An Investigation of the Impact of Mask Shadowing Effect on Flare in Extreme Ultraviolet Lithography

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Introduction

• Extreme Ultraviolet Lithography (EUVL) is a hot candidate for 22nm line and space (L/S) pattern. One of the critical issues in EUVL is Flare, which is integrated light scattering from surface roughness in an optical system.

• Flare degrades the control of critical dimension (CD) uniformity across the exposure field. Also, it generates more CD sensitivity as L/S half pitch size decreases. Therefore it is more important to predict accurate flare map for flare compensation.

• The oblique illumination in EUVL system generates mask shadowing effect which affects flare.

• In this paper, The impacts of mask shadowing effect on flare in EUVL are investigated through flare map prepared by MATLAB simulation. Flare map is based on the pedestal model.

Rule-based Flare Compensation Method

• In rule-based flare compensation method, accurate calculation of flare map is important.

▪ Rule-based Flare Compensation Method

I. Ideal mask pattern is defined.
II. Flare level is calculated at all points within the mask through flare map using point spread function(PSF) of camera.
III. Effect of flare level on CD is determined by experiments.
IV. Finally, we bias mask features based on flare map and experimental data.

• Flare PSF of EUVL optics describes the response of EUVL imaging system to a point source. Also, we have approximated flare PSF to triple gaussian profile based on POB2 of the engineering test stand(ETS). Its intrinsic flare approximation is 16% including DC flare(4%) and local flare(12%).

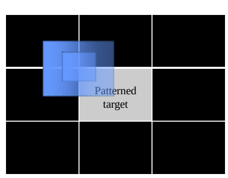
Flare Map Preparation

• We have calculated flare level using Pedestal model. Once the flare PSF is determined, flare level depends on the absorber density of clear-field mask.

▪ Pedestal model

$$Flare(x,y) = T_{MASK}(x,y) \otimes PSF_F(x,y)$$

: Computationally, flare is defined as a convolution of the flare point spread function (PSF) with the clear-field mask. This definition of flare is called 'Pedestal model'.



• The exposure field size and resolution are properly set up by PC hardware capabilities, 1x1 mm^2 area and 40nm respectively.

• 3x3 mm^2 area should be considered to accurately calculate flare to the very edge of the 1x1mm^2 area. The rest of 3x3mm^2 is dark field filled with absorber.

Ref.) Christof Krautschik, "Implementing Flare Compensation For EUV Masks Through Localized Mask CD Resizing, SPIE Vol. 5037 (2003)

Flare Map for 40nm L/S Pattern

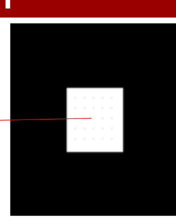
• The exposure field consists of 25 patterned targets where 40nm L/S is patterned with 50% open ratio.

• 40nm L/S patterned target in the center of exposure field is focused on by flare map.

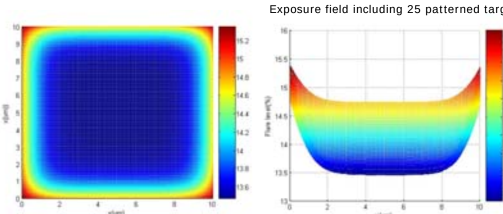
• Particularly, Maximum flare level is located in the vertex of patterned target.

• Even in the 10x10um^2 area, flare level variation is about 2%.

40nm L/S in a 10x10 um^2 patterned target



Exposure field including 25 patterned targets

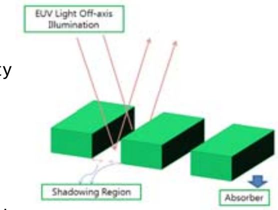


Flare map of 40nm L/S patterned target in the center of exposure field

Impact of Mask Shadowing effect on Flare

• In view of mask shadowing effect caused by surface topography of multilayer mask and oblique illumination, the effective absorber density of clear-field mask changes from the original absorber density of clear-field due to shadowing region.

• Accordingly, absorber thickness, off-axis angle, azimuthal angle and L/S half pitch size not only affect shadowing effect but also change flare level.

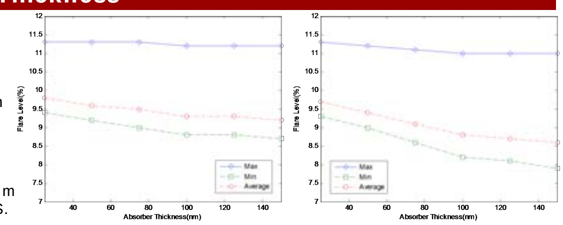


EUVL mask topography

1 Absorber Thickness

• Flare level was reduced when the absorber thickness increases. But the flare level variation in a patterned target increases.

• Flare level was changed more at 20nm L/S than at 40nm L/S.

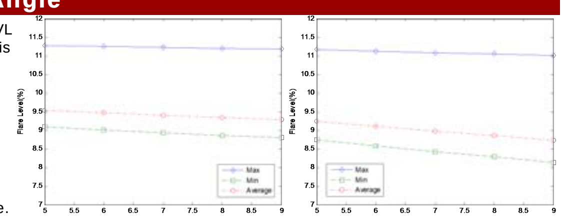


[Condition] : 40nm (Left figure), 20nm (Right figure) half pitch size, 0° azimuthal angle, 6° off-axis angle

2 Off-axis Angle

• Conventionally, EUVL tool uses 6° as off-axis angle.

• Increasing off-axis angle reduced flare level slightly. But at 20nm L/S, it should be taken into consideration when calculating flare.

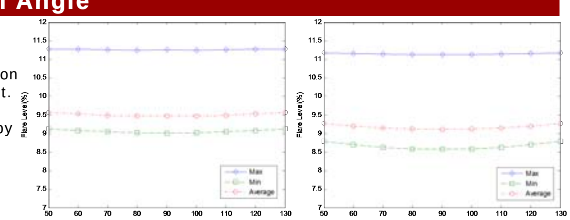


[Condition] : 40nm (Left figure), 20nm (Right figure) half pitch size, 0° azimuthal angle, 75nm absorber thickness

3 Azimuthal Angle

• Azimuthal angle is caused by feature orientation and position in the bow-shaped slit.

• Flare level change by azimuthal angle is negligible when compared with other factors.

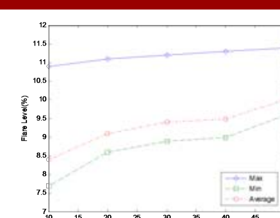


[Condition] : 40nm (Left figure), 20nm (Right figure) half pitch size, 6° off-axis angle, 75nm absorber thickness

4 L/S Half Pitch Size

• When the area of L/S patterned target is constant, the more L/S half pitch size decreases, the more shadowing region area increases.

• Flare level was reduced when the L/S half pitch size decreases. But the flare level variation in a patterned target increases.



[Condition] : 75nm absorber thihckness, 0° azimuthal angle, 6° off-axis angle

Conclusion & Future Works

• In this paper, we have investigated the impact of mask shadowing effect on flare in EUVL. We have shown that absorber thickness, off-axis angle and L/S half pitch size affect on calculating flare level. Also, azimuthal angle affects on flare, but it is negligible.

• In spite of significant improvements in EUV optical fabrication technology, mask compensation will be required to reduce flare effect for CD uniformity. To compensate flare, we need more elaborate flare map and smaller flare bin at more advanced technology nodes in terms of increasing CD sensitivity.

• Consequently, in order to obtain more accurate flare level, flare should be calculated with considering EUVL mask topography and other conditions, such as material type, EUV reflectivity variation of thin absorber.

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