Next Generation EUV Mask Blank Absorber Development

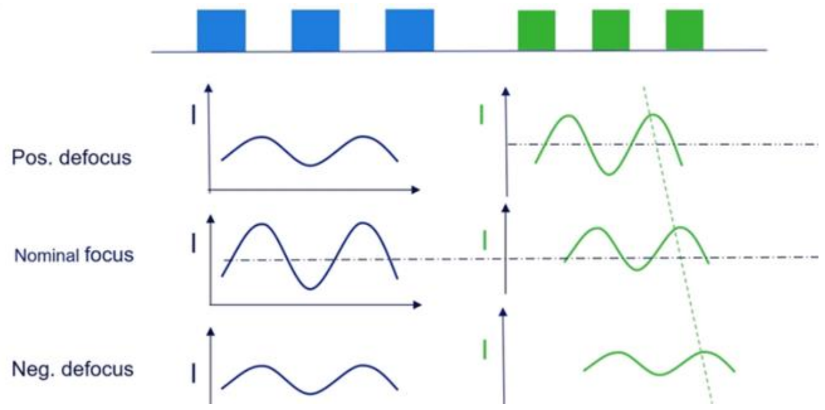
Vibhu Jindal, Shuwei Liu, Kan Fu, Weimin Li, Wen Xiao, Khor Wui,
Abbas Rastegar, Sankesha Bhoyar, Madhavi Chandrachood

Applied Materials

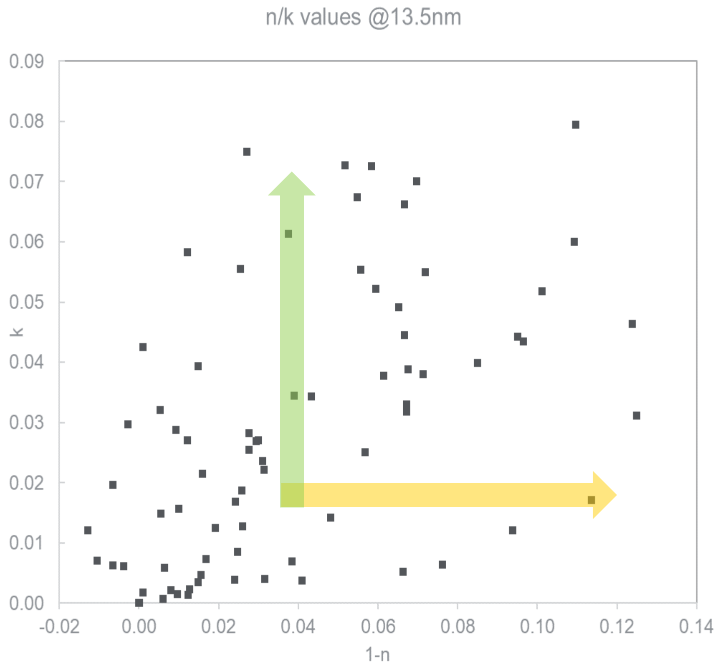
Why change in EUV Absorber?

- Mask 3D effects
  - Feature dependent placement shift through-focus => Edge placement errors
  - Best focus variation through feature size => Process window
  - Contrast loss

- Investigation of new materials
  - Increase extinction coefficient (k) => high k absorber
    - Reduce Mask 3D effects
  - Decrease refraction index (n) => Use phase shift
    - Enhance NILS
  - Combination of two



Jo Finders, SPIE, 1095714, 2019

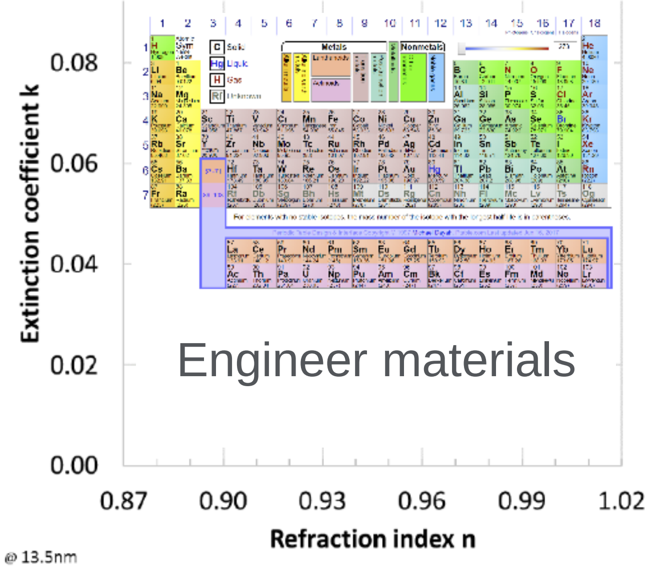


Applied's Absorber Development: Methodology

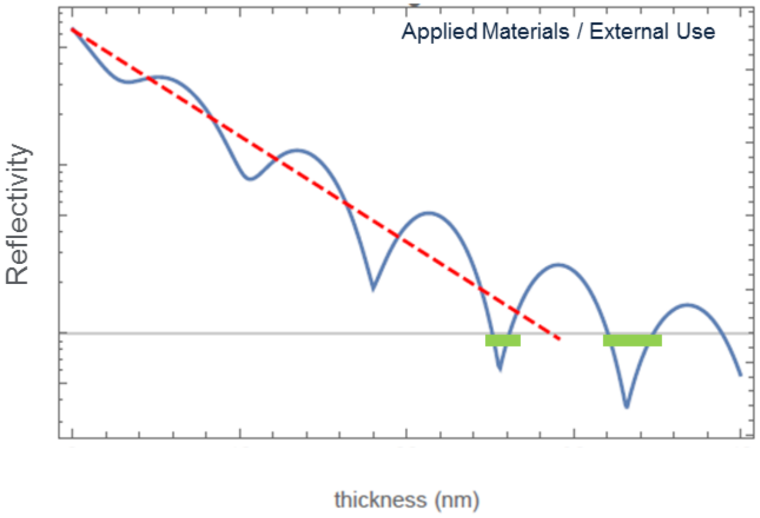
- Deposition Requirement
  - Ability to have single phase material system
    - Multiphase and composite systems will not be able to generate good absorber properties
    - Need multivariate simulations to determine the material system
  - Ability to deposit amorphous films
    - Thermodynamically: Requires thermodynamic assessment of amorphous formability in higher order material system. Simulation dependent approach.
    - Film development: Utilize kinetic and parametric models based on legacy knowledge to determine deposition methods and conditions
- First principle approach
  - Development of density models for higher order material system (Simulations)
  - Thermodynamic assessment for amorphous formability (Simulations)
    - Minimize ΔG
    - Semi empirical formula for formation of enthalpy ΔH

$\Delta H = \Delta H^{chemical} + \Delta H^{elastic} + \Delta H^{structure} + \Delta H^{topological}$ H_f(amorphous) should be less than H_f(solid)

  - Utilize Kinetic and parametric models based on legacy knowledge to select deposition methods and conditions (Internal database)



Engineer materials



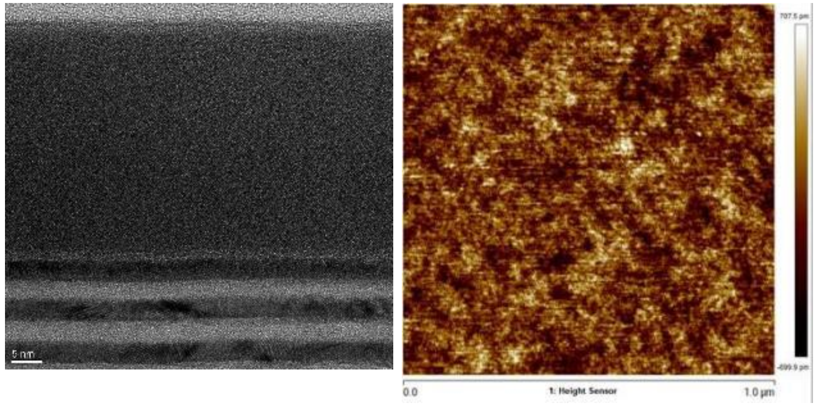
Impact of process window

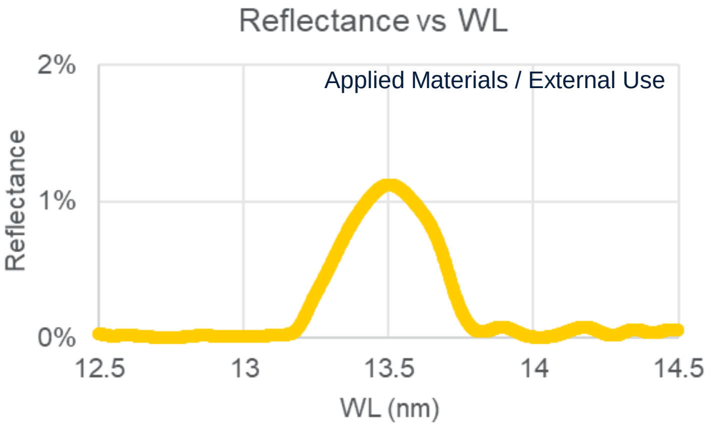
Do Simulations and Parametric Models work ?

Material System A

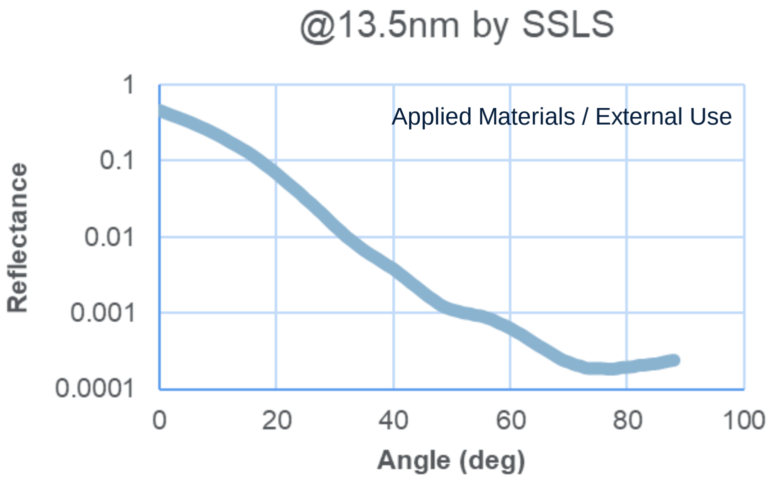
ML	Absorber (A)	
Reflectivity	Thickness (nm)	Reflectivity
65.7%	34.7	1.1%
65.4%	40.4	0.7%
65.2%	44.1	0.4%

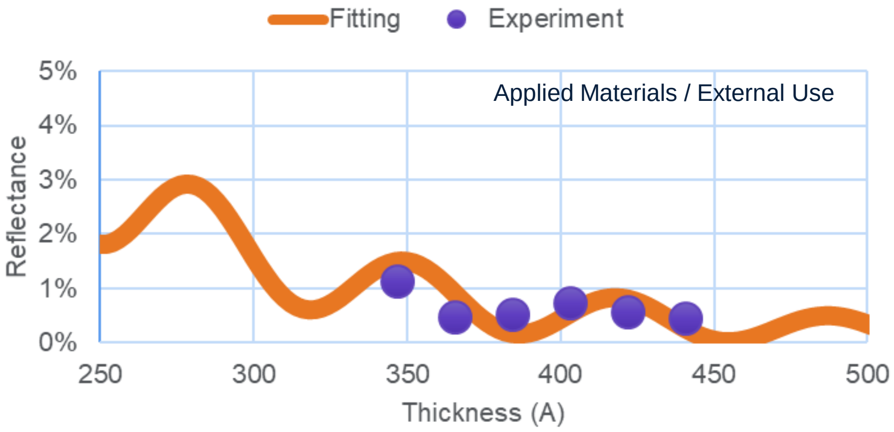
Applied Materials / External Use TEM





- Material system A shows amorphous
- Material system A shows <2% R_max with **<35nm** film thickness
- Experimental result matches well with simulation data

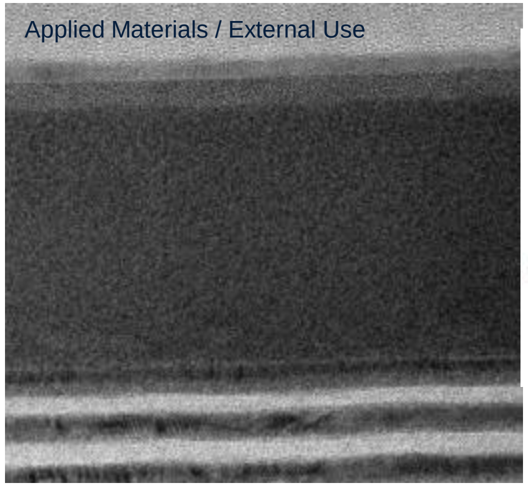


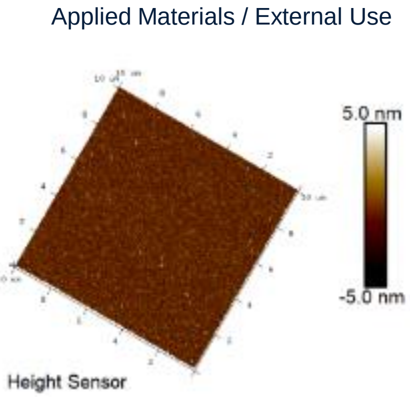


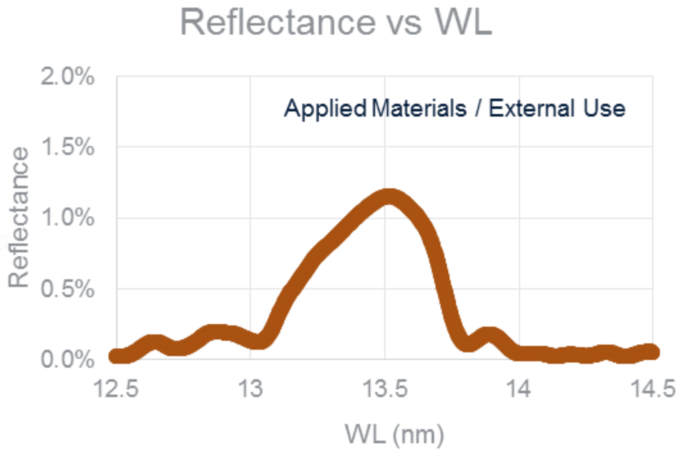
Material System B

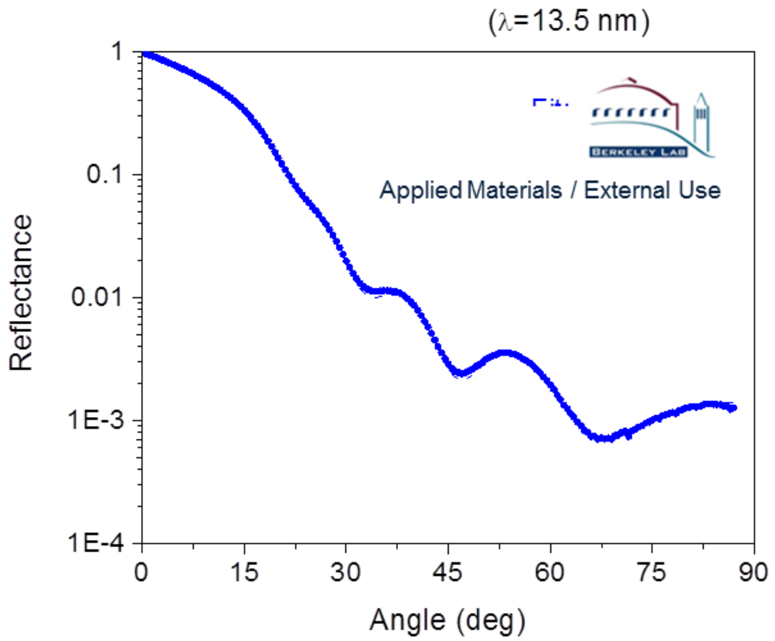
ML	Absorber (B)	
Reflectivity	Thickness (nm)	Reflectivity
66.87%	35	1.96%
66.02%	40	0.98%
66.82%	45	0.82%

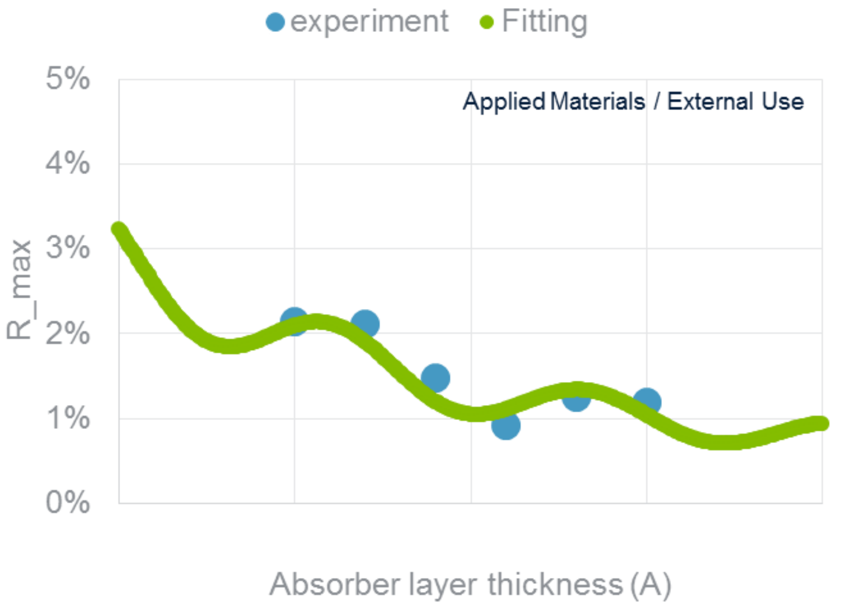
- First principle approach successfully helped to determine multiple material systems
- Material system A shows <2% R_max with **<35nm** film thickness
- Optimized deposition techniques provide amorphous, low reflectance films









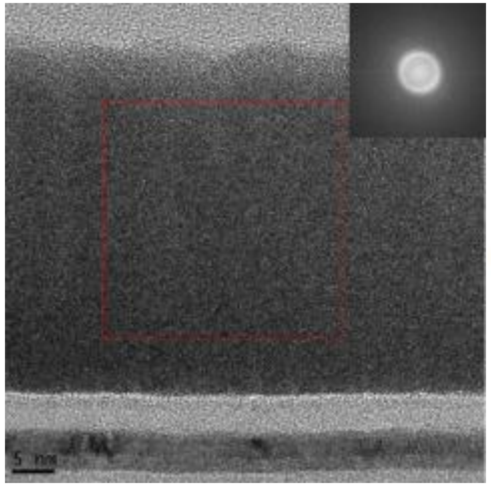


Material System C

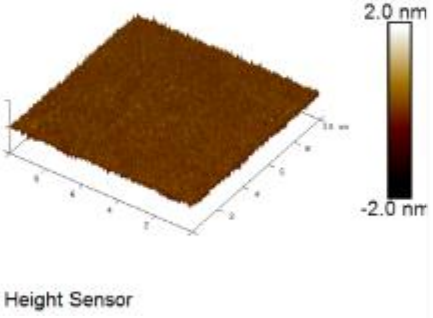
ML	Absorber (D)	
Reflectivity	Thickness (nm)	Reflectivity
66.3%	35	3.5%
66.5%	40	1.8%
66.0%	45	0.2%

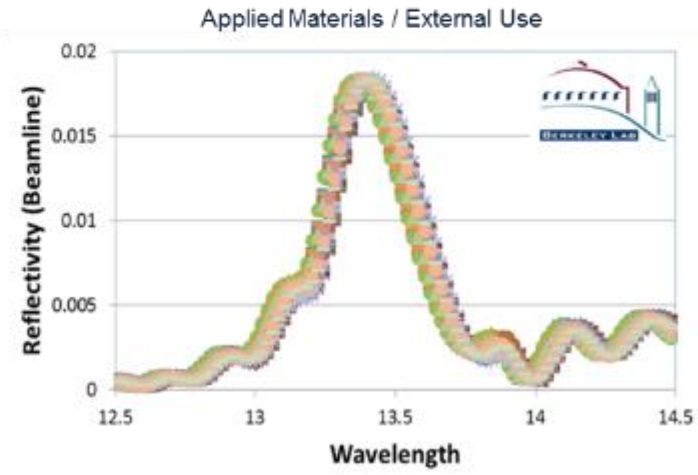
- First principle approach successfully helped to determine multiple material systems
- Optimized deposition techniques provide amorphous, low reflectance films

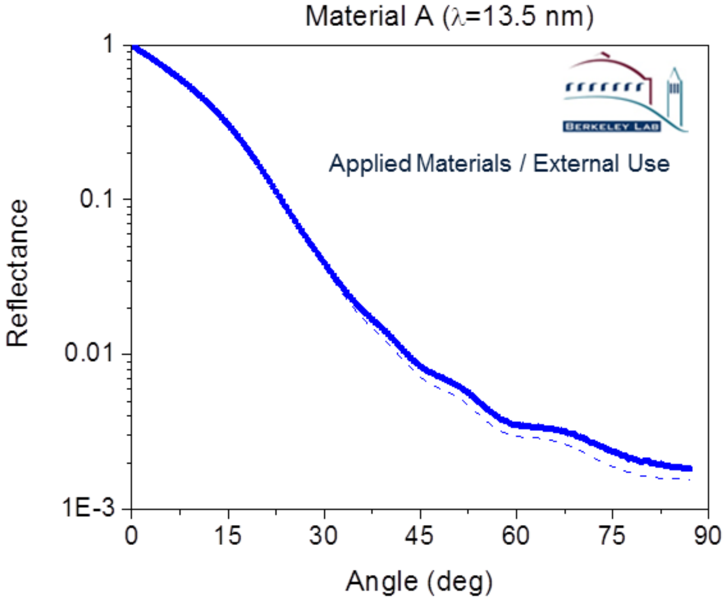
Applied Materials / External Use TEM

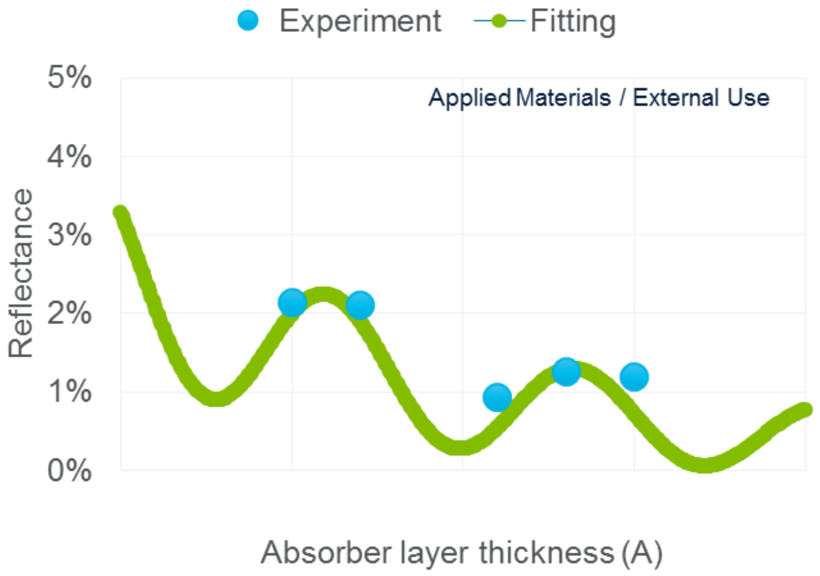


Applied Materials / External Use AFM

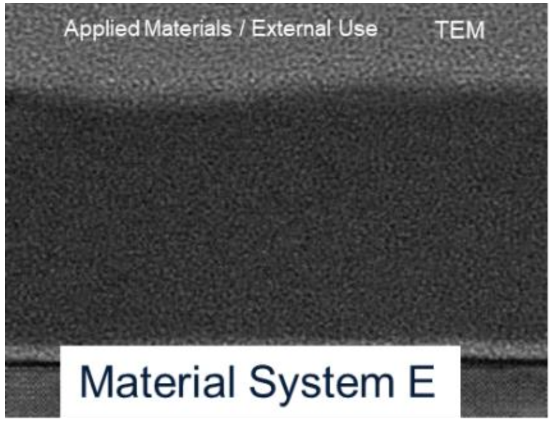




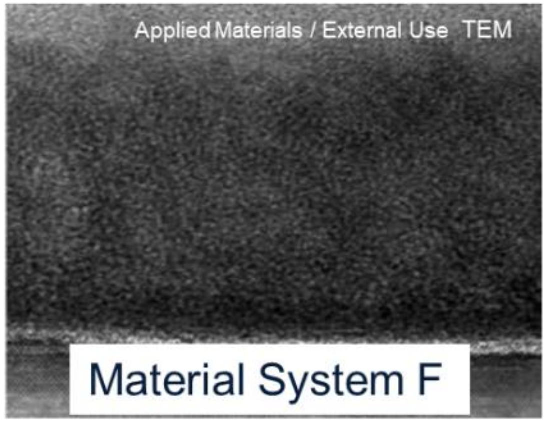




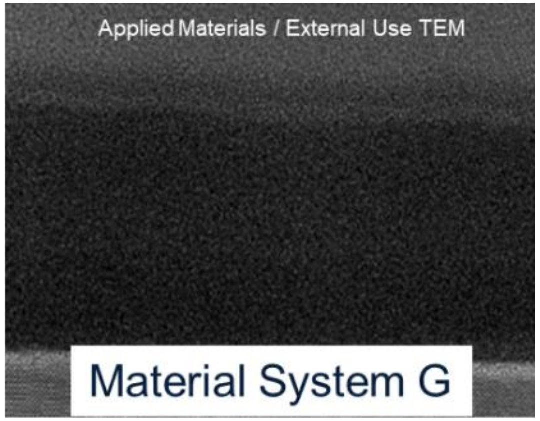
Other material system development in progress



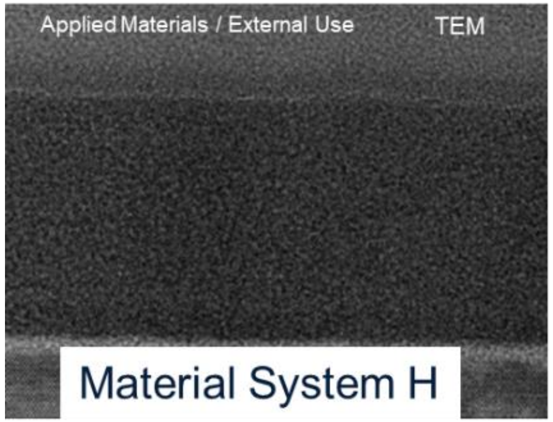
Material System E



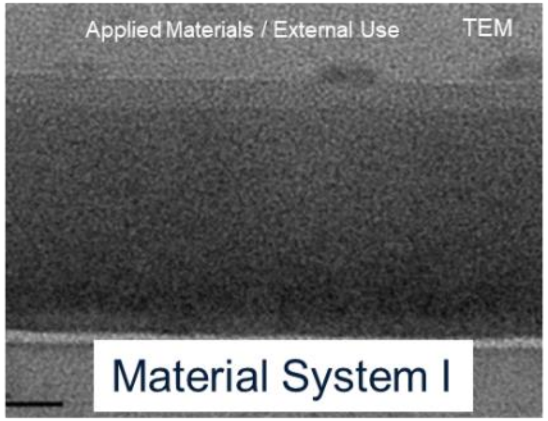
Material System F



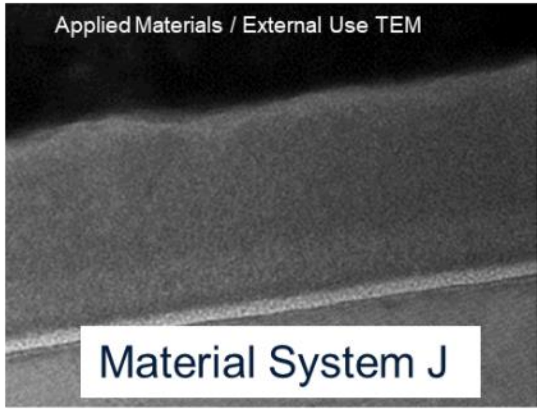
Material System G



Material System H



Material System I



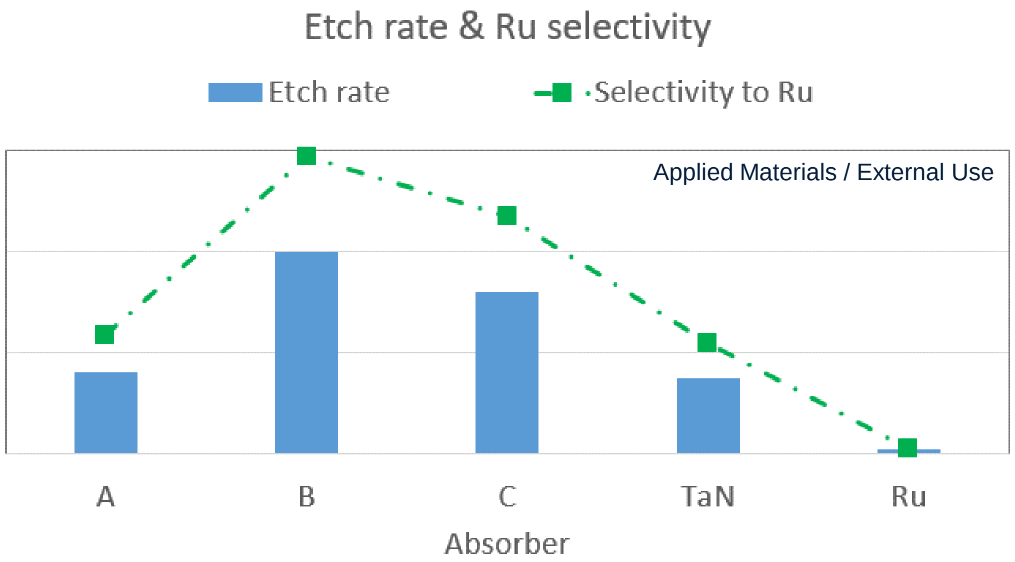
Material System J

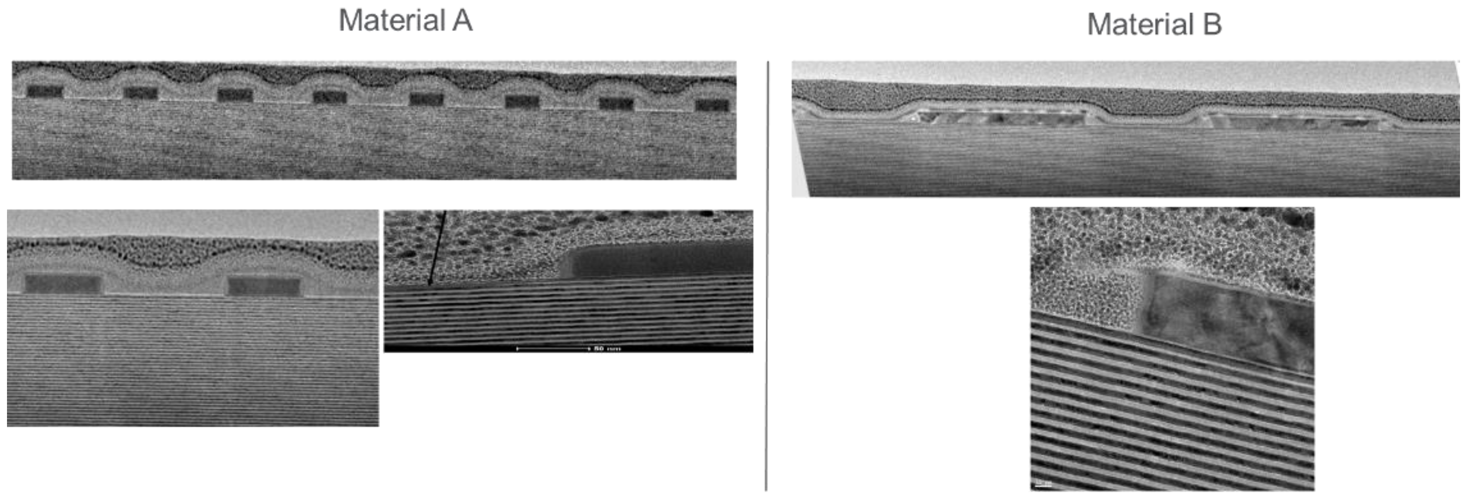
- Multiple other material systems exhibit amorphous single phase that provide less than 2% reflectivity for sub 45 nm thickness

Advanced Absorber Status

Key Objectives	Status	Comments
Develop fundamental simulation model to identify material systems	Done	
Verify deposition material systems for key dep characteristics	Done	
Achieve <2% Ref with sub 45nm	Done	10 promising material systems
Etchability	Done	Using traditional chemistries
Selectivity with Ru	Done	Good etch stop with Ru
Cleaning durability	Done	No damage until 50X cleans
Inspection	Done	Using 193nm and 266nm inspection
Scanner environment compatibility	In process	Working with ASML and TNO
Defect Repair	In process	Engagement with Zeiss
Scanner Image	In process	Early SHARP imaging completed Working with customers • Imaging at SHARP, MET • Imaging at Scanner

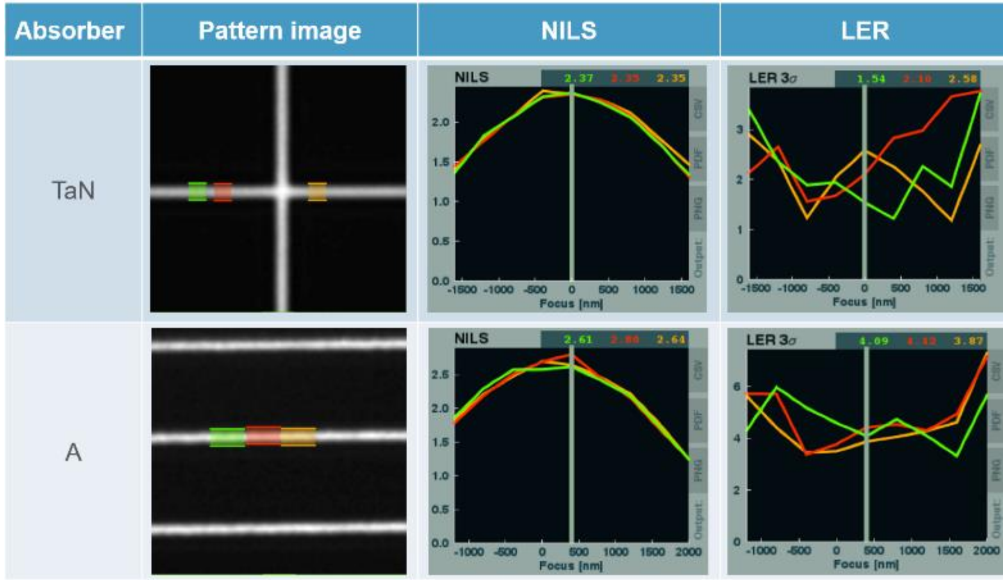
Etch for Advanced Absorbers



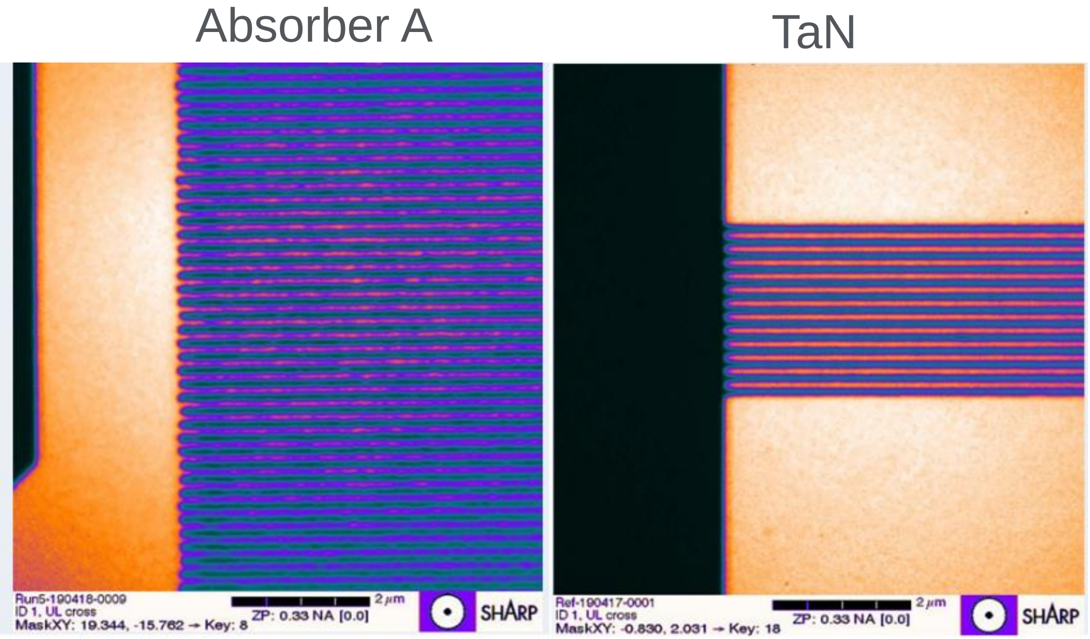


- Material System A, B and C show good etch rate and Ru selectivity under traditional RIE chemistries
  - Material system A shows comparable etch rate & selectivity to POR TaN
  - Material systems B & C show better etch rate & selectivity to POR TaN

SHARP Imaging Result of Material A



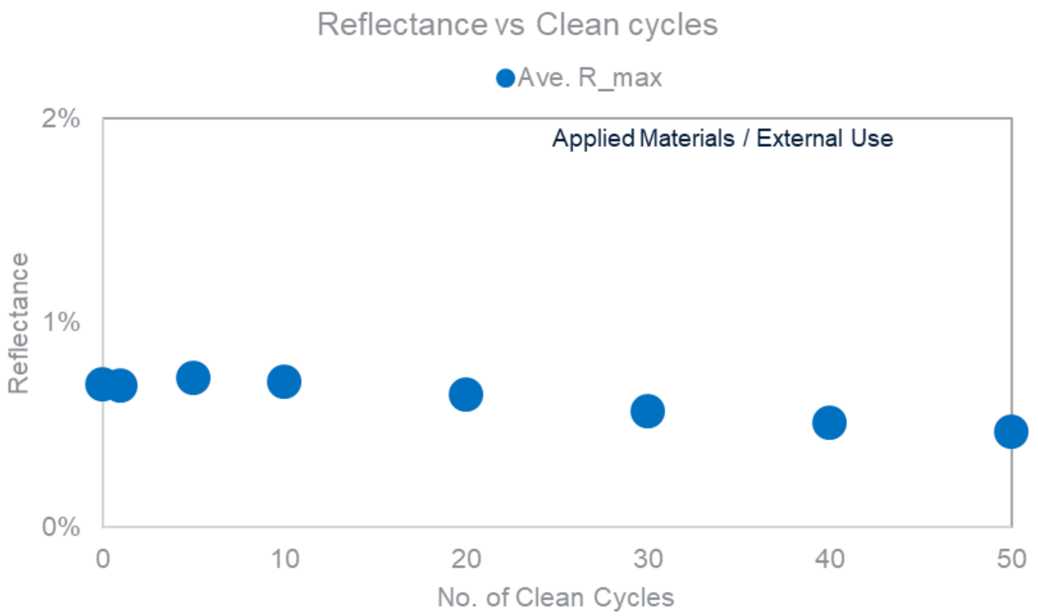
Absorber	Pattern image	NILS	LER
TaN			
A			

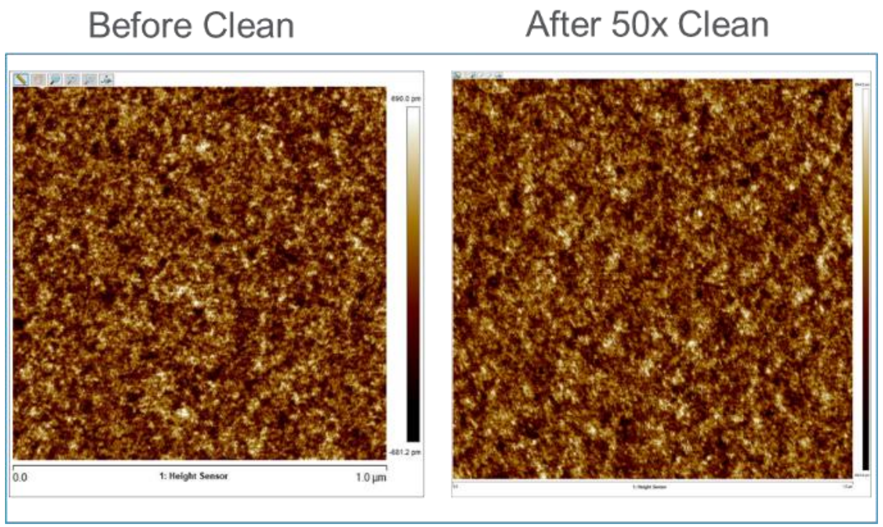


- Absorber A shows better NILS and contrast than TaN
  - Absorber A patterning process can be optimized further to reduce LER which will further improve NILS

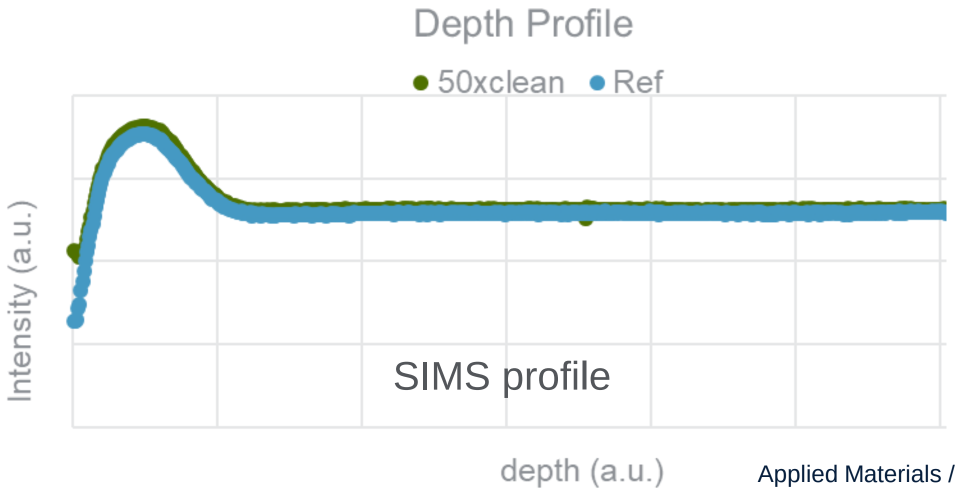
Credit: Markus Benk, CXRO

Clean Reliability of Absorber A





AFM 1by1um



- Absorber A demonstrated good cleaning reliability, after 50x Clean
  - No discernable film deterioration
  - Optical reflectivity is stable
  - No composition change across the film

EUV Mask Blanks: Gen 2 Product Development

Key Objectives	Status	Comments
Develop fundamental simulation model to identify material systems	**Done**	
Verify deposition material systems for key dep characteristics	**Done**	
Achieve <2% Ref with sub 45nm	**Done**	10 promising material systems
Etchability	**Done**	Using traditional chemistries
Selectivity with Ru	**Done**	Good etch stop with Ru
Cleaning durability	**Done**	No damage until 50X cleans
Inspection	**Done**	Using 193nm and 266nm inspection
Scanner environment compatibility	In process	Working with ASML and TNO
Defect Repair	In process	Engagement with Zeiss
Scanner Image	In process	Early SHARP imaging completed Working with customers • Imaging at SHARP, MET • Imaging at Scanner

- Multiple material system available demonstrating 35nm, 2% Ref that can be etched using traditional chemistries and selective to Ru
- One system completed all internal validation
- SHARP imaging completed. Working with customer on full mask patterning for scanner imaging

ML	Absorber (A)	
Reflectivity	Thickness (nm)	Reflectivity
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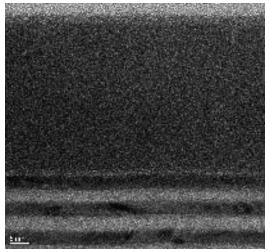
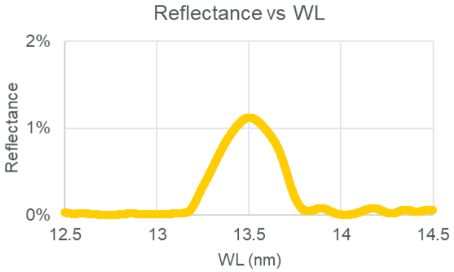
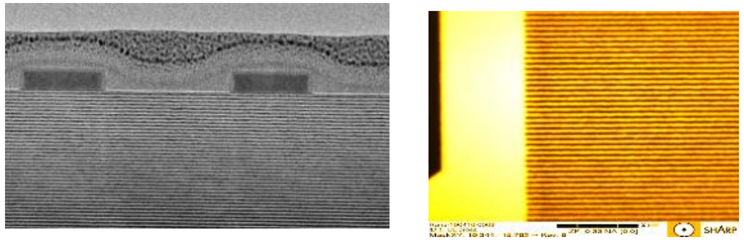
65.4%	40.4	0.7%
65.2%	44.1	0.4%





wavelength	n	k
12.5	0.958483	0.0574797
13.5	0.974095	0.0641557
14.5	0.987374	0.0653529

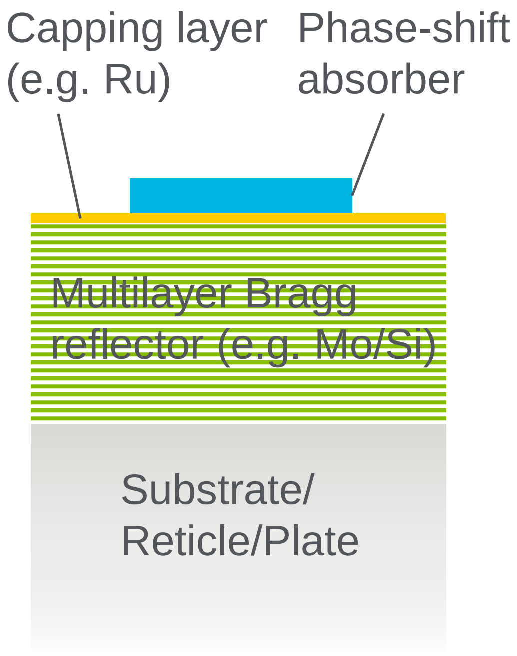


Patterned adv absorber using RIE and imaging under SHARP

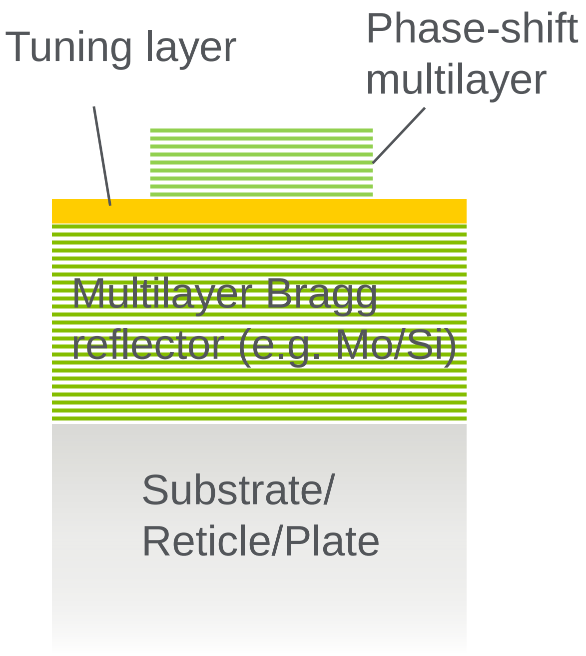
Blank structure development: PSM- C&F

EUV Phase Shift Mask: C&F

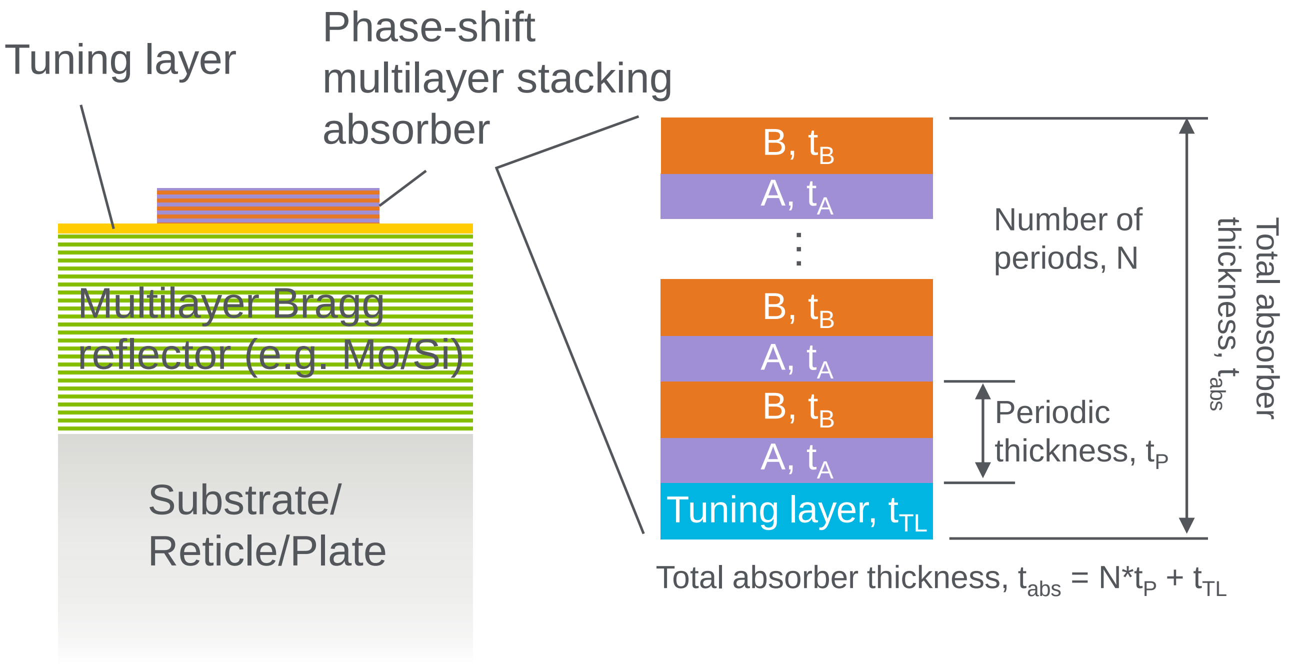
- Applied exploring feasible concepts for PSM leveraging materials innovation and ability to provide integrated solution to improve imaging quality.
- Solutions with strong customer collaboration



Single layer Absorber-based PSM



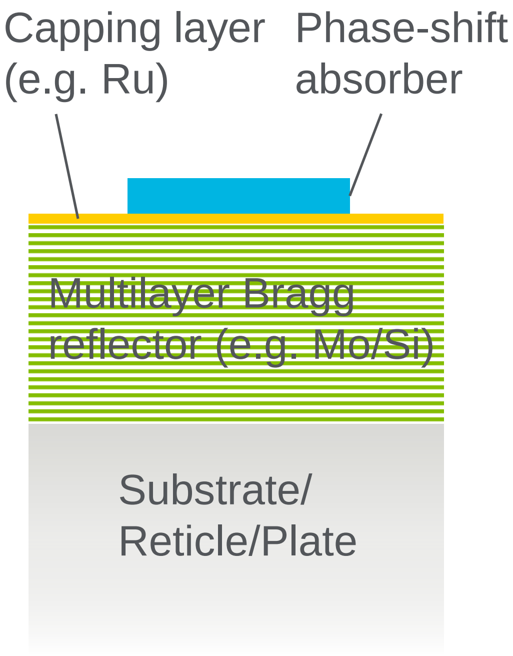
Multilayer-based PSM



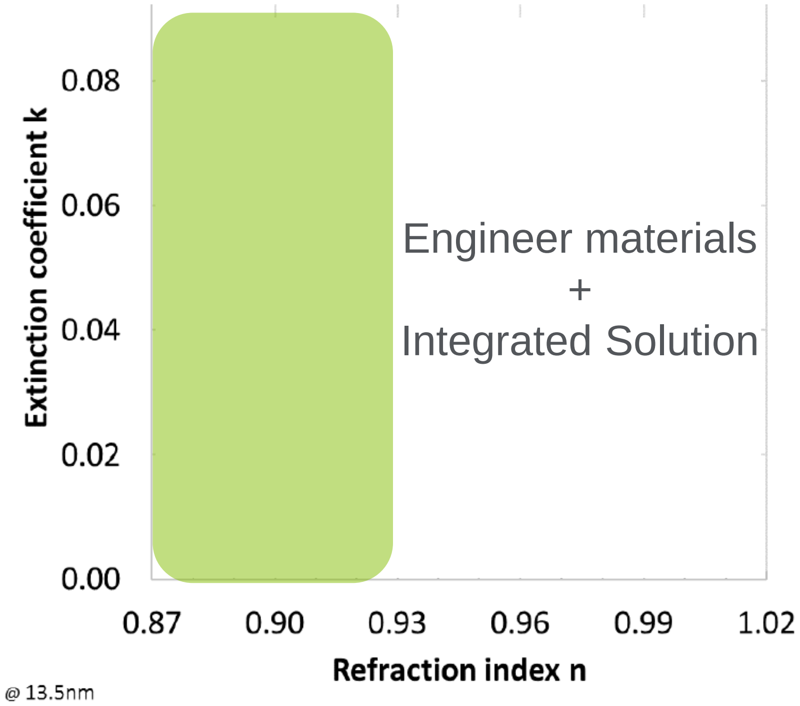
Multilayer-absorber PSM

EUV Phase Shift Mask: C&F

- Applied can tune n,k for single layer phase-shift multilayer based on same approach as taken for high-k
  - Similar challenges (Deposition, Etch, Clean, Repair, Inspection, etc)

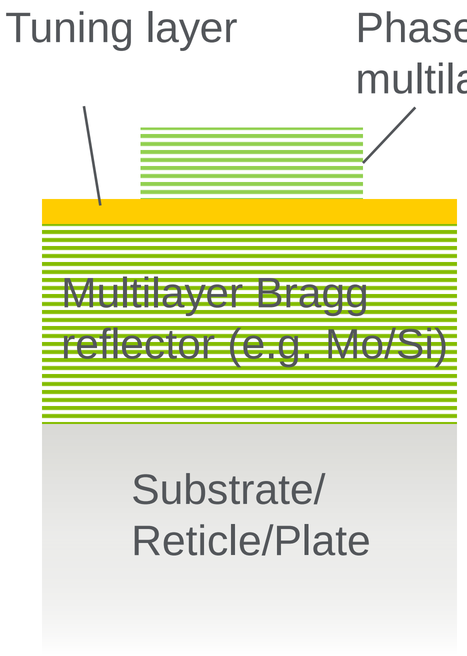


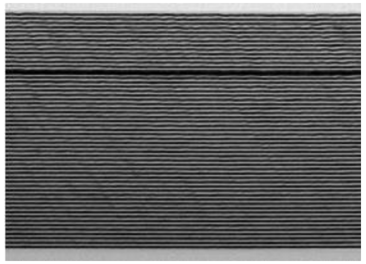
Single layer Absorber-based PSM

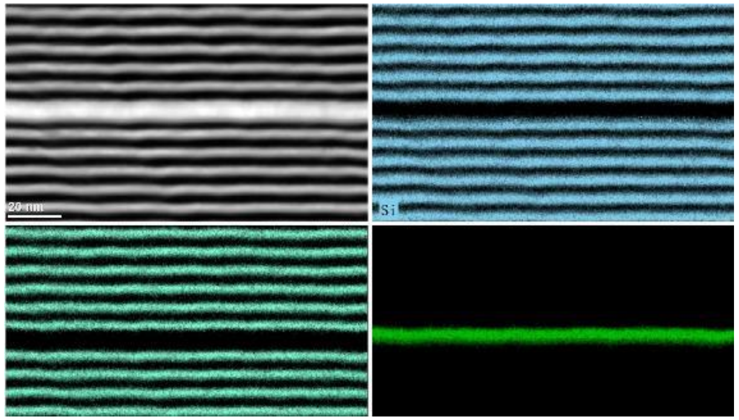


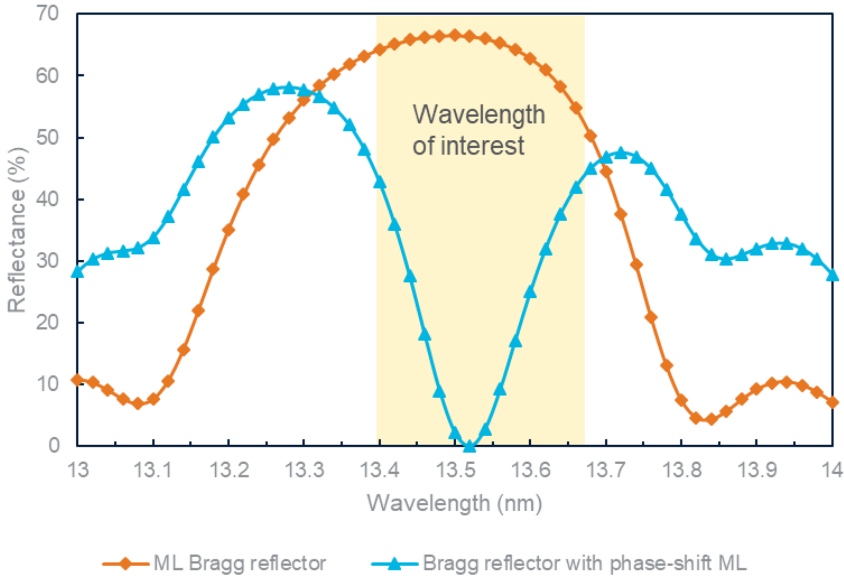
Multilayer-based PSM: Mo/Si and spacer

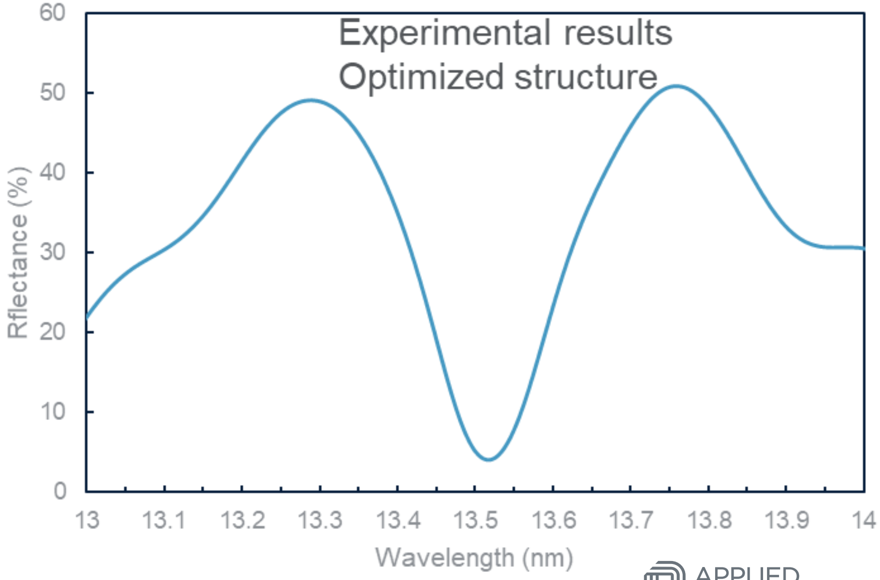
- 40xML / spacer layer / ML-(Mo/Si)











Multilayer-based PSM

- PSM with optimized spacer layer was proven in C&F.
- Precise etching and cleaning (undercut) is one of the major issues.
- Progress is made by etch stop precision and 3D cap layer for cleaning durability

Applied's commitment to provide holistic solution

Next Generation EUV Mask Blanks Requires Materials Innovation, Defect Control, and working closely on custom solutions

	Process Steps	Applied Presence
Mask Blank Manufacturing	ML Deposition	✓
	Ru Dep	✓
	Inspection	✓
	Absorber Dep	✓
	Mask Cleaning	✓
Mask Patterning	Patterning (BB)	✓
	Etch	✓
	Inspect	✓
	Defect Review	✓
	Mask Clean	✓

Top Customer
Insights / Problems
Customer Leverage

Customer focused Product
Development Process

APPLIED
MATERIALS ®

make possible