An Estimation of the Mask Shadow Effect and its Compensation as Flexible Illumination system in EUVL

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Introduction

• Extreme Ultraviolet Lithography (EUVL) is the most promising candidate for sub-22 nm node and beyond. One of the critical challenges in EUVL is the shadow effect caused by EUV light illumination with oblique incidence angle of 6° due to an asymmetric structure of EUVL scanner.

• Analysis of normalized image log slope (NILS) value decrease by the shadow effect is very important to find optimized compensation methods. We calculated NILS values of aerial images with various sidewall angles, and we propose methods to increase aerial image NILS value by using a Flexible Illumination.

Sentaurus Lithography (Synopsys Inc.)

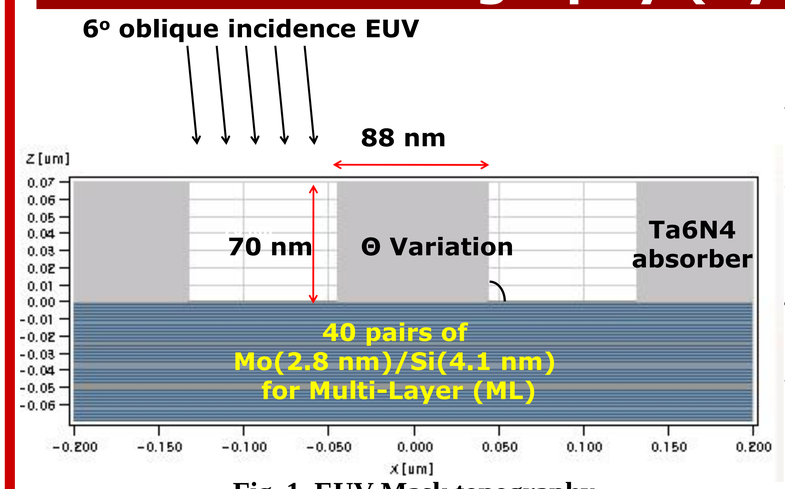


Fig. 1. EUV Mask topography

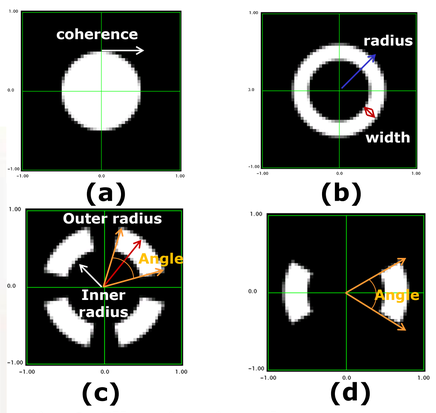


Fig. 2. Illumination shape
a) conventional b) Annular
c) Quasar d) Dipole

• We calculated shadow effect using the conventional illumination with the sidewall angle variance. The shadow effect is shown with aerial image NILS values. In order to compensate the shadow effect, we used flexible illumination shape of Off-Axis Illumination (OAI).

The Shadow Effect

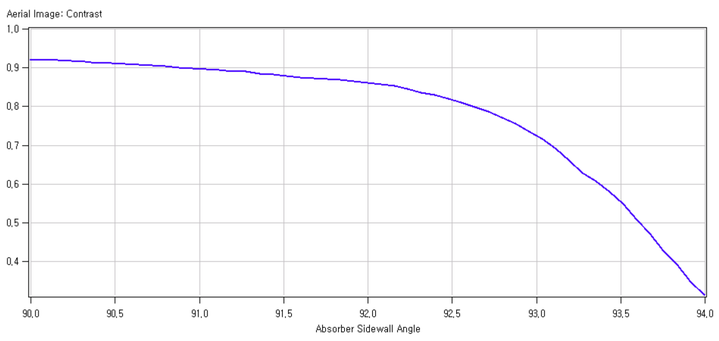


Fig. 3. Aerial image contrast degradation with sidewall angle variance

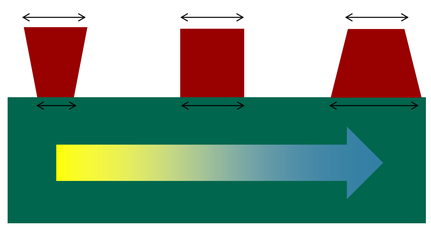


Fig. 4. ML area change with sidewall angle

• The Aerial image contrast is decreased with a gentle slope of absorber. This phenomenon is caused by a reduction of the reflective area of EUV mask. The sidewall angle variance can change bottom CD of absorbers.

EUV Mask Diffraction and OAI.

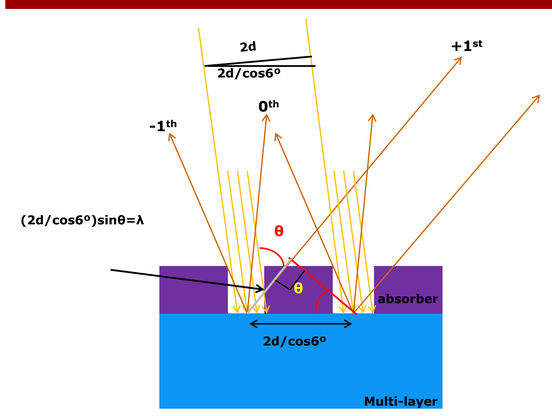


Fig. 5. The diffraction at EUV Mask

Table 1. Calculation of diffraction angle with various CD

Half Pitch	Diffraction angle	2d value
32 nm	12.5°	64 nm
22 nm	17.8°	44 nm
16 nm	24.9°	32 nm
10 nm	42.4°	20 nm

• EUV mask does not require complicated Optical Proximity Correction (OPC). (short wavelength)
• Diffraction angle change is crucial in 22 nm and sub-10 nm node.
• A high diffraction angle can reduce the aerial image contrast due to a limited NA value of lenses.
=> EUVL also needs OAI system.

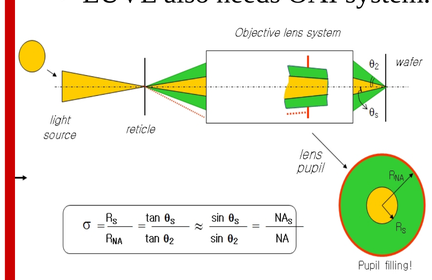


Fig. 6. The definition of a sigma value

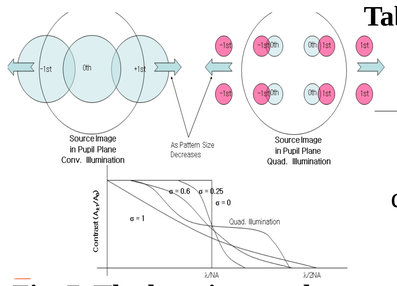


Fig. 7. The low sigma value by OAI

Table 2. Comparison of Conventional and Quadrupole Illumination

	Conv.	Quad.
Light power	high	low
diffraction light	0th	0th & 1st or -1st
sigma Value	High	low
resolution	Bad	Good

The Compensation of the Shadow Effect

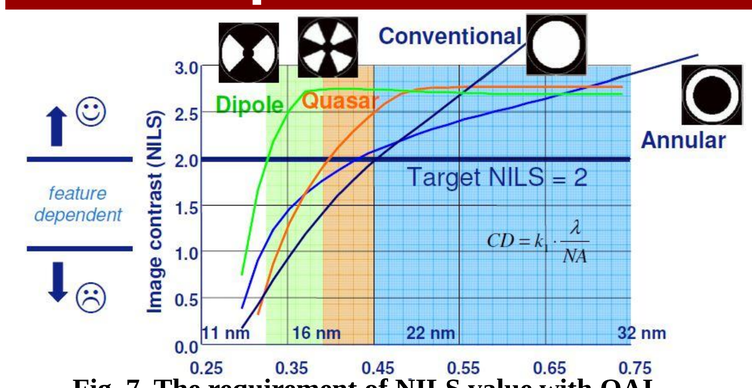


Fig. 7. The requirement of NILS value with OAI

• This is the ASML roadmap for the required NILS values depending on scale down and illumination system (Fig.7). NILS is the slope of the natural logarithms of aerial image intensity and width.

$$NILS = L\frac{\partial \ln I}{\partial x}, \qquad (1)$$

I : aerial image intensity, L : width

Ref : ASML roadmap

1 Flexible Illumination using OAI

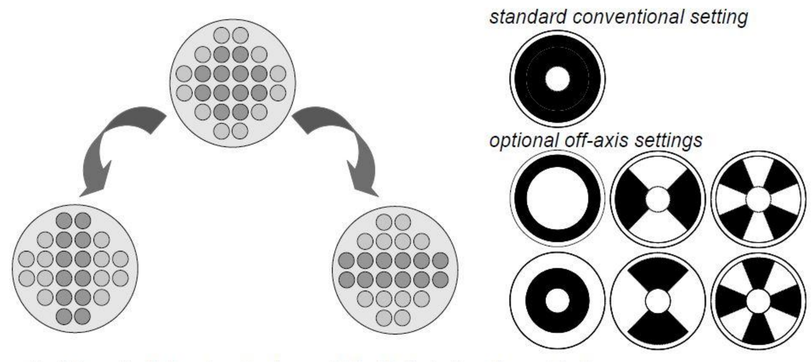


Fig. 8. Flexible Illumination of Off-Axis Illumination

• NXE:3300B is expected to adopt Off-Axis Illumination (OAI).

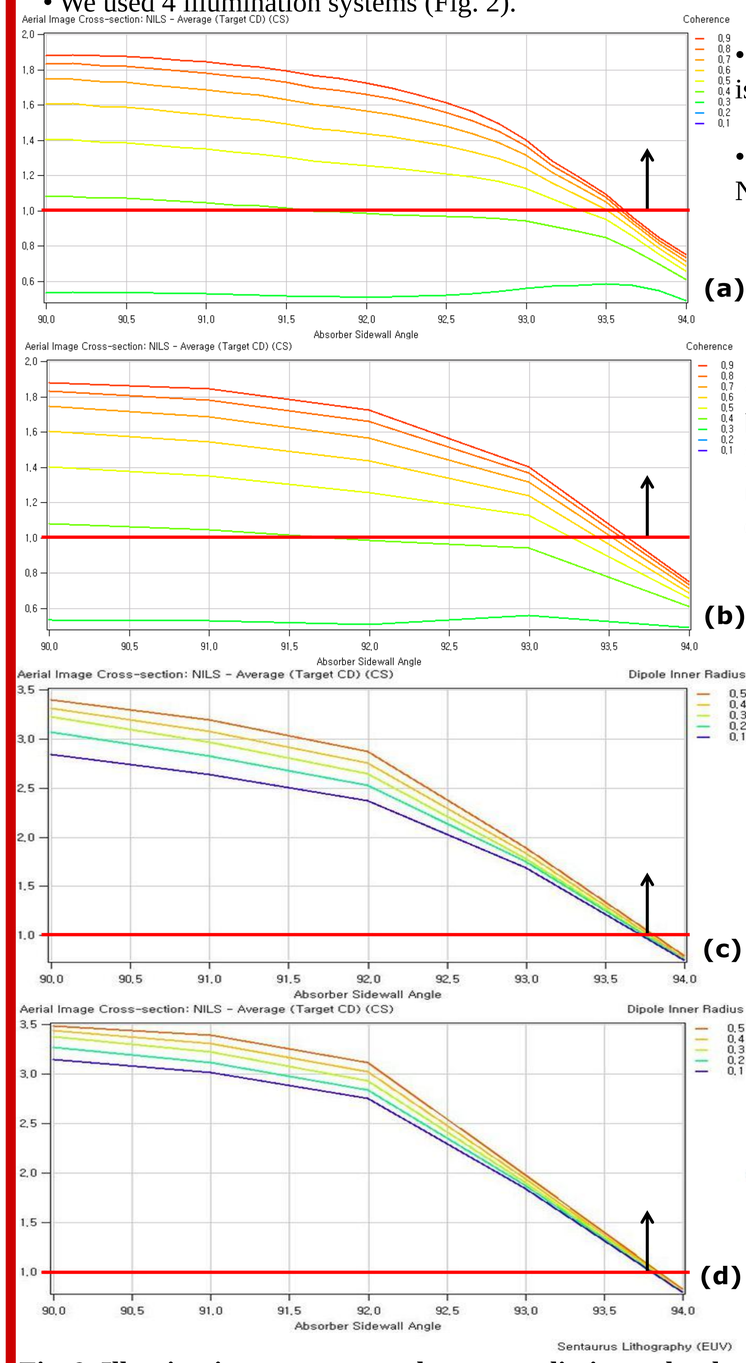
• In NXE:3300B, illumination shape can be changed optimally by micro-mirror controls to increase NILS values of aerial images, and can offer better resolution.

Depending upon the EUV mask, illumination shape will be changed to obtain the high NILS values.

Ref : Optics for EUV production, 2010 SPIE

2 Parameters change of illuminations for higher NILS

• We used 4 illumination systems (Fig. 2).



• In conventional illumination, NILS value is decrease with gentler sidewall angle.

• But, higher coherence makes higher NILS values compared to small coherence.

(a) Conventional illumination

• The annular illumination can offer better NILS value than conventional illumination, also this illumination can make higher NILS value with higher coherence and wider width.

(b) Annular illumination

• The dipole illumination can implement higher NILS value compared to above illuminations. This is very efficient illumination for sub-22 nm node and beyond.

(c) Dipole illumination

• The quasar illumination has the most efficient illumination system in these calculation.

(d) Quasar illumination

Sentaurus Lithography (EUV)

Fig. 9. Illumination parameters changes to eliminate the shadow effect

Conclusion & Future Works

• The shadow effect is very critical with sidewall angle variance, and it can be slackened using the parameters change of OAI system in NXE:3300B.
• Even if, the diffraction of the EUV is very small, it must be considered in sub-22 nm and beyond. In NXE:3300B, the oblique incidence angle will be steeper due to adoption of higher NA.
• To establish the exact shadow effect compensation modeling, we need to consider various parameters which are steeper oblique incidence angle and scanner slit direction with HV-CD direction.

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