Properties and performance of EUVL pellicle membranes

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Outline

Introduction

Transmission and process methods

Thermal considerations and carbon nanomaterials

Summary

Measurement methods explained in Ivan Pollentier's poster P-MP-06 "Optical testing of EUV pellicle materials"

Pellicle perspective - EUV

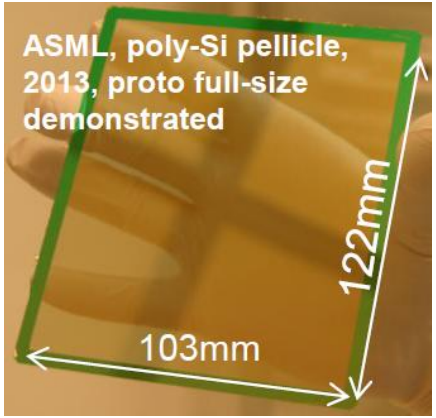
Most materials absorb strongly at 13.5nm

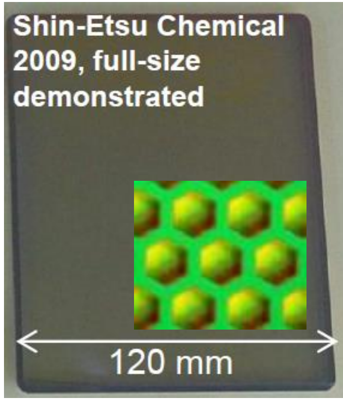
- DUV polymer pellicles have >99% transmission; this is not possible
- Developing an EUVL pellicle is difficult

Initial solutions exists

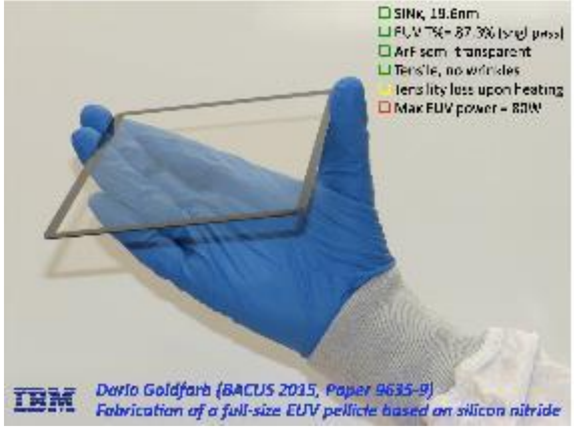
- Si based: free standing and grid-supported
- SiN based: free standing

imec is developing **alternative** membrane materials that meet or exceed ASML specifications*





F. Dhalluin et al., "Grid-supported EUV pellicles: A theoretical investigation for added value," Proc. SPIE 9658, Photomask Japan 2015



Pellicle requirements

High EUV transmission: 90% single-pass

- Uniform → optical variations minimized

Tensile intrinsic stress

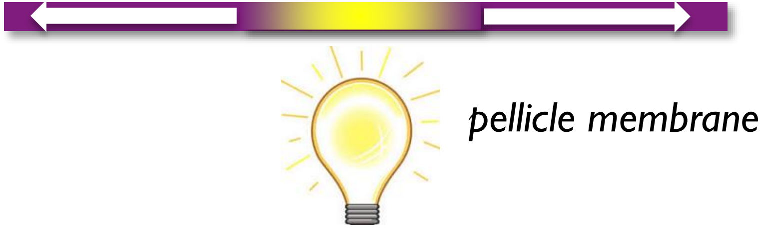
- No wrinkles
- Unchanged by handling, pump-down, shipping

Lifetime

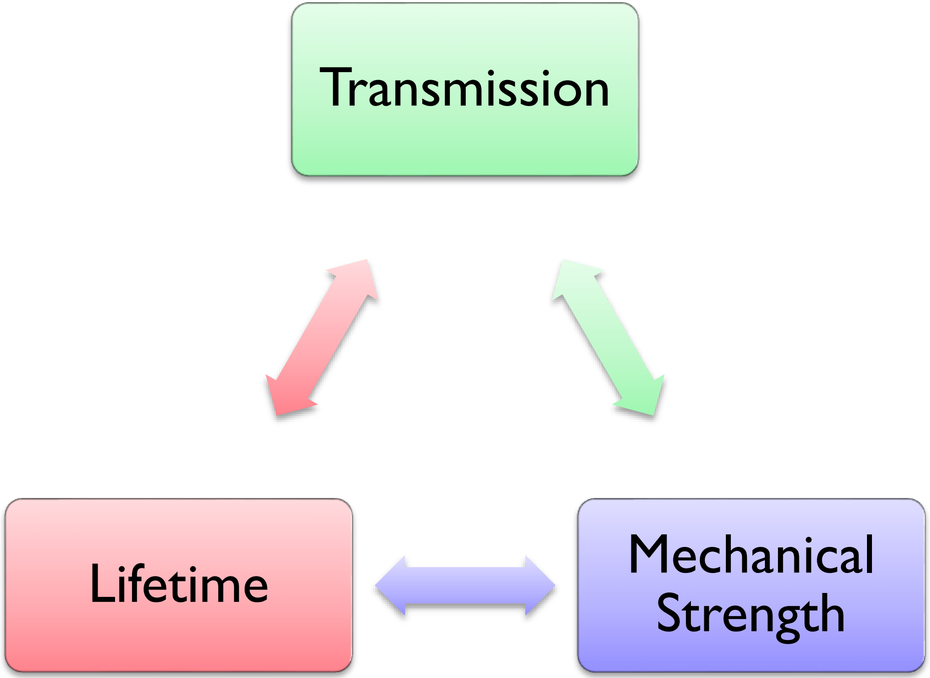
- No change during exposure to EUV light & H*

* C. Zoldesi, et al., "Progress on EUV pellicle development," Proc. SPIE 9048 (17 April 2014)

	Pellicle Requirement	HVM Value*
membrane	EUV transmission	90% single pass
	EUV T spatial non-uniformity	< 0.2%
	EUV T angular non-uniformity	<300 mrad angle @ pell.
	Withstand dynamic heat load	5 W/cm2 incident EUV
	Lifetime EUV+H2	3 Pa > 315 hours
with frame	2D size inner	110.7 x 144.1 mm2
	2D size outer	117 x 151 mm2
	Stand-off distance	2.5 +/- 0.5 mm
	Max acceleration	100 m/s2
	Max ambient pressure change	< 350 Pa/s



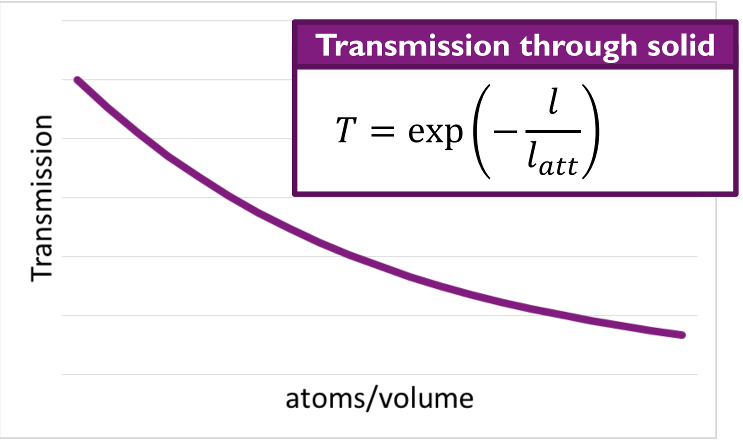
EUV Pellicle triangle?



General approach to EUV pellicle development

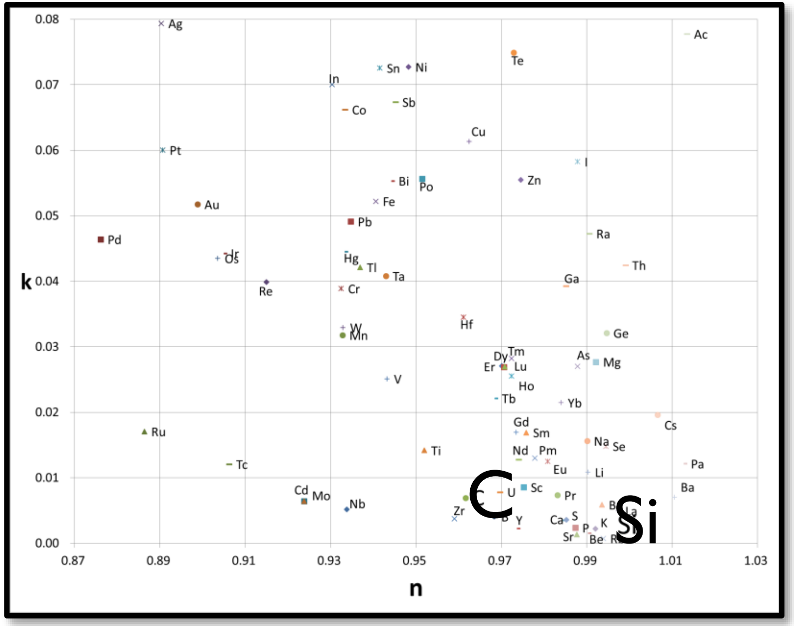
To reduce absorption (increase transmission)

1. Choose the appropriate materials: n ~1 and low k
2. Reduce number of atoms



Transmission through solid

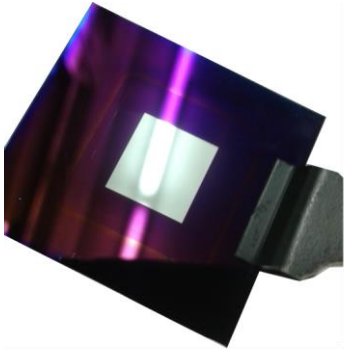
$$T = \exp\left(-\frac{l}{l_{att}}\right)$$



Strategies to reduce absorption

Thin films

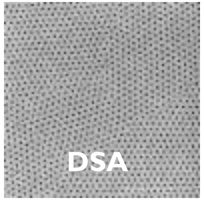
Start with low-absorption films and thin



Induce voids in continuous films

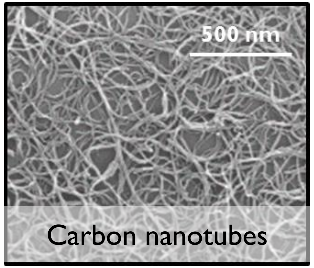
Etch into continuous film

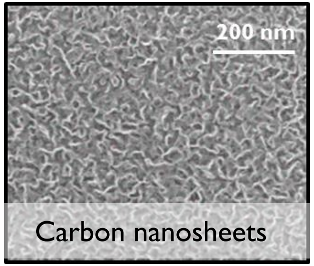
- DSA pattern
- Porous hard mask

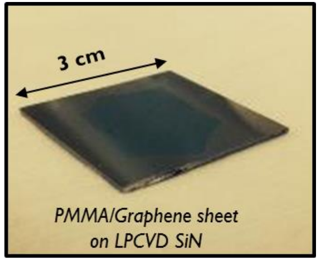


Deposit materials with inherent voids

Carbon-based nanomaterials







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Wafer-based process flow

(1) Wafer with SiN on front and back internal LPCVD SiN deposition

(2) Deposit protective layer on front (SiO_2)

(3) Flip; coat resist on back

(4) Pattern window in resist (different sizes possible)

(5) Dry Etch SiN; strip resist

(6) Flip wafer; wet etch SiO_2 (HF)

Lab processes

(7) Deposit membrane material

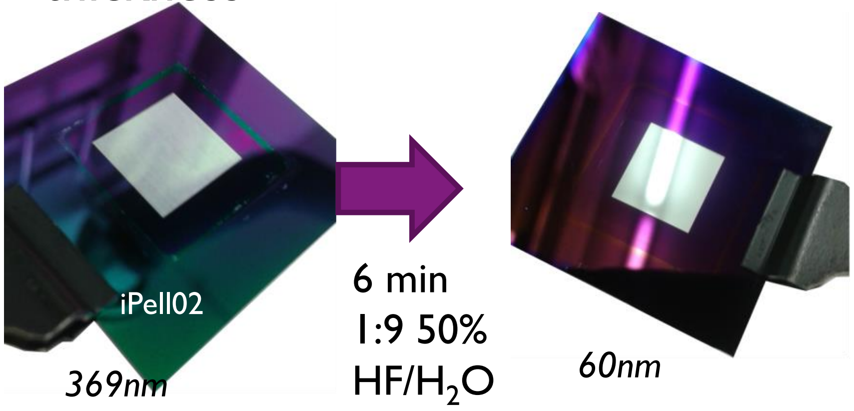
(8) Backside Si wafer etch (KOH)

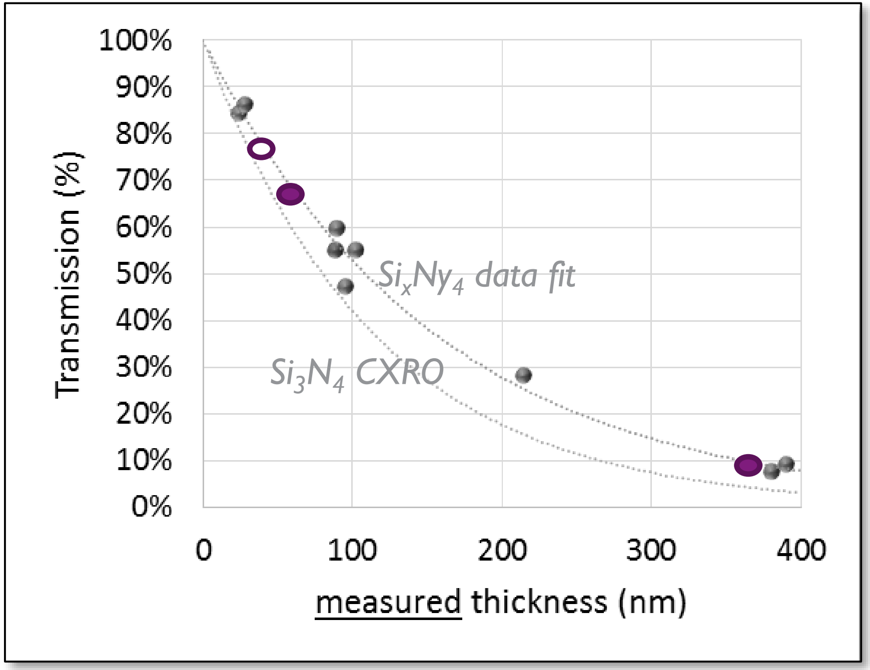
(9) Wet etch SiN layer

Thinned Si_xN_y film

SiN can have many roles: substrate (sacrificial), pellicle membrane or part of composite membrane

SiN can be thinned from as-deposited thickness





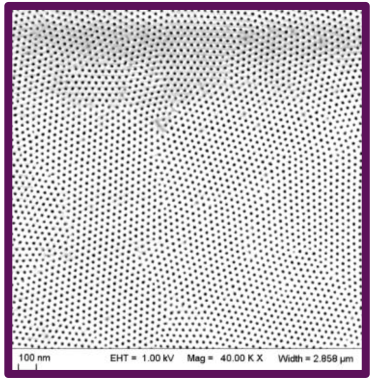
Note: External and internal films graphed; stoichiometry varies in the sample set

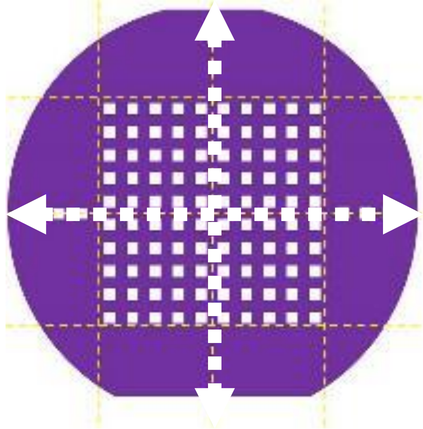
DSA-patterned membrane: plan

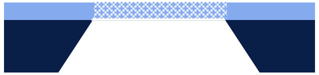
Leverage cylinder polymer DSA used for photolithography with tunable pitch

Methodology for initial test:

- Wafer with SiN membrane windows ~100nm thick
- Coat wafer with block copolymer PS-b PMMA
- Cleave into pieces for etch
- Strip PMMA







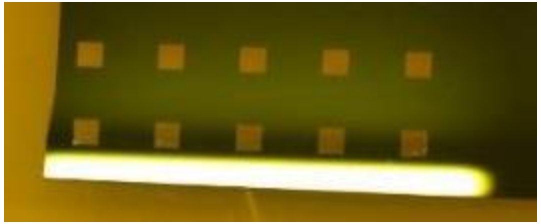
(10) After DSA etch and strip
Etched SixNy membrane

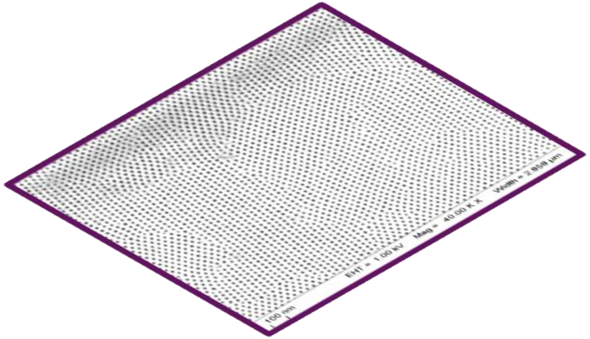
DSA-patterned membrane: images

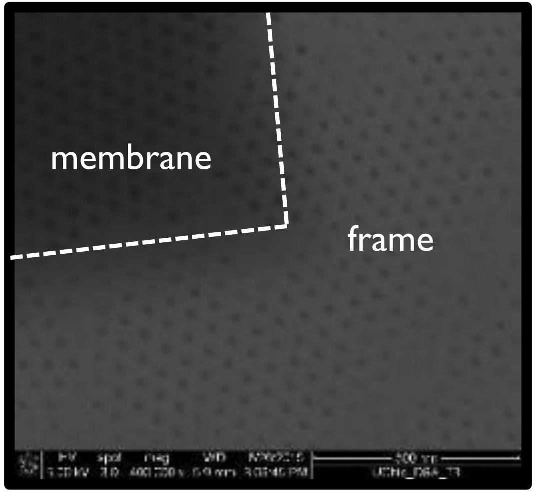
Membrane windows visually intact

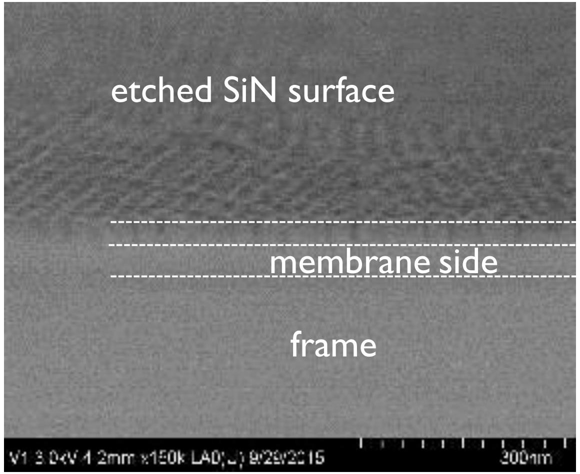
Top down SEM shows etched pattern mimics DSA pattern

X-section shows partial removal of top layer





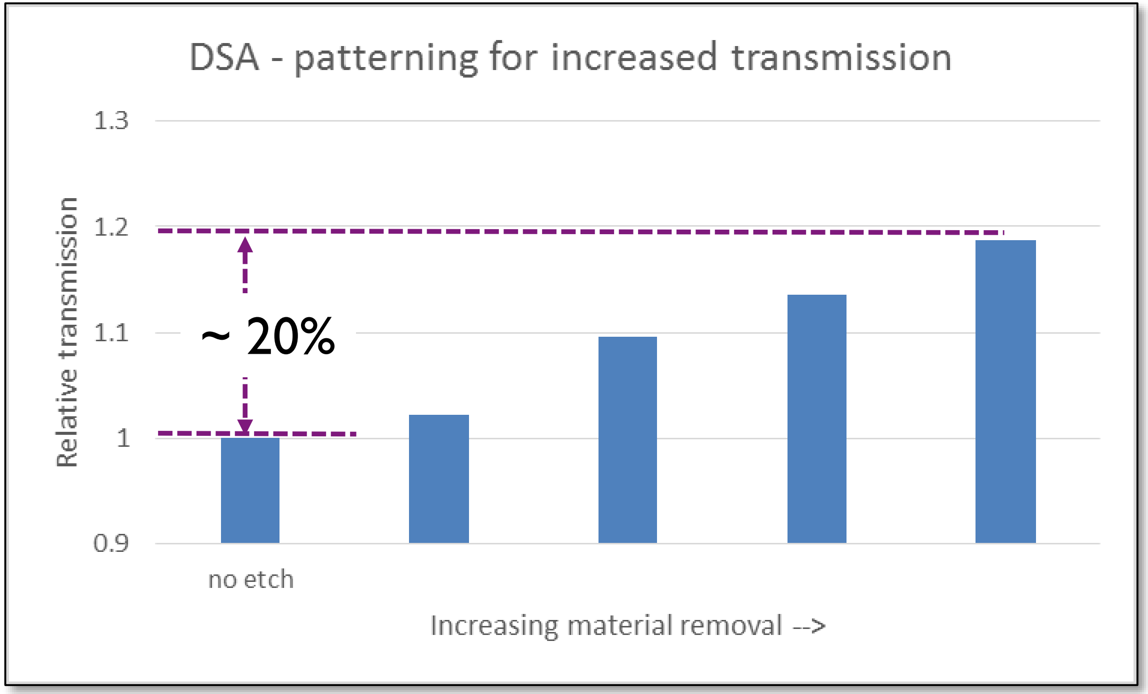




DSA-patterned membrane: results

Initial results show enhanced transmission

Next: systematic study (vary DSA pitch, thickness, etc.) to study mechanical strength and scattering



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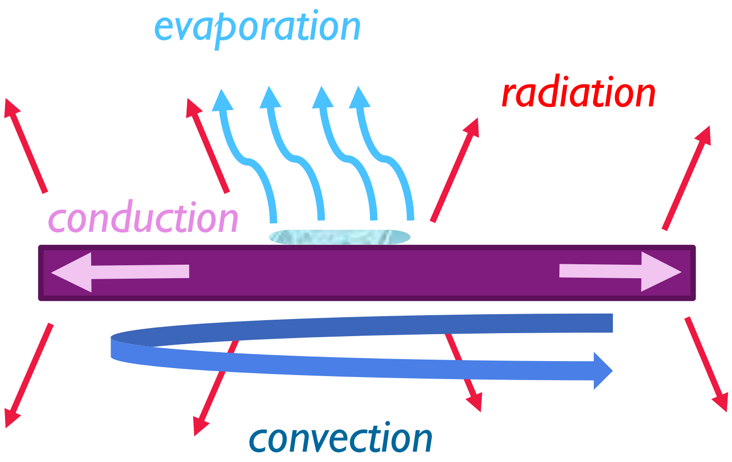
Heat : transfer options for pellicle membrane

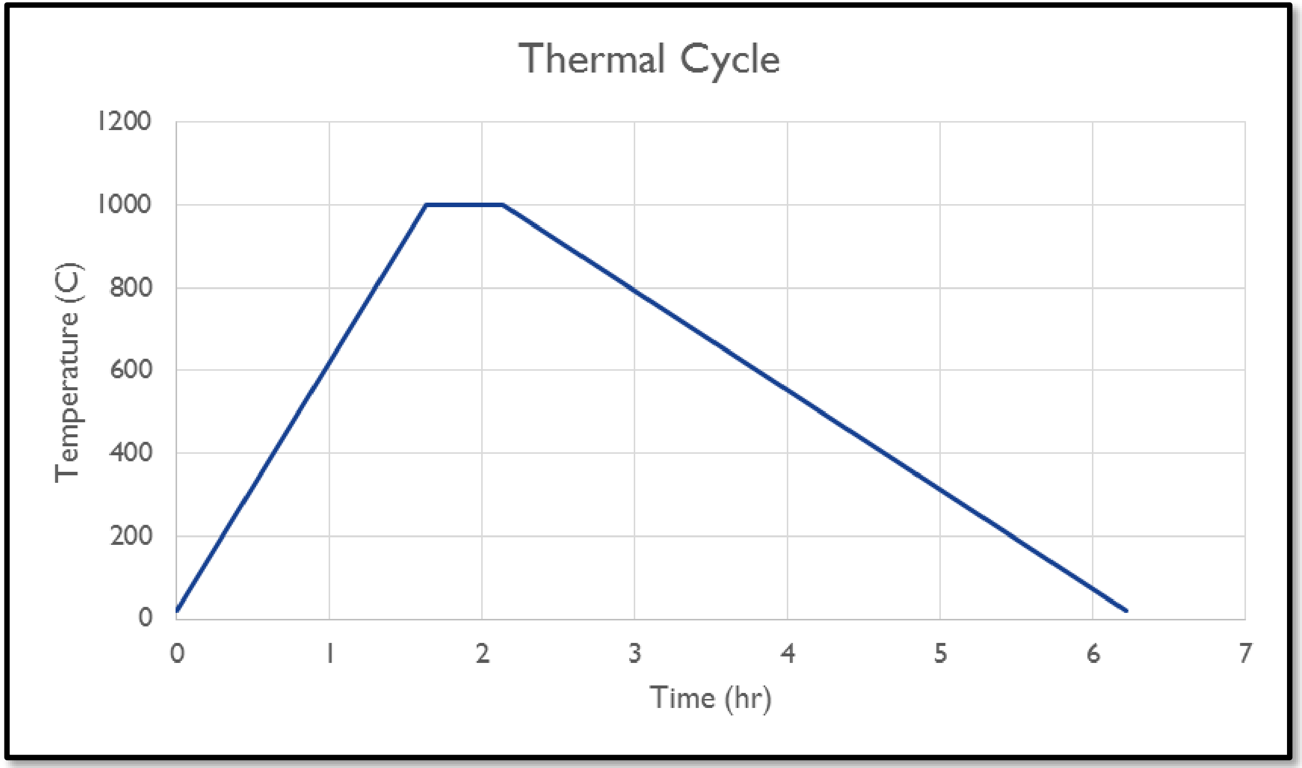
- Vacuum prevents: evaporation, convection
- Conduction is very limited in thin films
- **Only option is radiation**
  - Depends on material emissivity
  - Test must be developed



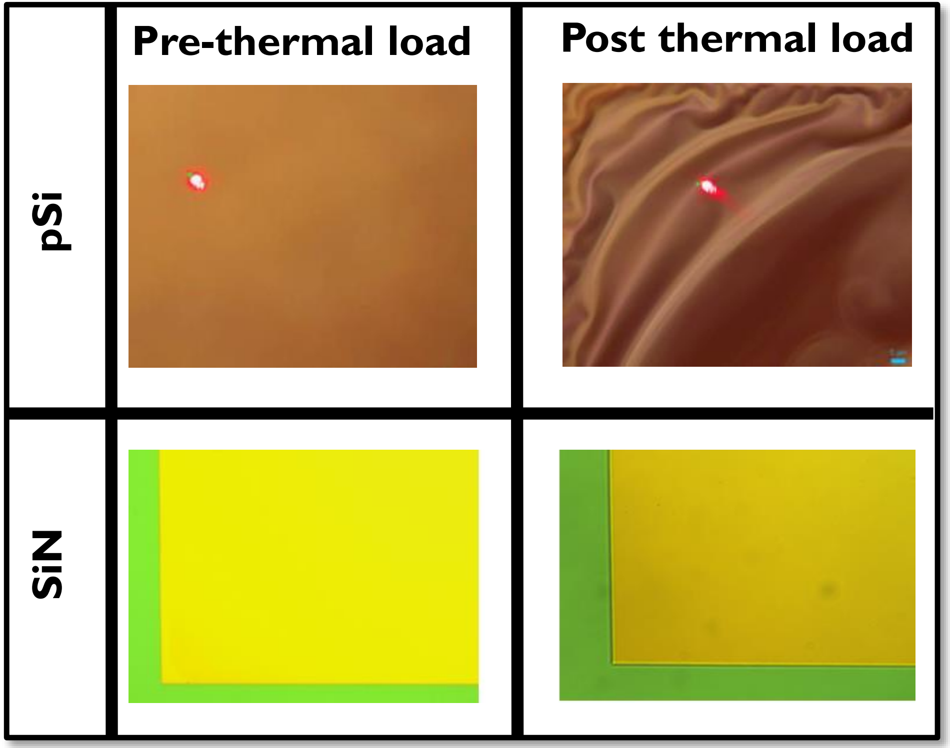
Heating : furnace cycle

Furnace heating in argon environment

May not be matched to EUV heating, but accessible method to add visibility to lifetime concerns



Heating results : microscope images



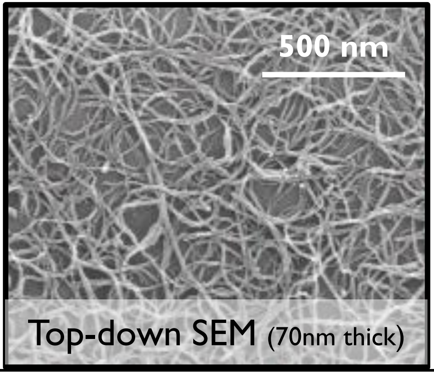
Visible change in polysilicon

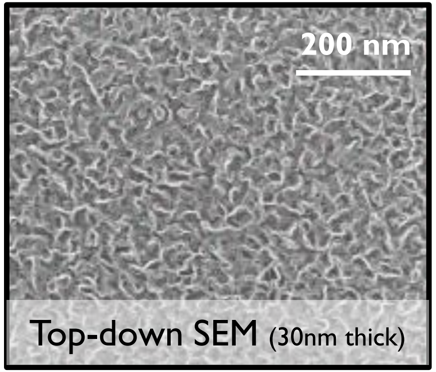
No change in SiN

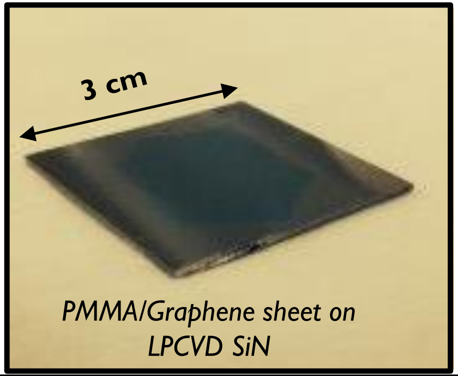
Good screening test, but must correlate heat cycle to realistic to EUV heating

Carbon nanomaterials

All have desirable thermal properties and can be very thin







	Carbon nanotubes CNT (in collaboration w/ university)	**Carbon nanosheets CNS (imec)**	**Graphene (imec)**
+	Lowest density	Grow on any surface, no catalyst	Uniform thickness
-	Impurities and optical uniformity tbd	Density higher than CNT, dangling bonds	Transfer and scaling to full size will be difficult

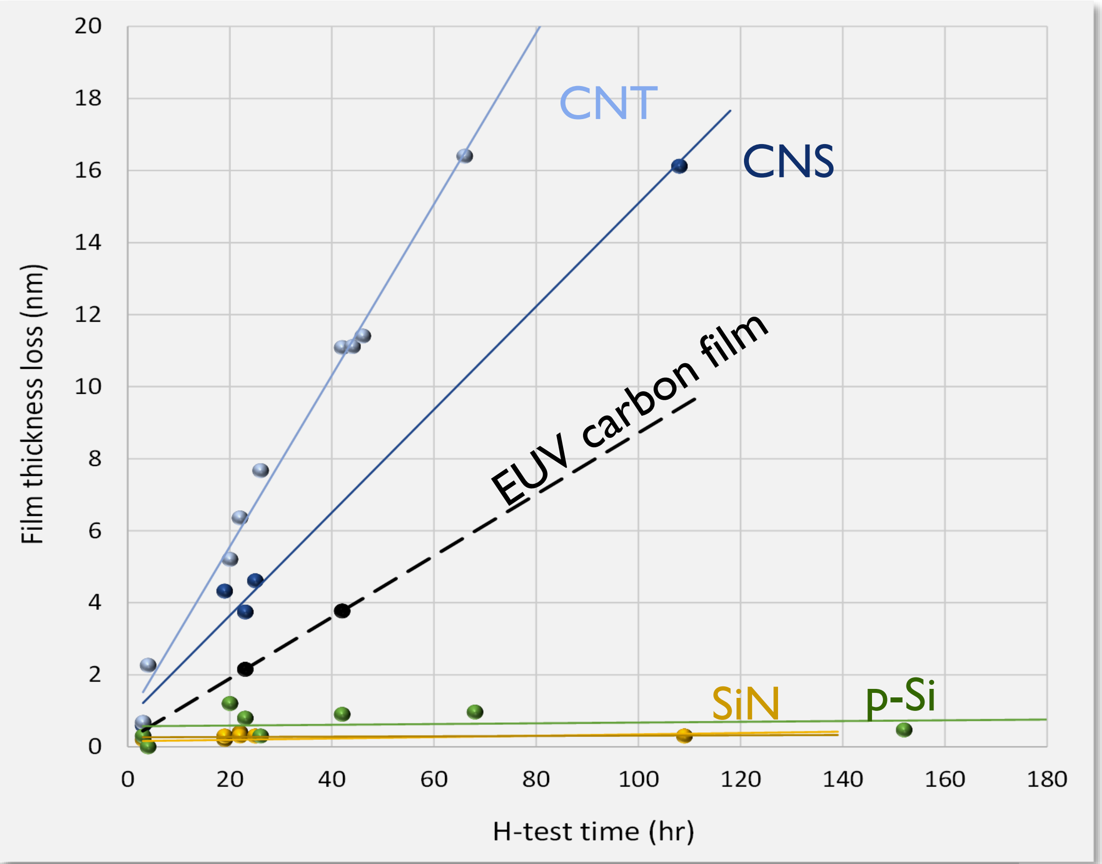
Caution: may change when exposed to EUV + H

H* exposure of carbon materials

CNT and CNS are thinned by exposure to H-radicals

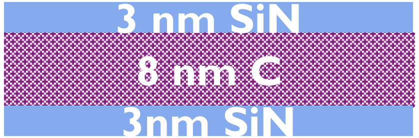
P-Si and SiNx do not show any significant change

Carbon nanomaterials cannot be used as a pellicle without capping layers

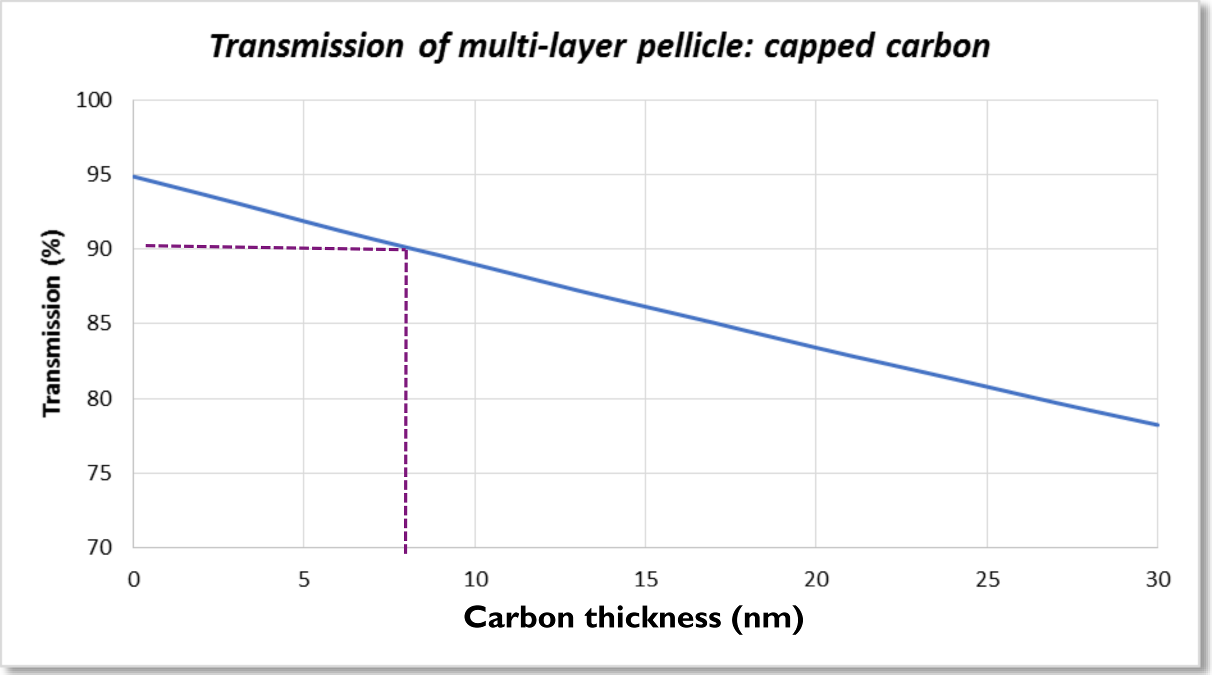


Combine films for pellicle solution

Simulated transmission of a carbon pellicle (effective thickness) with 3nm SiN capping layers



90% EUV transmission



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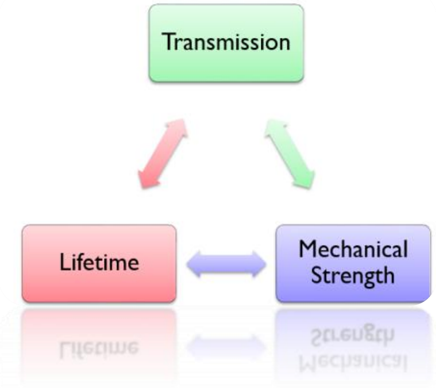
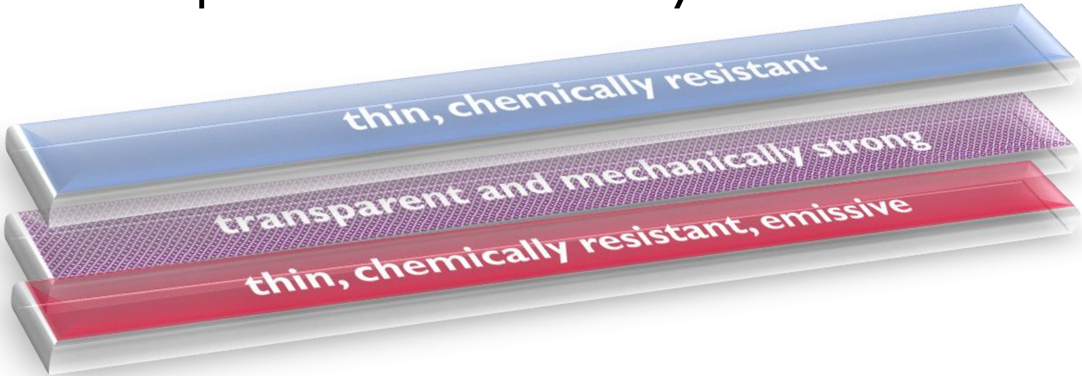
Fabrication and testing of EUVL pellicle candidates established at imec

Meeting all requirements simultaneously is a large challenge

Anticipate best EUV pellicle will be multi-layered





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