EUVL Flare Modeling with an Improved Accuracy for Feasibility Study of Sub-22 nm HP Node

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Introduction

- Extreme Ultraviolet Lithography (EUVL) is a leading candidate of next-generation lithography for sub-22nm half pitch (HP) technology node. many results and discussion of this year for EUVL pre-production tool (PPT) will be important in considering EUVL high-volume manufacturing tool (HVMT) insertion timing.

- Flare, the total integrated light scattering from surface roughness at wafer level in EUVL system including reflective mask, is supposed to arouse serious problems in critical dimension (CD) uniformity.

- As HP technology node shrinks, flare degrades CD more aggressively. Therefore, it is required to predict accurate flare value with reducing maximum flare error and compensate it at OPC level. Calculation of accurate flare value requires lots of computational time and resources.

- In this paper, we show novel flare modeling technique considering three-dimensional (3D) EUVL mask topology, which is suitable for sub-22 nm HP node. Additionally, the feasibility of mask e-beam writing correction method for flare compensation under upcoming advanced optics was investigated with optimization among accuracy, resources, and computational time.

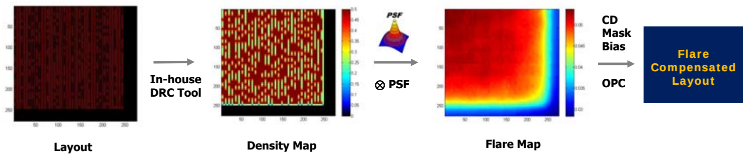
Flare Modeling & Compensation Flow

- Pedestal model (Used in our Simulation)

$\mathrm{Flare}_I(x,y) = \mathrm{FPSF}_{sc}(x,y) \otimes R_{mask}(x,y)$

- Rule-based Flare Compensation Flow

$\text{CD Mask Bias} = -\partial CD/\partial \mathrm{Flare}|_{\mathrm{Flarelocal}} [\mathrm{Flare}_{nominal} - \mathrm{Flare}_{local}] / \mathrm{MEEF}$



- **Total Flare Modeling Error**

1. Original PSF Measurement Error
2. PSF Sampling Error
3. Effective Mask Reflection Coefficient Error
4. Mask CD Bias Sampling Error (Flare Bin)

→ We need to reduce these factors to improve flare modeling accuracy. Especially, We should leave a margin of flare sensitivity by flare modeling with enough accuracy.

▣ Goal: 0.3% max flare error for development applications
0.15% max flare error for high volume manufacturing

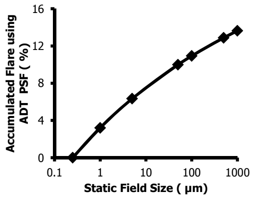
Point Spread Function (PSF)

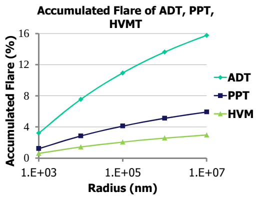
- We have extracted the PSF of Alpha Demo Tool (ADT) of which intrinsic flare value is about 16% and estimated several PSFs of upcoming advanced EUV tool optics.

- **PSF (Single Fractal Model)**

$Y(psf) = [Scale] \times x^{[N]}$

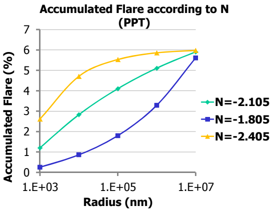
- N= -2.105 for ADT, Scale is calculated from N and intrinsic flare value.
- We suppose that pre-production tool (PPT) has 6% and high-volume manufacturing tool (HVMT) has 3% intrinsic flare value.

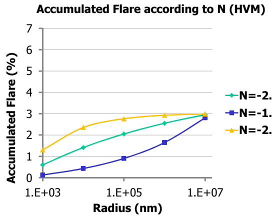



Accumulated Flare of ADT, PPT, HVMT

- First, accumulated flare of PPT and HVMT were predicted through just scaling with same N.

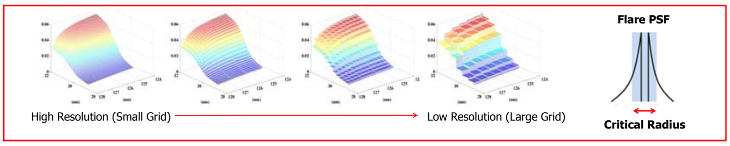
- Second, N effect on accumulated flare of PPT and HVMT were studied when manipulating N.

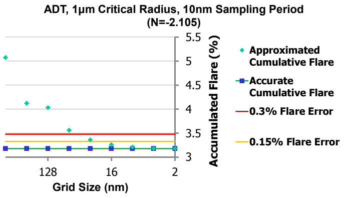

Accumulated Flare according to N (PPT)

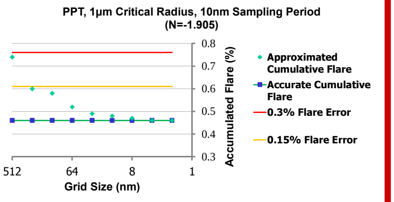

Accumulated Flare according to N (HVM)

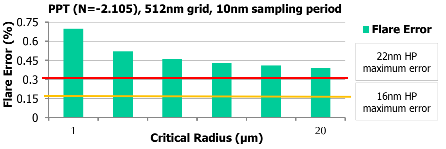
- Most PSF sampling error comes from the short range where the gradient of PSF is high. As N decreases, we can easily reduce this error as well as computation time, even with relatively limited hardware sources.

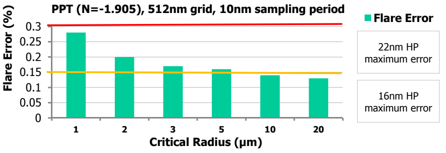
Basic Grid Size & Critical Radius




ADT, 1μm Critical Radius, 10nm Sampling Period (N=-2.105)


PPT, 1μm Critical Radius, 10nm Sampling Period (N=-1.905)

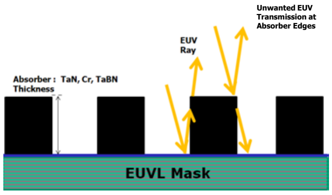

PPT (N=-2.105), 512nm grid, 10nm sampling period

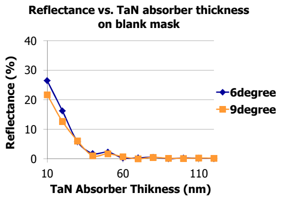

PPT (N=-1.905), 512nm grid, 10nm sampling period

- We can obtain flare value in reasonable time as an expense of some accuracy and memory resources. Therefore, Flare modeling condition is important.
- At PPT (N=-2.105), acceptable grid size would be same with ADT's. But, N changes from -2.105 to -1.905, even below 256nm grid size can be accepted.
- Also, critical radius of PSF, in which sampling period is shortest when performing multi-grid strategy PSF sampling, affects flare calculation error.

- Critical radius of over 10 μm is appropriate for PPT (N=-1.905). But, any critical radius cannot reduce flare calculation error to acceptable level with N=-2.105.
- Optics manufacturer, Semiconductor company, and EUV OPC software company should be refer this kind of analysis to develop flare compensation tool.
- From results, E-beam direct writing correction method, which needs 128nm ~ 512nm grid size at wafer level, seems to have an effect in flare compensation. It can be implemented with conventional OPC tool at PPT, perhaps alone at HVMT.

Effective Mask Reflection Factor




Reflectance vs. TaN absorber thickness on blank mask

- EUVL Flare is affected by 3D topological EUVL mask effect, unlike almost conventional 2D mask in ArF lithography.
- $R_{mask}(x,y)$ is not just average pattern density in EUVL.
- So, we proposed flare modeling technique using effective mask reflection factor.

$$\frac{\text{Average reflectance at the each location}}{(\text{Reflectance of blank mask} - \text{Reflectance of absorber})}$$

- In order to produce real reflectance with different incident angle, materials, absorber thickness at each point, we used TFCal software, rigorous optical constant simulator.
- Because this phenomenon is related to shadowing effect, we should consider off-axis angle, azimuthal angle, and absorber thickness.
- Detailed analysis and results are in progress.

Conclusion & Future Works

- Comparison to conventional 2D flare modeling, Our rigorous 3D flare modeling method seems to reduce flare calculation error in EUVL.

- Computing capabilities (CPU, Memory) should be enhanced to exhibit flare map of entire exposure field simultaneously with acceptable flare calculation accuracy in real manufacturing process.

- It is expected to lighten the load of computing capabilities greatly by upcoming EUV optics system of lower flare in near future.

- It is estimated that Mask e-beam dose writing level correction method for flare compensation will be effective with OPC level correction until the stage of PPT optics. Finally, Mask e-beam dose writing level correction method may be used alone enough at the stage of HVMT optics.

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