# Thin Half-tone Phase Shift Mask Stack for Extreme Ultraviolet Lithography

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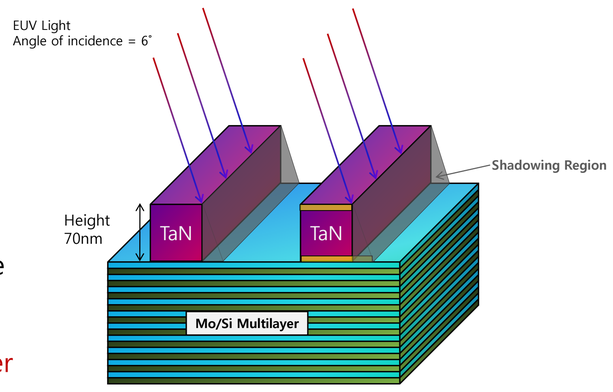
## Introduction

**What is EUV Lithography ?**

Extreme ultra violet lithography (EUVL) using 13.5nm wavelength is expected to be the mainstream of production process for 22nm half pitch and below. Mask shadowing is a unique phenomenon caused by using of multilayer mirror-based mask with oblique incident angle of light. Reducing the absorber thickness is the most effective method to minimize the mask shadowing effect. A phase shift concept is a potential solution to improve the image contrast with a thinner absorber stack. The concept of a phase shift mask for EUVL has been studied for a number of years. However, there are many fabricating issues to be solved before it can be applied to manufacturing.

**What is the mask shadowing effect?**

- The illumination beam is shadowed by the edge of the absorber.
  - → The effective mask CD is changed.
  - → Printed pattern shifted and biased.
- Correction for shadowing effect should be considered.
  - → Reducing the absorber thickness is the key issue.
  - → How about using phase shift concept to improve image contrast with thinner absorber stack?

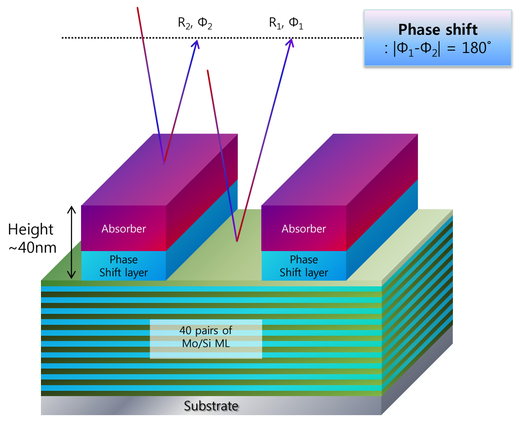



*Schematic diagram of EUV conventional binary mask*

## Schematic image of proposed EUV PSM & aerial simulation conditions

**The phase shift mask in EUVL**

- EUVL could be more easily extended to 22nm node and below by applying PSM.
  - → However, it is very difficult to make a reliable and manufacturable PSM.
- What is the main factor to control the phase shift in EUVL mask?
  - → The structure of capping layer is one of the main factor to influence the phase shift.
  - → The optimization of capping structure is needed.




*Schematic diagram of EUV PSM*

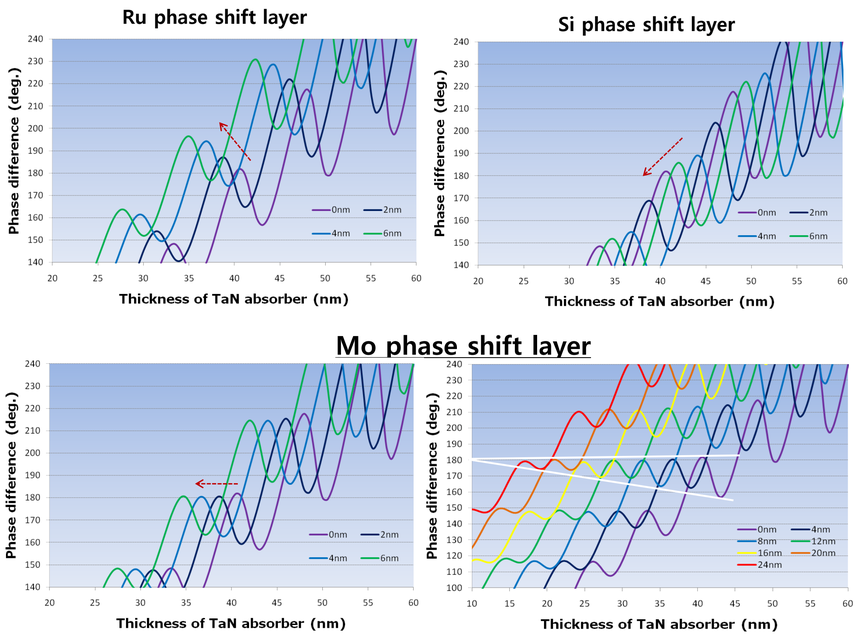
**Phase shift (ΔΦ) = (2πδ/λ)*Δr**
**(Δr = propagation distance)**

| Material | δ | β |
|---|---|---|
| TaN | 0.0730 | 0.0436 |
| Si | 0.0010 | 0.0018 |
| Mo | 0.0761 | 0.0064 |
| Ru | 0.1137 | 0.0171 |

**Refractive index (n)= 1-δ + iβ**

## The characteristics of proposed PSM

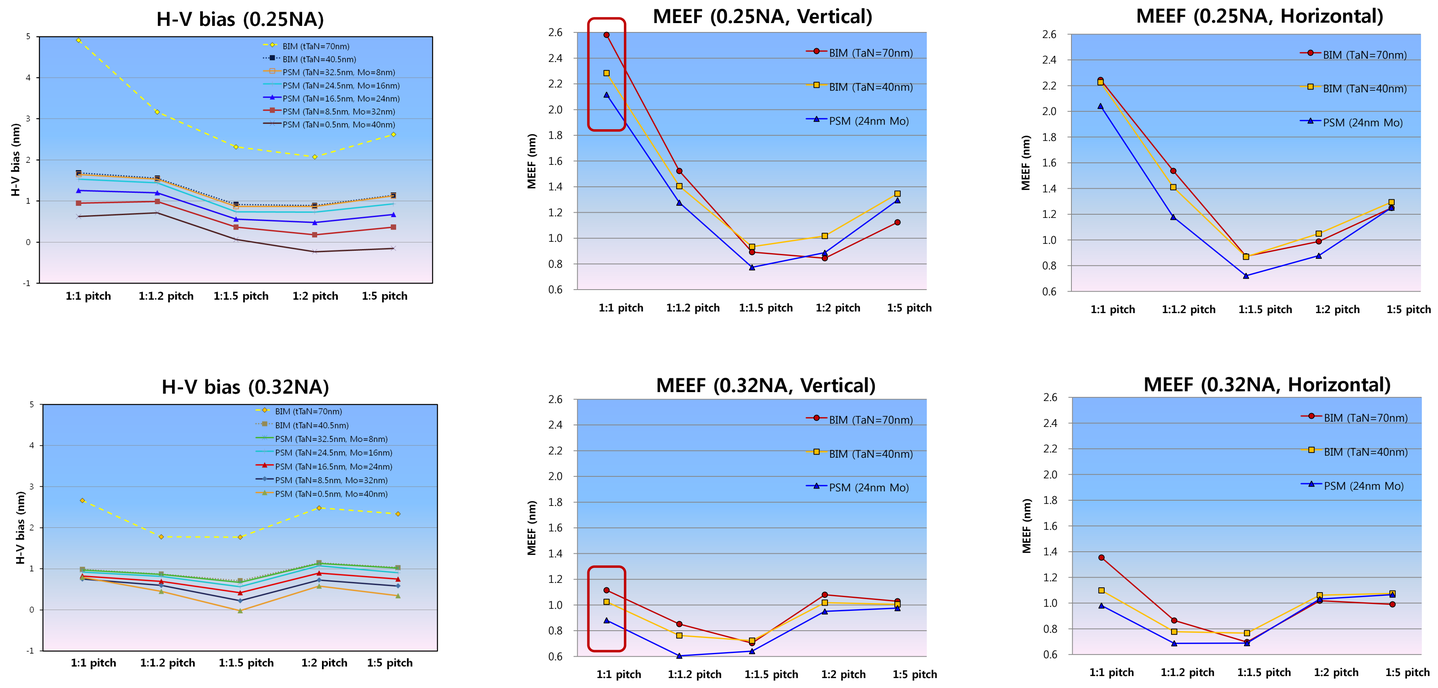
**Phase difference as a function of TaN absorber and various phase shift layer thickness**




- The out of phase condition was achieved at the ~40nm absorber stack (absorber + phase shifter) thickness.
- Although the Mo phase shift layer thickness varies, phase difference does not change and the slope of valley position shift is also nearly zero.

## The improved imaging properties (reduced shadowing effect)

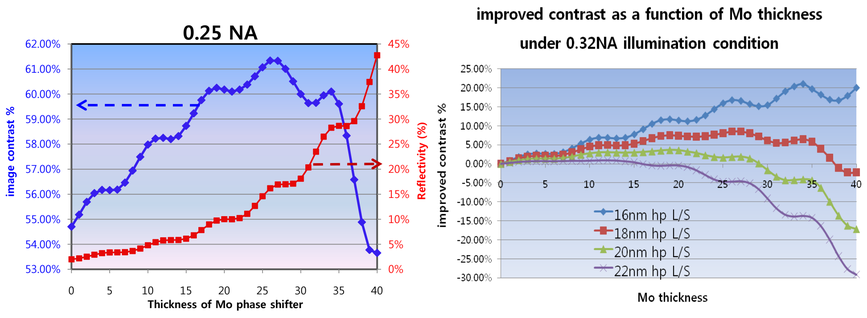
**Calculated H-V bias, MEEF (conventional BIM vs. proposed PSM for 22nm hp L/S pattern)**



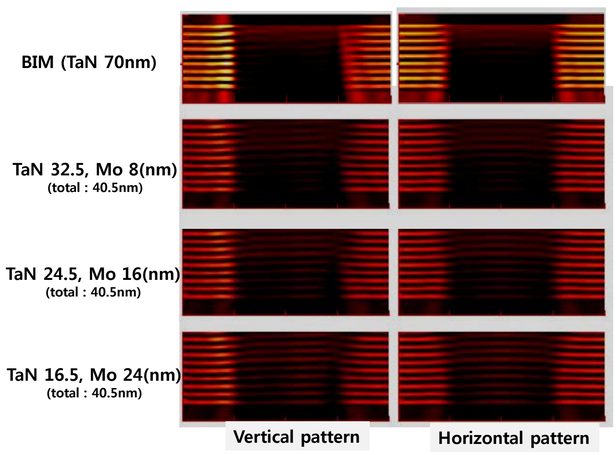

- For all pitch conditions, PSM having 40.5nm thick absorber stack shows the lower amounts of H-V CD bias, MEEF value compared with conventional BIM having 70nm thick absorber.
- As Mo phase shift layer thickness increases, amount of H-V CD bias, MEEF value decreases.

## Optimization of thin half-tone PSM

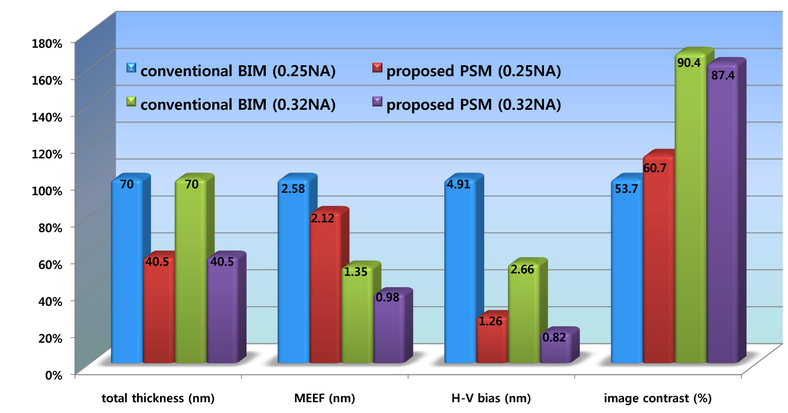
**Image contrast & reflectivity as a function of Mo phase shift layer thickness**



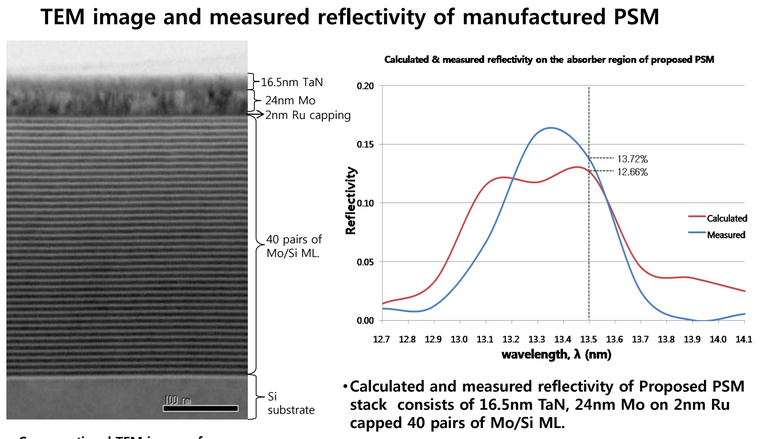

**Near field intensity profiles (BIM vs PSM with Mo thickness variation)**




**Normalized comparison of conventional BIM vs optimized PSM for 22nm hp L/S**




**TEM image and measured reflectivity of manufactured PSM**

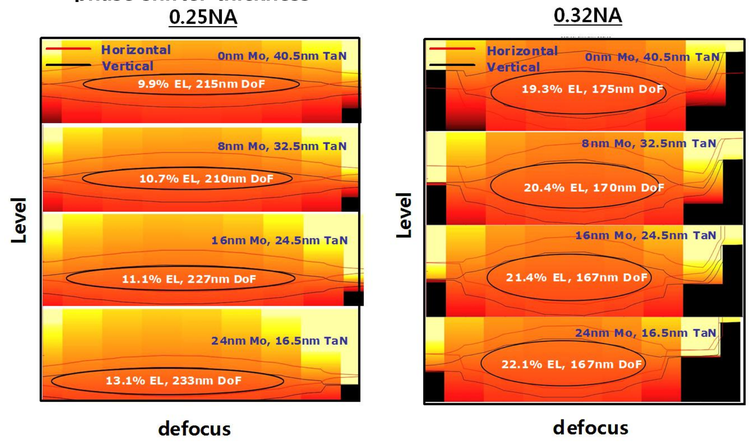



- Cross-sectional TEM image of optimized PSM stack.




- Calculated and measured reflectivity of Proposed PSM stack consists of 16.5nm TaN, 24nm Mo on 2nm Ru capped 40 pairs of Mo/Si ML.
- Measured reflectivity (13.72%) is well-matched with the calculated reflectivity (12.66%) @ 13.5nm centroid wavelength.

**H-V overlapping PW for 22nm L/S patterns depending on Mo phase shifter thickness**




| NA | 0.25NA | | | | 0.32NA | | | |
|---|---|---|---|---|---|---|---|---|
| Absorber type | BIM | proposed PSM | | | BIM | proposed PSM | | |
| | Real value | Real value | Offset | Reduction% | Real value | Real value | Offset | Reduction% |
| Absorber thickness | 70 | 40.5 | − 29.5 | - 42.14% | 70 | 40.5 | − 29.5 | − 42.14% |
| MEEF | 2.58 | 2.12 | − 0.46 | - 17.98% | 1.35 | 0.98 | − 0.37 | - 27.52% |
| H-V bias | 4.91 | 1.26 | − 3.65 | - 74.37% | 2.66 | 0.82 | − 1.84 | - 69.03% |
| Image contrast | 53.73 | 60.71 | + 6.98 | + 12.98% | 90.44 | 87.44 | −3.00 | - 3.33% |

## Conclusion

- PSM concept can be applied relatively easily in EUV Lithography process through proposed half-tone PSM structure in order to improve CD uniformity and process window.
- This improvement depends on the pattern pitch and illumination conditions, but is most effective in dense patterns for 22nm hp L/S pattern with 0.25NA and 18nm with 0.32NA.

## Acknowledgement

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