MITIGATING EUV MASK 3D EFFECTS BY ALTERNATIVE METAL ABSORBERS

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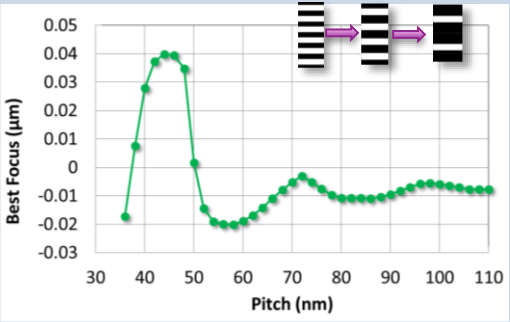
MASK 3D EFFECTS & MITIGATION STRATEGIES

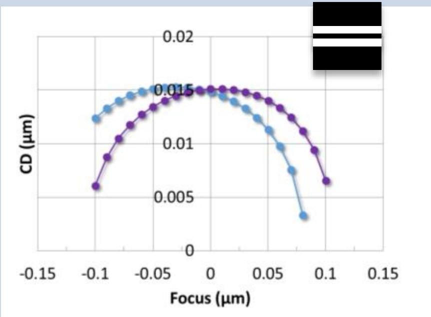
ONGOING EFFORT TO UNDERSTAND AND MITIGATE

***M3D observations at NA0.33* ***
using reference mask with 70nm Ta-based absorber

* See e.g., Philipsen EUVL symposium 2015



Best focus shifts through pitch

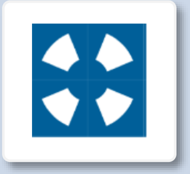


CD asymmetry through focus in 2bar

→ *will consume increasing part of focus and overlay budgets*

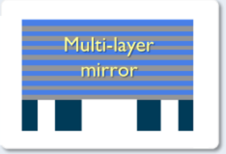
Mitigation strategies

Source optimization



See today Session 3 by L.Van Look
See Wed. Session 2 by A. Erdmann

Assist Feature placement



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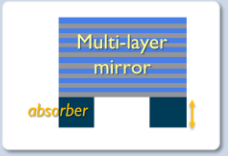
Absorber optimization



This presentation

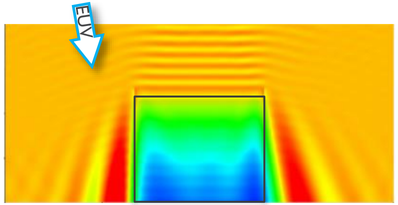
Goal is a feasibility study that singles out one suitable material that initiates the EUV blank supply chain to make the alternative commercially available

EUV MASK ABSORBER OPTIMIZATION

HOW DOES THE ABSORBER INFLUENCE M3D ?

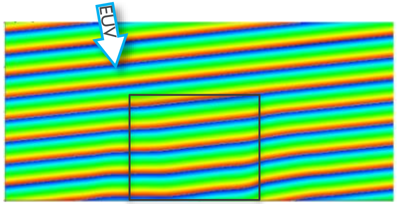
Reference = 70nm Ta-based

Nearfield intensity



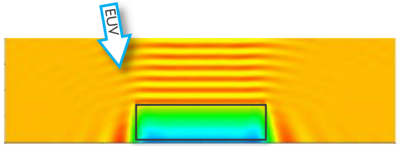
shadowing

Nearfield phase



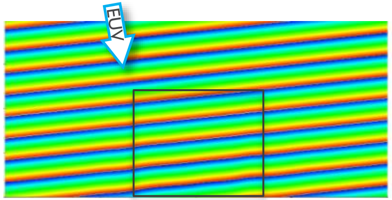
phase jump at absorber edges

① Reduce thickness, increase k



reduced shadowing and sufficient absorbing

② n closer to 1

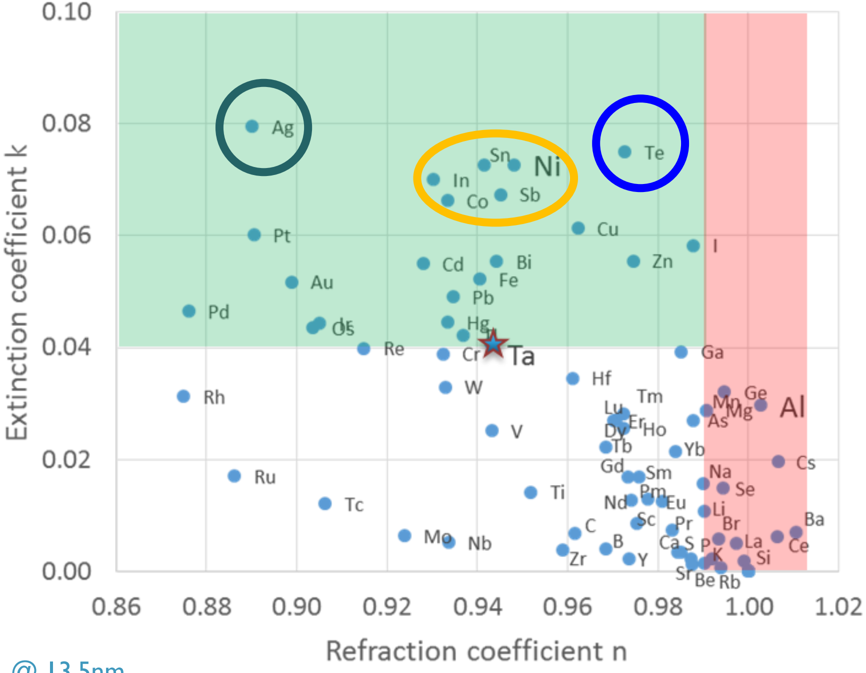


no phase jump at absorber edges

Absorber material and thickness influence the nearfield – high k and n~1 preferred

EUV MASK ABSORBER OPTIMIZATION

MATERIAL SELECTION



@ 13.5nm

Reducing thickness of current Ta material is not fully mitigating M3D effects *

Candidate high EUV absorbing materials:

- High k & n close to 1
  - Te
- High k & n similar to Ta
  - Ni, Co, Sb
- High k & n lower than Ta
  - Ag

Validate imaging performance of absorber candidates by

Rigorous simulations & modeling

* See e.g., Davydova, SPIE8886 (2013); Last, SPIE9650 (2015)

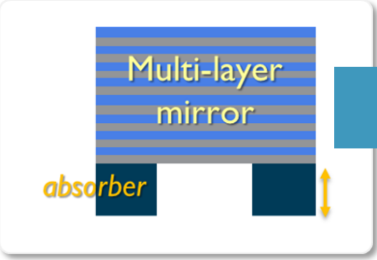
EUV MASK ABSORBER OPTIMIZATION

COMPLEX AND DIFFICULT CHANGE IN MASK TECHNOLOGY

- Uniform and amorphous deposition
- Defect free
- Reticle compatible
  - No interaction with and good adhesion to Ru cap
  - Stability of optical properties
  - Low surface roughness
  - …
- Patterning process
- Repair & clean process
- …

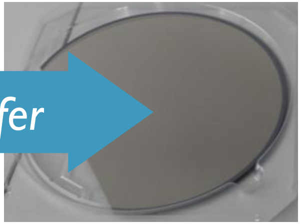
Film characterization
- XRR, XPS for material composition
- XRD, XTEM for structural information
- AFM, XRR for layer roughness
- EUVR for optical properties

Etching
- Optimizing etching processes
- Absorber profile (XSEM)
- Roughness (SEM)



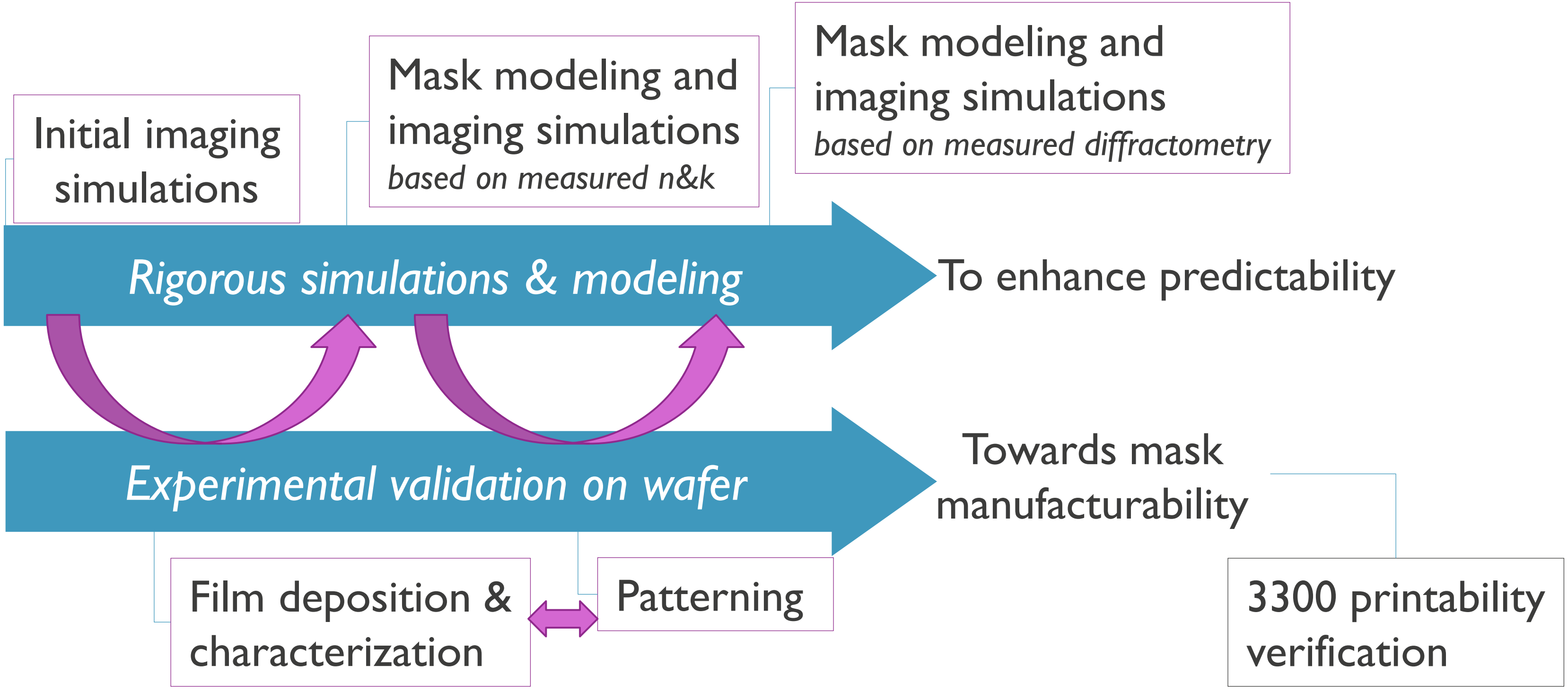
Experimental validation on wafer

Learning cycle on wafer is faster



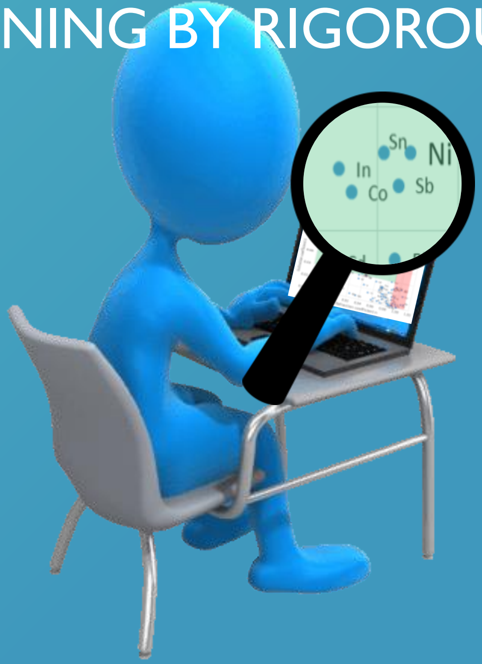
EUV MASK ABSORBER OPTIMIZATION

STRATEGY

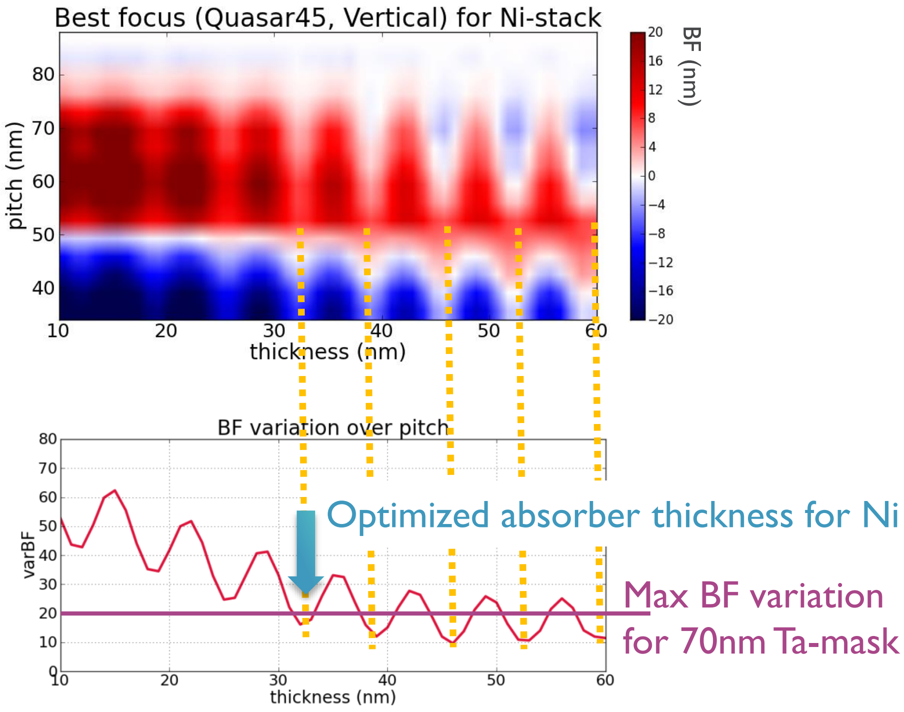


We started this comprehensive path to valorization to narrow down options for a complex and difficult mask technology change towards foundry N3

ABSORBER SCREENING BY RIGOROUS SIMULATIONS



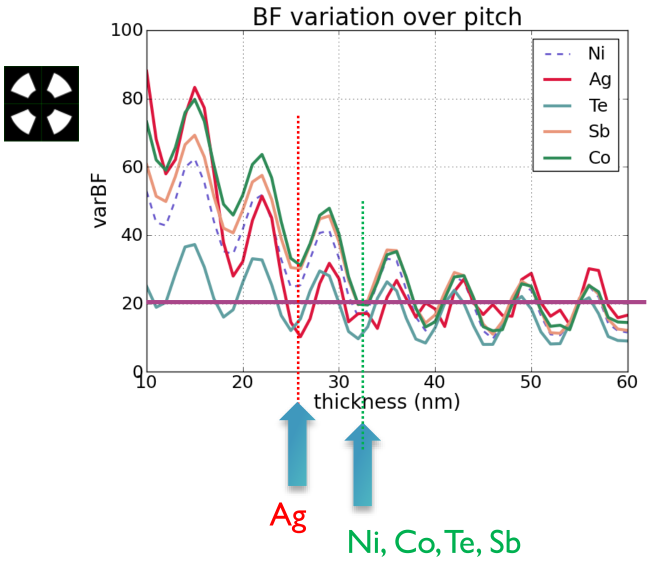
SIMULATION SCREENING PROCEDURE
ABSORBER THICKNESS OPTIMIZATION



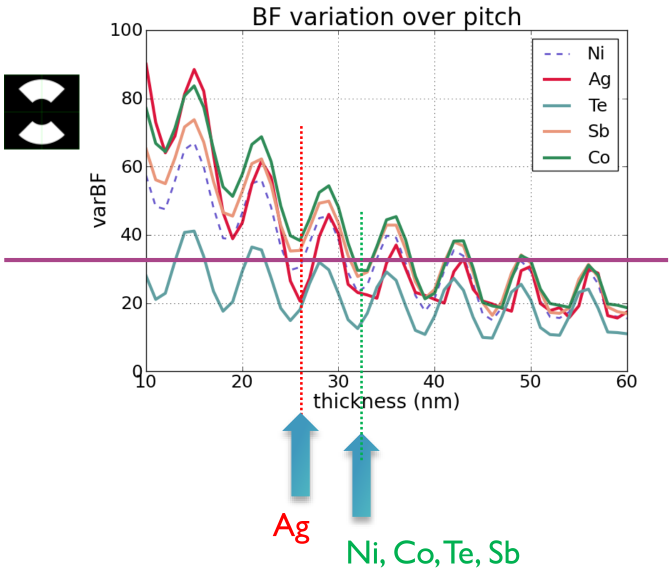
For each candidate absorber material and illumination:

- Computation of Best Focus through pitch and absorber thickness
- Extraction of range of Best Focus variation through absorber thickness
- Characteristic curve depends on illumination shape
- Identification of optimum absorber thickness

SIMULATION SCREENING
ABSORBER THICKNESS OPTIMIZATION



Max BF variation for 70nm Ta-mask

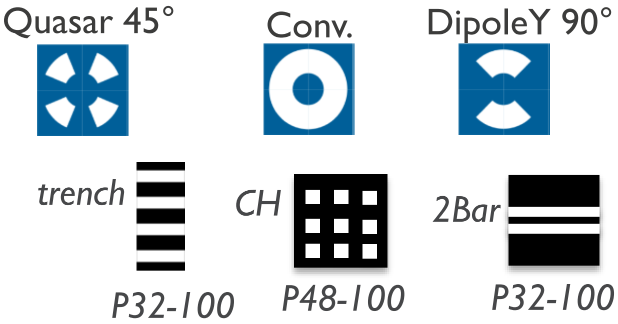


- Optimized metal film thicknesses around 30nm

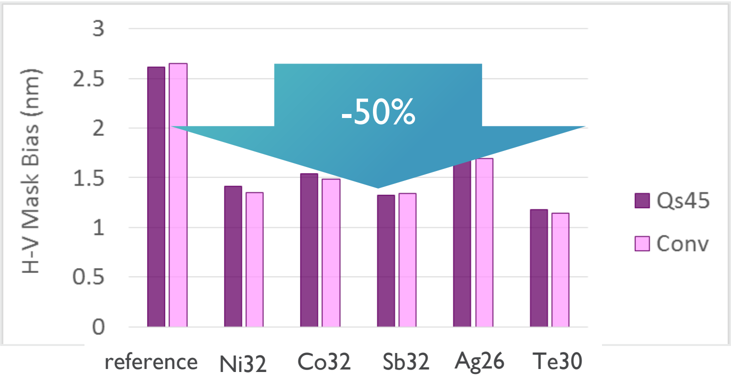
Candidate absorber material can be used at strongly reduced thickness compared to 70nm Ta-reference

IMAGING SIMULATIONS

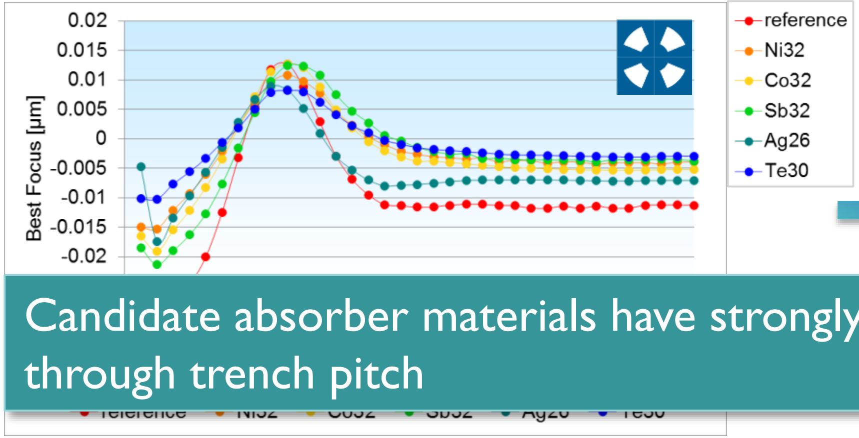
SETTINGS

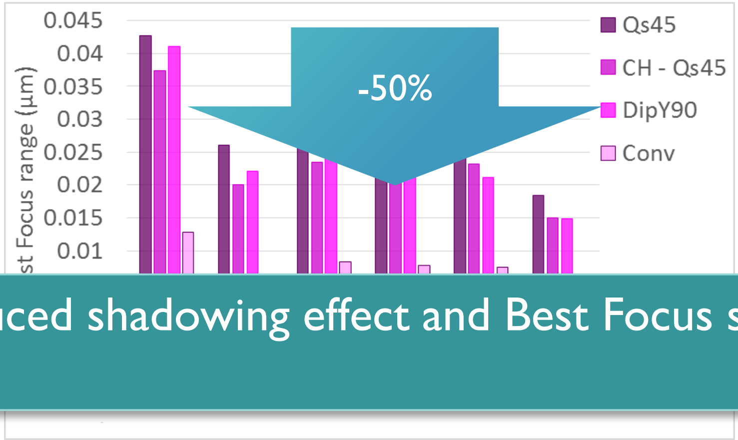


SHADOW BIASING



BEST FOCUS THROUGH PITCH

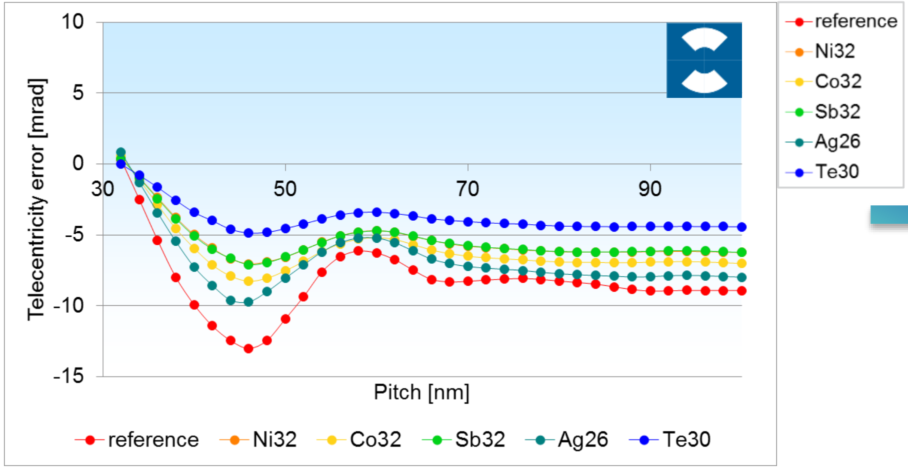


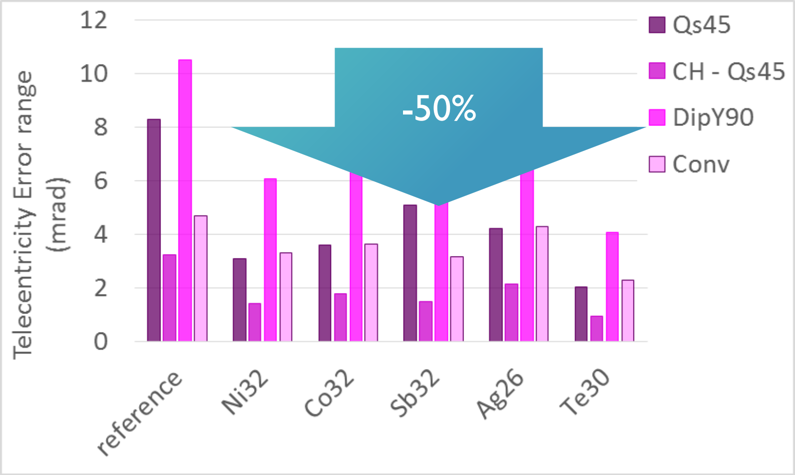


Candidate absorber materials have strongly reduced shadowing effect and Best Focus shift through trench pitch

IMAGING SIMULATIONS

PATTERN SHIFT THROUGH FOCUS

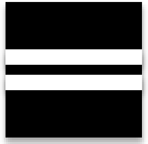




Candidate absorber materials have reduced pattern shift through focus for trenches and contacts through pitch

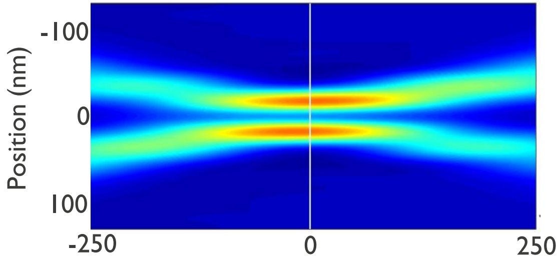
IMAGING SIMULATIONS

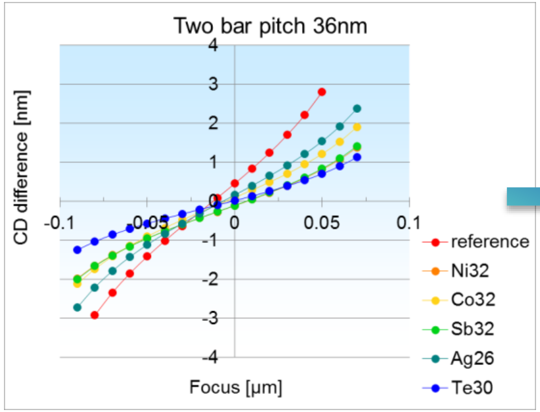
2BAR CD ASYMMETRY THROUGH FOCUS

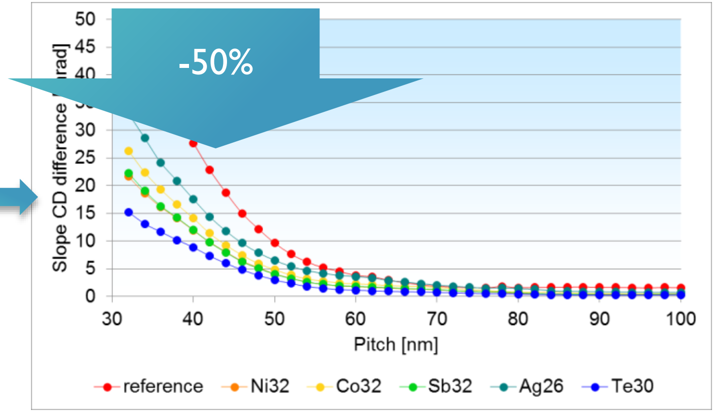


P32-100

Aerial image for 2BAR pitch 36nm
using Reference mask stack

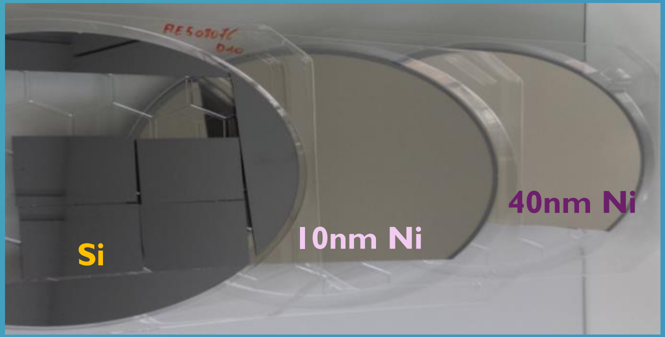






Candidate absorber materials have strongly reduced 2Bar CD asymmetry through focus for 2Bar trenches through pitch

ABSORBER FILM CHARACTERIZATION



EUV MASK ABSORBER OPTIMIZATION

COMPLEX AND DIFFICULT CHANGE IN MASK TECHNOLOGY

- Uniform and amorphous deposition
- Defect free
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  - No interaction with and good adhesion to Ru cap
  - Stability of optical properties
  - Low surface roughness
  - …
- Patterning process
- Repair & clean process
- …

Film characterization

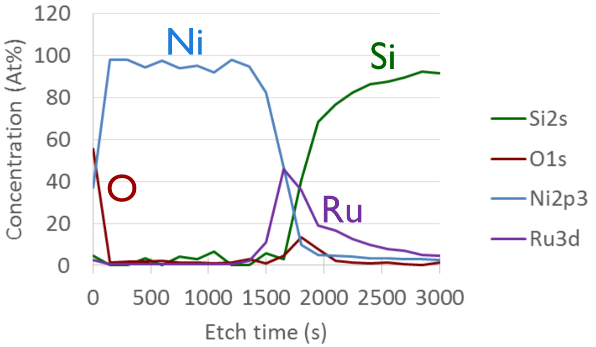
- XRR, XPS for material composition
- XRD, XTEM for structural information
- AFM, XRR for layer roughness
- EUVR for optical properties

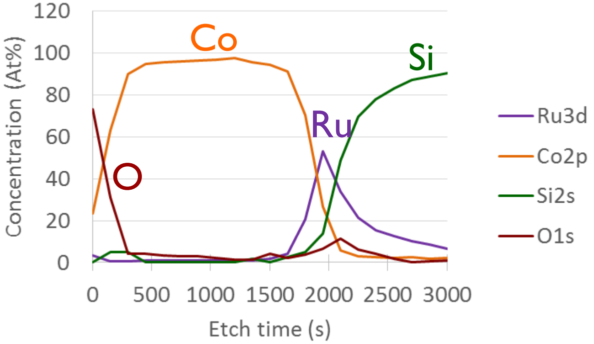
FILM CHARACTERIZATION

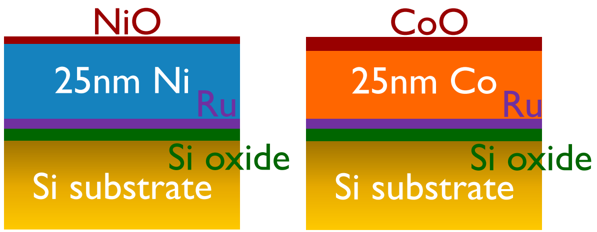
LAYER COMPOSITION IN PURE METAL FILM

Ni and Co are selected as two viable candidate absorber materials to characterize experimentally

XPS	*Layer model*





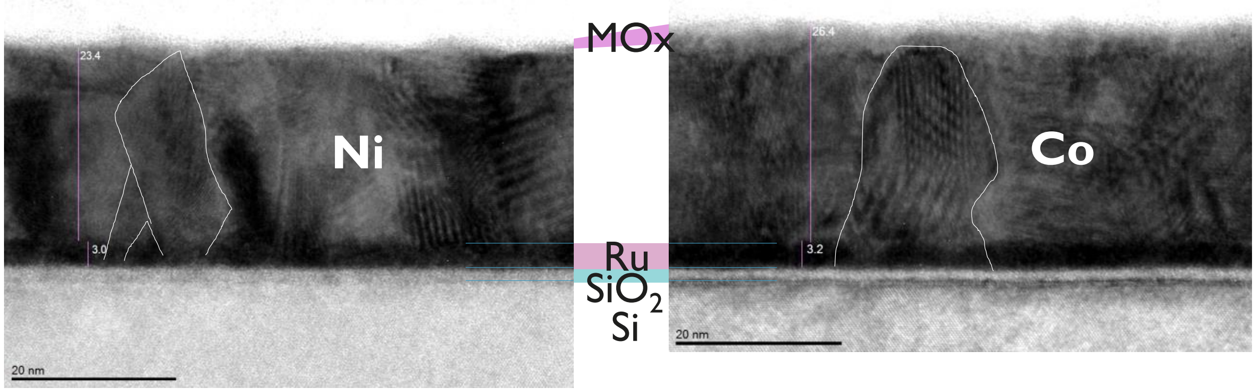


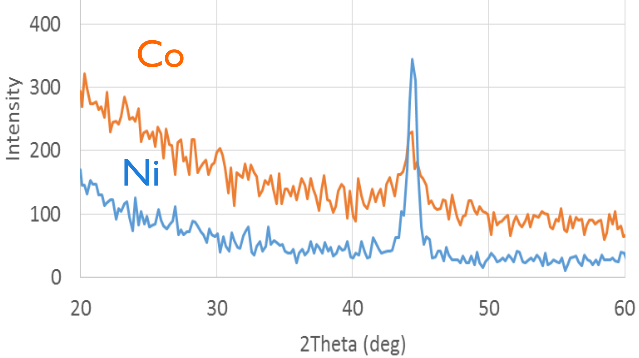
- Formation of native oxide layer on top of the metal
- Oxidation slightly larger on Co surface

FILM CHARACTERIZATION

MICRO CRYSTALLINITY IN PURE METAL FILM

XTEM	*XRD*





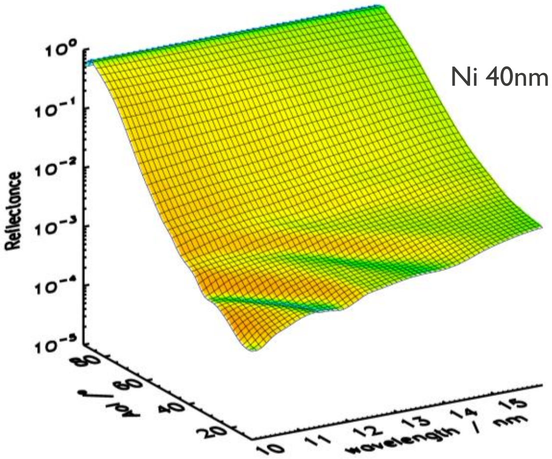
- Large grains spanning the full film thickness
- Grains seem to originate from Ru capping layer (templating effect)
- XRD response indicates smaller grains in Co than in Ni film

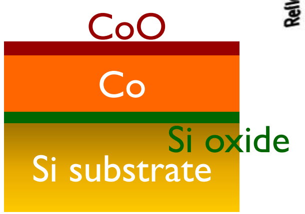
FILM CHARACTERIZATION

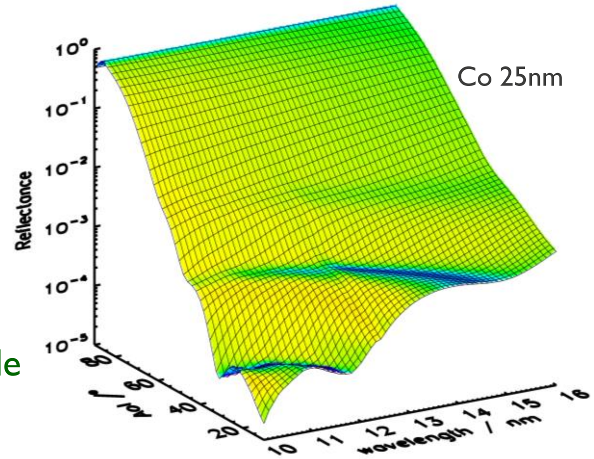
EUV OPTICAL PROPERTIES

EUV reflectometer at soft X-ray radiometry beamline at BESSYII (PTB, Berlin)

- measures EUV reflectance through incidence angle and wavelength







- using geometrical layer model the thickness and optical properties of each layer are derived.
- *More details on poster F. Scholze*

FILM CHARACTERIZATION
EUV OPTICAL PROPERTIES

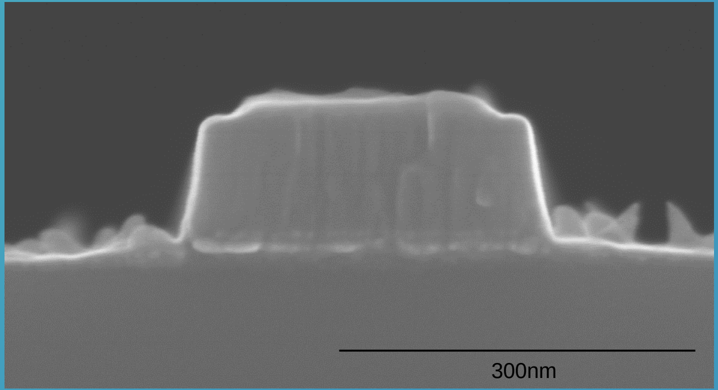
@EUV	Henke*		Measured in this work	
	n	k	n	k
Ni	0.948	0.0727	0.948	0.0783
Co	0.934	0.0662	0.931	0.0719

* B.L. Henke, et al., Atomic Data and Nuclear Data Tables Vol. 54 (2), 181-342 (1993).

- Close match of measured n&k of thin film with tabulated bulk values.

Imaging predictions of reduced M3D with measured n&k of metal absorber stay valid

INITIAL ABSORBER PATTERNING RESULTS



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  - …
- Patterning process
- Repair & clean process
- …

Etching
- Optimizing etching processes
- Absorber profile (XSEM)
- Roughness (SEM)

ABSORBER PATTERNING

BY PHYSICAL ETCHING

Ni cannot form volatiles with the usual etching gasses

- **Reactive Ion Etch**
- Lithography patterning in resist
- Ni is patterned - using resist mask – in dry etch tool with sputter beam in gas environment
- Resist removal

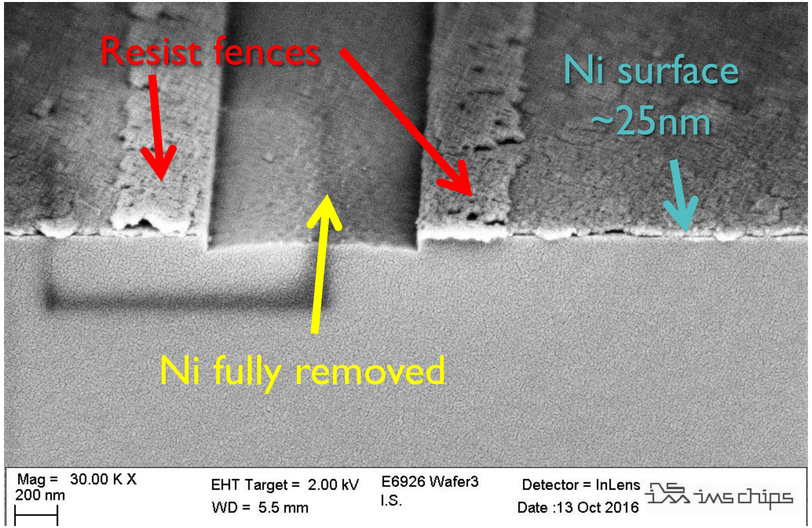
- **Ion Beam Etch**
- Lithography patterning in resist
- Transfer into hard mask
- Ni is patterned - using hard mask - in dry etch tool with sputter beam

Challenge for physical etching is to stop at the interface with underlying layer

ABSORBER PATTERNING

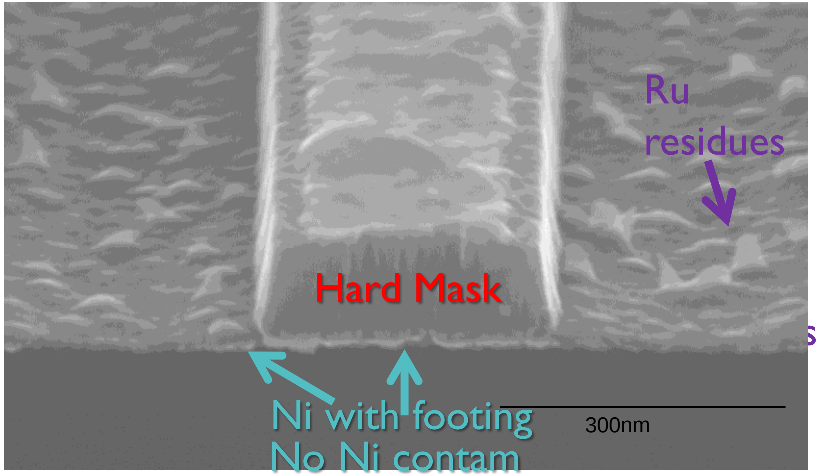
BY PHYSICAL ETCHING

- Reactive Ion Etch



- Further process optimization planned

- Ion Beam Etch



- Further process optimization planned

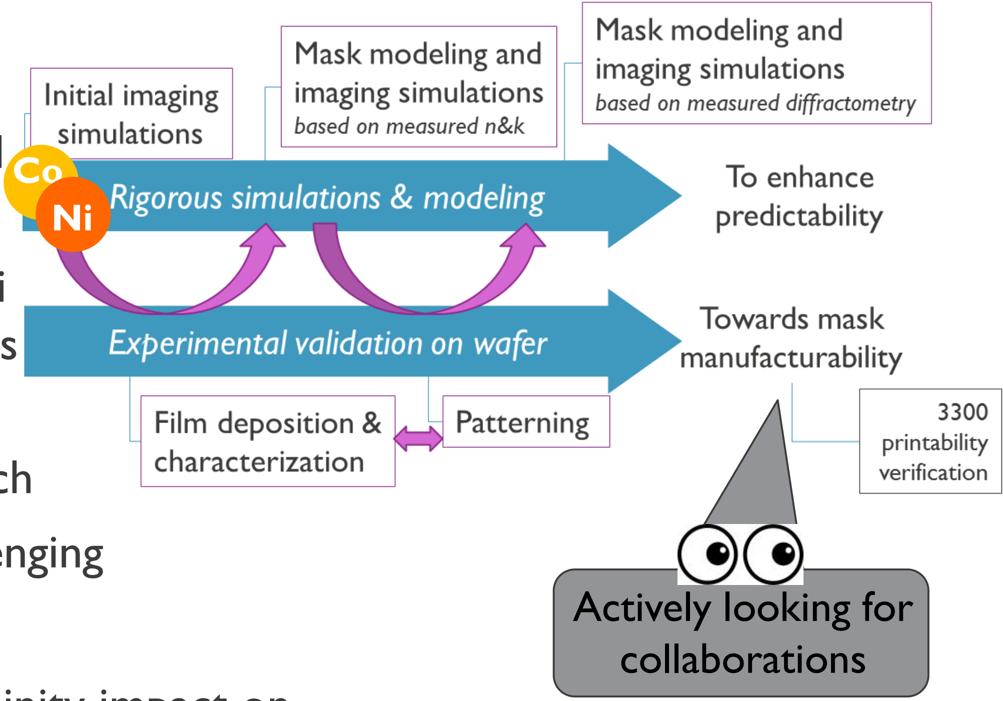
Ni etching is demonstrated, but critical challenges remain due to physical etching.

- Etch stop on underlayer

CONCLUSIONS

METAL ABSORBERS

- The work until now has achieved
  - Selection of absorber candidates Ni and Co with predicted M3D improvements
  - Experimental film characterization of Ni and Co, including EUV optical properties
  - Demonstration of initial absorber patterning tests on Ni films with dry etch
- Single element absorber solution is challenging
  - Physical etching
  - Investigation of absorber poly crystallinity impact on processing and imaging
    - *See next presentation by Vu Luong*



THANK YOU

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Laurent Souriau, imec / ETCH

SeNaTe T5.3 partners

Weimin Gao, Synopsys

Nadia Vandenbroeck, Emily Gallagher, Rik Jonckheere, Kurt Ronse, imec / AP
Prof. Dr. Marc Heyns, imec-KULeuven

and Thank You for listening!

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