TOSHIBA

Leading Innovation

Mask structure for high NA EUV lithography

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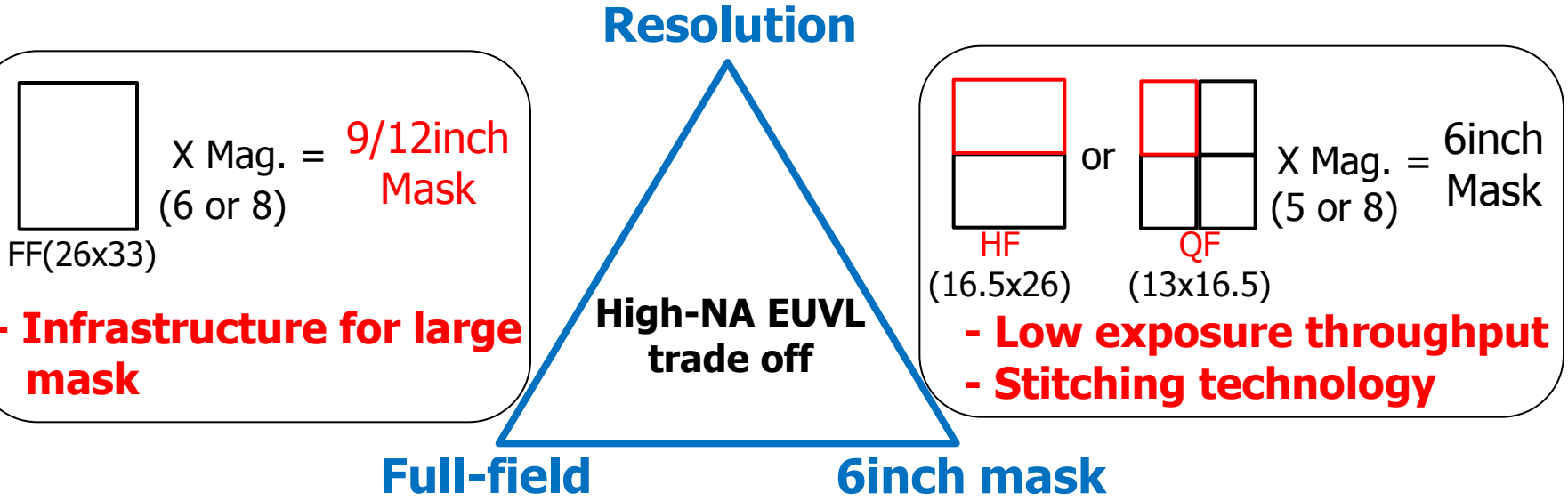
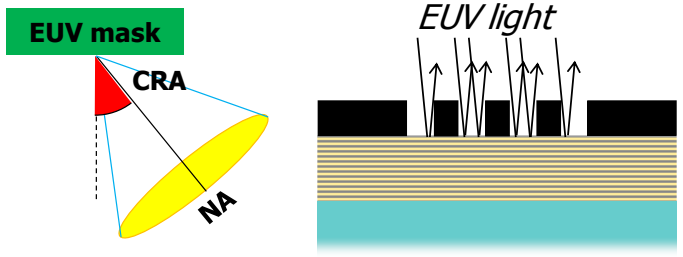
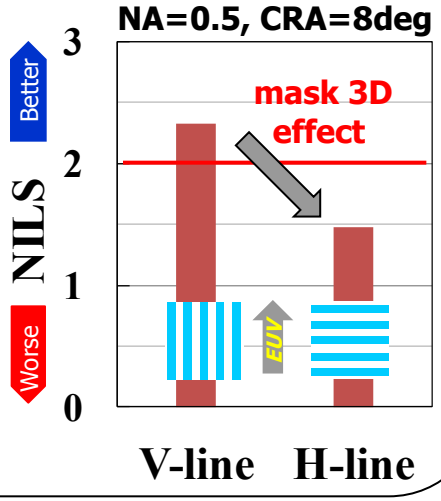
Outline

Challenges for High-NA EUVL







- High NA by increasing CRA leads to large mask 3D effect

Motivation

High-NA EUVL

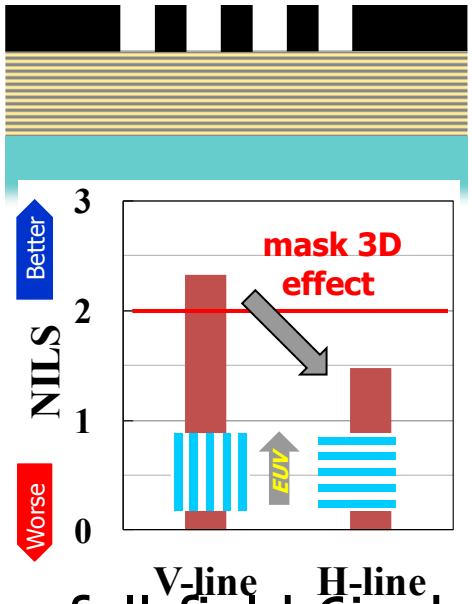
FF, 9/12inch

HF/QF, 6inch

Full-field, 6inch

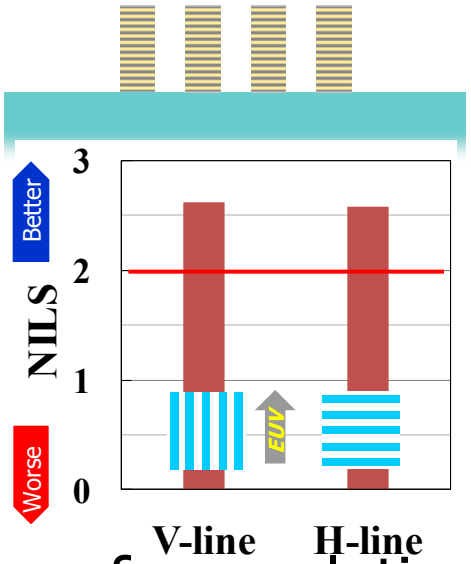
\+ High Resolution

Ta based absorber



lower mask 3D effect

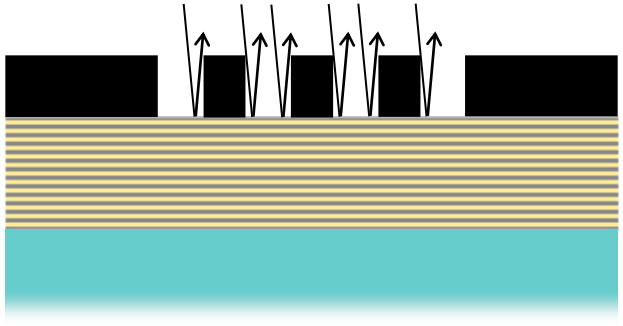
Etched Multilayer



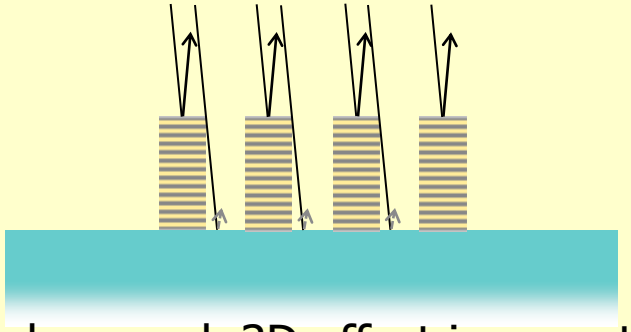
to keep full-field 6inch mask with high wafer resolution by optimizing mask structure.

Mask Structure Options

Ta based absorber



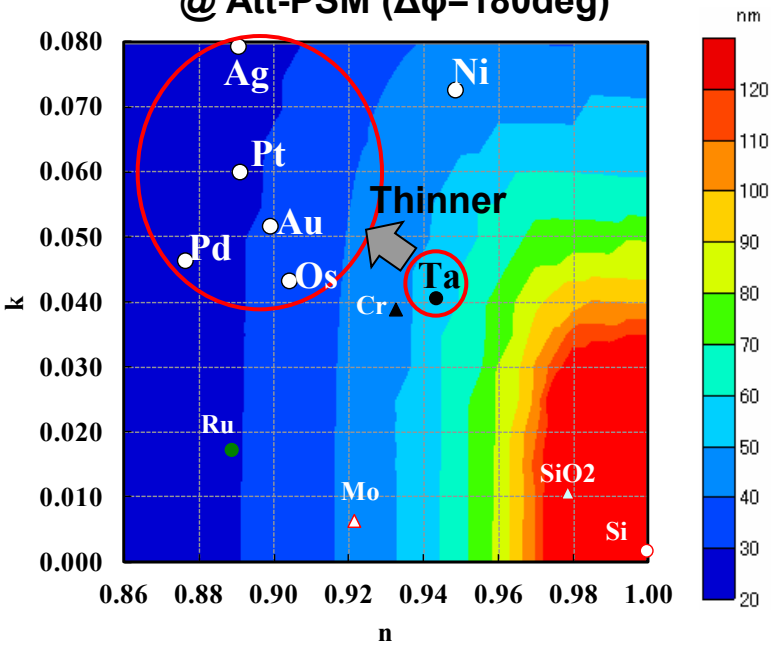
Etched multilayer



Quite low mask 3D effect is expected.
ML etch of fine pattern is a challenge.

Absorber Thickness Contour

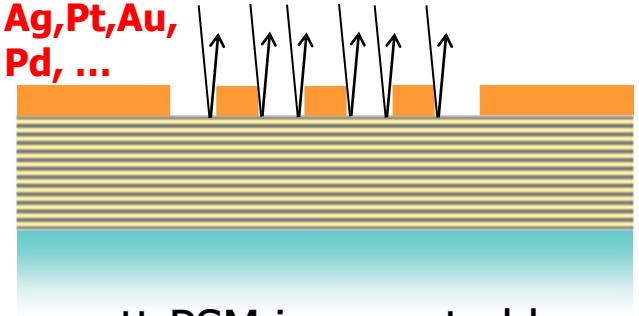
@ Att-PSM (Δφ=180deg)



n, k value @13.5nm wavelength: http://henke.lbl.gov/optical_constants/

Thin absorber material

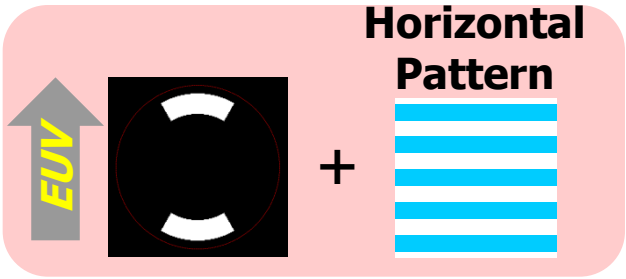
Ag,Pt,Au,
Pd, …



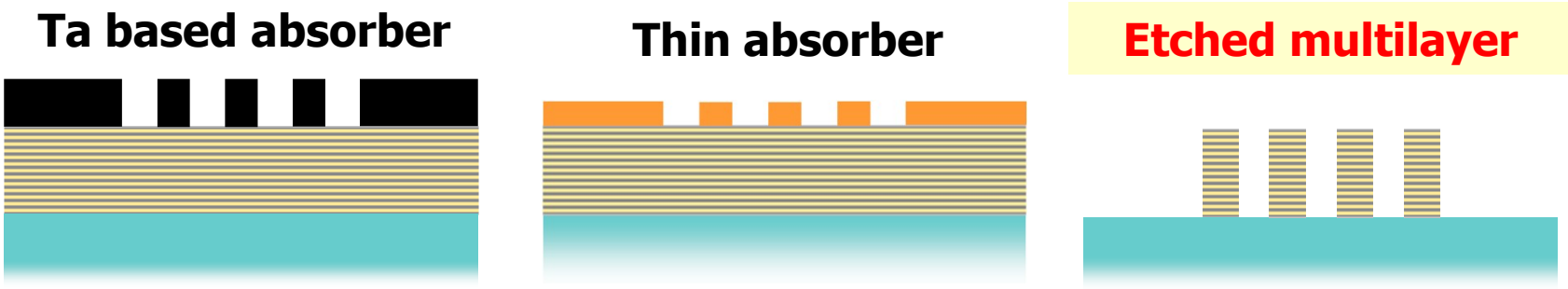
Thinner att-PSM is expected by optimizing absorber material.
Thin absorber materials will hardly be etched.

Simulation Condition

- NA: 0.50
- Magnification: 4x, 6x, 8x
- CRA: 6, 8deg.
- Pattern: hp10nm L/S
- Illumination: Dipole

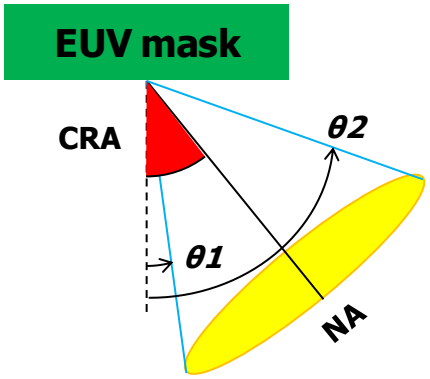


- Mask Structure:



- ML Structure: Mo/Si pairs (Mono-stack, Bi-stack)

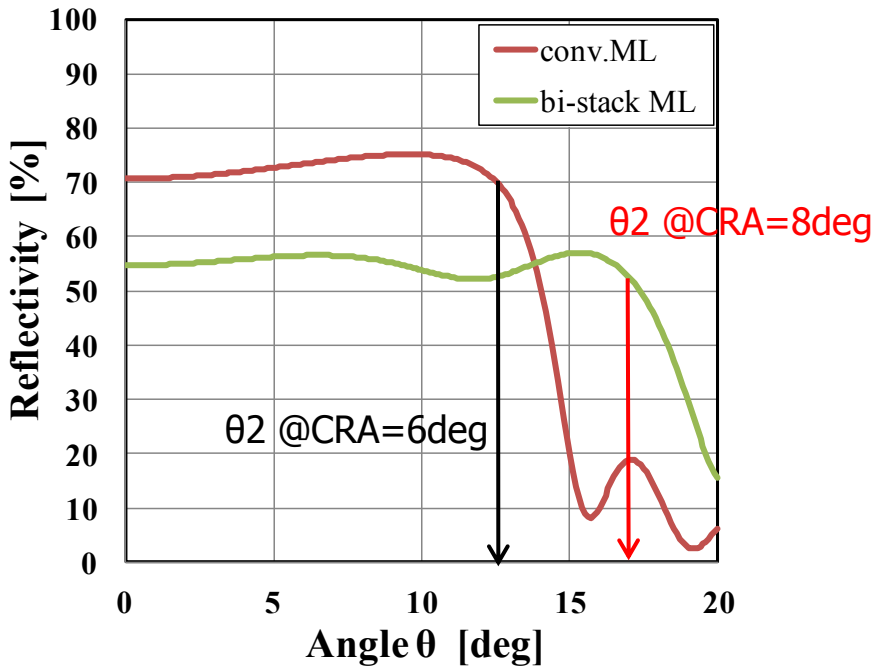
Multilayer Structure



When CRA is increased from 6deg to 8 deg, the range of angle to mask object gets wider.
Mask structure with bi-stack multilayer is also simulated in case of CRA=8deg.

Mono-stack ML (conventional ML)

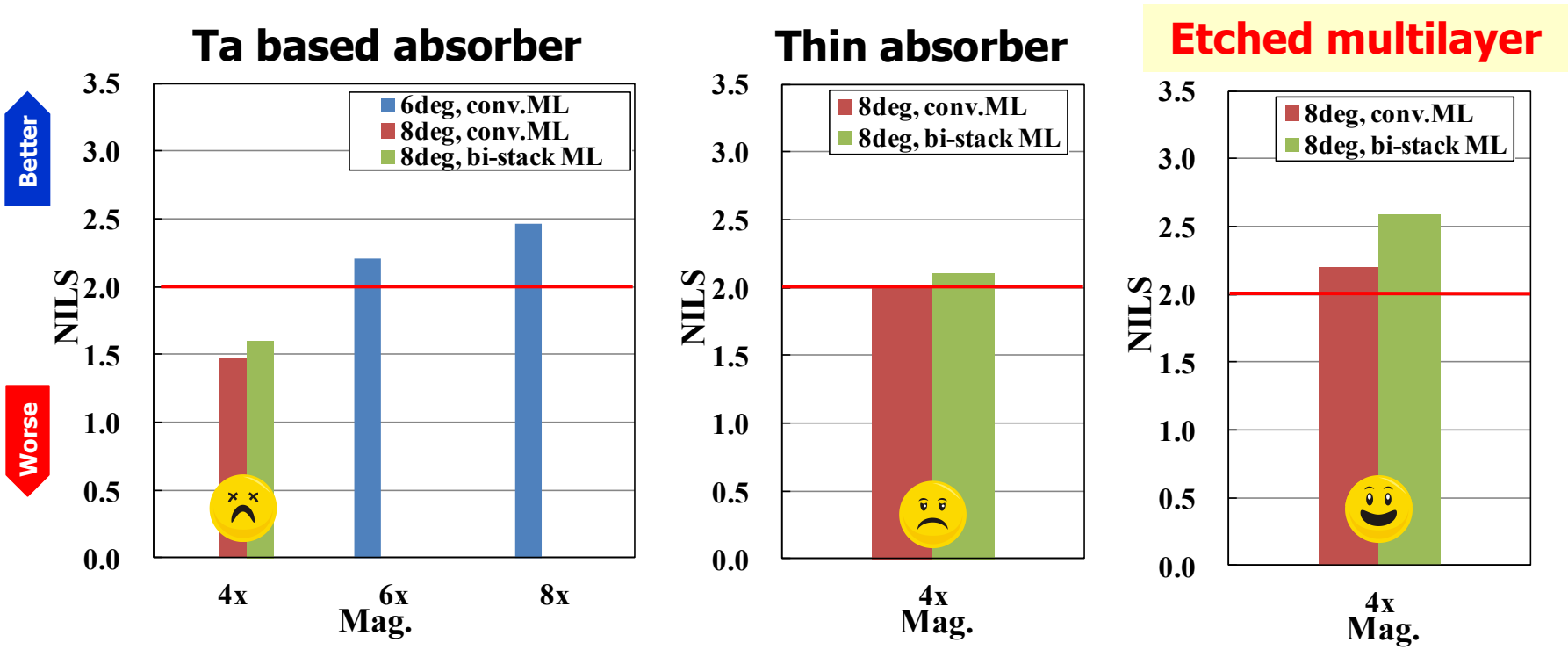
Bi-stack ML*



* J. Ruoff, Proc. SPIE 7823, 78231N (2010)

NILS Dependence on Mask Structure

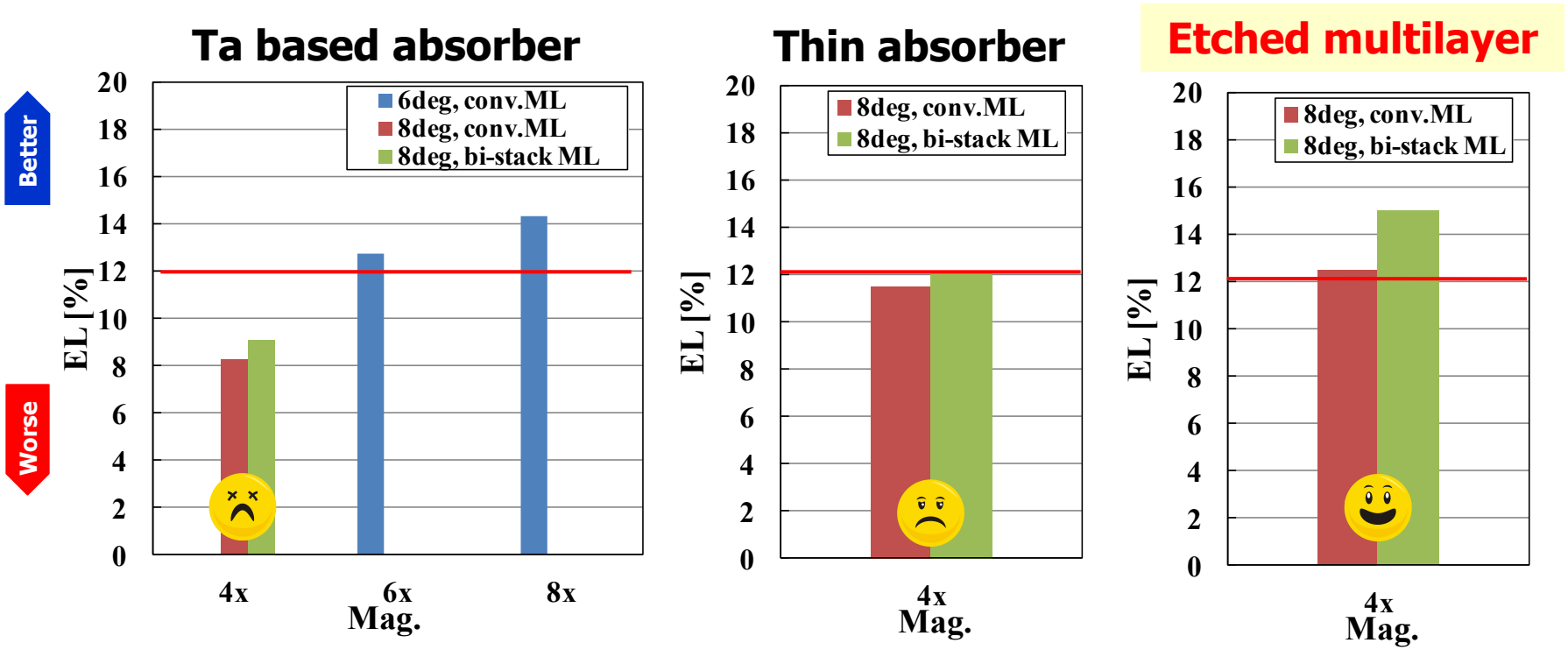
Normalized Intensity Log Slope



✓ In case of 4x (CRA=8deg), etched multilayer mask is best choice.

EL Dependence on Mask Structure

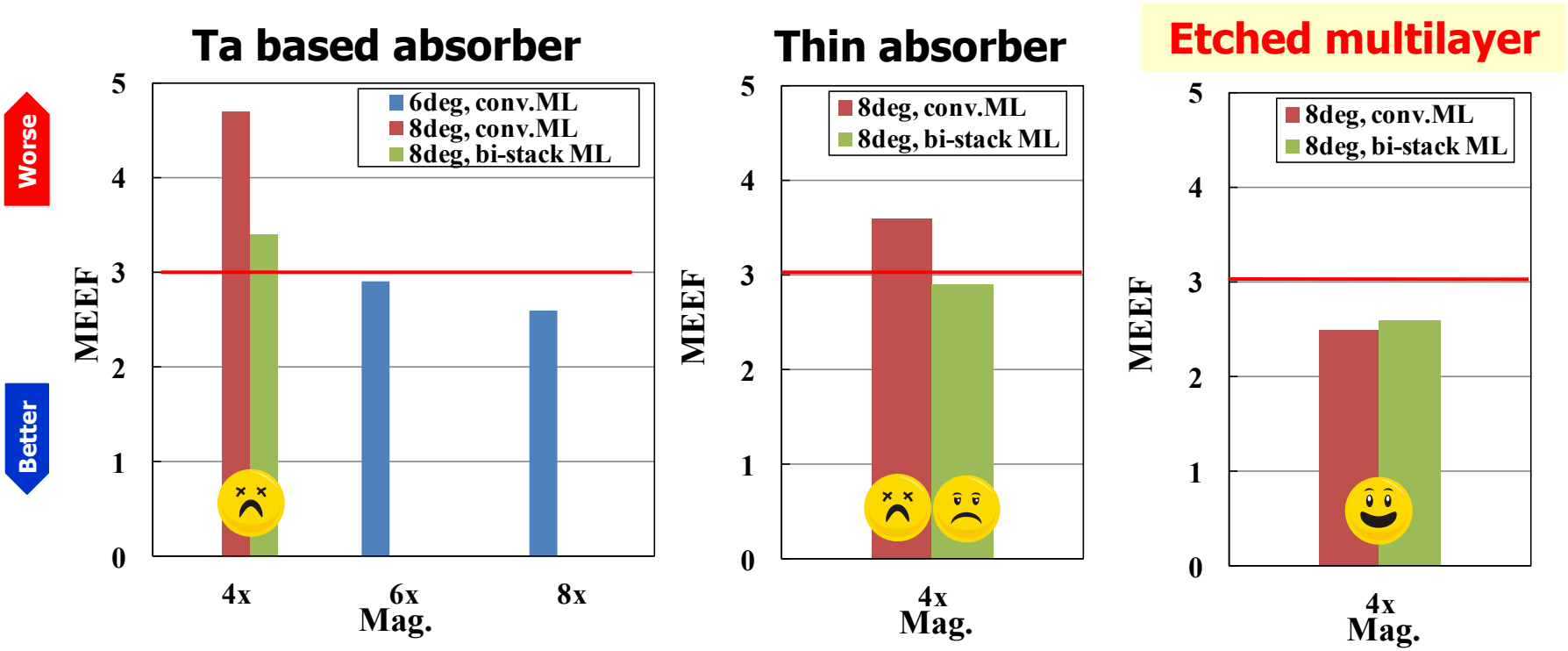
Exposure latitude @ DOF100nm



✓ In case of 4x (CRA=8deg), etched multilayer mask is best choice.

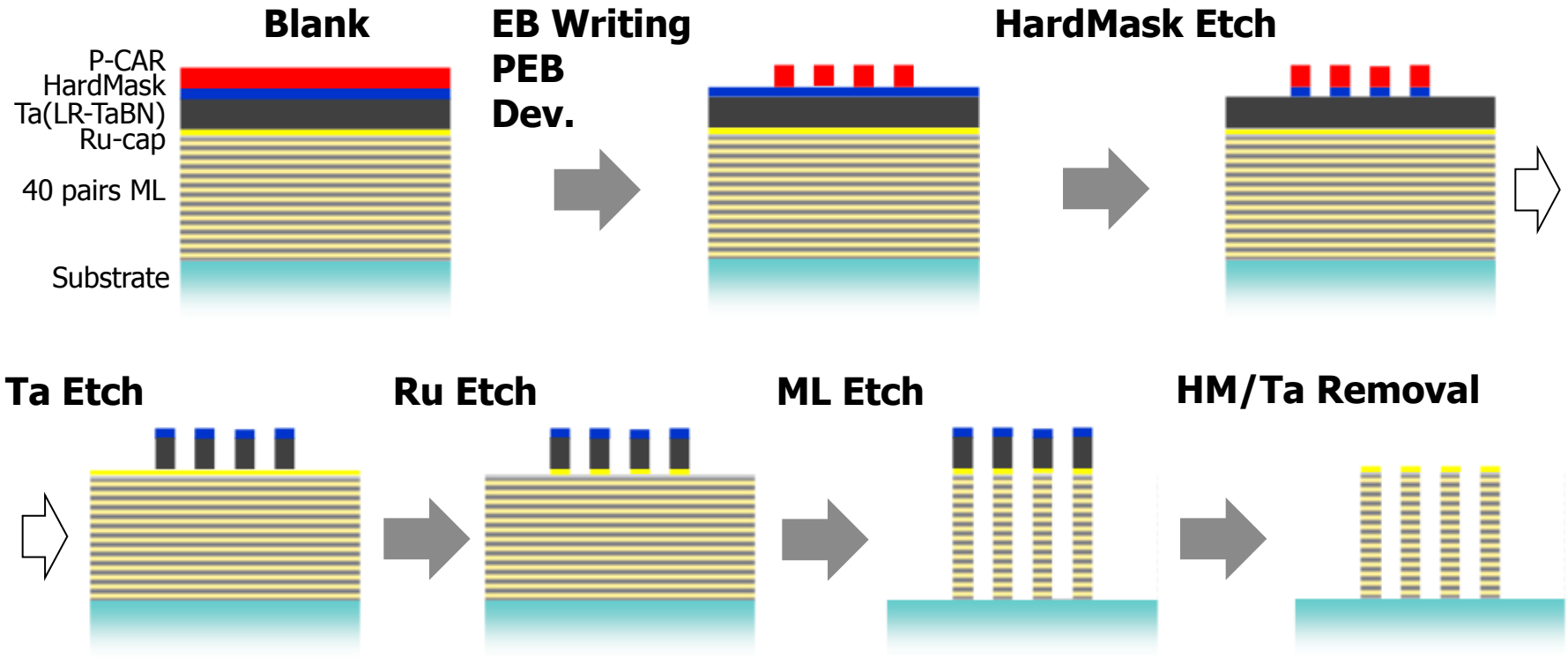
MEEF Dependence on Mask Structure

Mask Error Enhancement Factor



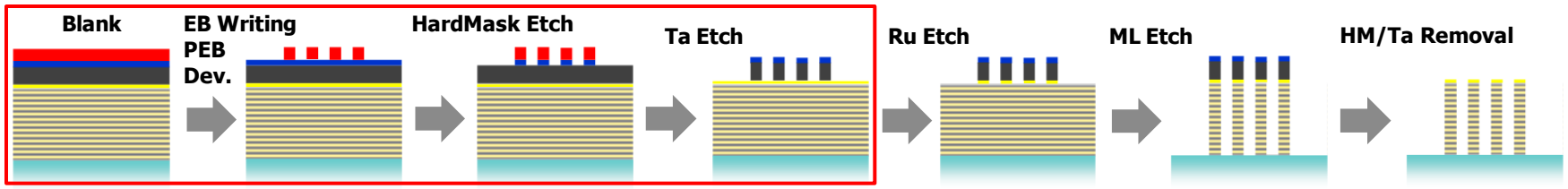
✓ In case of 4x (CRA=8deg), etched multilayer mask is best choice.

Process Flow

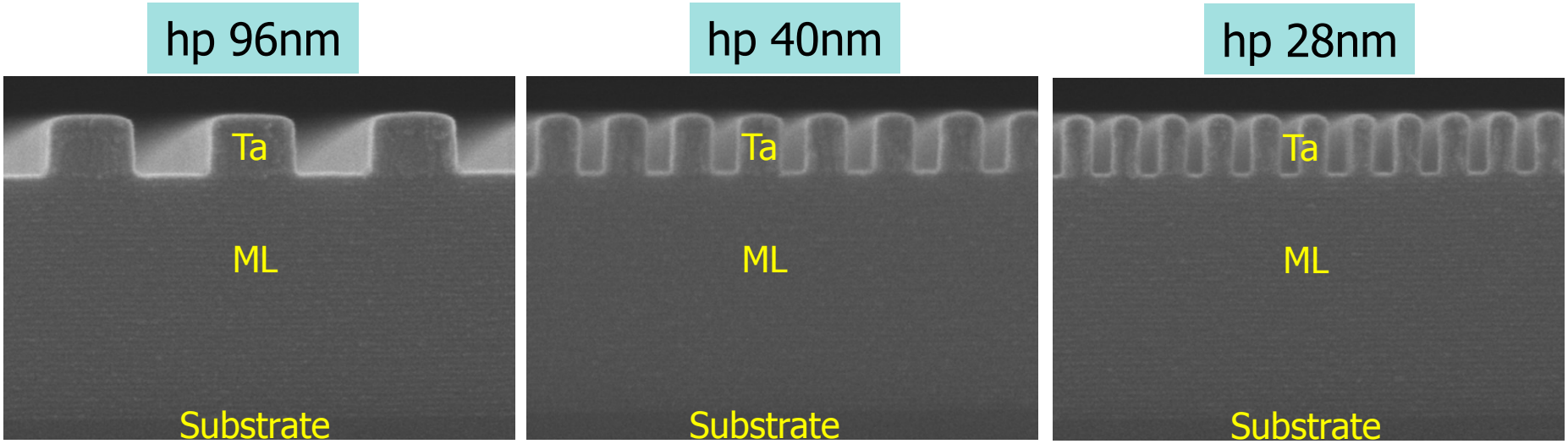


- In order to fabricate fine pattern, hardmask process is selected. Ta layer works as a secondary hardmask to etch underlying layers.
- All the dry etching processes are carried out by ARES™ (Advanced Reticle Etch System).

Hardmask and Ta etching process

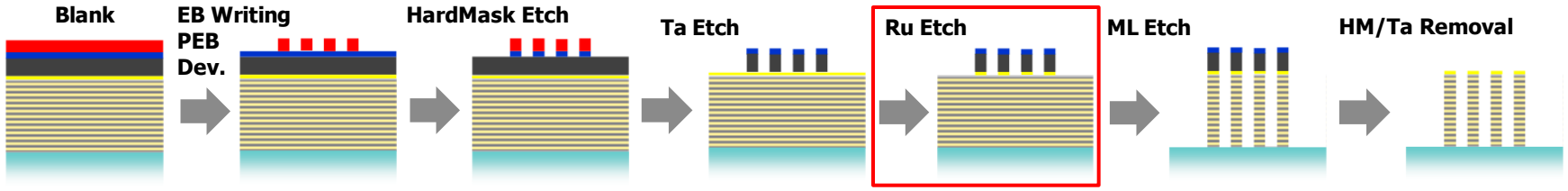


SEM images after hardmask and Ta(LR-TaBN) etching



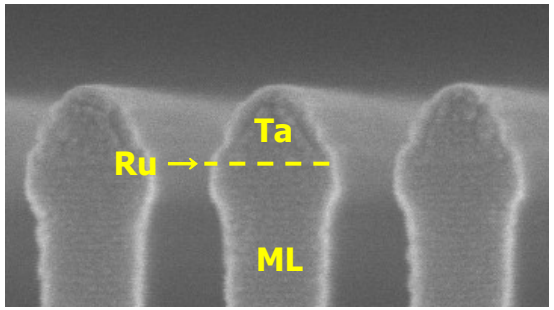
Hardmask process is promising method for fabricating Ta pattern of hp40nm and beyond.

Ru Etching Process Optimization

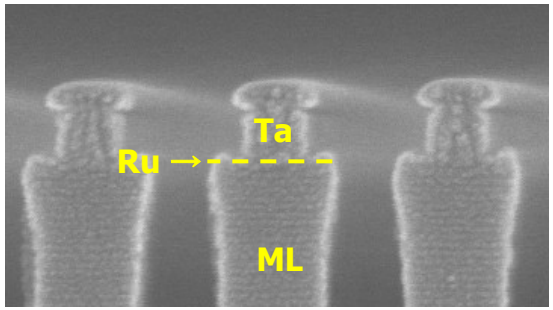


SEM images of hp80nm (4x) pattern after Ru and ML etching

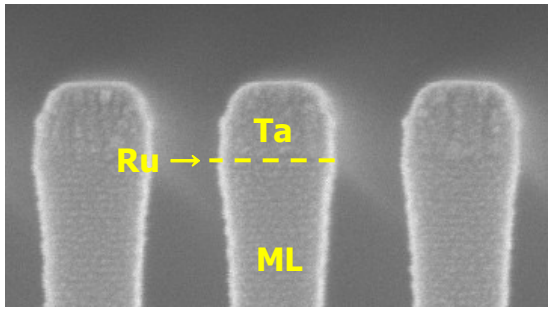
Process Gas A



Process Gas B



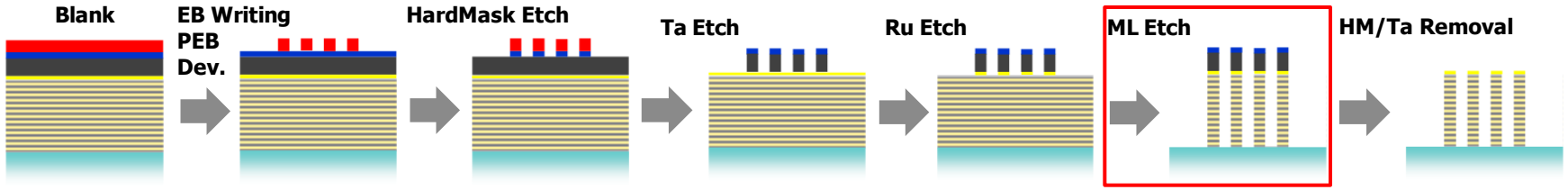
Process Gas C



- Gas A and Gas B have low etching selectivity (Ru/Ta) and Ta pattern is set back.
- Gas C has a good etching selectivity and sidewall profile of the bottom of Ta is nearly vertical.

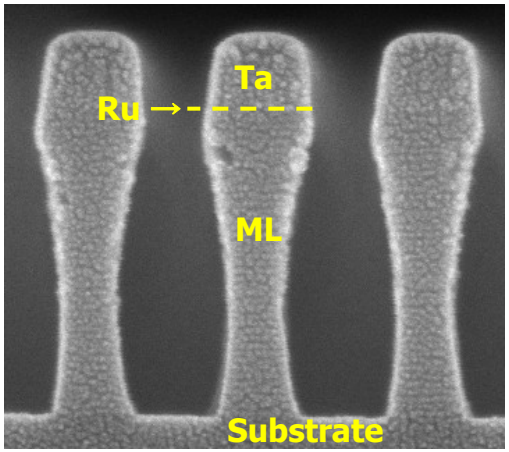
Process Gas C is selected for Ru etching.

ML Etching Process Optimization

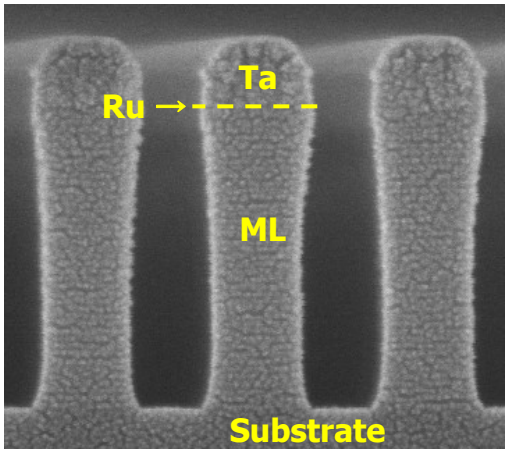


SEM images of hp80nm (4x) pattern after ML etching

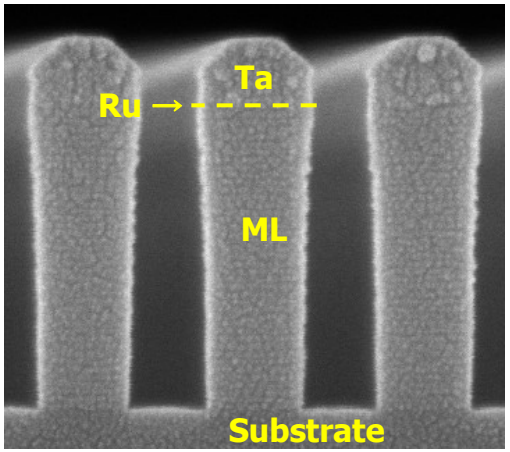
Process C1



Process C2



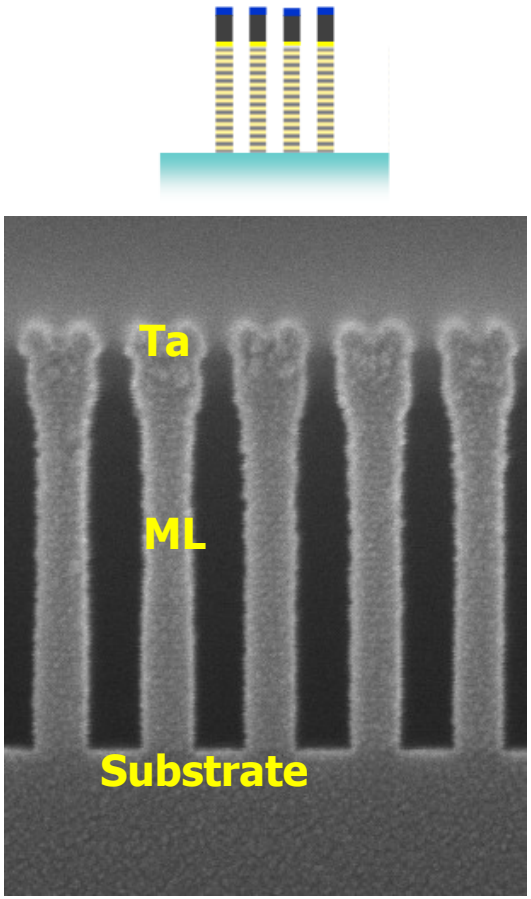
Process C3



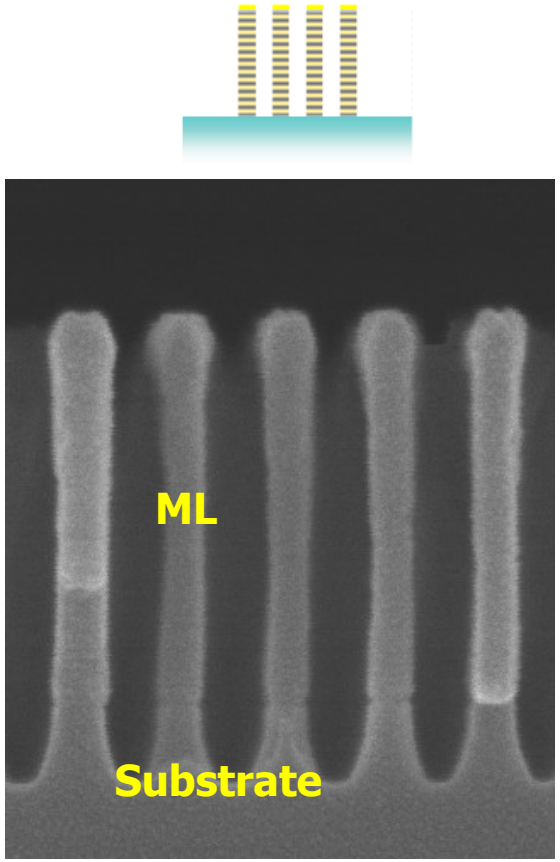
- Undercut is attributed to chemistry unbalance between etching and sidewall deposition (Process C1, C2).
- Multilayer sidewall profile (Process C3) becomes nearly vertical by controlling process parameters.

Etched ML pattern of hp40nm

After ML etching



After HM/Ta removal



Etched multilayer L/S pattern of hp40nm on mask (hp10nm on wafer using 4X optics) is achieved.

Summary

From simulation:

- ✓ In case of 4x (CRA=8deg) optics, etched multilayer mask is most effective in improving NILS, EL and MEEF.
- ✓ Lithographic performance of 4x etched multilayer mask with conventional multilayer is comparable with that of 6x Ta-based absorber mask, and 4x etched multilayer mask with bi-stack multilayer is comparable with 8x Ta-based absorber mask.

From multilayer etching experiment:

- ✓ Etched multilayer pattern of hp40nm on mask (hp10nm on wafer using 4X optics) is demonstrated using EUV mask blank with hard mask process.

These results show the potential capability of etched multilayer mask structure for high-NA EUVL with 4X full-field 6 inch mask.

Acknowledgement

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