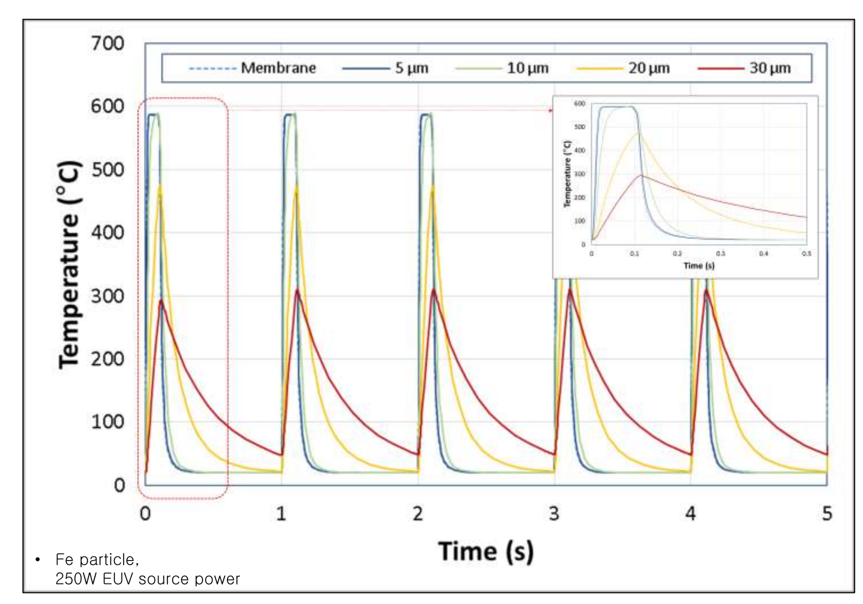
- Material properties of pellicle and particle species

Parameter	Density (kg/m^3)	Specific heat (J/kg·K)	Thermal conductivity (W/m·K)	Emissivity
SiN_x	3170	673	2.5	0.0035
Ru	12500	238	11.7	0.4
Ti	4510	544	21.9	0.70
Fe	7874	450	80.4	0.70
C	2267	734	96.0	0.95

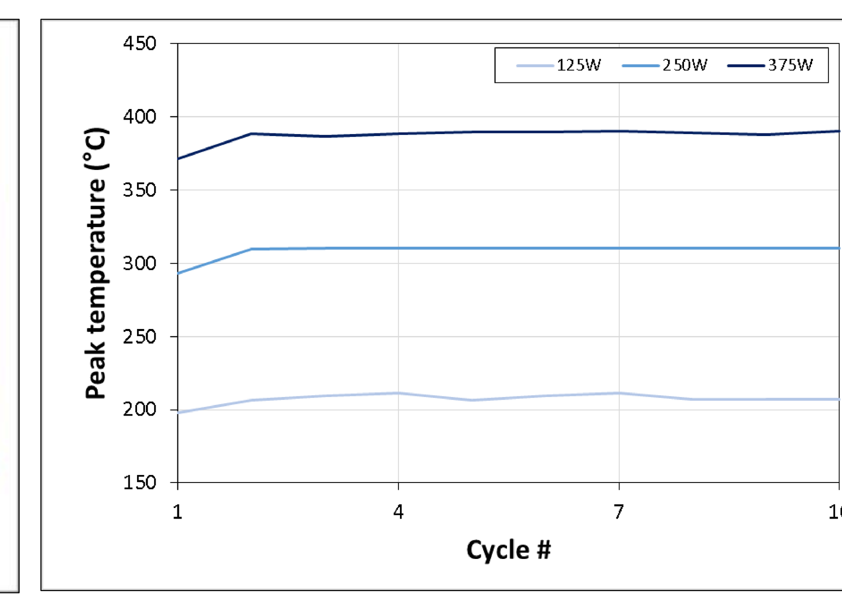


<Temperature distribution depending on particle species>

- Heat transfer simulation for the pellicle composite w/ single microparticle was performed based on heat load by EUV source power



<Temperature distribution depending on particle size>

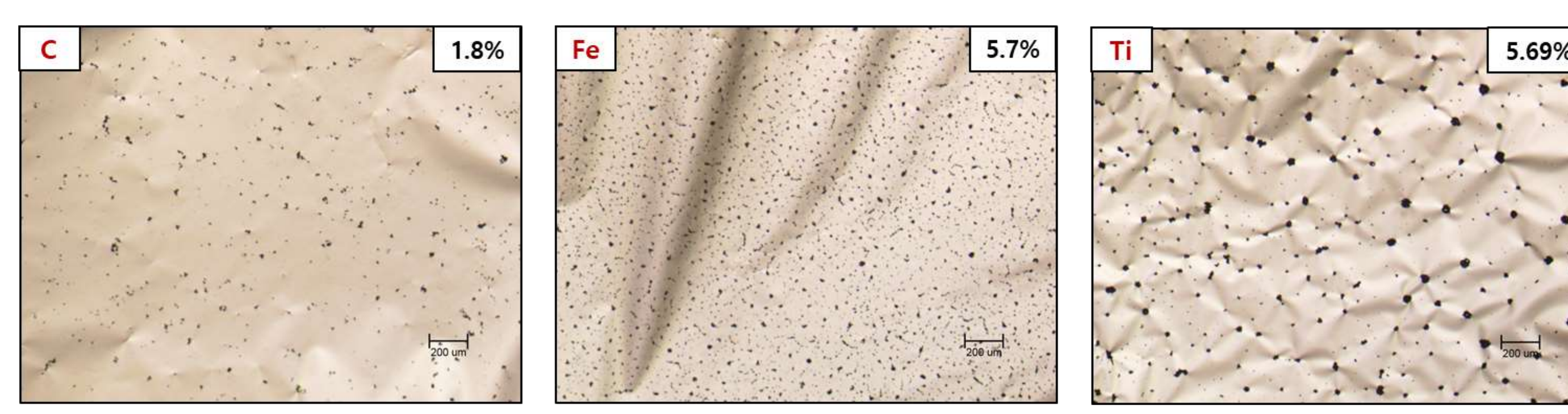


<Peak temperature of Fe particle w/ 30μm size>

- Heating/cooling rate was determined by heat capacity of the particle – density, specific heat, particle size
- Thermal durability of EUV pellicle with larger particle could be deteriorated due to additional thermal stress by temperature gradient between the pellicle and particles during heating/cooling process
- Peak temperature of particles depending on cycle number remained constant

RESULTS & DISCUSSION – Heat load test results

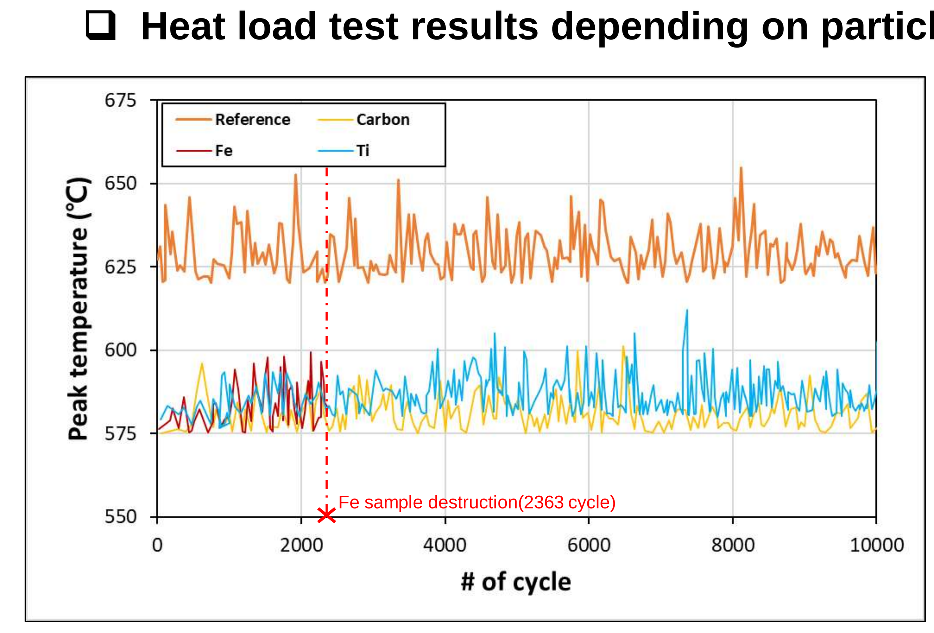
❑ Pellicle contamination

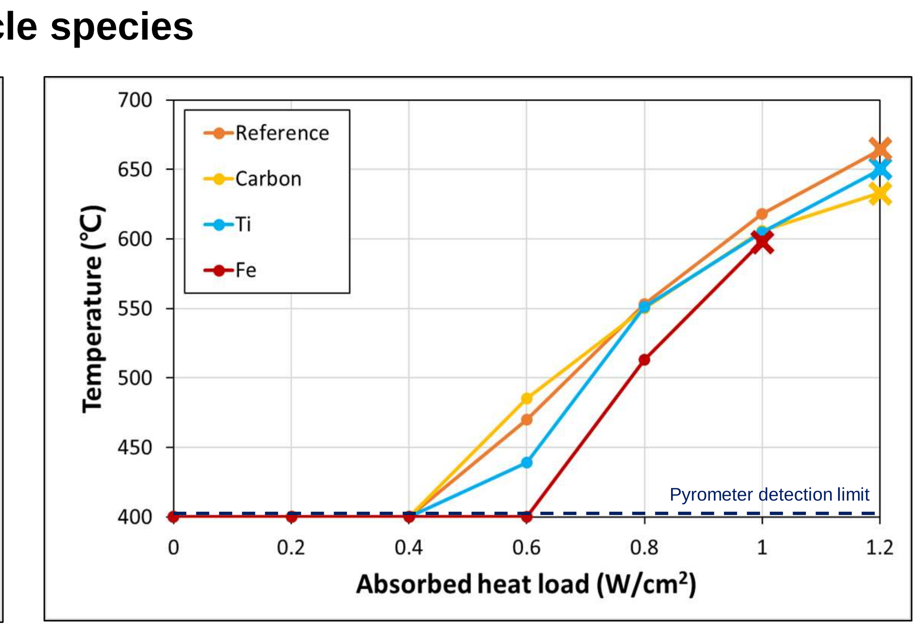


<Optical microscopy result of contaminated pellicle >

- The distribution of adders was observed by optical microscopy and occupied area of particle was investigated as 1.8% (C), 5.7% (Fe), 5.69% (Ti), respectively.
- In terms of adder size, C and Fe are similar size to 35 microns or less, but Ti was more aggregated so that particles having a maximum diameter of 65 microns were formed

❑ Heat load test results depending on particle species





<Heat load test results of contaminated pellicle depending on (right) cycle number (left) and absorbed heat load>

- Since the total heat capacity of the contaminated pellicle is small at the same area, temperature of the contaminated pellicles was measured lower
- Fe contaminated pellicle was destroyed at 2363 cycles, and the other pellicles were alive over 10,000 cycles at absorbed heat load of 1 W/cm^2
  - ➢ Fe particles have the worst effect on the thermo-mechanical properties of the pellicle considering temperature gradient at the simulation results

CONCLUSION

- Temperature gradient between the pellicle and particle adder during exposure process was determined by heat capacity of the particle adder
- Thermo-mechanical property of contaminated pellicles depending on particle species was confirmed
  - ➢ The thermal durability of pellicle was deteriorated by Fe particle adders
- Thermal stress analysis due to temperature gradient between the pellicle and the particle adder will be further performed