Super Resolution Techniques for DUV Optical Lithography

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Abstract - As device geometries shrink, new illumination sources will be needed to obtain practical resolution. The krypton fluoride (KrF) excimer laser (248nm) is capable of 0.30 µm resolution with conventional illumination methods. A weak quadrupole off-axis illumination technique combines the advantages of two-beam imaging (off-axis illumination), and three-beam imaging (conventional illumination). This allows for the advantage of increased Depth-of-Focus (DOF) without the degradation of isolated patterns. This method is suitable for use with an attenuated phase shift mask (APSM) which also enhances resolution and DOF.

I. INTRODUCTION

The 248-nm Krypton Fluoride (KrF) excimer laser is a good candidate for the next generation of sub-quarter micron semiconductor devices. The practical resolution and DOF needed to obtain the required lithography can be achieved using these enhancement techniques. Weak quadrupole off-axis illumination (OAI) and APSM are the techniques used in conjunction for this preliminary study. This research involves simulating these techniques on Prolith/2 (Finle Technologies) with a 2D mask containing 0.19 µm features (k_1 = 0.4). This study is done as a precursor to fabricating a weak quadrupole OAI aperture to be used in a KrF GCA/ISI stepper.

II. OFF AXIS ILLUMINATION

A mask object is illuminated obliquely so that the fundamental (0^{th}) and first diffraction orders coincide and are distributed symmetrically in the projection lens pupil on either side of the optical axis as shown in Fig. 1 (two-beam imaging). This results in the possibility of resolution doubling and a theoretically infinite DOF. Typically, features in integrated circuits are limited to horizontal and vertical orientation therefore a quadrupole OAI scheme is implemented where illumination from the four poles are optimal for these features as shown in Fig. 2. Another OAI technique involves a ring or annular illumination scheme which could deliver illumination at all angles but power would be lost since all information wouldn't be used for imaging. The quadrupole technique enhances DOF and resolution for dense features but degrades them for isolated features.

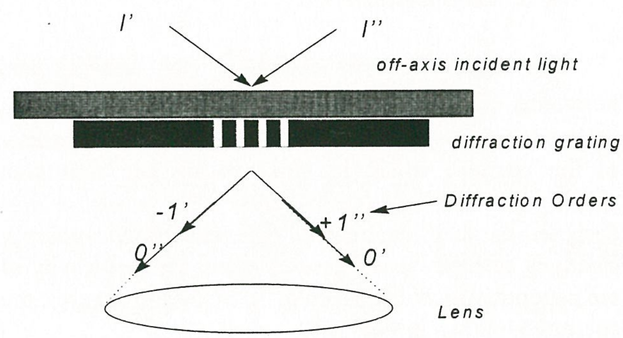

Fig. 1. Off-axis illumination, the zero and first diffraction orders coincide in the lens pupil.

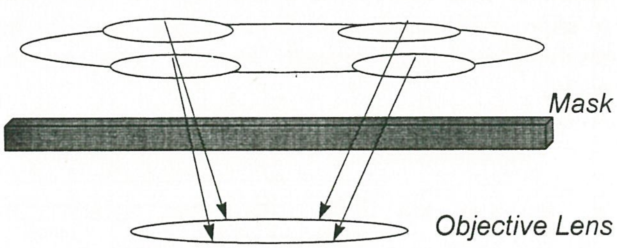

Fig. 2. Quadrupole illumination scheme.

The weak quadrupole OAI allows for illumination to pass through the center of the aperture which provides the benefit of conventional illumination (3 beam imaging). This technique allows for the minimal degradation of isolated features.

The weak quadrupole OAI aperture was designed optimizing certain design conditions under specific constraints: the KrF GCA/ISI stepper has a σ_{max} 0f 0.74, the relative light intensity at the center of the aperture is required to be 20 -30%.

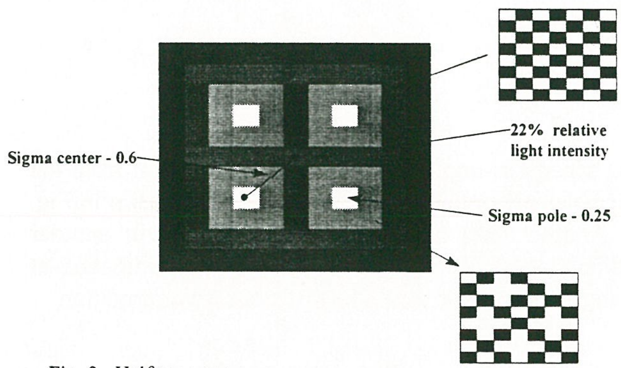

Fig. 3. Half-tone aperture.

The σ_{center} controls the DOF for vertical and horizontal features of dense patterns. The σ_{pole} controls the relative light intensity that is transmitted at the center of the aperture which in turn controls the resolution performance for isolated patterns. The aperture was designed on an IC layout tool (Mentor Graphics Corp.). The light intensity was varied by changing the density of the patterns, which consisted of 50 by 50 μm squares, the aperture is shown in Fig. 3.

III. ATTENUATED PHASE SHIFT MASK

The APSM is composed of a partially transmissive material (usually 5 - 15%) which gives a π phase shift. It replaces the nontransparent chrome material. This technique uses constructive and destructive interference to improve both DOF and resolution. Fig. 4. shows the resulting aerial image intensity which is delivered to the wafer.

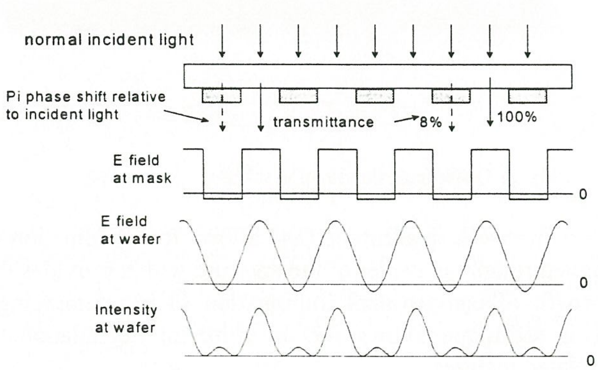

Fig. 4. Attenuated Phase Shift Mask.

IV. CONCLUSION

These techniques when combined enhance the resolution and DOF. The DOF was calculated using a +/- 10% CD spec at zero defocus. The DOF was calculated using image CD vs. Focal position as simulate on Prolith/2. In all simulated cases, a mask bias would be necessary to obtain the required CD of 1.9μm (k_1=0.4). The metric used for resolution is the image-log slope (ILS) which is the change in the natural log intensity by the change in distance: δln(x)/δx.

	DOF (μm)	
	dense features	isolated features
conventional	0.70	0.42
OAI	1.09	0.41
APSM	0.60	0.51
combination	1.09*	0.56*

	Image-Log Slope (μm^{-1})	
	dense features	isolated features
conventional	6.90	10.89
OAI	9.33	9.88
APSM	10.06	16.40*
combination	11.57*	14.16

The combination technique yields the largest DOF for both dense and isolated features. Resolution obtained for dense features is optimal and comparative for isolated features.

REFERENCES

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