

Quadrupole Apertures for 193nm Lithography

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Abstract- Strong and weak quadrupole apertures have been optimized and fabricated for relatively dense 0.12 μ m geometry's. All of the apertures were optimized using PROLITH/2 simulation software. The apertures were fabricated as fused silica reticles that are inserted at the lens pupil plane. The apertures change the illumination profile that is collected by the condenser lens. Depth of focus (DOF) is increased using quadrupole illumination when trying to resolve specific pitch values.

I. Introduction

The functional relationship between normalized image log-slope and focus is extremely important in that it delineates the focus latitude available. The defocus tolerance, or DOF, becomes even more significant as the industry moves to smaller critical dimensions.

Off-axis illumination schemes have been developed to improve DOF of optical lithography tools. In order to produce an image of some suitable quality, the zeroth and first diffraction orders must be collected by the objective lens. Figure 1 shows that if the illumination is positioned at the correct angle, the zeroth and first diffraction orders travel the same path length.

Quadrupoles apertures are able to deliver illumination at the proper angle.(Figure 2.) This creates the larger effective DOF because the is no significant optical path difference.

II. Design and Optimization

The strong quadrupole apertures are specified in relative sigma values, σ_{center} and σ_{radius} . The σ_{center} specifies where the center of the pole is from the center of the aperture. The σ_{radius} designates the size of the pole's radius. Each quadrupole aperture was designed to be optimized for a specific feature size and would provide non-optimal illumination for all others. The σ_{center} for a quadrupole was determined by

$$\sigma_{\text{center}} = \frac{\sqrt{2} * (\lambda/2p)}{NA_o}$$

The apertures were made for a 193nm laser with a NA_o of 0.6.

The weak or gaussian apertures are specified in relative sigma values σ_{center} and $\sigma_{\text{gauss width}}$, and $\sigma_{\text{hard stop}}$. The gaussian width is the relative size of the gaussian distributed poles. The $\sigma_{\text{hard stop}}$ is the relative size of the hard stop the blocks the excess light. Figure 3 shows schematic examples of apertures made.

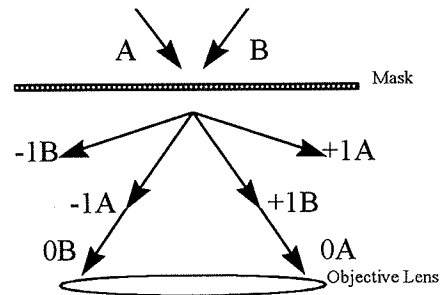


Figure 1. Off-axis illumination where a mask is illuminated in order for the zeroth and first diffraction orders coincide in the objective lens.

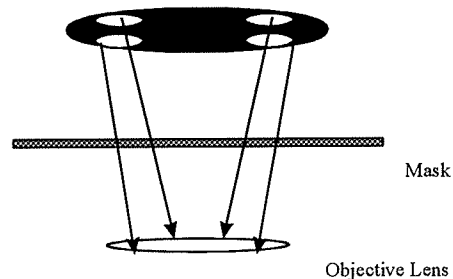


Figure 2. Off-axis illumination scheme using quadrupole aperture.

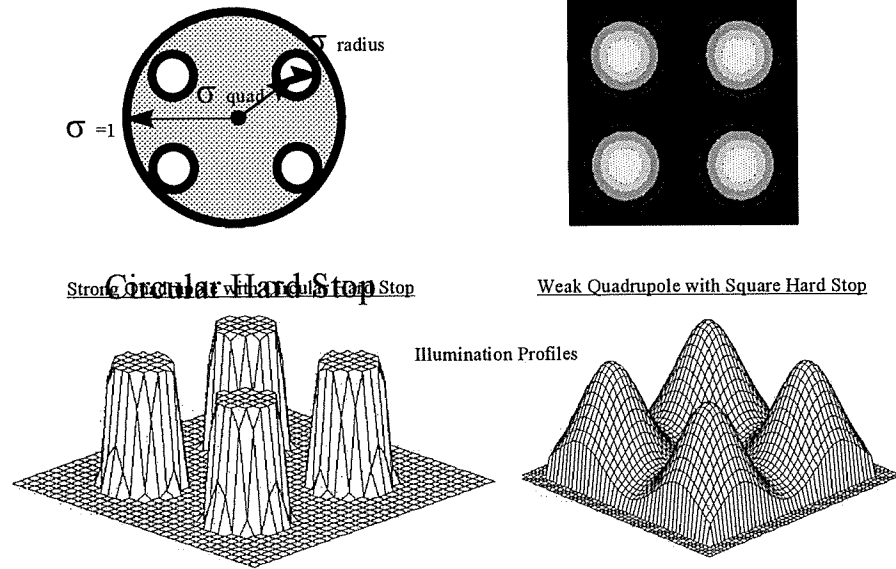


Figure 3. Schematic of strong quadrupole with circular hard stop and weak quadrupole with a square hard stop. Also shows illumination profiles.

III. Results

There were eight apertures optimized for various pitch values. The resulting sigma values using strong quadrupole scheme are shown in Table 1. Each aperture was optimized for a specific pitch or range of pitch values. The common solution is optimized for a range of pitch values instead of one specific value.

Figure 4 displays the diffraction orders for the common strong quadrupole solution. The goal was to place the common 0th order where the greatest overlap of the diffraction orders. This overlap of the 0th and 1st orders allow imaging to occur and increases the effective depth of focus. Graph 1 is a typical strong quadrupole versus conventional illumination. This shows that when using strong quadrupole illumination, the DOF is larger. This allows for a larger defocus latitude. Even a large change in focus only results in a small change in resist process performance (NILS).

The weak quadrupoles were optimized for 0.36 μ m pitch values and for a pitch range of

0.24 μ m to 0.48 μ m. Table 2 shows the subsequent sigma values for the weak gaussian quadrupoles. The weak quadrupoles allow some energy between the poles. This approach allows some on-axis illumination for more isolated features. The weak quadrupoles were also modified by attenuating the illumination energy with a specific circular or square hard stop. Graph 2 shows similar results to Graph 1. The weak quadrupoles tend to have a larger defocus latitude than conventional illumination

Duty Ratio	Pitch[μ m]	σ_{center}	σ_{radius}
1:1	0.24	0.95	0.20
1:2	0.36	0.63	0.20
1:3	0.48	0.47	0.20
common solution	0.24to0.48	0.72	0.27

Table 1: Sigma's and corresponding pitch values for strong quadrupole apertures.

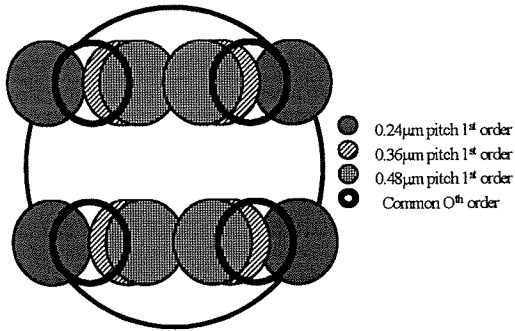
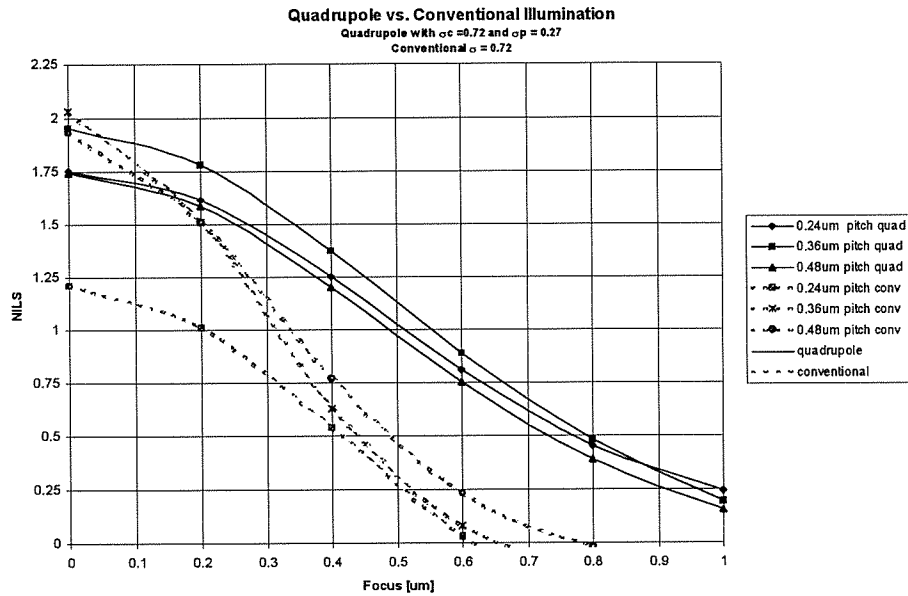


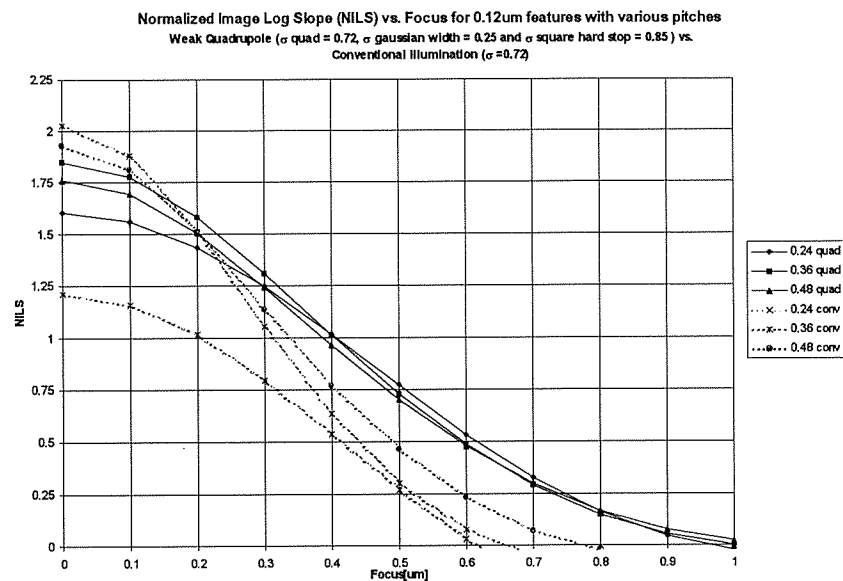
Figure 4. Diffraction orders in frequency plane of the objective lens for common solution

Hard Stop	Pitch [μm]	σ quadrupole	σ gaussian width	σ hard stop
circular	0.36	0.63	0.20	0.75
square	0.36	0.63	0.20	0.65
circular	0.48	0.72	0.30	0.85
square	0.24 to 0.48	0.72	0.25	0.85

Table 2: Sigma's and corresponding pitch values for weak gaussian quadrupole apertures.



Graph 1: Advantage of improved depth of focus by using quadrupole illumination over conventional illumination.



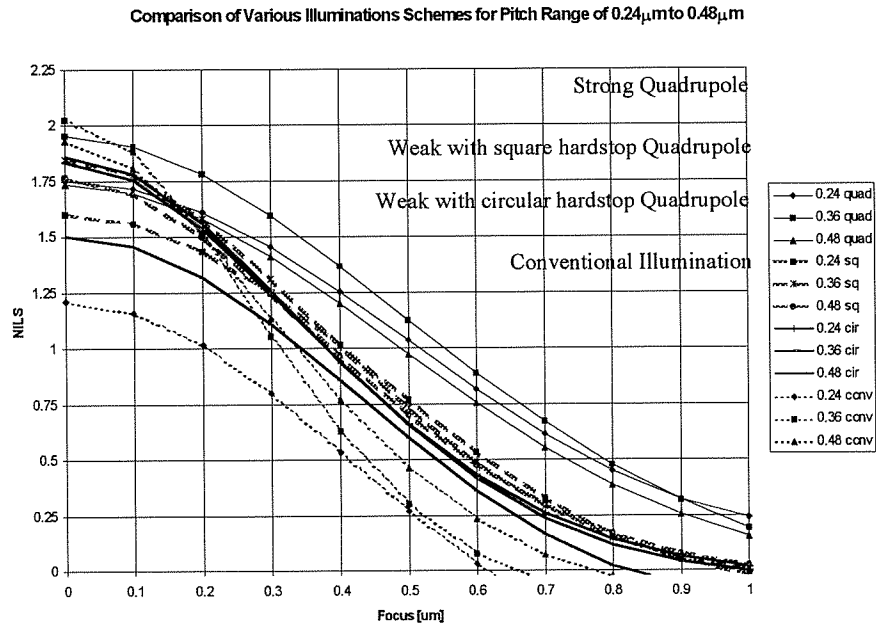
Graph 2: Advantage of improved depth of focus by using weak quadrupole illumination over conventional illumination.

IV. Conclusion

Graph 3 compares all of the various illumination schemes for pitch range of $0.24\mu\text{m}$ to $0.48\mu\text{m}$. DOF is increased using quadrupole illumination when optimized for specific pitch values. Strong quadrupoles have a tendency to have a larger DOF than weak quadrupole for dense features. Weak quadrupoles are preferred when

considering a wide range of pitch values. The square hard stop has a slightly larger usable DOF range than a circular hard stop because it allows for extra intensity at its corners.

A larger DOF allows for greater latitude from best focus when trying to produce images of suitable quality. These apertures may ultimately help extend the effective utilization of optical lithography in integrated circuit manufacturing.



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