IMPACT OF MASK STACK ON HIGH NA EUV IMAGING

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INTRODUCTION

Increasing NA beyond 0.33 at reduction ratio 4X

• Angular range at mask side increases

Impact on
• Reflectivity (multilayer and absorber)
• Diffraction (intensity and phase)
• Imaging (contrast and pattern shift through focus)

Can mask stack tuning help?

ML = MultiLayer
CRA = Chief-Ray Angle
INTRODUCTION

Increasing NA beyond 0.33 at reduction ratio 4X

• Rigorous lithography simulations assess impact of high NA on EUV imaging
• Good description of 3D mask stack in simulator required
• Benchmark to current mask stack through experimental validation
In this presentation: Reduction ratio is always 4X
EXPERIMENTAL ML REFLECTIVITY THROUGH WAVELENGTH AND INCIDENCE ANGLE

- ML reflectivity measured in clear areas of 5x5mm² on 51nm Ta-based mask
- at LBNL reflectometer beamline for EUV

- Uniform over NA0.33
- Experimental peak ML Reflectivity below 0.65

- Current ML blank has good reflection control for NA up to 0.33
ML DEFINITION IN SIMULATOR
FITTED TO EXPERIMENT AS ML WITH INTERMIXING

- In simulator we assumed until now ML consisting of 40 repetitions of Si/Mo layer with perfect interface
- From literature* we know intermixing at the interfaces will occur
- Experimental reflectometry as input for fitting mask ML in simulator

Definition in simulator = ML with intermixing
- fitted to mimic experimental measurement on ML blank

* Seo et al., SPIE2007
OUTLINE

▸ ML definition
  - Reflectometry on current EUV mask

▸ Absorber definition
  - Reflectometry on current EUV mask
  - Mask design & measurements
  - Diffractometry on current EUV mask

▸ Imaging at NA0.45 4X reduction
  - ML tuning
  - ML impact on imaging
  - Absorber impact on imaging

▸ Summary & Conclusion
MASK ABSORBER REFLECTIVITY THROUGH WAVELENGTH AND INCIDENCE ANGLE

- **Absorber** reflectivity measured on 51 nm Ta-based mask
- at LBNL reflectometer beamline for EUV

- Absorber definition in simulator using CXRO n&k is good starting point
- Absorber definition in simulator can be fitted to experimental reflectivity by thickness and n&k fitting
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DIFFRACTOMETRY MASK

- Mask has 51nm Ta-based absorber
- Diffractometry L/S gratings

Mask topdown SEM images

40nm 1:1 (at mask)
i.e., 10nm LS at 1X

44nm 1:1 (at mask)
i.e., 11nm LS at 1X

52nm 1:1 (at mask)
i.e., 13nm LS at 1X

• Mask CD measurements from top-down CD SEM well documented

• Resolution down to 10nm hp (1X) over full field!
DIFFRACTOMETRY
SPECTRA OF 1:1 HORIZONTAL LS

“1:1” LS - **Horizontal** orientation only
Beam incident perpendicular on grating

- $0^{th}$ order decreases with increasing pitch
- $-1^{st}$ order drops with decreasing pitch $\Rightarrow$ absorber shadowing effect
DIFFRACTION SIMULATION
IMPACT OF SPACE WIDTH FOR 54NM PITCH

Zeroth order increases with decreasing mask line width
Horizontal orientation suffers from shadowing

- Zeroth order increases with decreasing mask line width
- Horizontal orientation suffers from shadowing
Severe shadowing (i.e., 3D mask effect) for small pitches:
- Vertical orientation: both first orders are impacted
- Horizontal orientation: minus first order gets blocked
Simulated diffraction (using fitted mask stack definition) needs only one fixed CD-offset for all mask line widths to get good correlation with experimental diffraction.

- Fitted mask stack definition in simulator allows interpretation of experimental diffractometry.
- Patterned absorber at small spaces is responsible for imbalanced diffraction pupil → causing asymmetric shadowing and pattern shift through focus.
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IMAGING SIMULATION AT NA0.45 4X
CURRENT ML INDUCES IMBALANCE

- Increasing NA and CRA increases angular range on mask
- ML reflectivity:

- Current ML: sharp reflectivity drop beyond 12° incidence angle is captured by NA0.45 ⇒ causing diffraction imbalance

- Compensate reflectivity by adjusting periodicity by ML factor
ML TUNING
FOR UNIFORM REFLECTIVITY WITHIN NA0.45

EUV ML reflectivity within NA0.45 at CRA 8deg 4X

• Bi-stack can give uniform reflectivity through large angles
ML IMPACT ON IMAGING AT NA0.45
PATTERN SHIFT THROUGH FOCUS

L/S imaging through pitch: Dipole90° σ0.74/1
at NA0.45 CRA 8° 4X reduction

- Pattern shift through focus can be reduced by tuning ML, but significant pattern shift remains in small-pitch region.
ML IMPACT ON IMAGING AT NA0.45
PUPIL FILLING

L/S imaging through pitch: Dipole90° σ0.74/1 at NA0.45 CRA 8° 4X reduction

Pupil filling for 11nm L/S at NA0.45:

- **mono-stack**
  - ML factor 1
  - Current ML

- **mono-stack**
  - ML factor 1.008

- **bi-stack**
  - 20 layers in each stack

• Imbalance in diffraction pupil remains after ML tuning
  → Absorber impact at high angles, as shown by diffractometry
Pattern shift through focus can be further reduced by tuned ML and thinner absorber, but not to acceptable level.

→ large angles at mask remain issue in small-pitch region
ABSORBER & ML IMPACT
UNDERSTANDING AT SMALL PITCH

Geometrical visualisation at small pitch

MLfactor 1

70nm Ta-absorber

MLfactor 1.008

44nm Ta-absorber

Pupil filling for 11 nm L/S at NA0.45 CRA 8° 4X reduction:

imbalance reduced

• Combined ML and absorber tuning helps reducing EUV-specific issues such as pattern shift through focus,

but strong mask effects remain in small-pitch region due to large angles.
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SUMMARY & CONCLUSION

Experimental assessment of current mask stack

- Fitting of mask stack (ML + absorber) in simulator to actual mask performance
  - based on reflectometry and diffractometry measurements
- **Experimental validation** of patterned absorber impact on diffraction and predicted by simulation

Imaging simulation at NA0.45 CRA8° 4X reduction

- **No solution** found yet that balances imaging performance due to complex interplay of large angles and mask stack (ML and absorber)

Outlook for high NA EUV

- **Reduce mask effects** (smaller range of incidence angles on mask) by
  - CRA ≤ 7° cf. previous talk of JT Neumann (Zeiss)
  - higher Reduction ratio
- Explore other tuning options
  - illumination tuning
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