Progress in high transmission pellicles for EUVL

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***SEMATECH**

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Overview

- Motivation & concept
- Pellicle spec proposal
- Transmittivity limit
- Thermal performance
- Fabrication
  - Sputtered silicon membrane improvement
  - Alternative SoQ based <Si> membrane
  - <Si> based mesh development
- Summary & future work

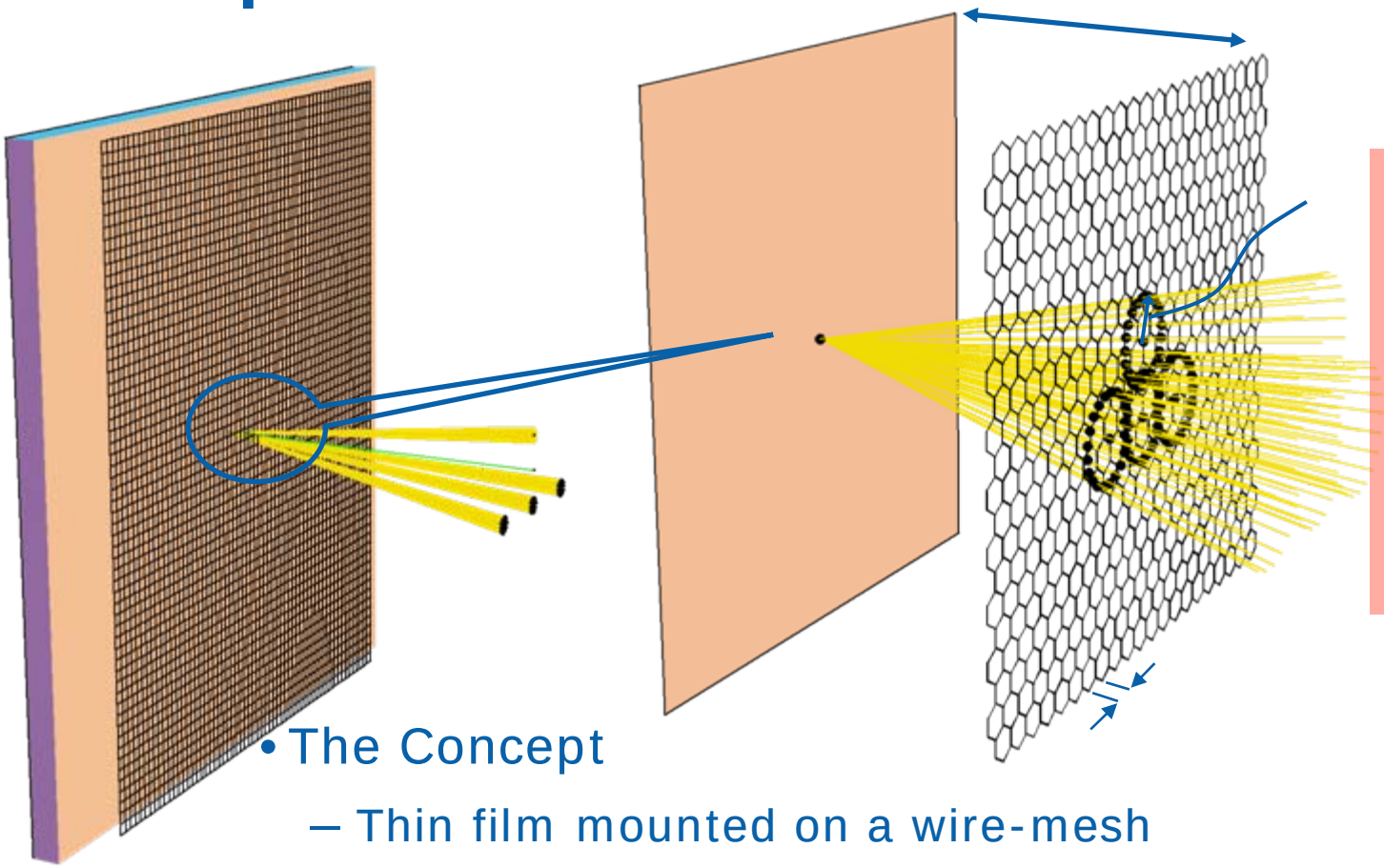
Need for an EUV pellicle

- Pellicle-less EUV lithography development is a priority, with risk
  - Dual pod reticle handing and shipping without generating particles
  - Operating within the lithography tool without added defects
  - Metrology confirmation of defect free reticles at sub-30nm

- The aim of this research is to create an EUV pellicle as a backup to pellicle-less operation

- An EUV pellicle is expected to have trade-offs
  - Moderate transmission loss
  - Minimal uniformity loss
  - Minimal contrast loss

Concept



- Mesh apodizes the illuminator exit pupil and PO entrance pupil.
- Mesh film absorbs with both passes.

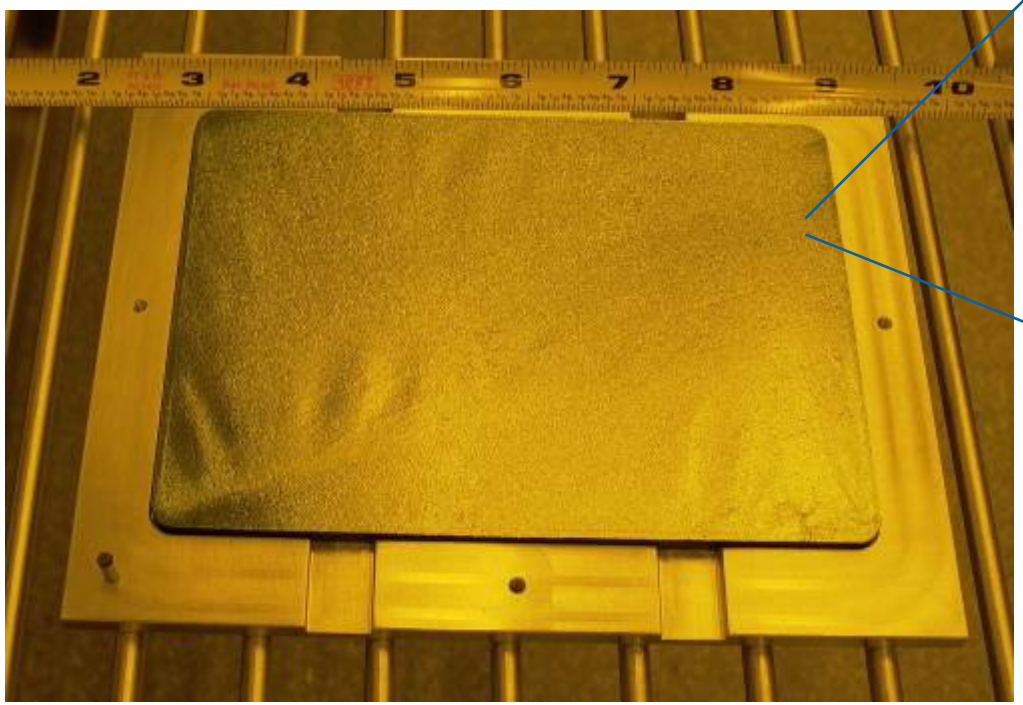
- The Concept
  - Thin film mounted on a wire-mesh
  - Mesh located “far” from reticle plane to defocus defects
  - Transmission requires a high percentage open area
  - Illumination uniformity requires partial coherence

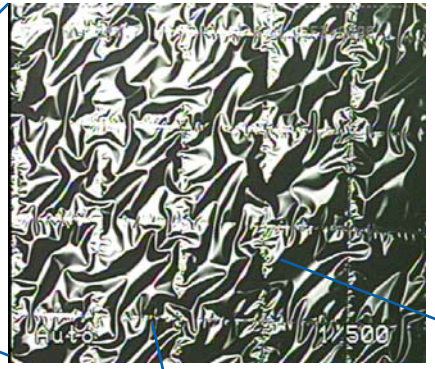
EUV pellicle specs

	Current	Target
Frame length/width	149/122mm	
Height	6.3mm	
Transmission	50%	60% (2007) 70% (2008)
Film thickness	100nm ± 4nm	50nm ± 2nm
Transmission uniformity	± 1%	± 0.6%
Film stress	Tensile (<50MPa)	
#wafers/pellicle	-	> 2000
Stiffness	193nm frame	
Defects (#broken cells/frame) For double-pass txm: 33.8% / 70%	0 / 30%	0
Pellicle material outgassing	-	TBD

Full-size pellicle developed

- Si membrane on 70LPI (363μm pitch) mesh





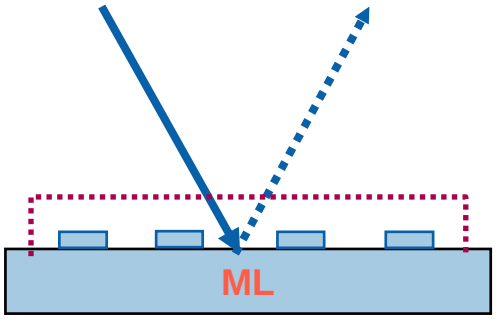
Transmission
- 1-pass: 58.1%
- 2-pass: 33.8%

Demonstrated in 10/2006

Transmission loss

	Single Pass			Double Pass
	Mesh	Si	Native SiO_2	T
Si d=50nm	**96%**	**91.8%**	**95%**	**71%**
Si d=60nm	96%	90.0%	95%	67%
Si d=70nm	96%	88.7%	95%	65%
Si d=80nm	96%	87.2%	95%	63%

Mesh: 10μm line/400μm pitch



- Best case of pellicle transmission double path we can achieve ~ 70%
  - Combining 96% mesh and 88% Si (50nm thickness) in the fabrication process

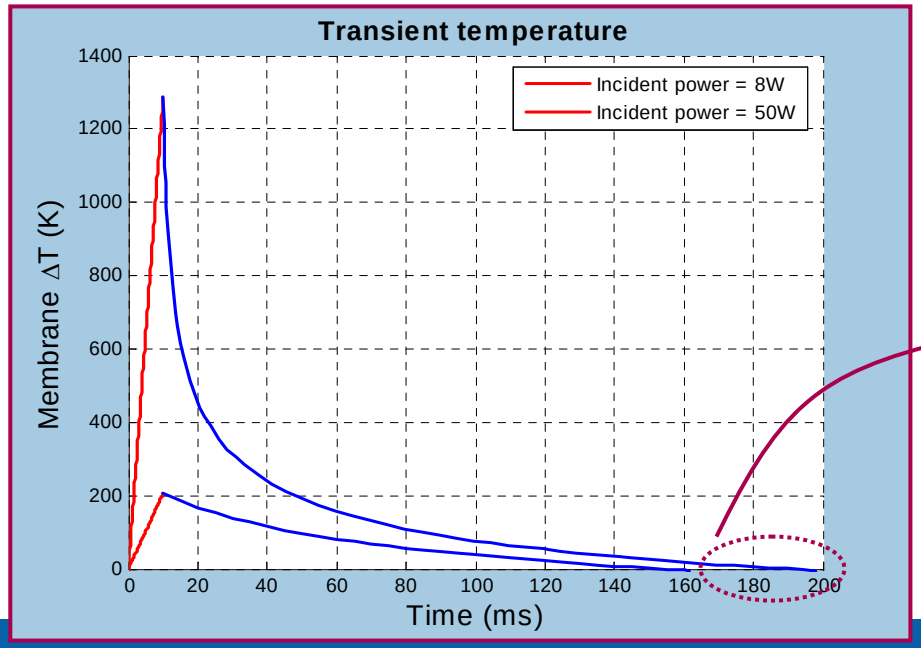
Thermal Considerations:
Pellicle heating/cooling cycle for HVM conditions

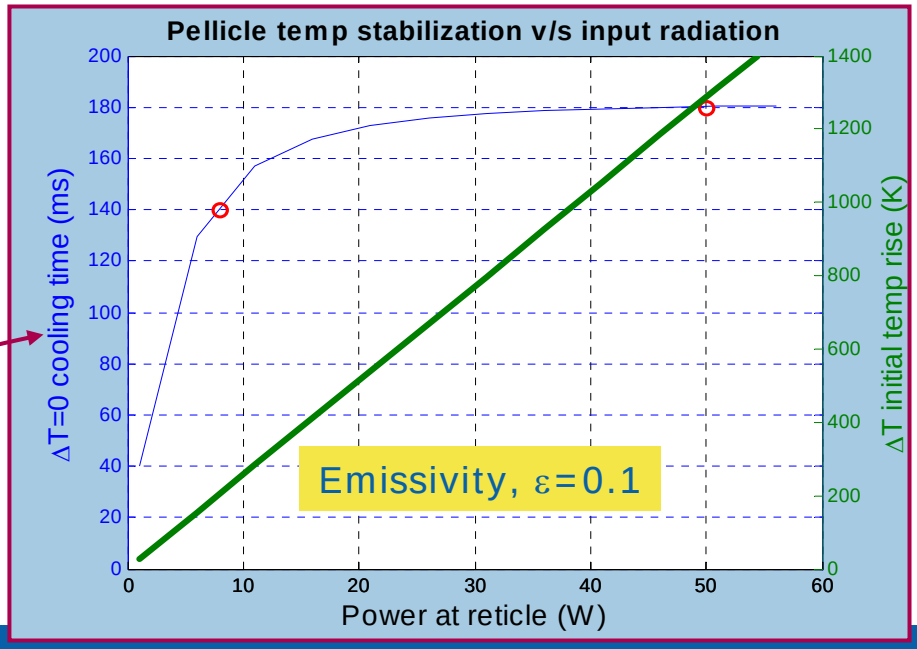
- Pellicle heating, modeling assumptions:
  - Primary cause of pellicle heating is from absorption of EUV and OoB radiation.
  - Slit scan speed: 10ms/cm (slit width 1cm)
  - Energy dump on pellicle during slit exposure only (t_{slit}=10ms)
  - 25.7% of incident power is absorbed by the pellicle (ML reflectivity = 65%)
- Pellicle cooling, modeling assumptions:
  - Radiation induced cooling – emissivity of Silicon, ε=0.1
  - Heat loss during slit non-exposure, available time: t_{die}~350ms
- If radiation induced cool down ($\Delta T=0$) time is less than the cycle time of the mask, additional cooling mechanisms are unnecessary. Let's look at the transient response of pellicle heating…

Transient Thermal Response

- Pellicle heating via absorption:
  - $Q = c \cdot m \cdot \Delta T_{Si}$
- Pellicle cooling via radiation:
  - $\frac{\partial Q}{dt} = A \cdot \varepsilon \cdot \sigma \cdot \left(T_{env}^4 - T_{Si}^4 \right)$

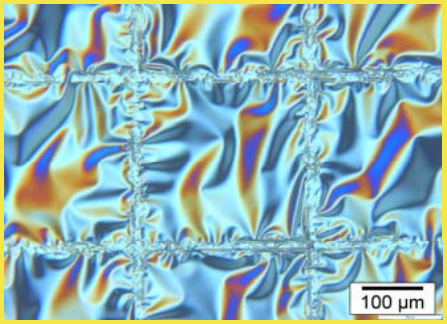
$$\frac{\partial T}{dt} = \left(- \frac{A \cdot \varepsilon \cdot \sigma}{c \cdot m} \right) T^4$$



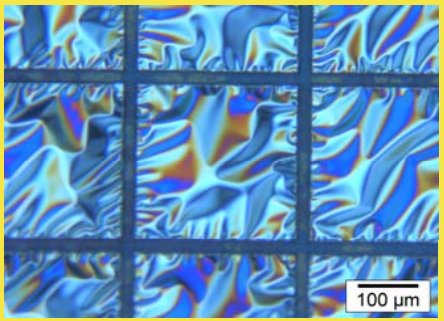


Pellicle Heating Impact

- Incident EUV power at reticle plane is expected to be ~5W for 100WPH tool. For 8W, the rise in temperature is <200K. Impact:
  - Si expansion inside hexagonal area bonded by Ni mesh has no impact on imaging due to almost matched index of reflection with that of vacuum
  - Experiment of pellicle heating at 240ºC for 3 hours showed no membrane damage



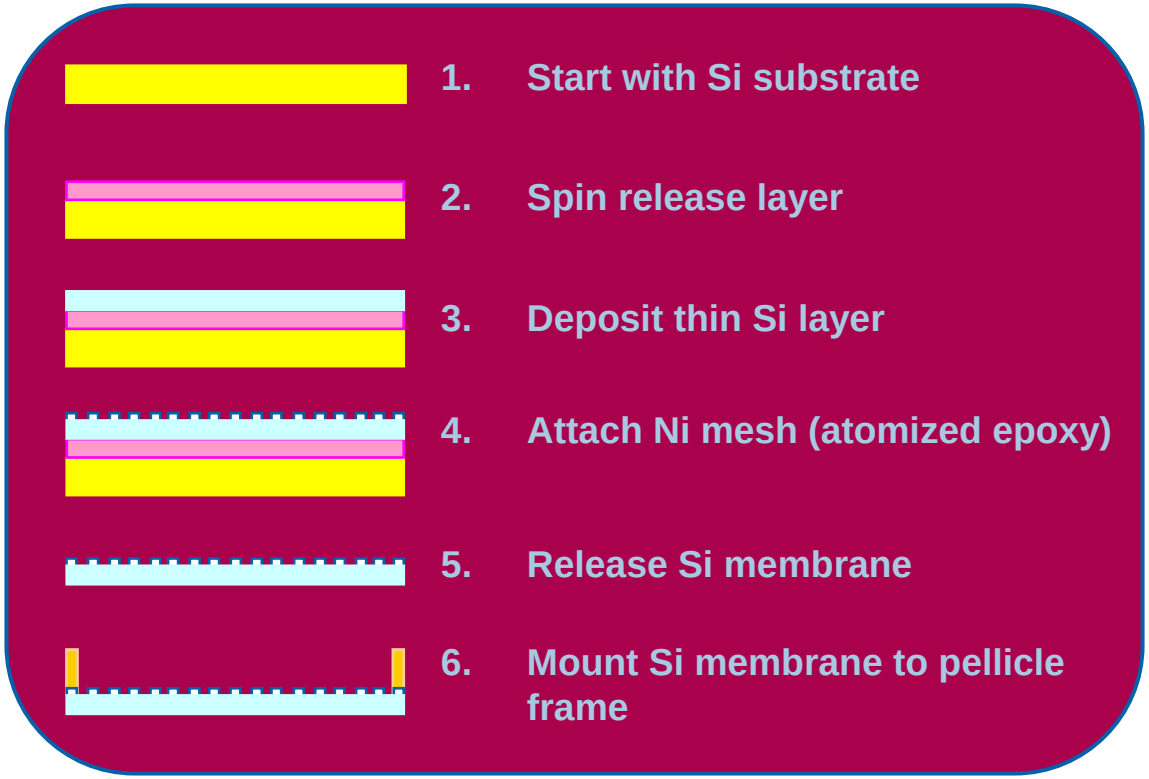
Pre-heating



Post-heating

- No concern on Ni expansion
  - Temperature increase in Ni mesh is estimated within a few degrees
  - Thermal expansion of Ni is negligible

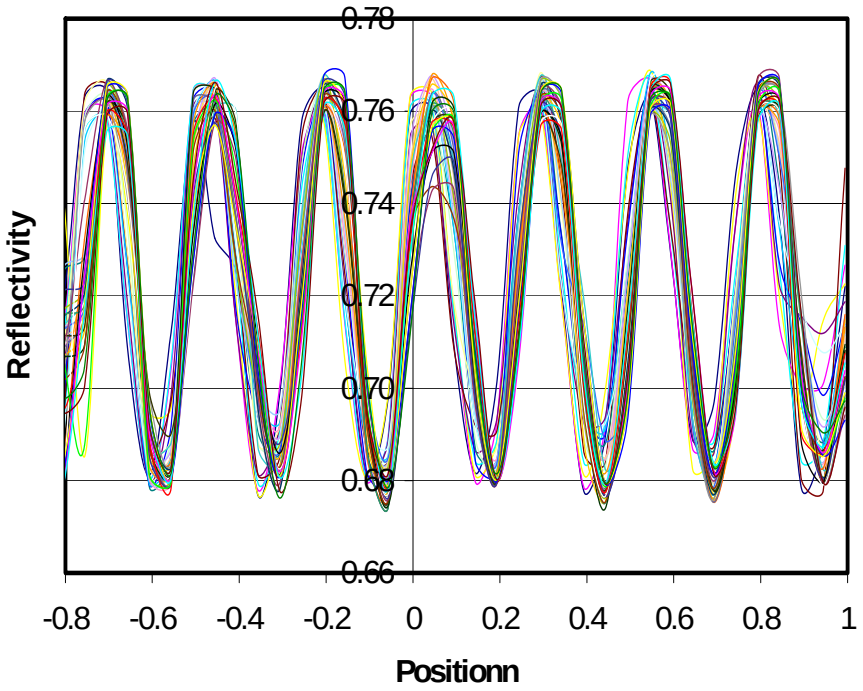
Sputtered Si based membrane fabrication



- Current process of record for making full-size EUV pellicles
- Mounting with 250μm pitch, 93% transmissive Ni mesh ongoing

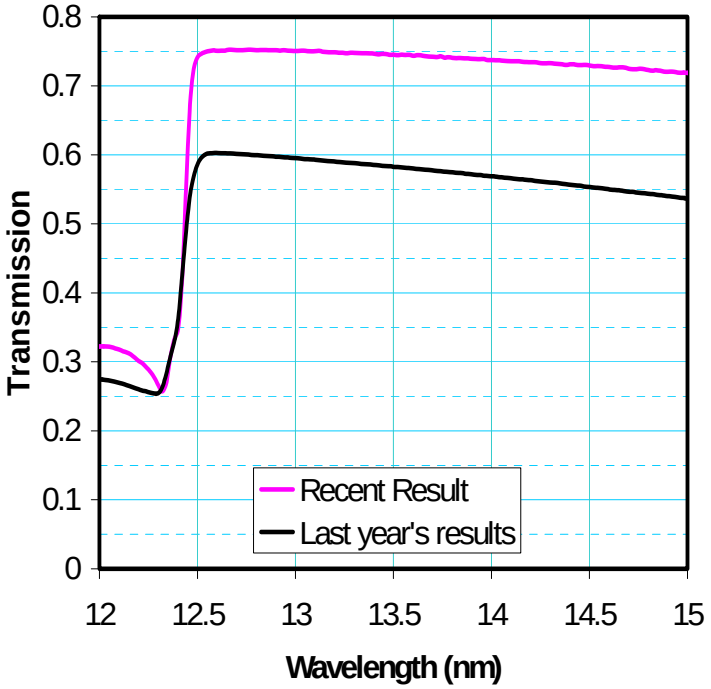
Pellicle transmission improvement

Current pellicle transmission



- Fabricated using LBNL Si deposition
- Mesh transmission: 90%
- 100nm Si membrane transmission: 80%

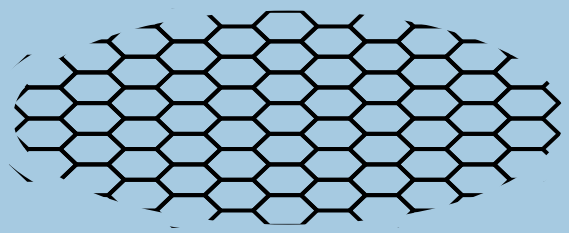
Comparison with last year

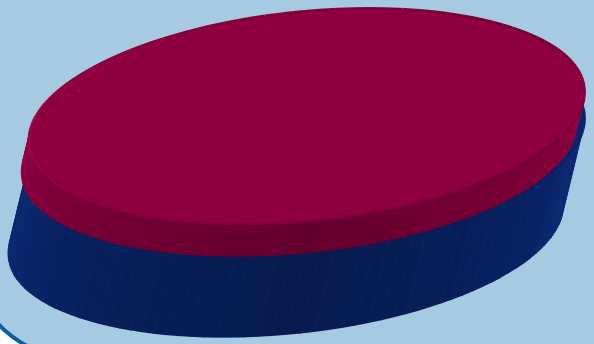


- Transmission improved by reducing C and O contamination during Si sputtering.

Measured average pellicle T = 72%

Alternative approach: Single crystal Si based membrane

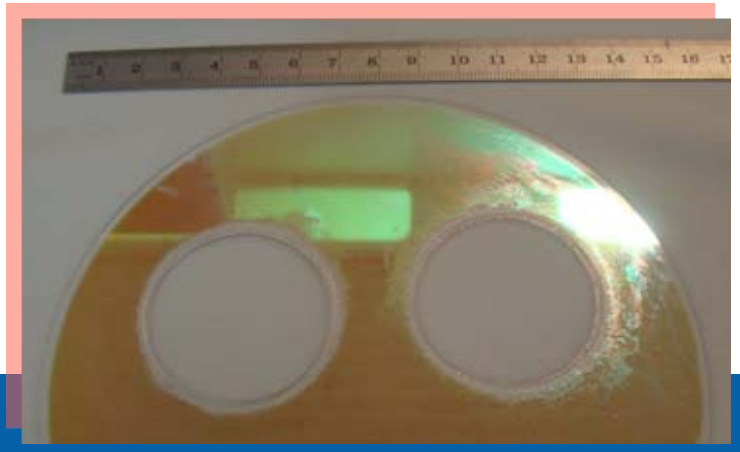


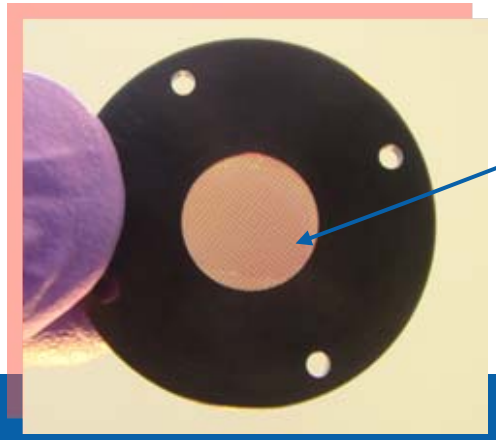


Mesh + SoQ wafer bond

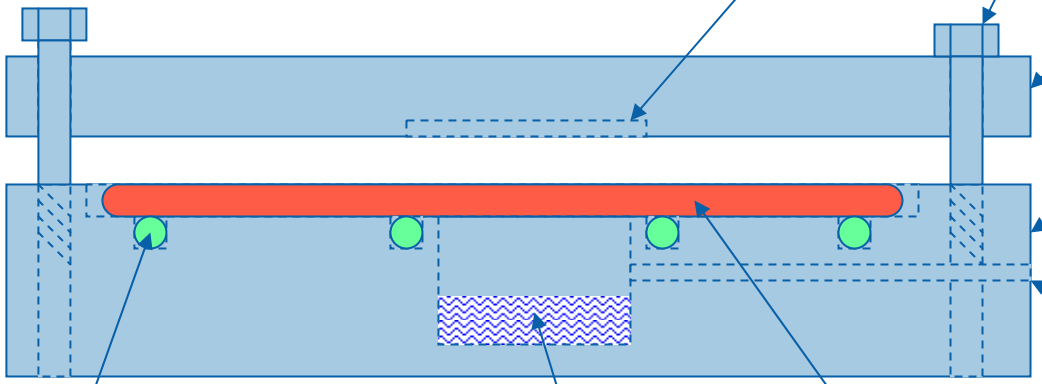
HF vapor etch

<Si> membrane





Release: Quartz Wafer Vapor HF-Acid Etcher*



Clearness for Film

Plastic Screws - holds the lid down # 3/8-16

Lid- holds the wafer down

Base – holds HF Acid under the wafer, and O- rings

Small Vent Holes

O-rings

Quartz Wafer - 150mm (5.92”)

Hydrofluoric Acid – to etch SiO2

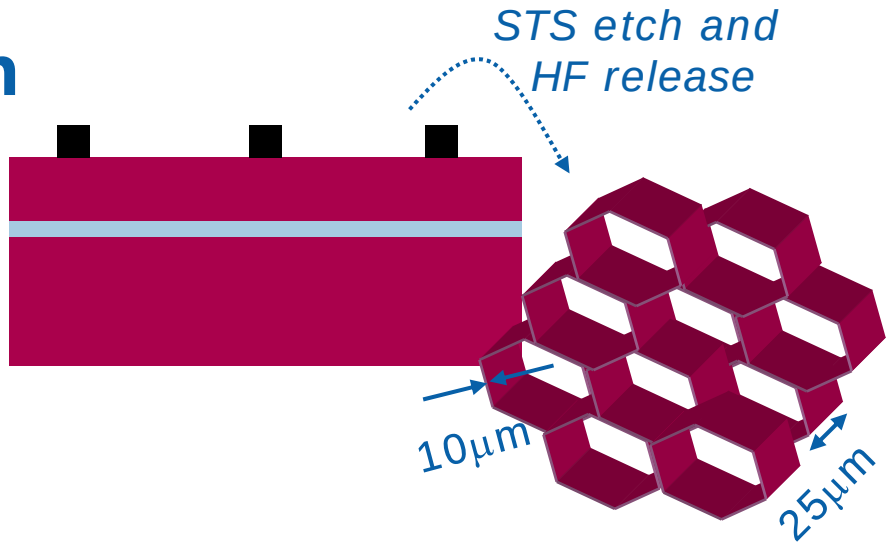
NO Metal - All Plastic

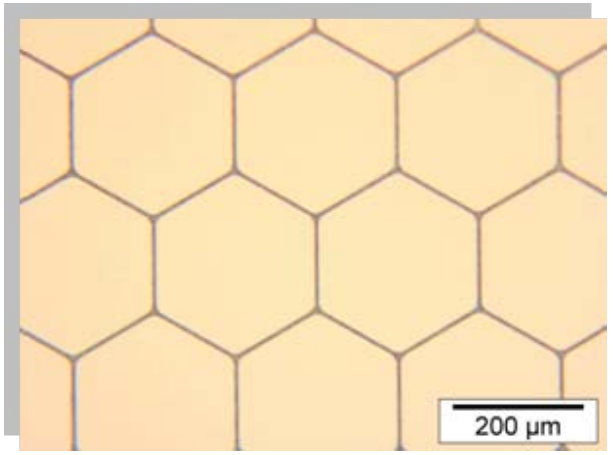
Can Be Turned Up-Side-Down

*Made by Luxel Inc.

Single Crystal Silicon based mesh fabrication

- Advantages:
  - Increase mesh height to CD aspect ratio: improves robustness for given transmission
  - Thermal: Mesh same as membrane (Si) removes impact from CTE mismatch
- Process flow:
  1. Start with 25μm device layer thickness SoI wafers
  2. Lithography: hex pattern on top
  3. STS based etch to achieve vertical sidewalls
  4. Release with HF
- Design:
  - Current: 10μm LW / 250μm pitch, 25μm deep (81% 2-pass txm)
  - Target: 8um LW / 400um pitch, 50μm deep (90% 2-pass txm)





Summary

- Thermal:
  - Transient analysis of pellicle heating indicates that cooling may be achieved with radiation.
  - For 8W incident EUV power and no OoB assumed, rise in pellicle temperature is <200^{o}C.
- Design & Fabrication:
  - High transmission (93% 1-pass) nickel mesh has been successfully bonded with a sputtered Si film.
  - Significant improvement in Si film deposition demonstrated: measured T=72% matches calculated transmission.
  - Silicon-on-Quartz based process developed to improve membrane robustness.
  - High aspect-ratio silicon-only mesh fabricated on a 4” wafer process with 92% 1-pass transmission.

Future work

- Demonstrate full-size 70% double pass transmission pellicle.
- Generate 8” SoQ based pellicle with target mesh transmission of 95%
- Bond Si mesh with SoI wafer to create Si-only mesh

Thanks to…

- Eric Gullikson at the Advanced Light Source EUV beamline (LBL) for at-wavelength transmission measurements and Si film depositions.
- Luxel Inc. for providing mesh bonding and release services.
- Stanford Nano Fab where some of the development work is accomplished.
- ShinEtsu for providing SoQ wafers.
- Committed support from senior management at Intel for funding and providing resources for the project.