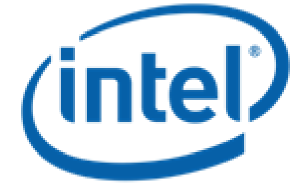

Development of EUV Pellicle for Reticle Defect Mitigation

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Pei-Yang Yan, Daniel Tanzil, Sang Lee, K. V. Ravi

Intel Corporation

October 18, 2006

EUVL Symposium, Barcelona

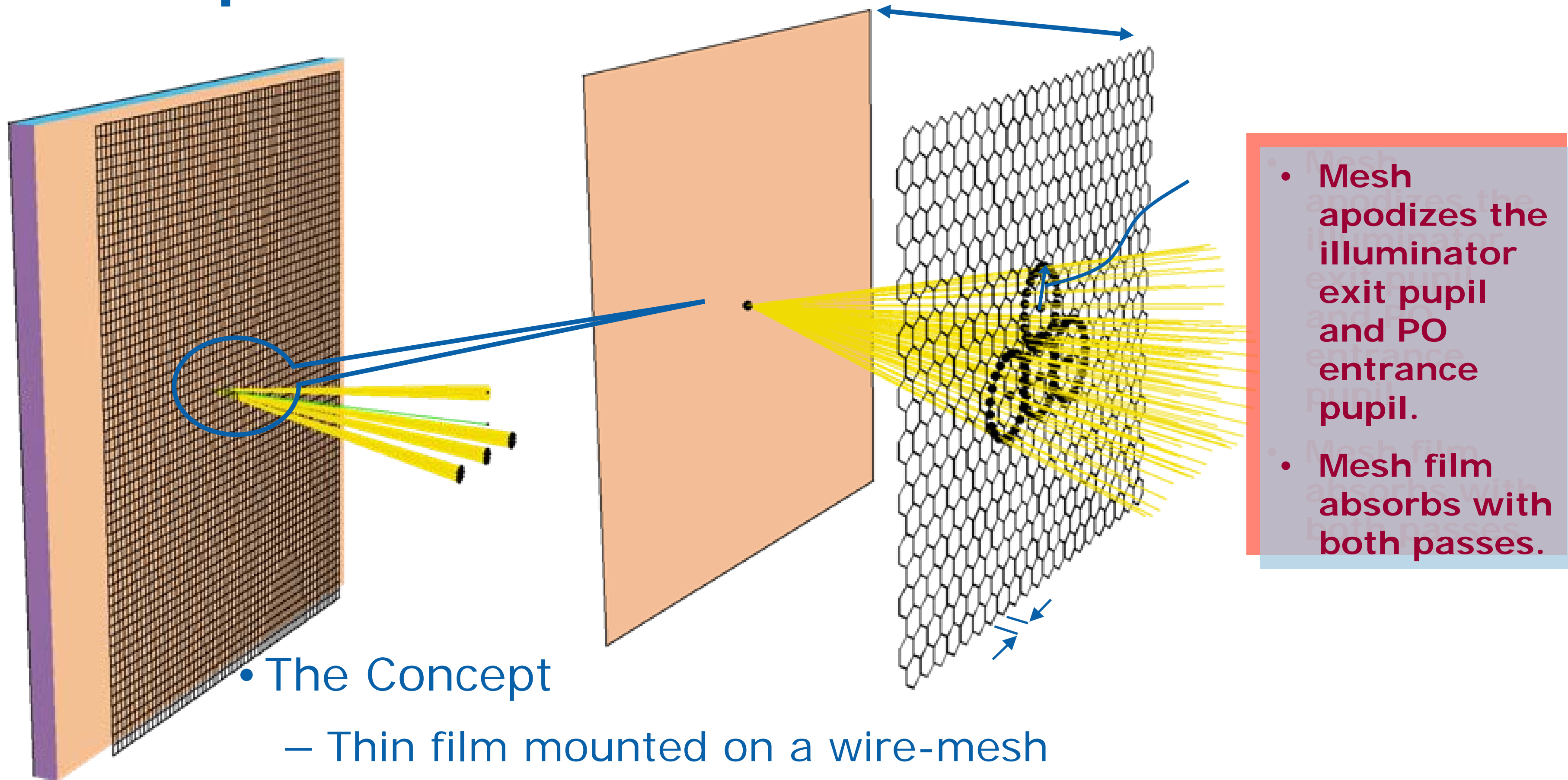
Outline

- Motivation
- Modeling results
  - Pitch, Transmission, Uniformity impact
  - Aerial image impact
- Experimental results
  - At-wavelength measurements
  - Full-size pellicle demonstration
  - Capping layer study
  - Pellicle optical metrology
- Field work results
  - CDU analysis at DUV wavelength
- Future work and summary

Need for an EUV pellicle

- Pellicle-less EUV lithography development is a priority, with risk
  - Swapping removable pellicles 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
  - Minimial 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

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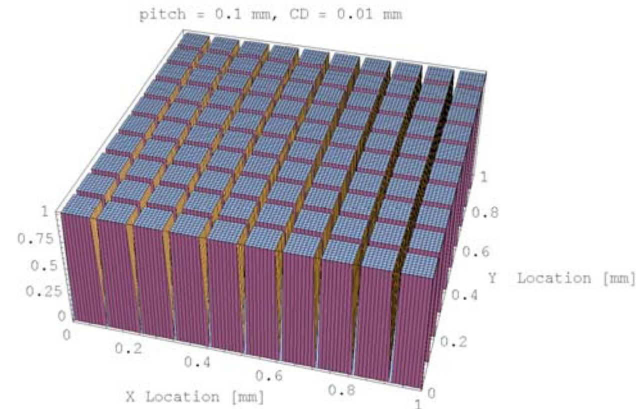
Numerical Model

1. Define mesh transmission:

$$T(x,y) = \text{UnitStep}\left[P\,\text{FractionalPart}\left[\frac{x}{P}\right] - CD\right] \times$$
$$\text{UnitStep}\left[P\,\text{FractionalPart}\left[\frac{y}{P}\right] - CD\right] \begin{cases} x \geq 0 \\ y \geq 0 \end{cases}$$

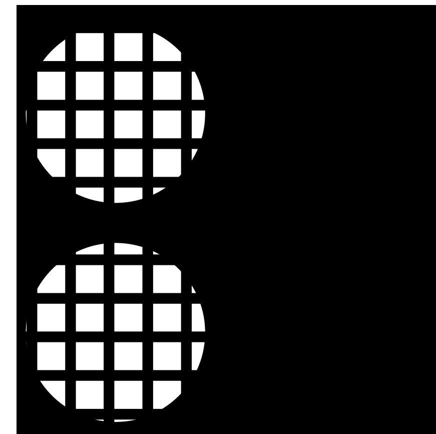
$$\langle T \rangle = \frac{1}{A} \iint T(x,y)\,dxdy$$



2. Define illumination spots, integrate mesh*spot transmission for each and take the product.

$$R = h\,\text{Tan}\left[\text{ArcSin}\left[\frac{\sigma\,NA}{\text{Mag}}\right]\right]$$

$$Circ = \text{UnitStep}\left[R^2 - (x - px)^2 - (y - py)^2\right]$$

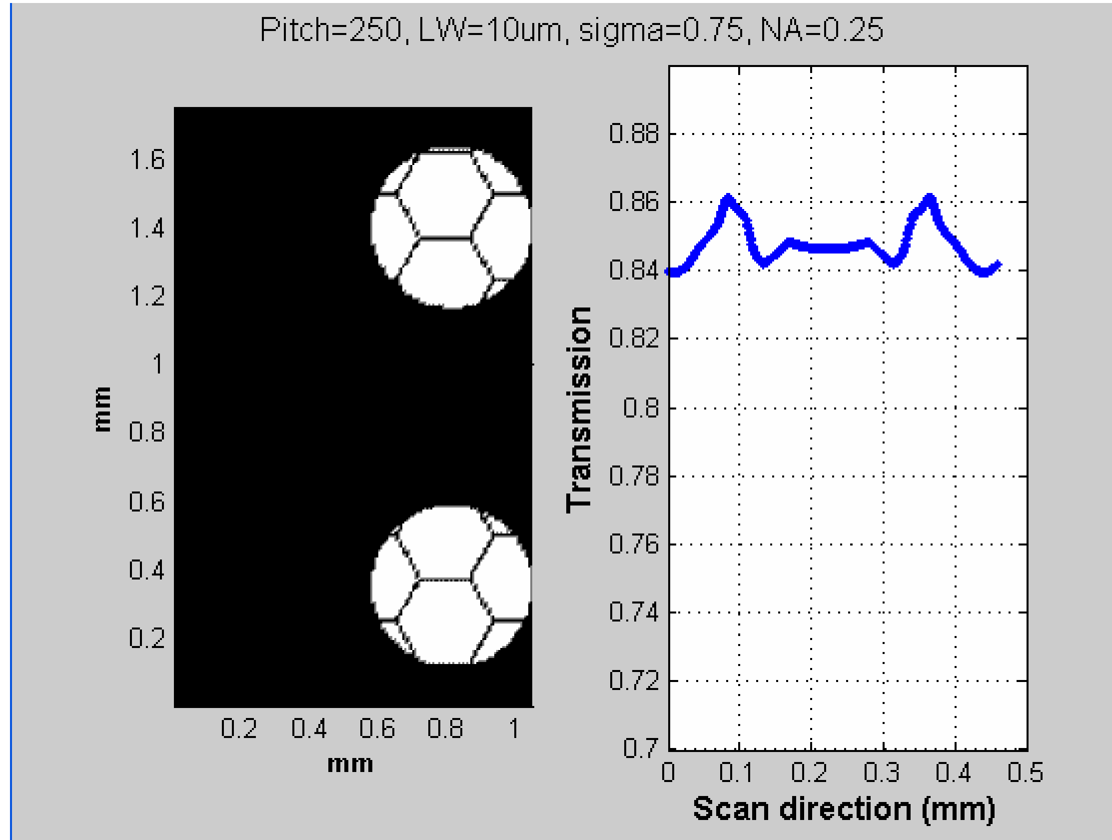


3. Slide location of illumination spot relative to the mesh to calculate non-uniformity.

$$T(px,py) = \frac{1}{\pi^2 R^4} \int T\,\text{Circ}_1\,dxdy \int T\,\text{Circ}_2\,dxdy$$

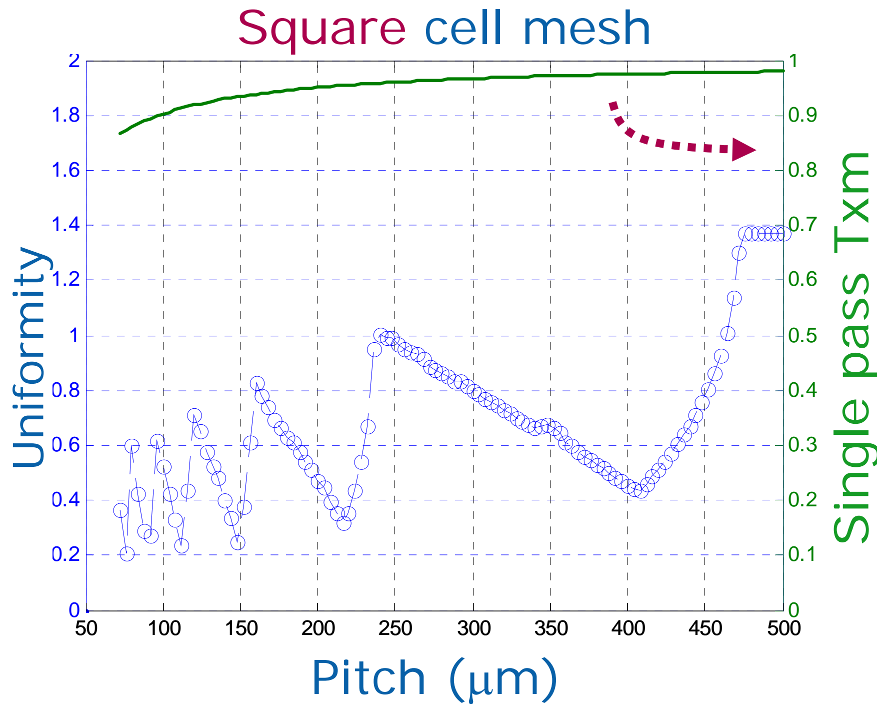
$$\Delta T \equiv \pm \frac{Max(T) - Min(T)}{2\langle T \rangle}$$

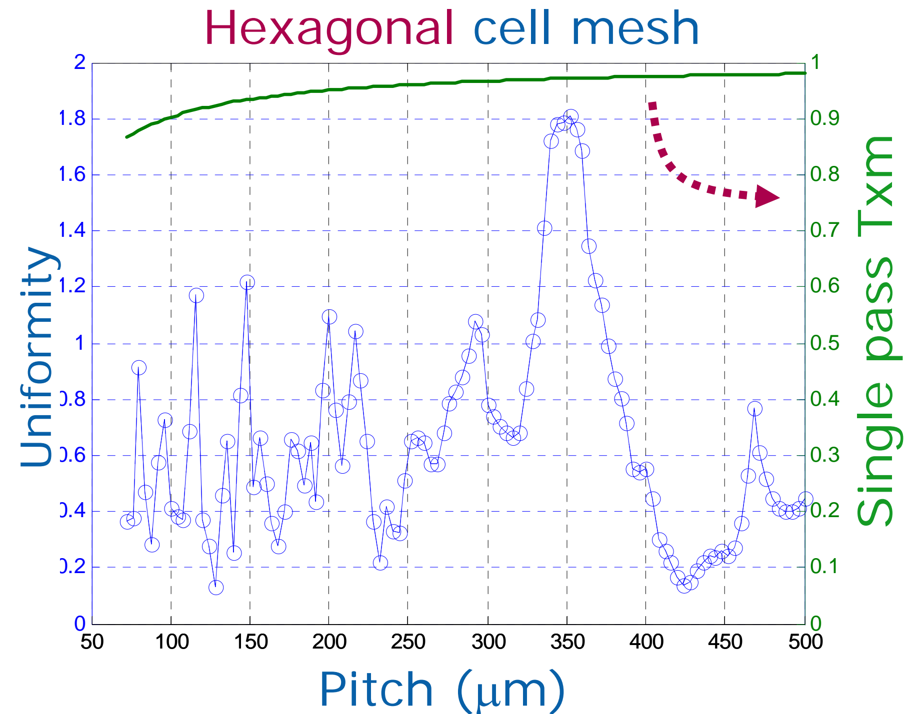
Far-field uniformity – Hexagonal mesh



Animation

Illumination non-uniformity through pitch (LW=5um)

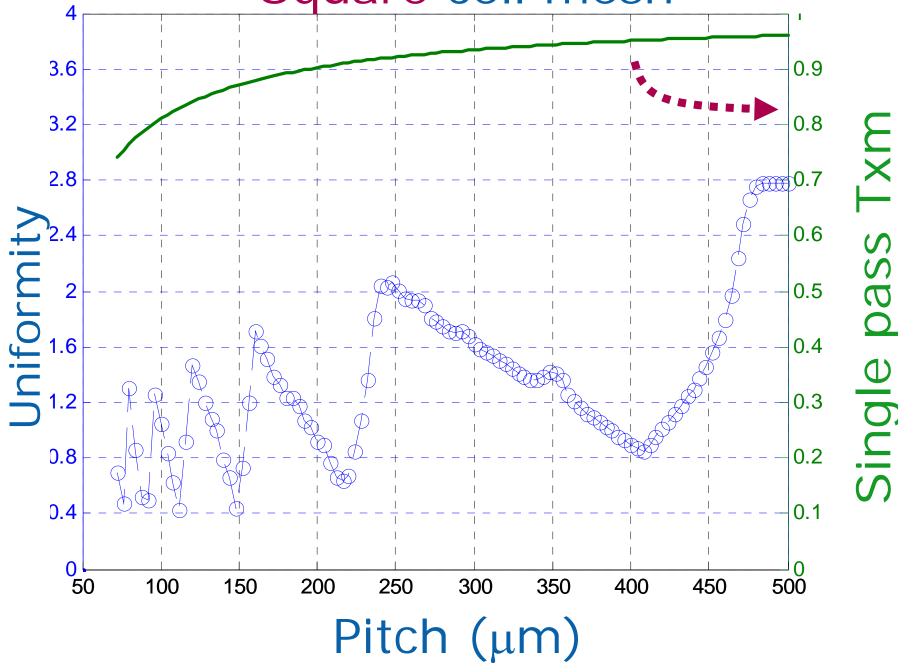


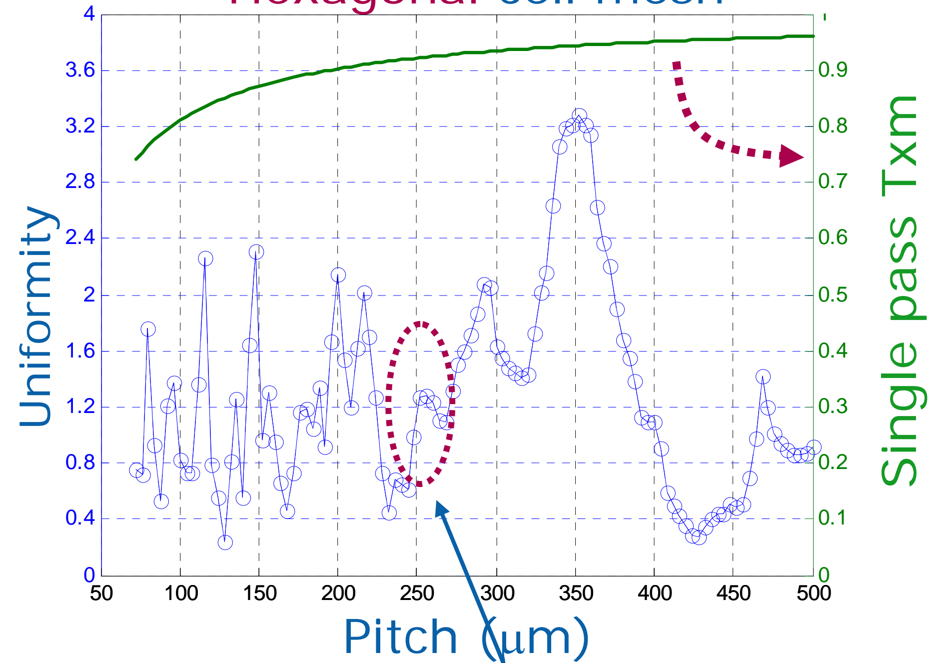


- λ=13.5nm, σ=0.75, NA=0.25
- Mesh-Reticle gap, d: 5mm
- Illumination tilt, θ: 6°

$$\text{NonUnifomity} \equiv \frac{1}{2} \times \frac{Range(T)}{\langle T \rangle}$$

Illumination non-uniformity through pitch (LW=10um)

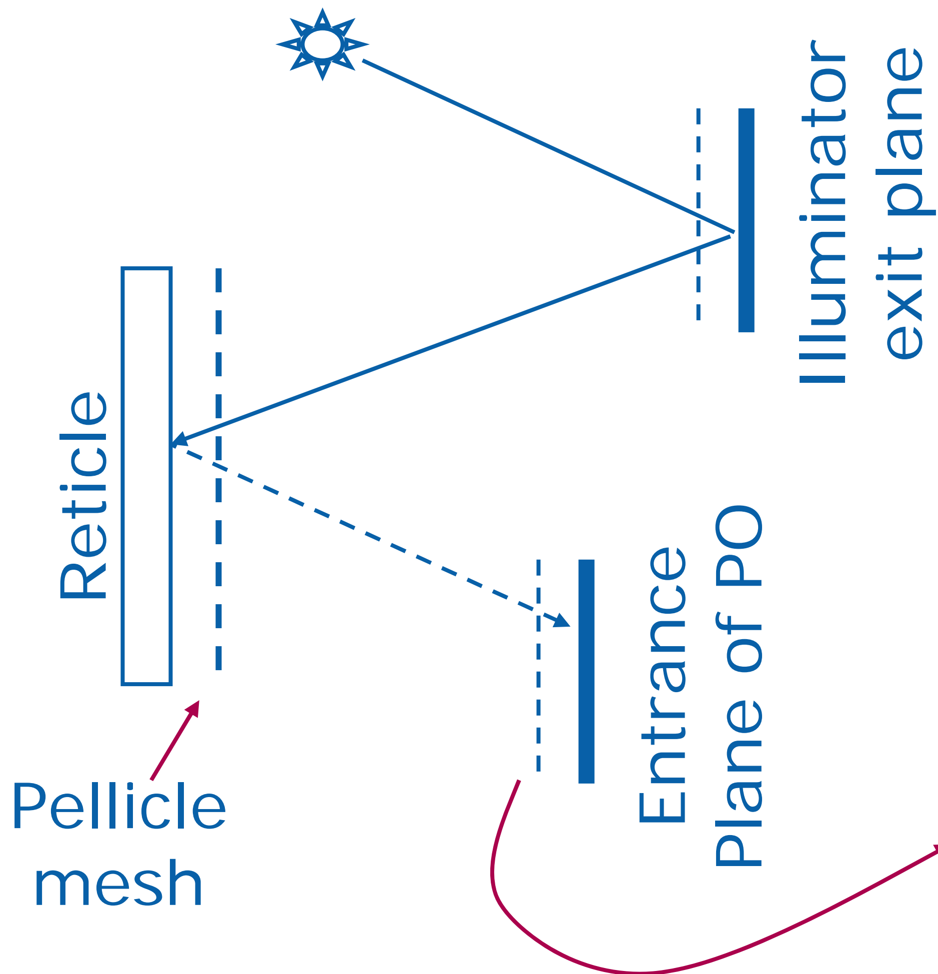




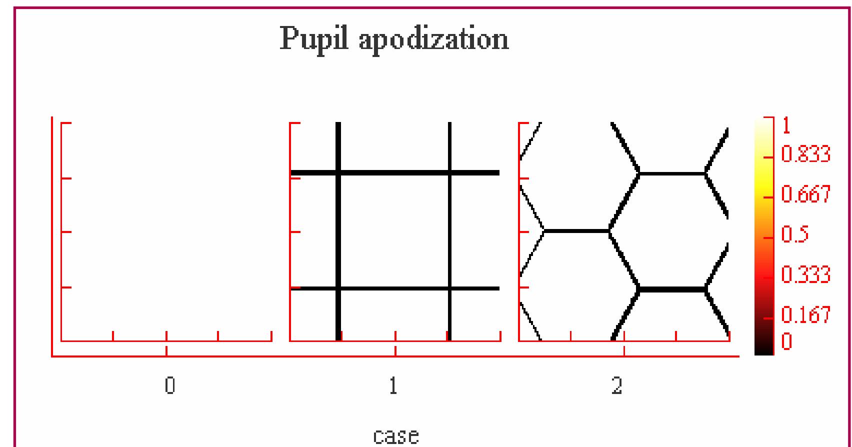
- Illumination non-uniformity is proportional to mesh line-width
- Hexagonal cell based mesh chosen for higher structural rigidity
- **Selected:** Hex cell pitch 250µm; target transmission 90%

Present work

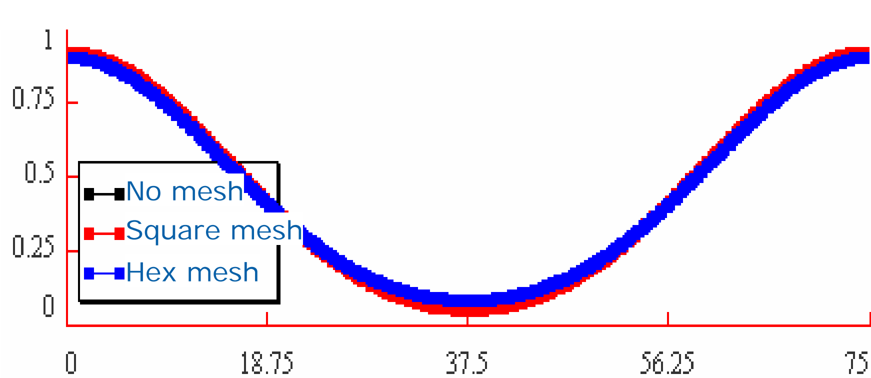
Aerial image modeling

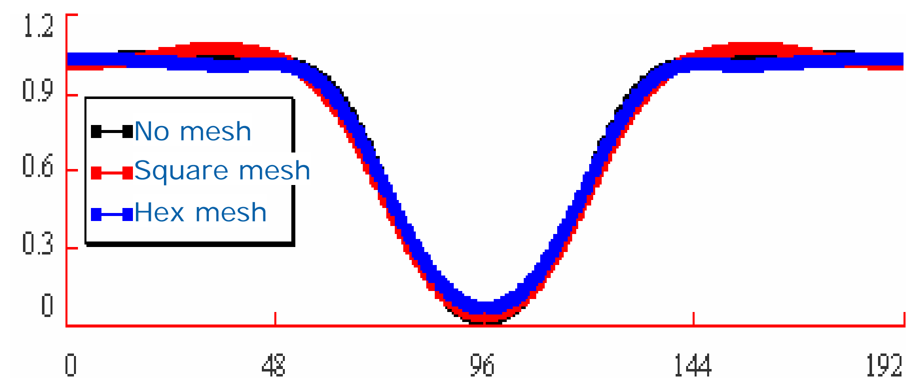


- Mesh extracted from 'near' reticle plane to source and PO exit/entrance planes
- 3 cases explored: no mesh, square, and hex mesh
- Mesh offset from reticle = 6mm
- Only PO entrance plane apodization is considered here.



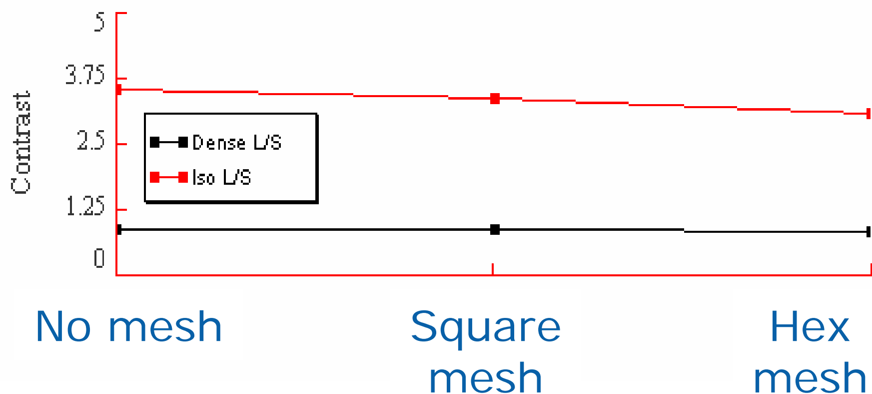
LW=10um, Pitch=250um: Hex & Sq comparison (NA=0.25, sigma=0.75, d=5mm)

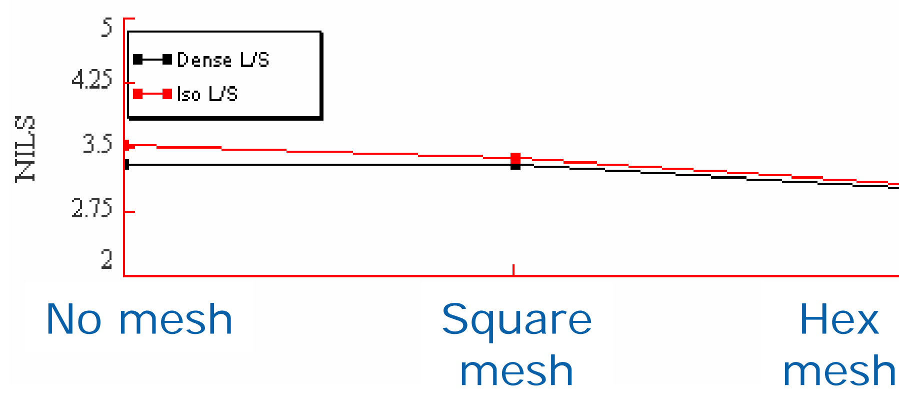




Dense pattern: 32/43nm L/S

Iso pattern: 32/160nm L/S





- ~7% reduction in contrast for iso and dense patterns for hex mesh.
- 7% / 13% reduction in NILS with dense / iso patterns for hex mesh

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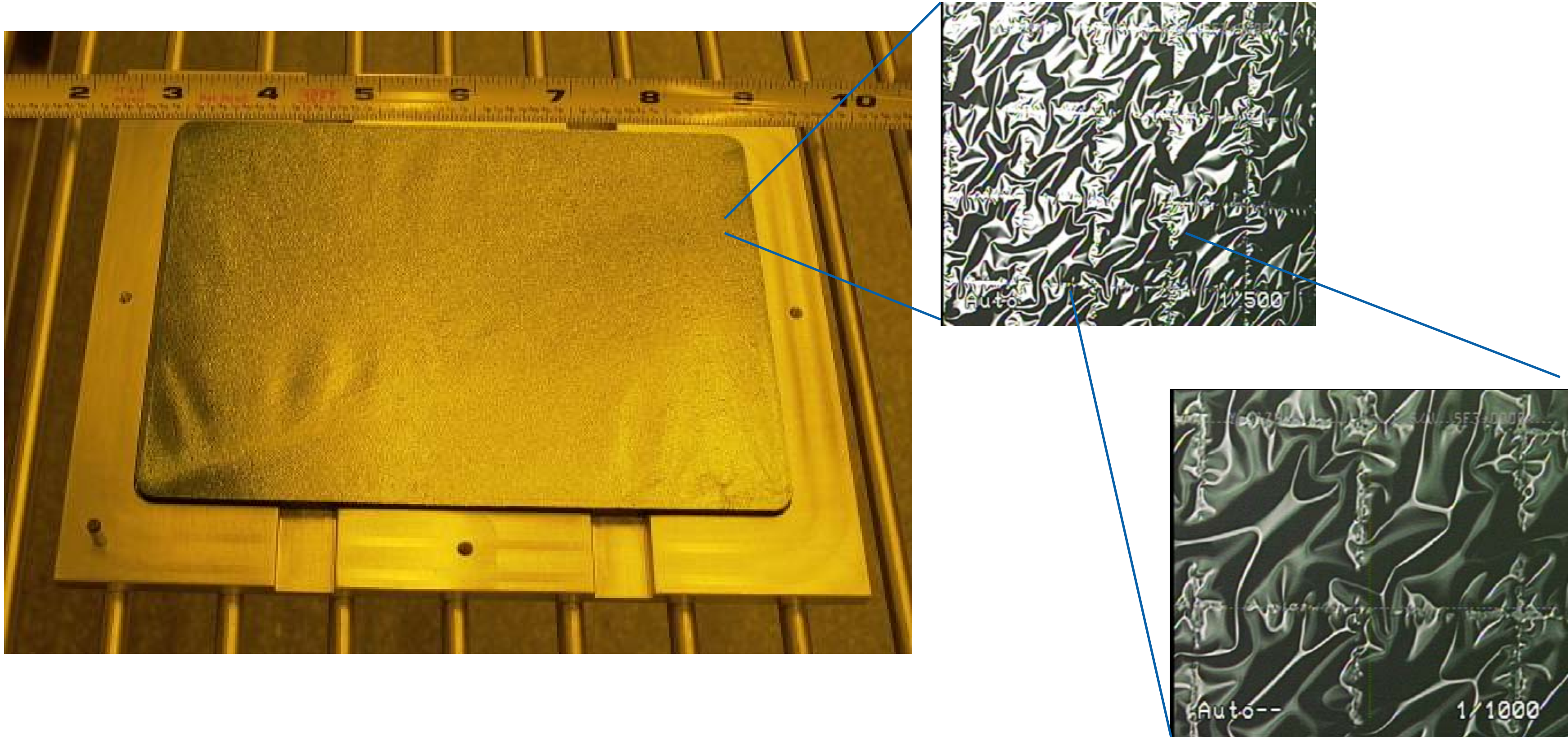
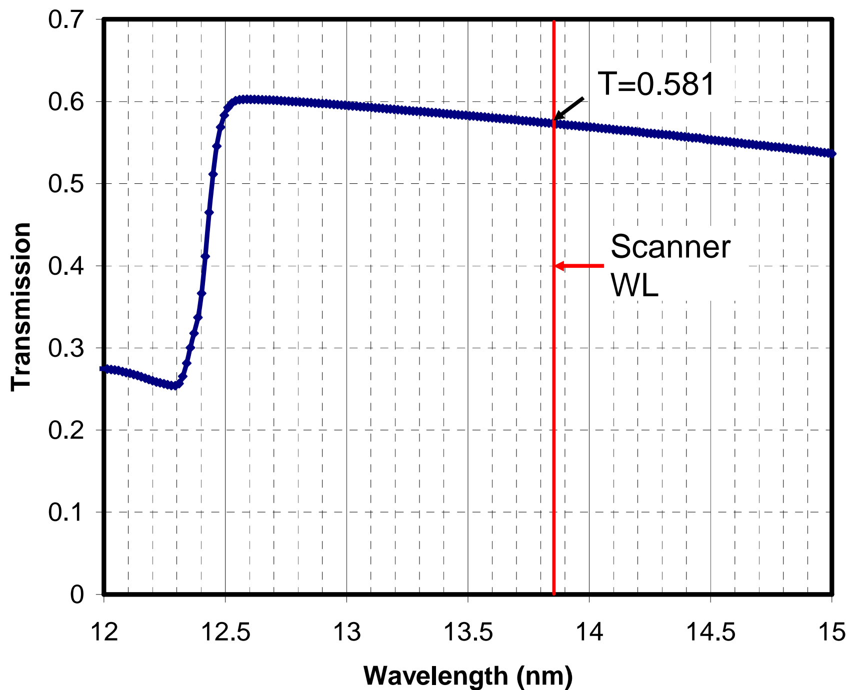
Full-size pellicle

- Si membrane on 70LPI mesh

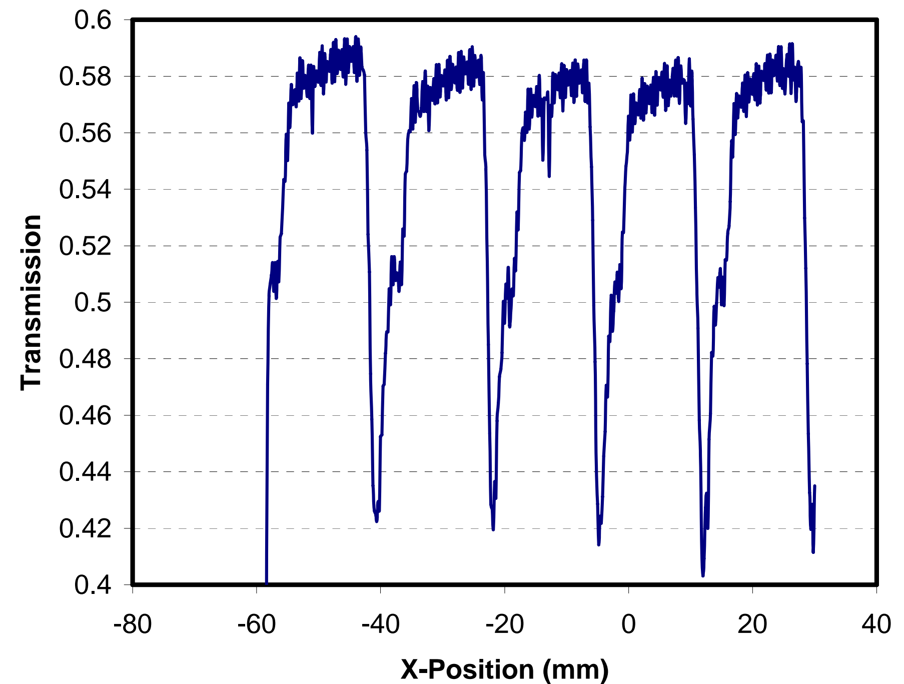


Transmission characteristics for full-size mesh

- Near EUV



- Across-field uniformity **at focus**

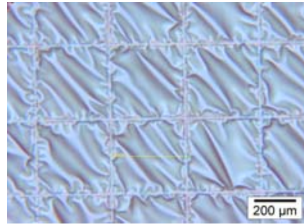


➢ Pellicle transmission at 13.57nm scanner wavelength is about 58%, double pass yields 33.6%.

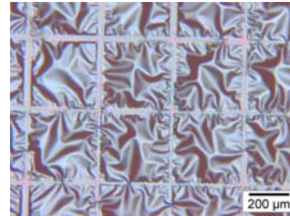
Capping layer optimization: Transmission vs. stress

- 4 capping layers investigated: Si oxidation mitigation

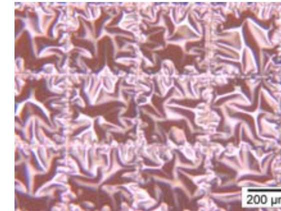
22Å Ti



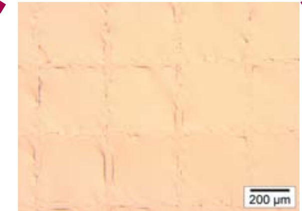
11Å Ru



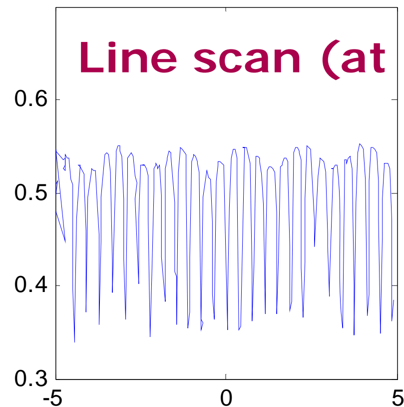
22Å Ru



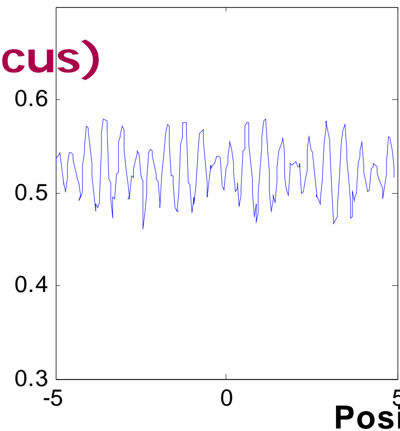
33Å Ru



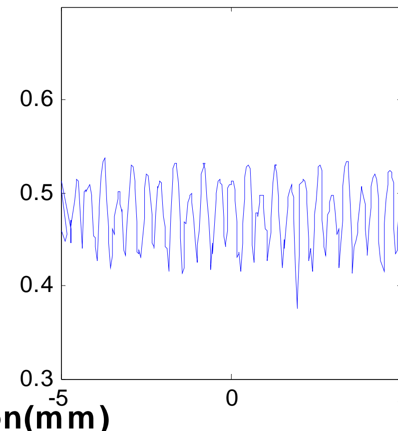
Ti/Si/Ti: 20A/767A/20A



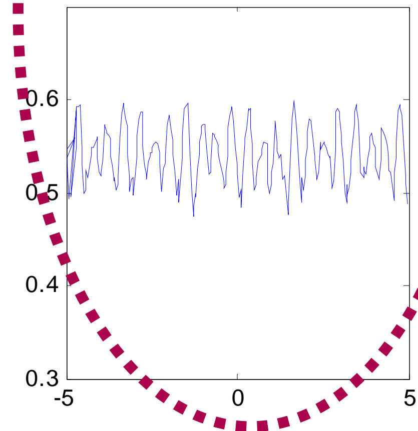
Ru/Si/Ru: 11A/819A/11A



Ru/Si/Ru: 22A/810A/22A



Ru/Si/Ru: 33A/829A/33A

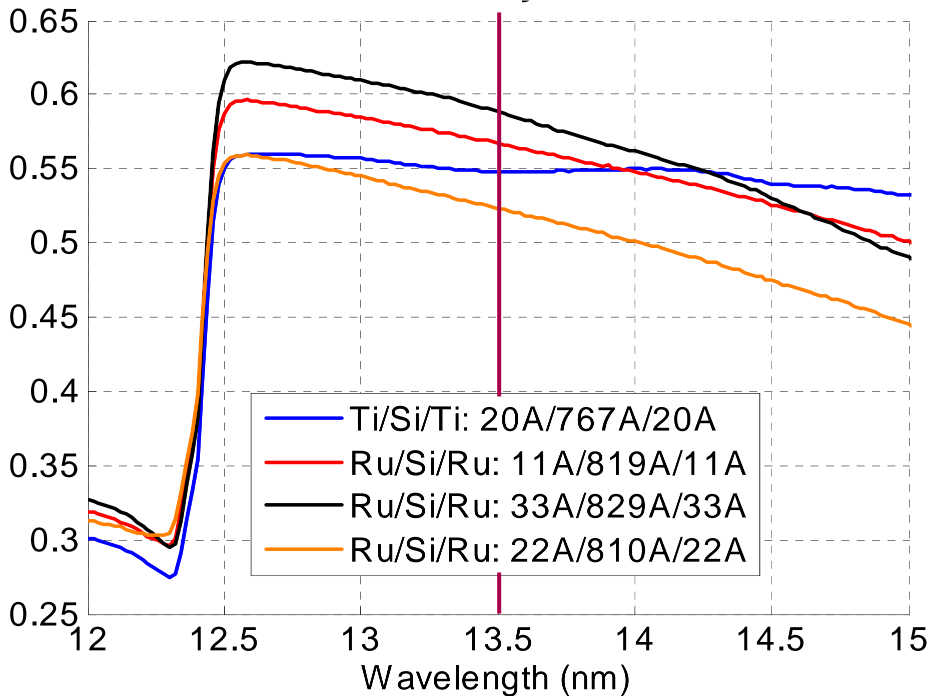


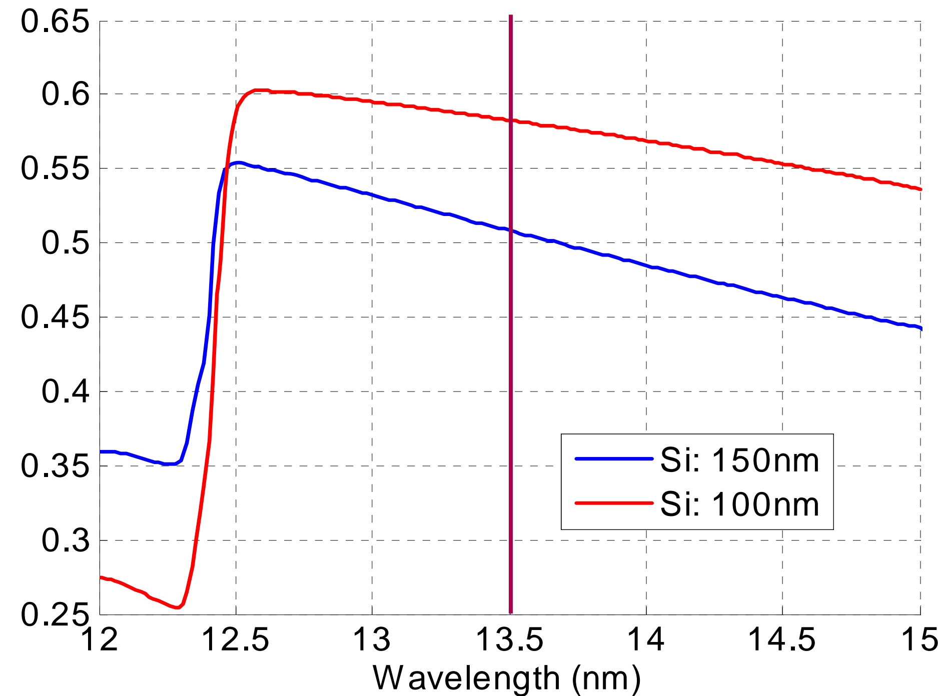
Position(mm)

- Line scan of pellicles with 300 x 50µ2m wide EUV beam at focus at ALS (LBL)
- Stable Ru capping layer helps optimize membrane stress (tensile) at high transmission

Note: At-focus scan. Average transmission matters.

Capping layer study: Transmissivity near EUV





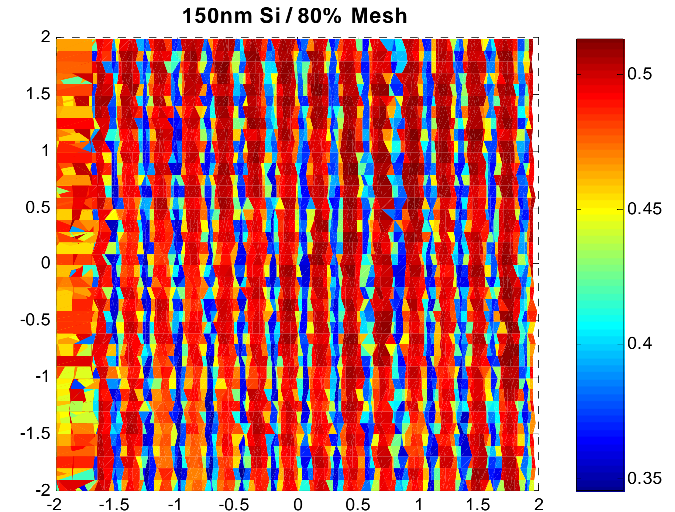
Mesh + membrane transmission @ scanner wavelength:

- 22A Ti cap: 55%
- 11A Ru cap: 57%
- 22A Ru cap: 52%
- 33A Ru cap: 59%
- 100nm Si: 58%
- 150nm Si: 51%

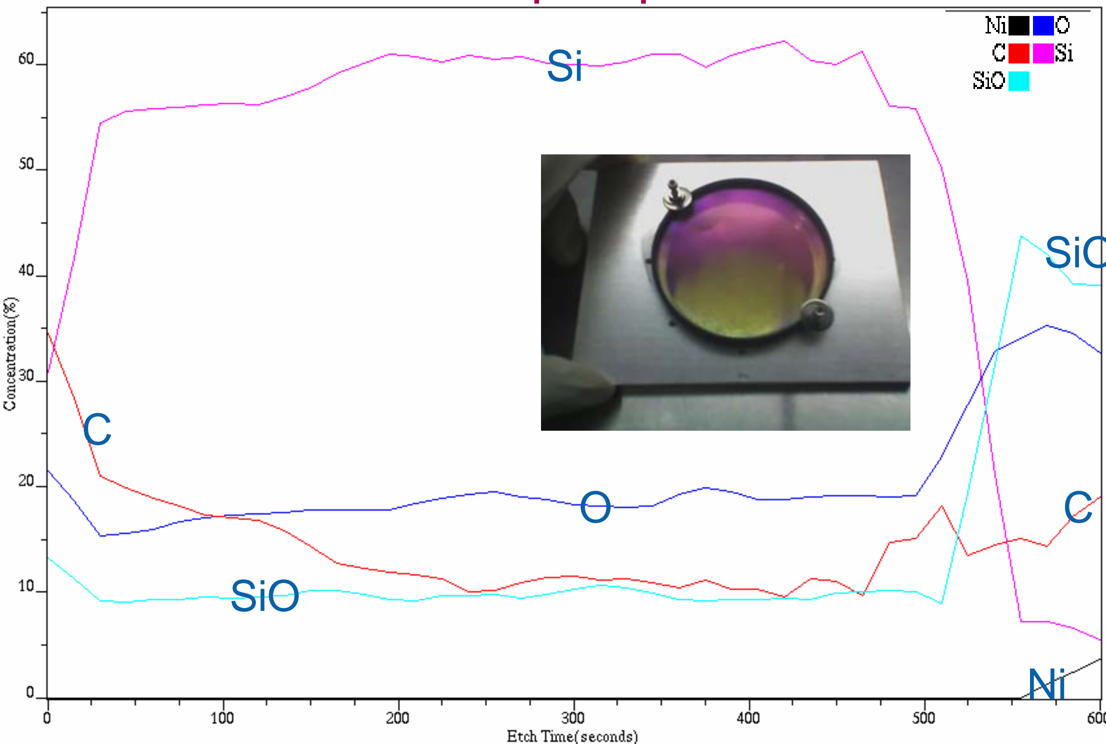
Mesh metrology: Si membrane study

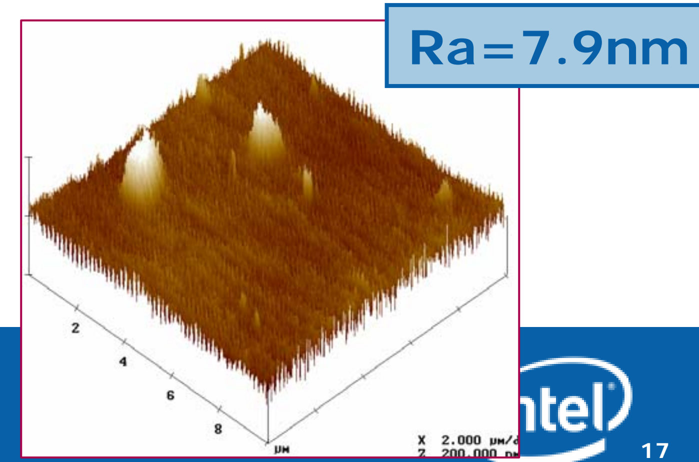
- 3″ sample
  - 150nm Si on 80% transmissive mesh
- Actinic measurement
  - Peak transmission = 53%
- Elemental decomposition via XPS indicates need for capping layer.

At-wavelength (13.5nm) in-focus scan



XPS depth profile

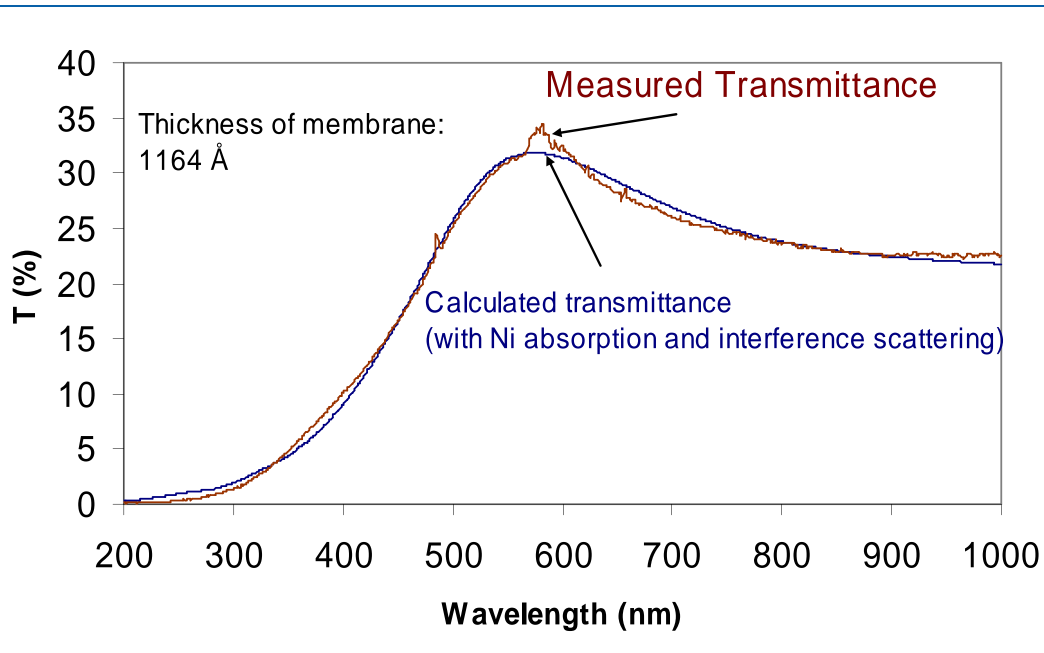


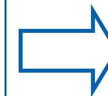


Full-scale pellicle optical metrology

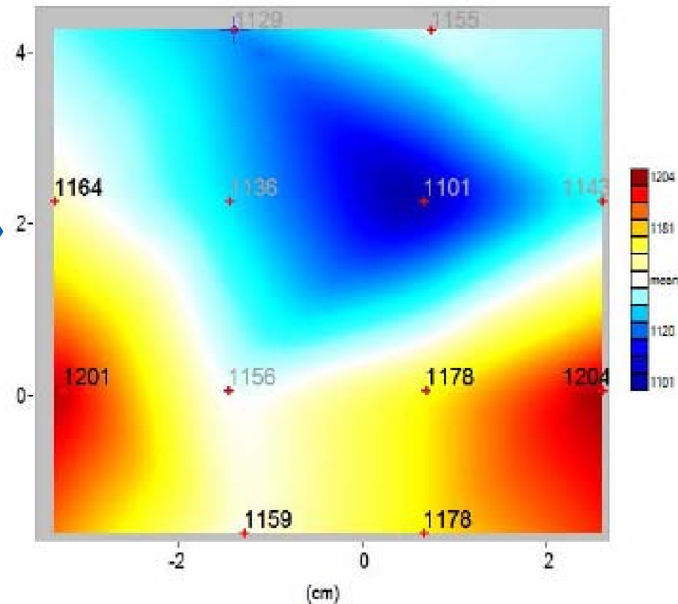
Non-destructive pellicle membrane thickness measurement is necessary to comply with high volume production requirements.

- An optical metrology model is developed and calibrated using (n,k).
- Rapid pellicle membrane thickness 2-D map generation capability.

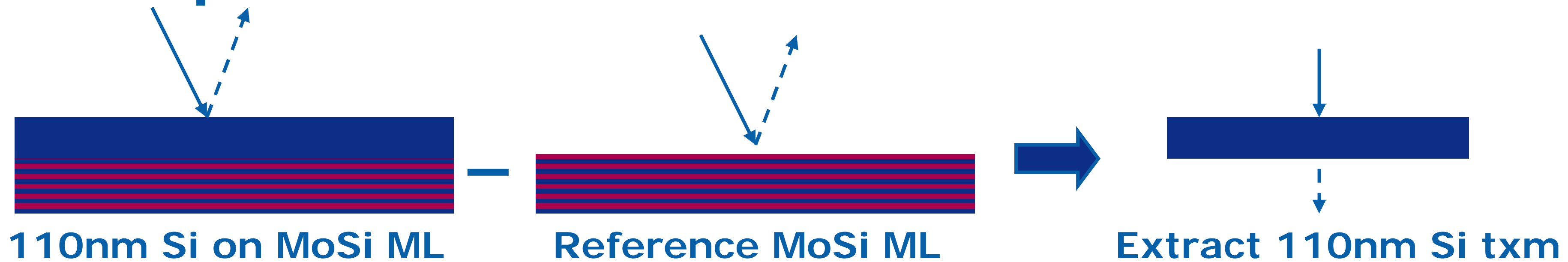


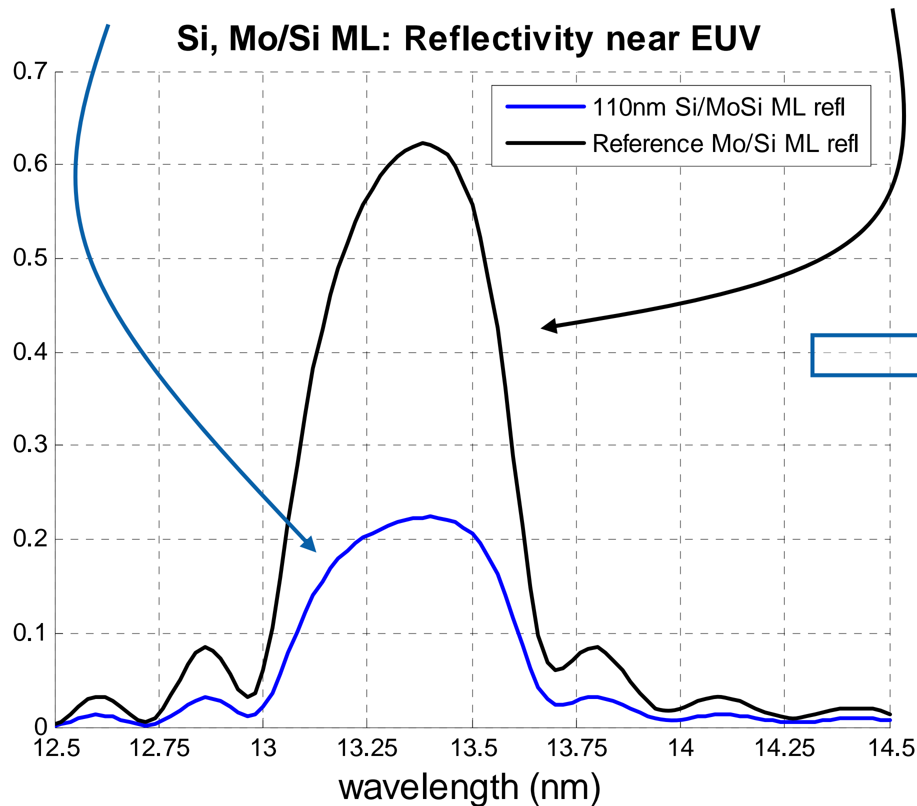


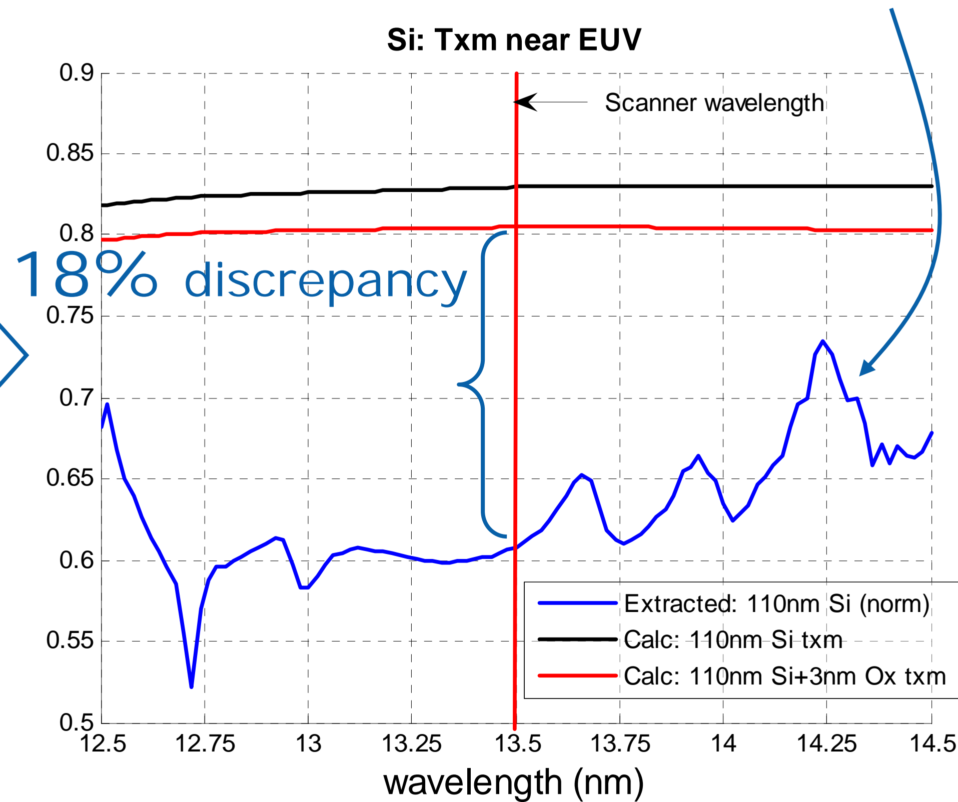
Film thickness Uniformity map



Si deposition on Mo/Si ML





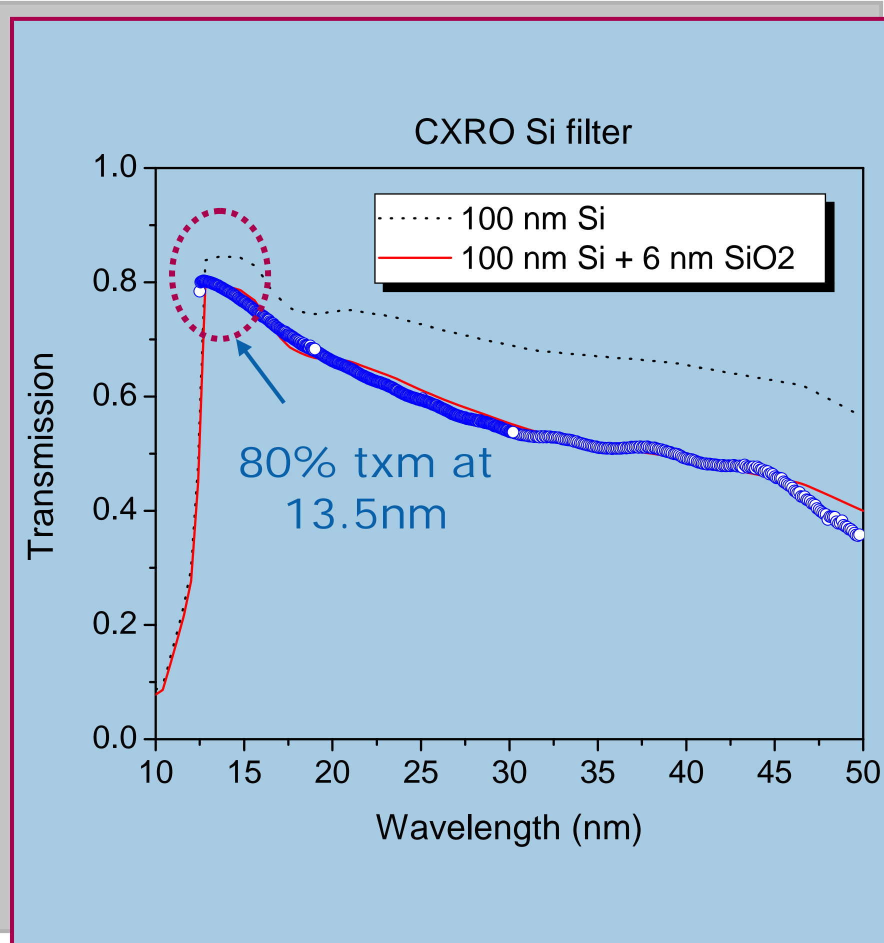


Note: Calculated Si and SiO2 transmissions are based on CXRO data

Towards improving pellicle membrane transmission

- Measured Si membrane transmission is lower than expected for crystalline Si with surface oxidation.
- Need to alter deposition conditions to improve intrinsic Si transmission.
- Magnetron sputtered Si proven for high transmission at EUV wavelength. See chart

  (Source: Eric Gullikson, ALS)



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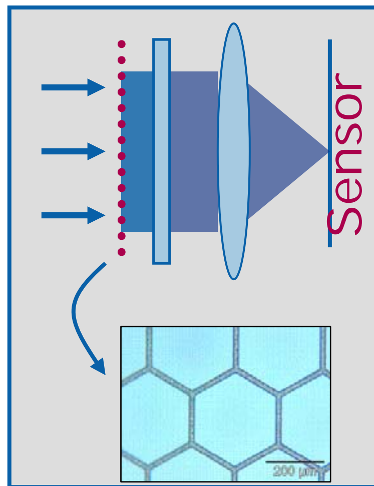
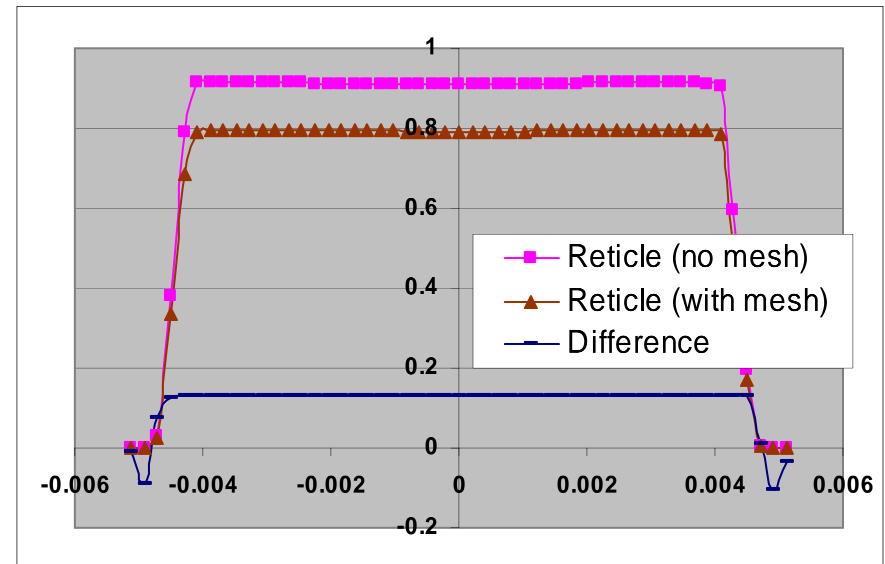
DUV exposure with blank mesh: Full scan speed

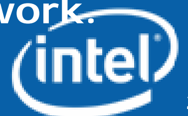
- Experiments run on an ASML XT 1400*
  - 23x26mm field, 11x51 point sampling
  - Mesh transmission 91%, LW = 18µm, pitch = 300µm
  - Reticle transmission 90%, stand-off height = 5mm
  - NA = 0.93, σ = 0.75
- Best dose for same CD is 10% higher for exposures with mesh pellicle. This is consistent with a mesh transmittance of 91%.
- Sensor at wafer-plane averages out mesh impact.



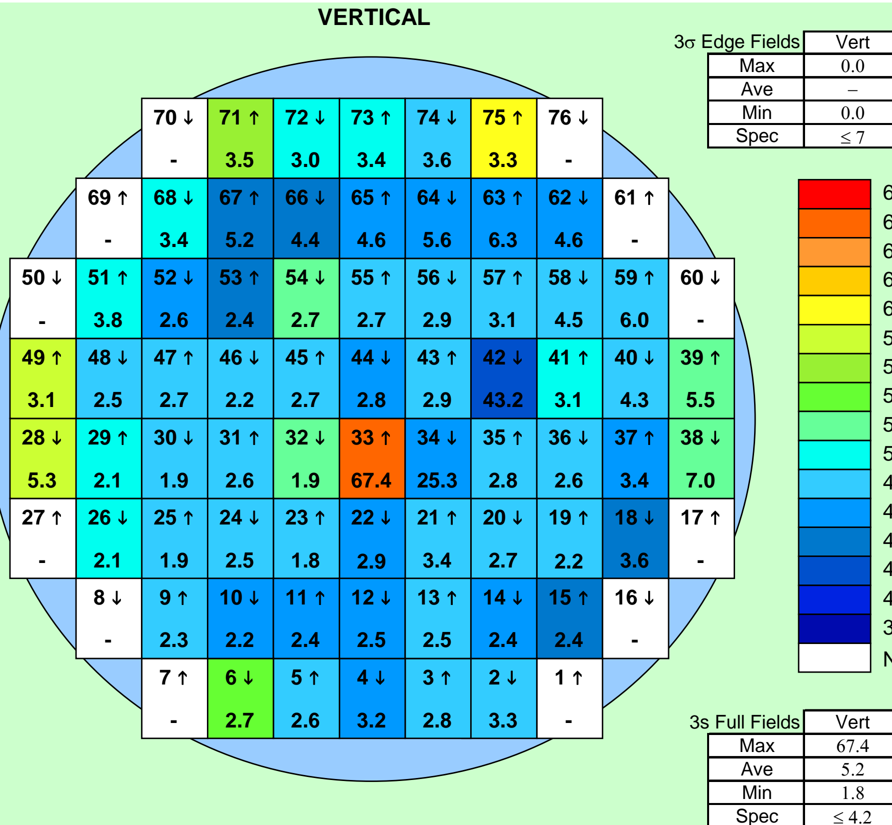
Blank reticle line scan



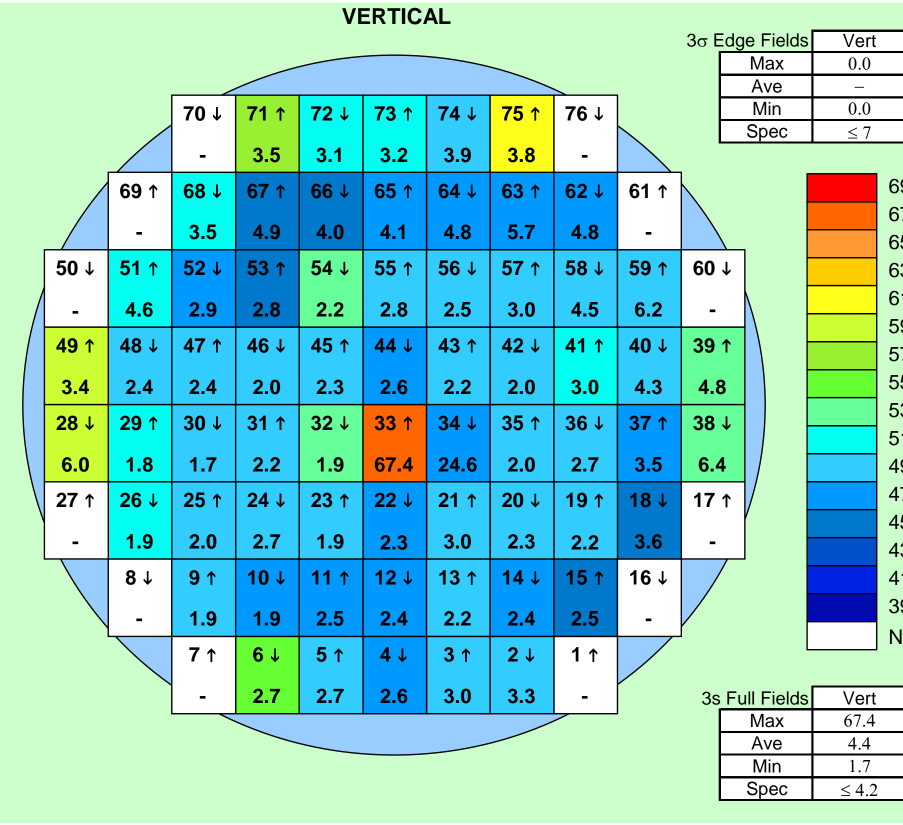
* Thanks to Nanda Samarakone and Jim Hunter of ASML for supporting this work.



CDU analysis – full field CD uniformity



With pellicle



Without pellicle

- **CD uniformity difference between wafers with and without mesh is negligible – on average 0.2nm difference observed.**

Summary

- A new model of illumination uniformity for pellicles has been created. Results are consistent with experimental data.
  - Mechanical stability in mesh is an important factor – low stress and high structural rigidity with decreasing line-width are needed.
  - Modeling results indicate linear dependence of LW to illumination uniformity. Hexagonal mesh with 250μm pitch chosen. Current line-width of 18μm will ultimately drive to 5μm.
- Full-scale pellicle created and at-wavelength transmission measured.
  - 100% yield in membranes. Process is reliable.
  - Single-pass EUV transmission at 58%
- Capping layer optimization shows 3.3nm Ru can improve membrane stress without compromising EUV transmission.
- Successful field run with ASML's XT1400 tool by mounting a blank mesh on patterning reticle. Negligible impact on CDU, process latitude at DUV.
- Created a model to measure pellicle uniformity using non-destructive optical techniques.
- Future work:
  - Quantify reticle defect mitigation using EUV pellicles
  - Improve single-pass transmission to 84% with implementation of suitable capping layer solution with improvement in sputter deposition process, reduction in film thickness, and higher mesh transmission.

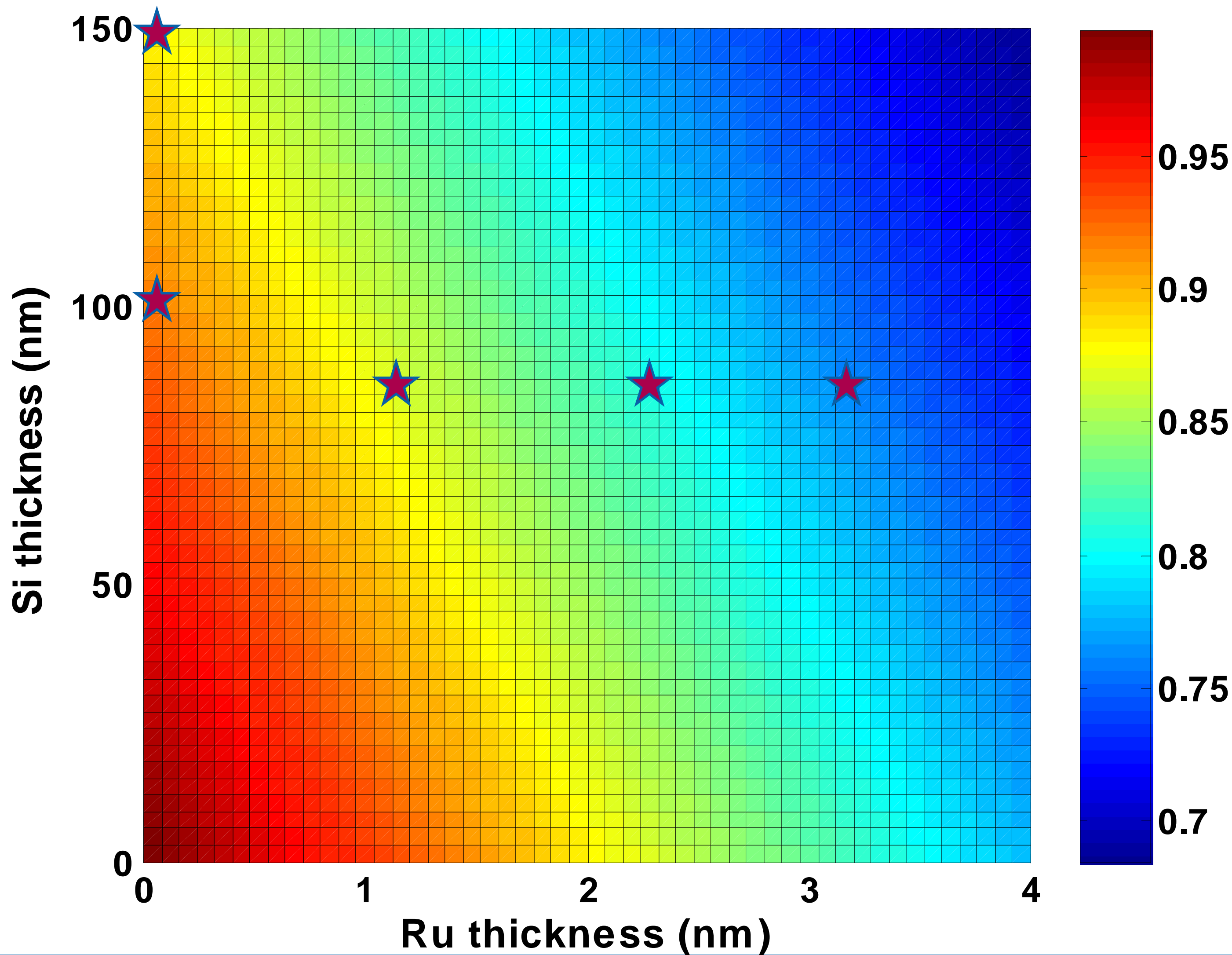
Thanks to...

- Eric Gullikson at the Advanced Light Source EUV beamline (LBL) for at-wavelength transmission measurements.
- ASML (particularly, Nanda Samarakone and Jim Hunter) for supporting mesh CDU imaging study at DUV with XT1400.
- Brian Coombs (Intel) for ECD measurements of wafers.
- MATTEC (Materials Technology) at Intel for AFM and elemental depth profiling of membranes via XPS.
- Ravi Mullapudi at Tango Systems (San Jose, CA) for helping develop reliable membranes on challenging substrates.
- Committed support from senior management at Intel for funding and providing resources for the project.

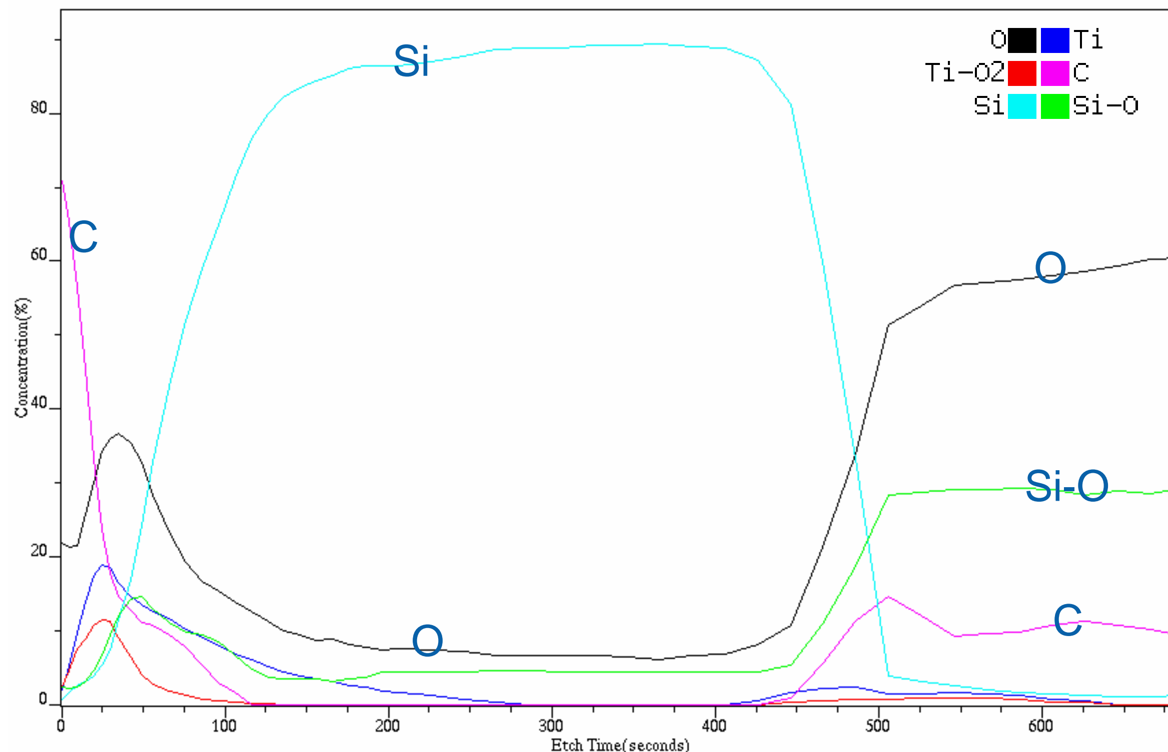
Backup

Si / Ru transmission

★ DoE: Cap layer optimizations

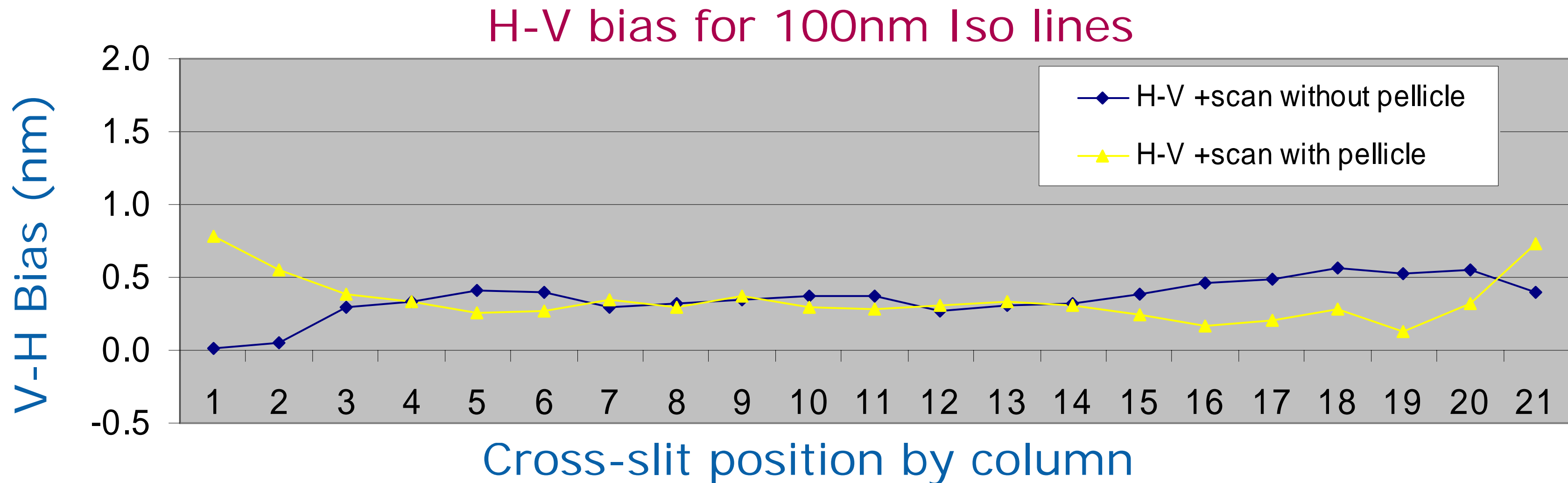


XPS metrology: Ti/Si/Ti profile



- Capping layer protects Si from oxidation, improving transmission
- Marginal cap layer oxidation observed

CDU analysis for mesh impact at DUV



- Process window curves with and without pellicle are comparable.
- Best dose for same CD is 10% higher for exposures with mesh pellicle. This is consistent with a mesh transmittance of 91%.