Enhanced imaging in Extreme UV lithography by optimising the Molybdenum/Silicon thickness ratio in 2-D phase shifting mask design

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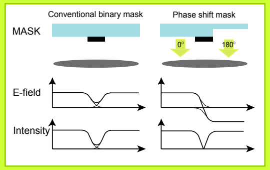
The optimisation of phase shift mask to enhance the image of mask patterns in extreme UV lithography is discussed.

Phase shift mask (PSM)



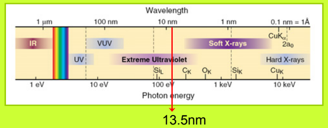
Resolution :

$$\text{Res} = k_1 \frac{\lambda}{NA}$$

k_1 = f(resist,mask,illumination)

→ Resolution enhancement with PSM of 180° phase shift

Extreme UV



Complex refractive index $\begin{cases} \mathrm{Re}(n) \sim 1 \\ \mathrm{Im}(n) > 0 \end{cases}$

(absorbing & low optical contrast)

Advanced PSM for extreme UV

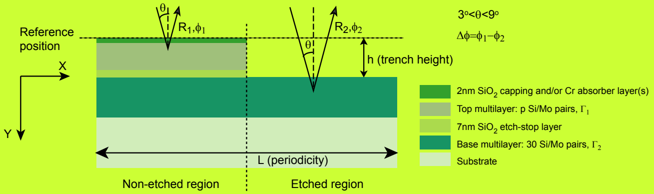
→ Multilayer Bragg-mirror mask structure in vacuum (n=1)

→ Materials used at 13.5nm-wavelength:

Silicon (Si) : lower absorption but lower optical contrast
Molybdenum (Mo): higher optical contrast but higher absorption

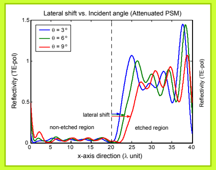
$$\Gamma = \frac{\text{Mo thickness}}{\text{(Mo+Si) thickness}}$$

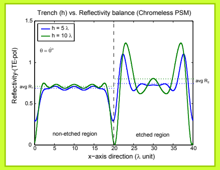
Structure of PSM



- Attenuated : with absorber for intensity modulation
- Chromeless : no absorber → high intensity in both regions
- Etch-stop layer : controls Si/Mo pairs to be removed for 180° shift

Problems: lateral shift & imbalanced reflectivity



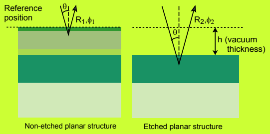


θ is given by the system, height (h) can be optimised, refl.(R) & height(h) decrease for higher Γ (Mo absorption)

Solution: Optimise Γ_1& Γ_2 (adequate R & minimum h)

Methods

1-D calculation (planar structure)



Chosen requirements:
ΔΦ = 180° ± 5°

PSM	R (on structure)	
	etched	non-etched
Attenuated	>0.65	<0.15
Chromeless	>0.65	>0.65

Find Γ_1&Γ_2 to reduce h

2-D calculation (periodic structure; L = 40 λ)

- Collimated point source illumination (TE&TM)
- Near field on mask using Fourier Modal Method

Optimisation of lateral shift & reflectivity balance

(evaluation: far field in image plane with NA=0.25)

2-D Fourier Modal Method

Field calculation with varying permittivity ε(x) and periodicity L

TE-pol: $\left(k_0{}^2[\boldsymbol{\varepsilon}] - \boldsymbol{\alpha}\boldsymbol{\alpha}\right)\mathbf{E} = \gamma^{\mathrm{TE}}\mathbf{E}$

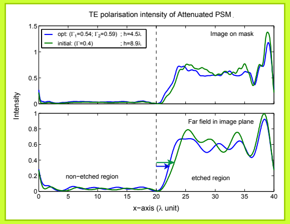
TM-pol: $\left[\boldsymbol{\varepsilon}^{-1}\right]^{-1}\left(k_0{}^2\mathbf{I} - \boldsymbol{\alpha}[\boldsymbol{\varepsilon}]^{-1}\boldsymbol{\alpha}\right)\mathbf{H} = \gamma^{\mathrm{TM}}\mathbf{H}$

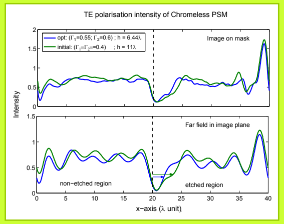
$$\begin{cases} \alpha_m = \frac{2\pi}{L} m + k_0 \sin\theta & \text{→ angular Fourier frequency for mode } m \\ \varepsilon(x) = \sum_{m=-M}^{M} \varepsilon_m \exp(i\alpha_m x) & \text{→ permittivity Fourier expansion} \end{cases}$$

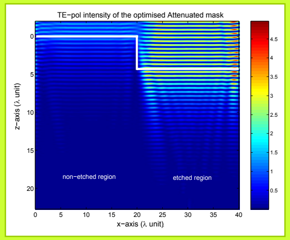
M = total number of modes

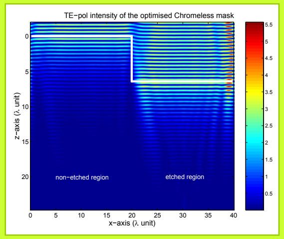
Results

- Comparison with Γ_1=Γ_2=0.4 (current EUV PSM structure)
- Analysis for θ=6° and TE polarisation









— = boundary between the structure and vacuum

- Reduced lateral shift for optimised Γ_1 and Γ_2 in both designs
- More balanced reflectivity between averaged R_1 and R_2; reduced peak intensity on the edge of the structure

Conclusion

It is shown that the PSM design optimisation by controlling the thickness ratio of the multilayer structure reduces lateral shift and imbalanced reflectivity of the imaged periodic pattern.

In general, the optimisation method allows for a complete control of all design parameters to produce the required image pattern in the far field.

This work is done in the framework of the European Project More Moore (IST-1-507754-IP)

EXTREME ULTRAVIOLET LITHOGRAPHY

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