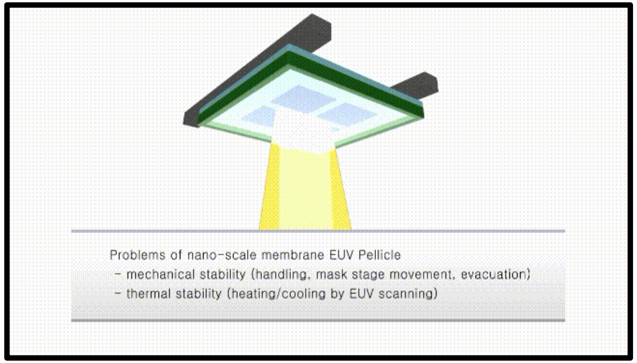
Characterization of SiN-based membrane for EUV pellicle application

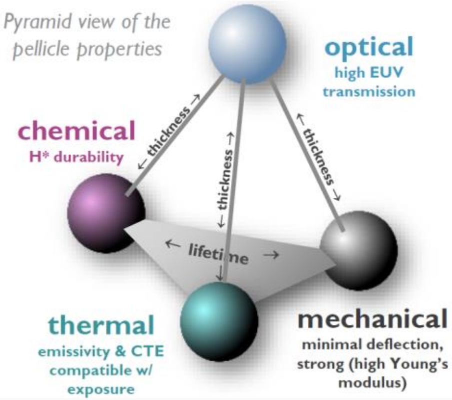
Junghwan Kim, Yongjoo Jang, Inseon Jung, Hyekeun Oh and Jinho Ahn
Hanyang University

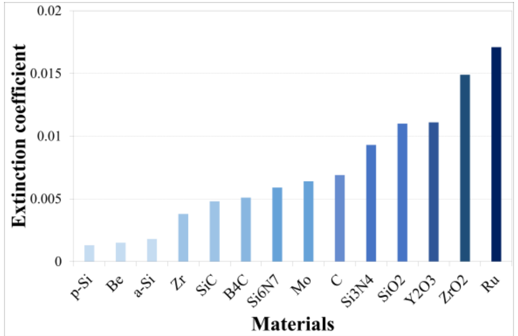
EUV Pellicle Requirements

Pellicle is a dust cover preventing particles and contaminates from falling on the mask.



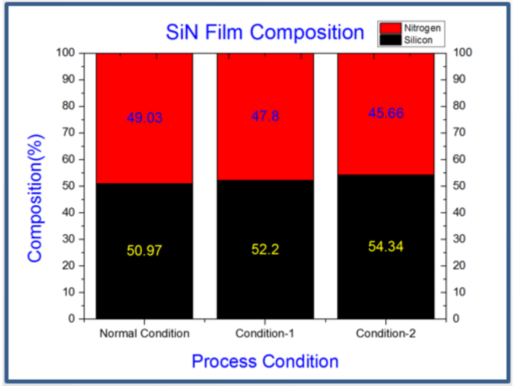
	Item	Requirement
Pellicle material requirements	Pellicle film EUV transmission	90% single pass (81% double pass)
	EUV transmission spatial non-uniformity	< 0.2% at reticle level
	EUV transmission angular non-uniformity	< 300 mrad max. local pellicle angle
	EUV intensity in scanning slit @ pellicle	5 W/cm^2 (250W EUV source equivalent)
	Lifetime	~315 hrs (production hours in a EUV+H_2 environment)
Pellicle + frame requirements	Standoff distance	2 ± 0.5 mm
	Max. acceleration	100 m/s^2 during scanning
	Max. ambient pressure rate of change	< 3.5 mbar/s (peak during pump-down/ vent in the load lock)
	Reticle reserved area for pellicle assembly (centered on substrate)	110.7 mm x 144.1 mm: inner 118.0 mm x 150.7 mm: outer
Pellicle impact on imaging performance: < 0.1 nm CDU impact on wafer		

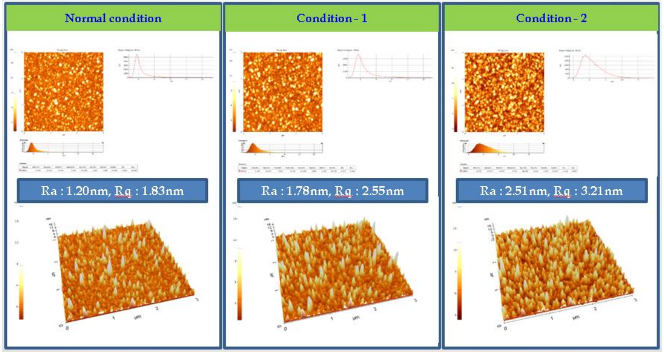


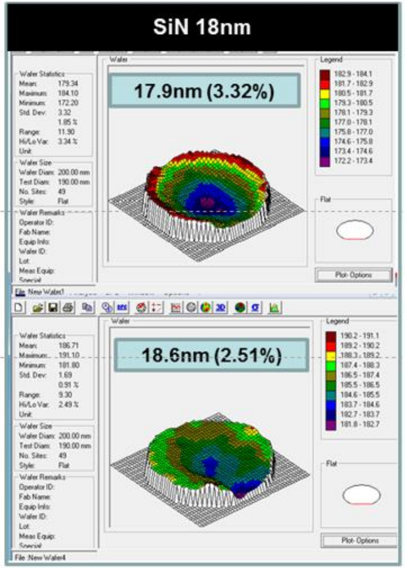


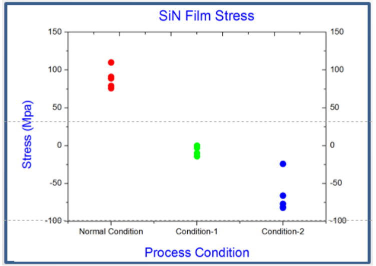
Ref. ASML, SPIE Advanced Lithography (2014) / IMEC (2017)

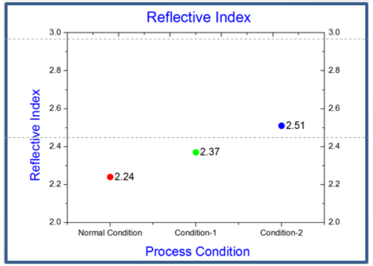
SiNx pellicle platform : Deposition

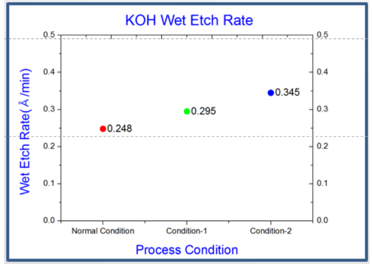






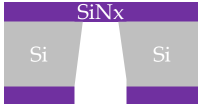
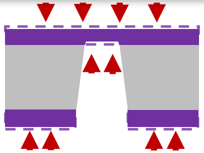
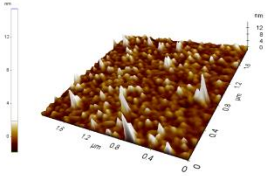
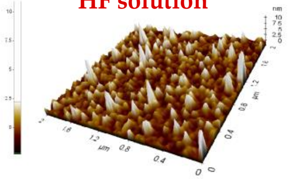






Atomically-smooth, uniform silicon-rich LPCVD SiNx
Stress controlled by Si:N ratio (tensile to compressive with increasing Si)

SiNx pellicle platform : Thinning Process

	SiNx pellicle	SiNx pellicle (thinning)
Schematic image		
AFM image		
Roughness (RMS)	1.0 nm	1.2 nm

	Measured
43 nm SiNx	79.7 %
28 nm SiNx	85.7%
16 nm SiNx	91.1 %

SiNx can be thinned with HF solution
Surface roughness is not much degraded

However, SiNx membrane shatters when broken due to brittleness !

Strengthening Solution

Grain Boundary Strengthening

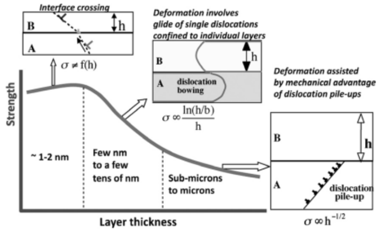
Materials with smaller grains shows higher yield strength

Hall-Petch Relation

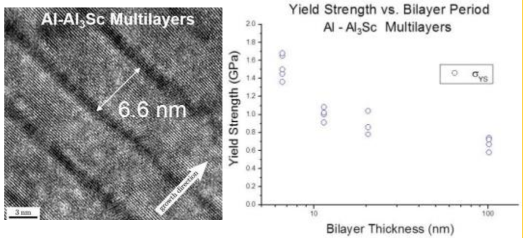
$$\sigma_{YS} = \sigma_0 + k_y \frac{1}{\sqrt{d}}$$

Nanoscale Multilayer

Multilayer is stronger than bulk material due to interface



Wang, Misra, *Curr. Opi. Sol. Sta. Mat. Sci.* 15 (2011)

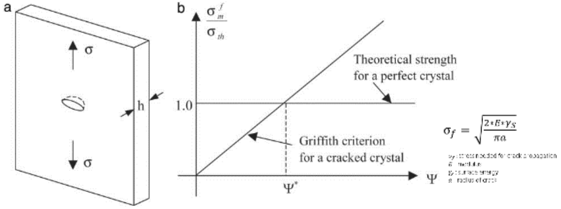


Han, Phillips, Nix, *Acta Mat.* 57 (2009)

At h =2–5 nm, experimental data exhibit maximum hardness.

Brittle to Ductile Transition

Fracture strength of brittle material is always lower than theoretical strength (crack propagation: Griffth)



Crack propagation depends the sample thickness (the thinner the tougher).

$$\sigma_m^f = \alpha E_m \Psi, \qquad \Psi = \sqrt{\frac{\gamma}{E_m h}}$$

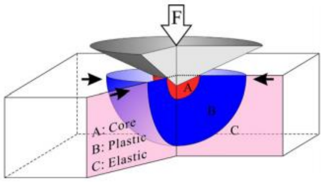
Critical thickness below which the fracture strength of cracked material is identical to that of perfect material.

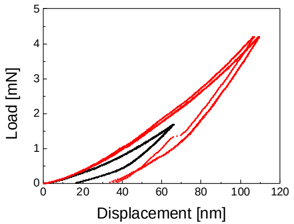
$$h^* \approx \alpha^2 \frac{\gamma E_m}{\sigma_{th}^2}$$

For SiNx case, h* ~ 40nm

Mechanical property characterization

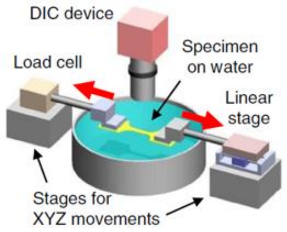
Nano Indentation

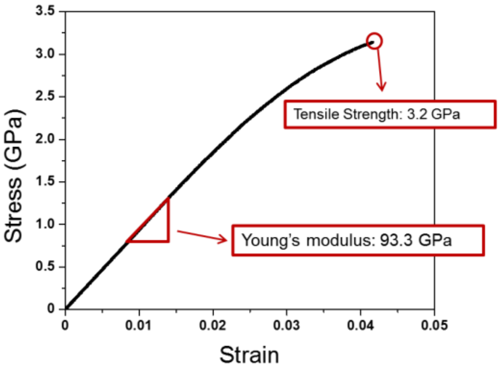




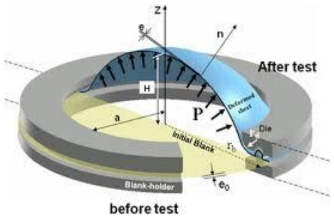
Material	Thickness	Hardness (Thin Film)
SiN_x	50nm	21.8 ± 0.42 GPa
	100nm	29.2 ± 0.05 GPa

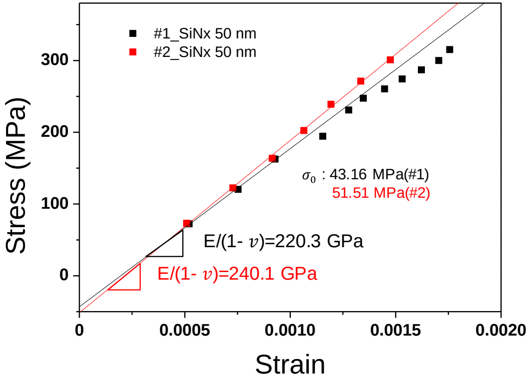
Tensile Test (in-situ SEM)



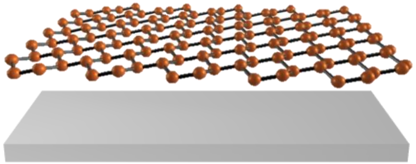


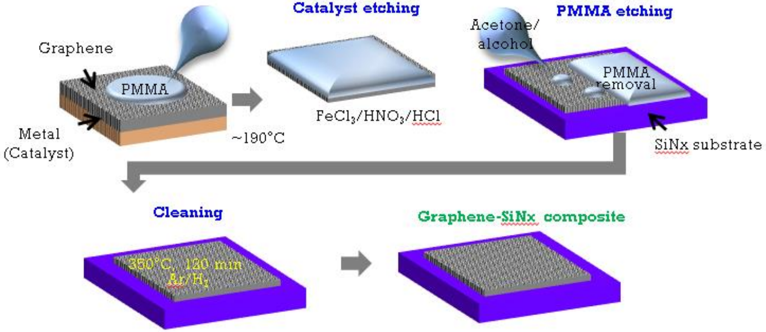
Bulge Test



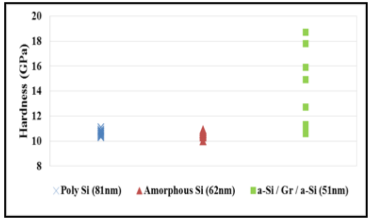


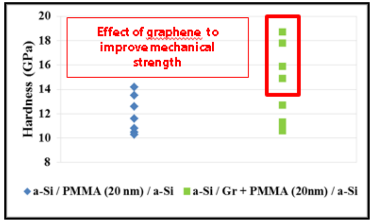
Graphene Composite : Strengthening

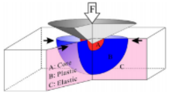




Strengthening effect by Graphene



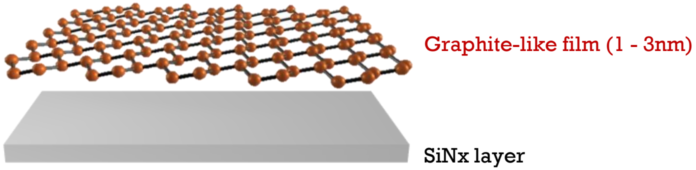




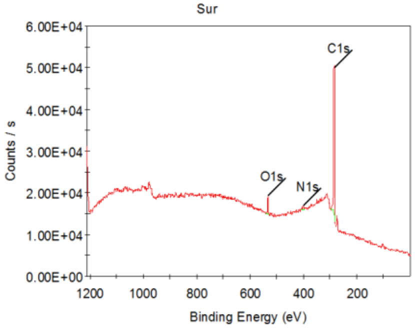
EUV absorbance of graphene ~ 0.2%/monolayer (vs. ~3% @ visible wavelength)
High possibility of composite structure with reinforcing effect of graphene
But PMMA, the material used for graphene transfer, leaves residue.

Graphite-like film using Plasma CVD

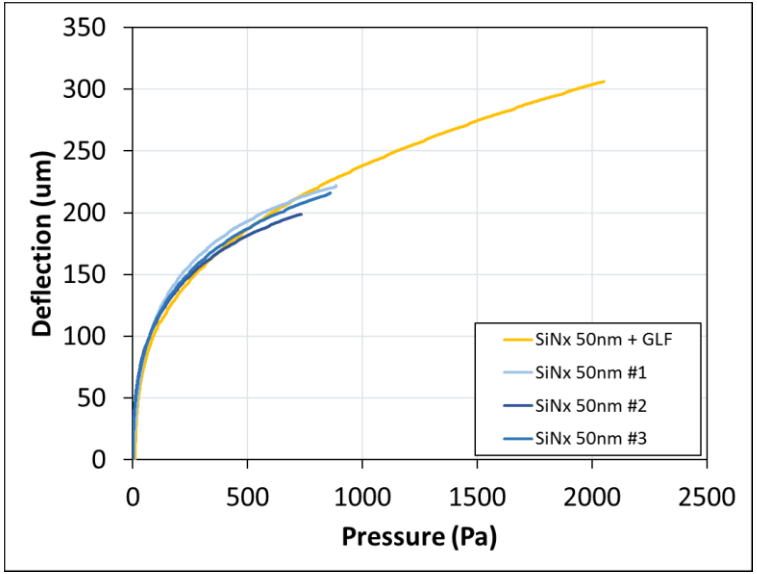
Concept



Film composition: almost carbon



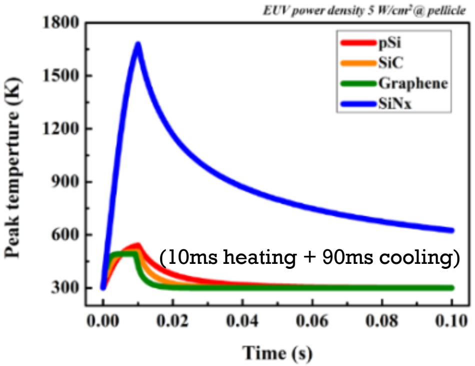
Bulge test



Nano-scale graphite film can be directly deposited on any substrate.
This composite structure shows >3X fracture strength.
Optimization will result in more improved mechanical property.

Thermal Load Simulation

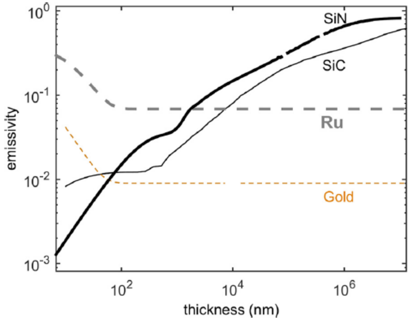
Emission is the only cooling mechanism of EUV pellicle (no conduction/ no convection)

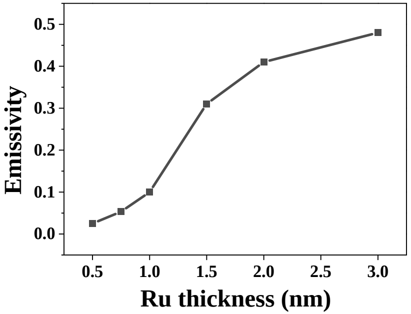


Material	Peak temperature [K]	Emissivity
pSi	541.71	0.5
SiC	505.15	0.75
Graphene	492.29	0.85
SiN_x	1678.5	0.0035

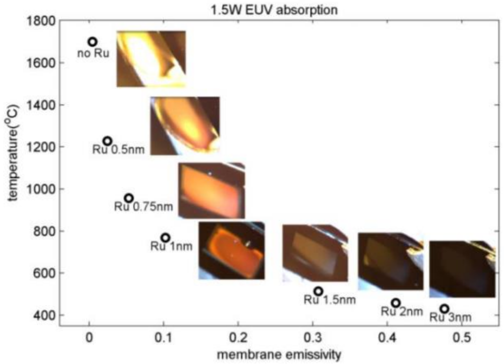
High emissivity material shows low peak temperature
Note: with bulk emissivity (not thin film emissivity)
with same thickness (not same transmittance)

Emissivity depends on the thickness !!



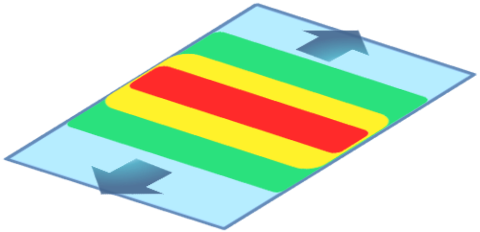


Thin metallic coating (~nm) enhances emission



Ref. P. J. van Zwol et.al., J. Appl. Phy., 118(21), 211307 (2013).

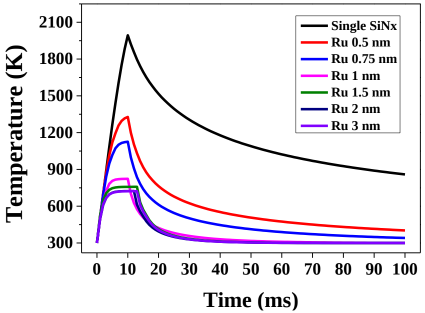
Thermal Stress

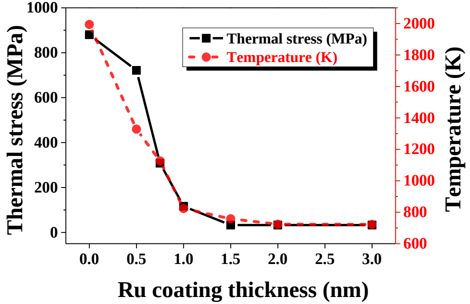


Single film thermal stress equation
(for edge clamped case)

$$\sigma = \frac{1}{2} \cdot E \cdot \alpha \cdot \Delta T$$

Ru coating enhances emission and decreases thermal stress

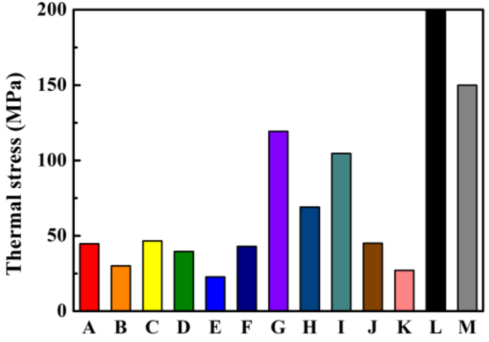




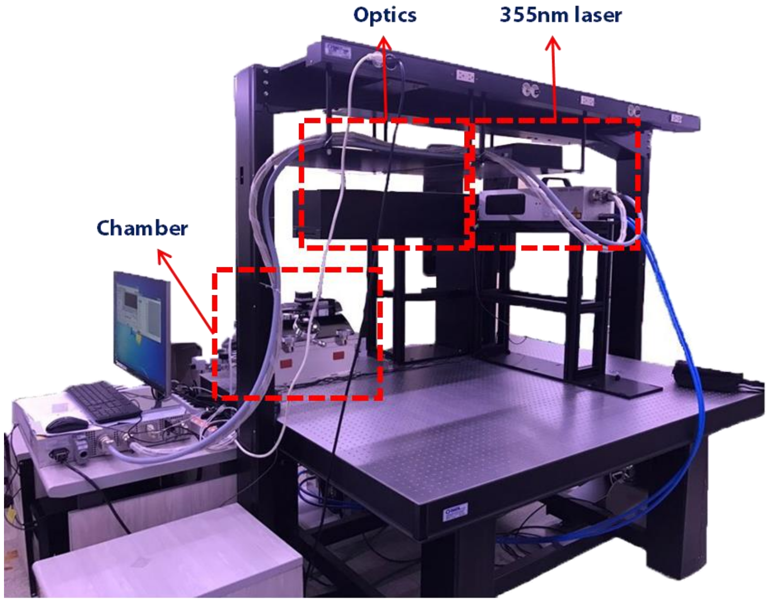
Emission layer candidates: B_4C as well as Ru

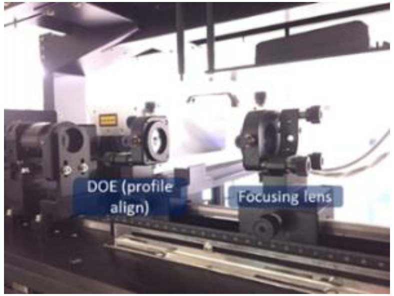
A	Ru	1 *nm*
	SiNx	8 *nm*
	Ru	1 *nm*
B	B_4C	1 *nm*
	SiNx	11 *nm*
	B_4C	*nm*
C	B_4C	4 *nm*
	SiNx	7 *nm*
	B_4C	4 *nm*
D	Ru	1 *nm*
	Carbon	11 *nm*
	Ru	1 *nm*
E	B_4C	1 *nm*
	Carbon	14 *nm*
	B_4C	1 *nm*
F	B_4C	4 *nm*
	Carbon	10 *nm*
	B_4C	4 *nm*
G	Ru	1 *nm*
	Carbon	12 *nm*
	SiNx	1 *nm*
H	B_4C	1 *nm*
	Carbon	14 *nm*
	SiNx	1 *nm*
I	B_4C	4 *nm*
	Carbon	8 *nm*
	SiNx	4 *nm*
J	Ru	1 *nm*
	SiNx	5 *nm*
	Carbon	5 *nm*
	Ru	1 *nm*
K	B_4C	1 *nm*
	SiNx	7 *nm*
	Carbon	5 *nm*
	B_4C	1 *nm*
L	ASML pellicle	
M	SAMSUNG pellicle	

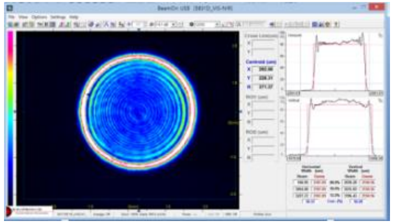
* EUV transmittance 90 %

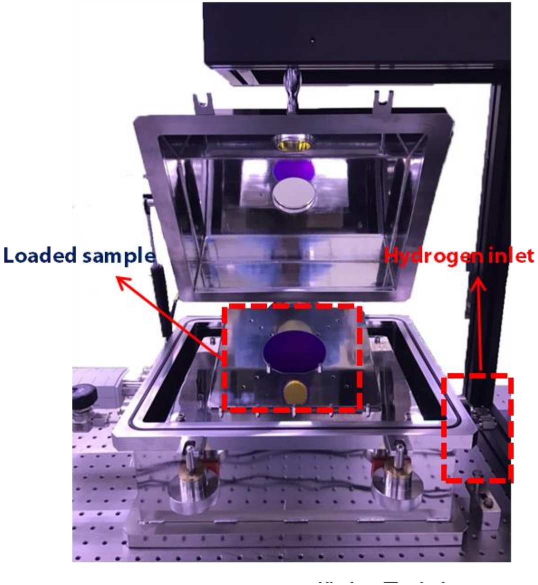


Thermal Load Test Platform





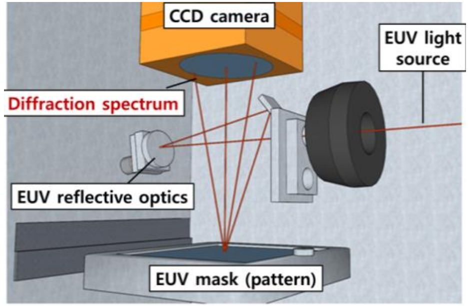


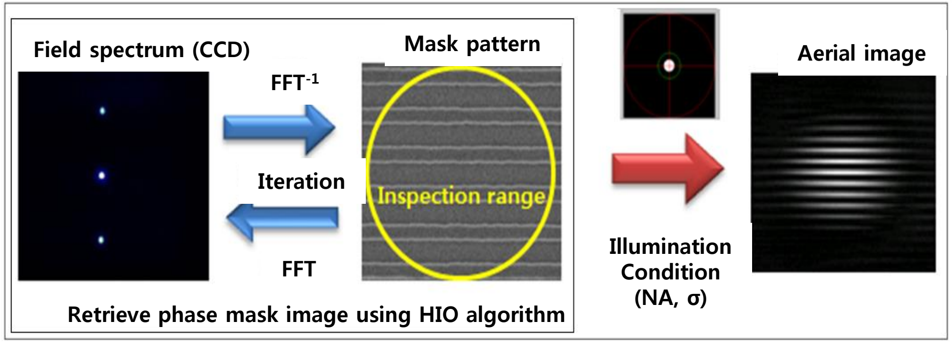


Thermal fatigue is an affliction occurring from sudden and repeated variations in the temperature of materials. The degree of damage is affected by the magnitude and frequency of the temperature swings. Damage comes in the form of cracking usually initiated on the surface and propagate through the material unless stopped until eventually causing structural failure.

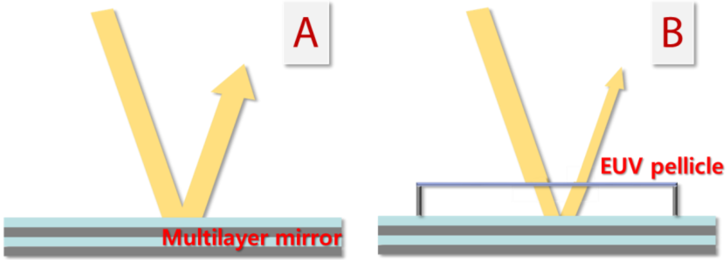
Optical Characterization

CSM (Coherent Scattering Microscope)



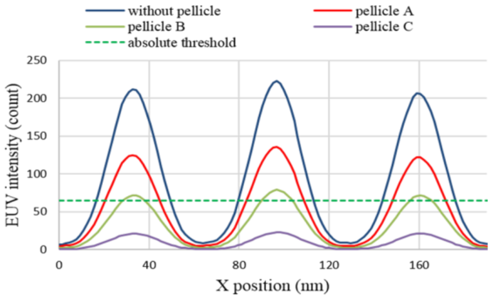


Evaluation set-up : Transmittance and Imaging Properties

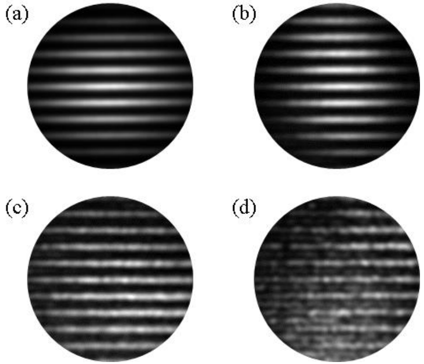


$$\text{one-pass EUV transmittance of pellicle} = \sqrt{\frac{B}{A}}$$

Optical Characterization

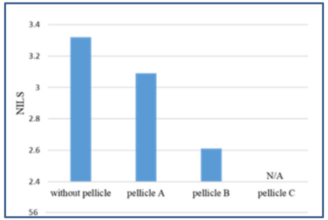


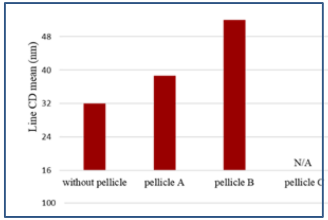
<Intensity profile of aerial image >

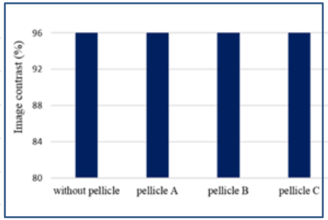


<Reconstructed aerial image>

Pellicle	A	B	C
Thickness (nm)	43	93	175
Transmittance (%)	78	60	30





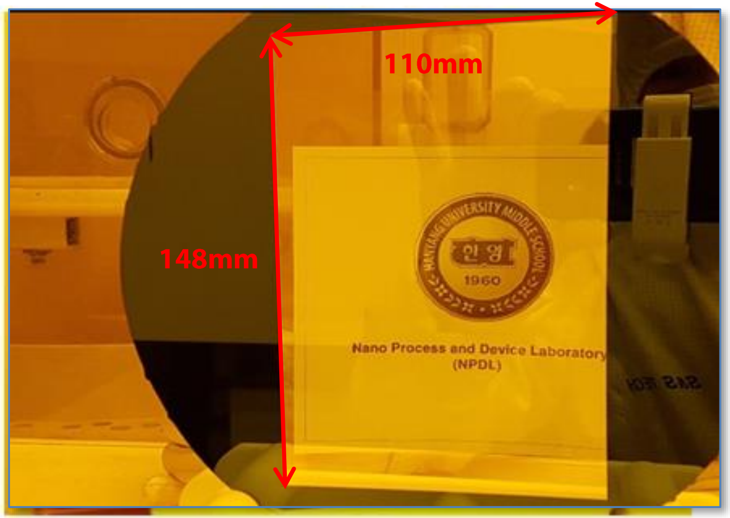


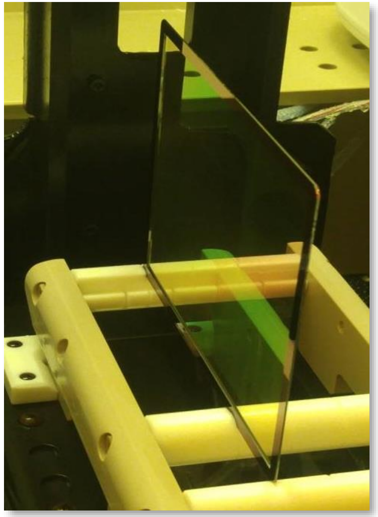
Line CD increased (+20.7%) and NILS decreased (-7.4%) with 78% transmittance pellicle by photon absorption

Although CD can be compensated by extending exposure time, high transmittance pellicle is desirable considering the throughput

Pellicle uniformity & local contamination control are more important for CDU

Full size SiNx pellicle platform





Membrane material : SiN_x

Membrane thickness : ~40 nm

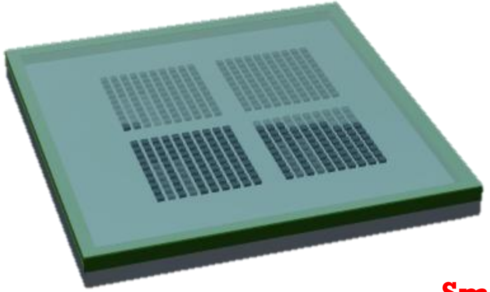
EUV transmittance : ~80%

Membrane size : 110 x 148 mm^2 (Full-size)

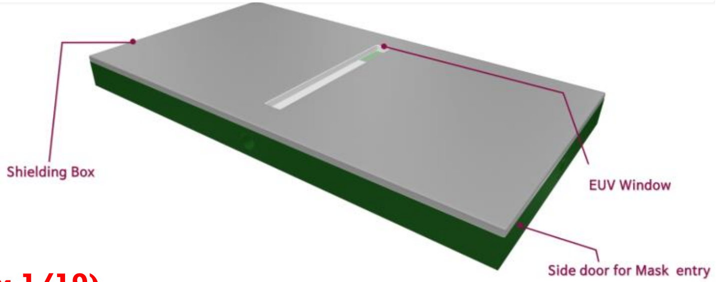
If pellicle solution is not available ……

Shielded Reticle Mini Environment (SRME)

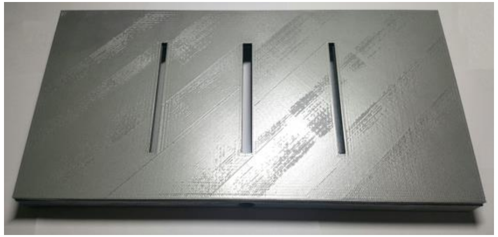
EUV Pellicle

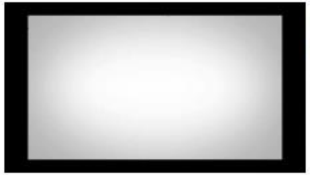


SRME



Small area membrane (x 1/19)
No risk of mechanical shock (No movement)
No repeated heating/ cooling (No fatigue)





Shielded Reticle Mini Environment(SRME)-EUV Pellicle, EUV 펠리클
HYU kim
1개월 전 • 조회수 54회
Alternative method for EUV Pellicle!!

Thank you for your attention