Influence of Incident Angle Change Caused by Different Off-Axis Illumination on 16 nm Node Extreme Ultraviolet Lithography

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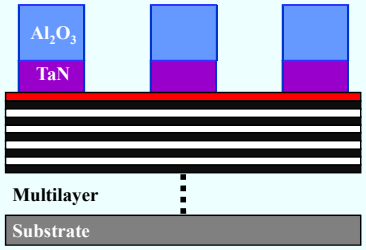
Introduction

- ❖ Currently, 6 degree oblique incidence is main stream, but 5 degree incident angle is also studied for 0.25 NA in EUVL.
- ❖ Incident angles larger than 6 degree are also considered for larger NA. This incident angle will affect many things, eventually to the line width.
- ❖ The shadow effect in the EUVL mask is an important factor that decreases the contrast of the aerial image and causes a directional problem, thus it will make line width variation.
- ❖ The off-axis illumination (OAI) will be used with conventional on-axis illumination to make much smaller patterns.
- ❖ This OAI will split the main beam and change the incident angle.
- ❖ We focused on influence of incident angle change due to illumination type for the 22 nm & 16 nm node line and space (L/S) patterns.
- ❖ We checked the influence of incident angel variation caused by different pole position of various illuminations. And, the influence of OAI was studied by checking horizontal-vertical (H-V) CD difference.

Simulation Condition

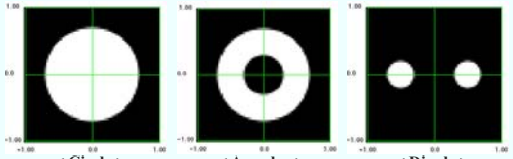


L/S pattern

▪ Exposure Condition

Wavelength (nm)	13.5 nm
NA	0.25 (22 nm), 0.32 (16 nm)
Reduction	4
Incident Angle	5°, 6°, 7°, 8°

▪ Illumination pupil images



< Circle > < Annular > < Dipole >

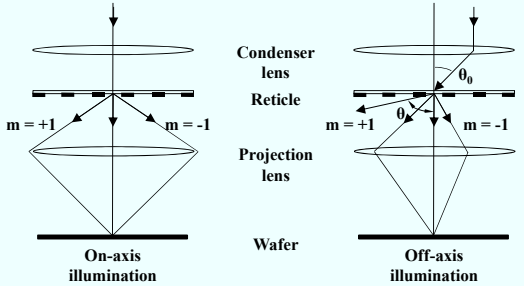
▪ Material Information (at 13.5 nm)

	Material	Thickness (nm)	n	k
Multilayer (Mo/Si)	Mo	4.1	0.999	0.00183
	Silicon	2.8	0.92388	0.00643
Capping Layer	Ru	1.8	0.88635	0.30171
Absorber	TaN	27.2	0.92599	0.04363
	Al_2O_3	20	0.96788	0.03899

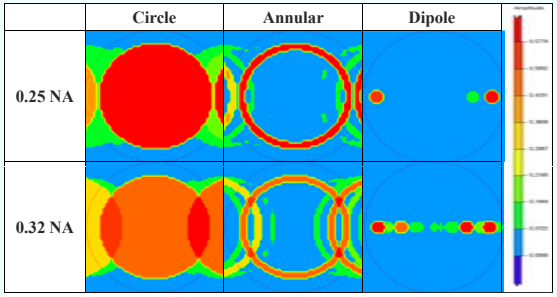
	Refractive Index	Dill A (1/μm)	Dill B (1/μm)	Dill C (cm²/mJ)
EUV-2D	0.9765	0	5.1851	0.195

Simulation Results

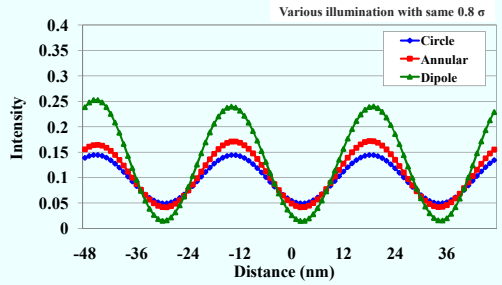
▶ Influence of various illumination type



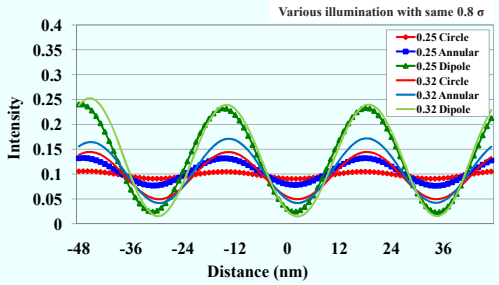
• On-axis and off-axis illumination. With off-axis illumination, diffraction orders>0 are propagated through the projection lens.



• Diffraction order for different illuminations (σ = 0.8)

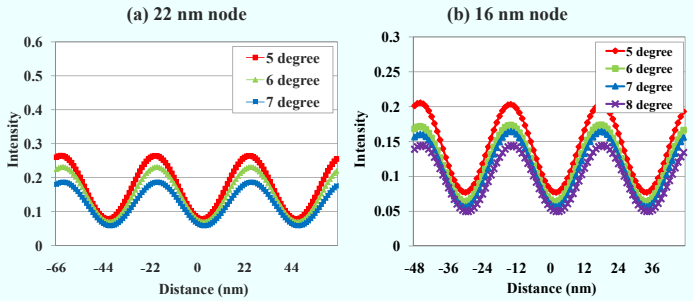


(a) Aerial image for the OAI

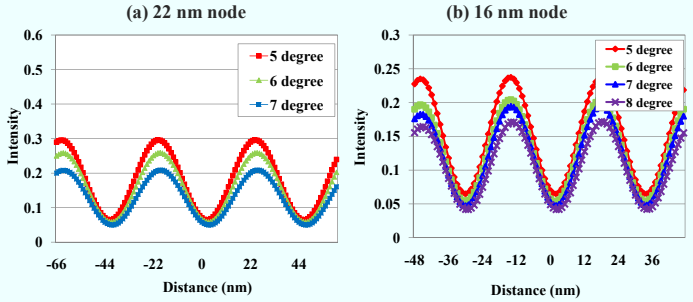


(b) Aerial image for the different NA

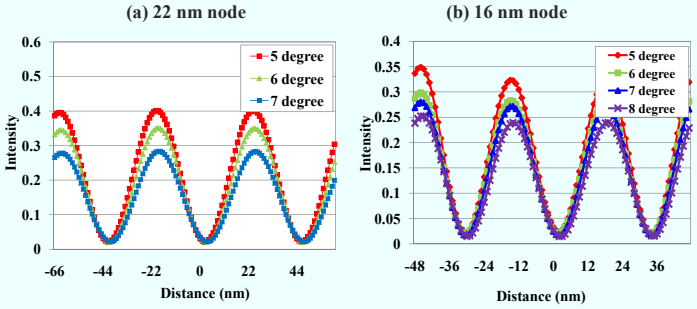
► Influence of incident angle for different illumination type



• Circle illumination : (a) 22 nm node and (b) 16 nm node

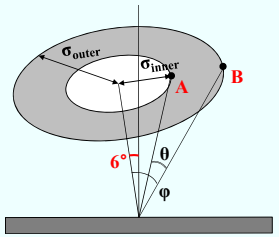


• Annular illumination : (a) 22 nm node and (b) 16 nm node

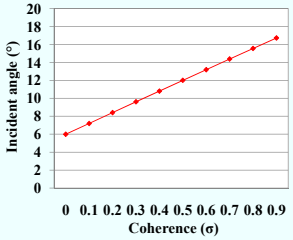


• Dipole illumination : (a) 22 nm node and (b) 16 nm node

► Influence of partial coherence (σ)

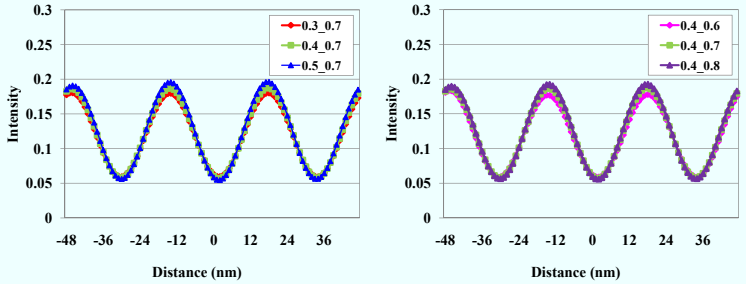


(a) Annular illumination diagram



(b) Real incident angle

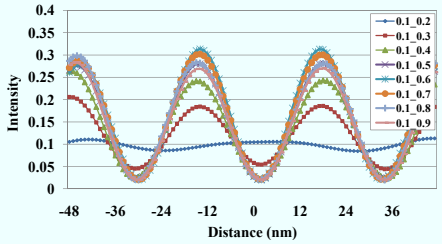
• Real incident angle from the pole to the mask for the annular illumination



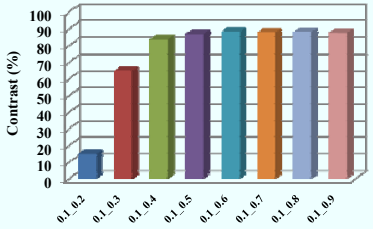
•Aerial image of different pole positions for annular illumination

• There is no difference of the aerial image in spite of the change of σ_{inner}.

► Influence of dipole illumination

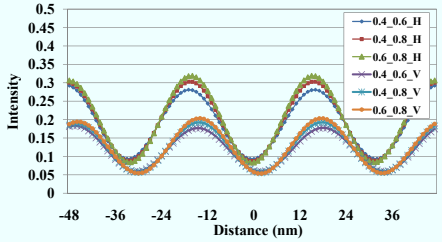


(a) Aerial image of dipole illumination

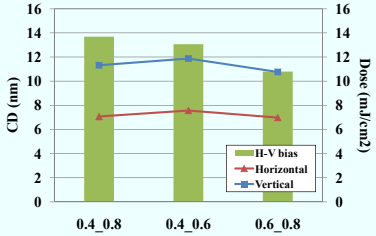


(b) Contrast of dipole illumination

• Aerial image and contrast for dipole illumination with different partial coherences



(a) Aerial image of annular illumination for horizontal-vertical pattern



(b) Contrast of annular illumination for horizontal-vertical pattern

•Aerial image comparison between horizontal and vertical mask for different degree of coherence for annular illumination

Coherence (σ)	Pattern shape	Resist profile	CD(nm)
0.4_0.8			15.99
			2.30
0.4_0.6			17.05
			3.99
0.6_0.8			15.99
			5.21

•Horizontal-vertical (H-V) critical dimension (CD) bias difference with different annular illumination

Conclusions

❖ The influence of the incident angle of EUV lithography for 22 nm and 16 nm node is studied.

❖ The oblique incidence to the EUV mask causes shadow effect and this will make H-V bias.

❖ In order to make 1:1 line and space pattern, off-axis illumination might be needed.

❖ This added incident angle to the oblique incident to the reflective EUV mask might cause another EUV process problem.

❖ We found that if the incident angle increased with higher σ of the off-axis illumination, the aerial image went worse.

❖ The CD difference between the horizontal and the vertical pattern is also dependent on the σ even though it is small.

❖ This makes more complex optical proximity correction in EUV.

❖ More study is needed to know the incident angle dependent CD control in EUV.

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