9-14-2001

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Recommended Citation

Martin McCallum, Bruce W. Smith, Steve Bassett, Julian S. Cashmore, James E. Webb, "Study of obscuration in catadioptric lenses", Proc. SPIE 4346, Optical Microlithography XIV, (14 September 2001); doi: 10.1117/12.435646; <https://doi.org/10.1117/12.435646>

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A Study of Obscuration in Catadioptric Lenses.

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Keywords: 157nm, catadioptric lens, obscuration

ABSTRACT

In this paper we will examine the effect of obscuration upon the various features we desired to image with a 157nm microstepper utilising a catadioptric lens. We will show the effect the obscuration has upon imaging when using not only conventional illumination and binary masks, but also when using a range of enhancement techniques such as off-axis illumination and phase-shifting masks. We will show how use of a large obscuration, whilst enhancing the signals for the densest features, actually degrades the signal for more isolated features. The level of obscuration must also take into account cross duty-ratio effects, i.e. the distribution of diffraction energy, for phase shifted features of various sizes. In this situation where a small sigma would be used a large level of obscuration can significantly increase biases. The choice of obscuration can have a major effect upon the imaging capabilities of a tool. In future, when the use of catadioptric lenses may be more widespread (for example this may happen at 157nm) it may be desirable to have the option to vary this obscuration dependant upon the pattern being imaged.

1. INTRODUCTION

In 1999 International SEMATECH made the decision to purchase a 157nm microstepper, the purpose being to provide an exposure tool that was available for resist developers to test out different chemistries and formulations for potential 157nm resists. This was previously successful at 193nm using the microstepper purchased from ISI and installed in the resist test centre in International SEMATECH's cleanroom facility. After an extensive discussion with multiple vendors a decision was made to purchase a tool from Exitech UK Ltd. The lens for this tool was to be supplied by Tropel Inc. Tropel had designed and supplied the lens for the 193nm ISI tool and the lens for the 157nm tool was to be based upon a very similar catadioptric design [1]. An integral part of this lens design is the obscuration build in. The purpose of this is to prevent zero order light passing straight through the lens. If we make the plate too small a 'halo' of light will occur and we will have an extra DC term of unwanted light; however, if we have the plate too large we will begin to impinge upon the frequencies we are trying to sample.

In order to establish the most appropriate obscuration we decided to use simulation to estimate the effect upon the aerial image of several different patterns: dense and isolated lines using both binary and alternating aperture phase-shifting masks (altPSM) and contacts using binary masking. The dimension of these was chosen to be 130nm, because this was the nominal value to which the lens was specified. We estimated that the majority of imaging would be initially completed at this dimension due to the 0.6 NA value of the projection lens and the very early generation 157nm resists that we would be using. The simulations were completed using a full scalar diffraction model in the PROLITH lithography simulation tool (version 6).

2. EFFECT OF ABERRATIONS

Most often, lens performance is evaluated assuming full use of the lens pupil. For an annular or an obscured pupil the variance of the phase aberration, $\sigma^2(\phi)$, evaluated across the lens pupil is confined to include only the outermost portions of the lens which are not effected by the obscuration. The variance of symmetrical aberrations such as defocus and spherical decreases with increasing obscuration as shown in figure 1. Each plot shows the standard deviation of the primary aberrations across the pupil, $\sigma(\phi)$, normalized to peak aberration value as a function of obscuration amount from zero to full (100%) obscuration.

Figure 1. Variance of symmetrical aberrations with increasing obscuration.

The variance of coma, astigmatism, and tilt generally increases with obscuration. The variance of balanced (Zernike) coma decreases with obscuration after a slight increase. The standard deviation of balanced coma and astigmatism with obscuration is shown in figure 2. To evaluate the impact of obscuration on imaging, aberrations need to be accounted for along with illumination coherence and geometry size and type.

Figure 2. Variance of asymmetrical aberrations with increasing obscuration.

In order to assess the impact of aberrations while we varied the obscuration, we assumed an aberration level of 0.05λ RMS. The file resulting in this was created by taking an actual thirty-seven term file from a previously produced 193nm microstepper lens and adjusting the values to give 0.05 waves. A graphical representation of this is shown in figure 3.

Figure 3. Graphical representation of the Optical Path Difference (OPD) for the aberration measurement file used to analyse the obscuration.

3. OBSCURATION INVESTIGATION

In order to gauge the effects of the obscuration we decided to use as a metric the Normalised Image Log Slope (NILS). This is a measurement of the slope of the aerial image normalised by the dimension being imaged and has the advantage of being related to the exposure latitude of the feature of interest [2]. A minimum NILS may be set in this way to allow a maximum allowable defocus to be defined while reasonable exposure latitude is present.

The patterns used to investigate the obscuration were: 130nm 1:1 line:space, 130nm 1:5 line:space, 130nm 1:2.2 contact:space all in binary masks and 130nm 1:1 line:space, 130nm 1:5 line:space with altPSM. For

each of the patterns using binary masking the partial coherence of the source was also varied from 0.3σ to 0.9σ , off-axis illumination was also investigated for a quadropole with radial partial coherence of 0.15 and multiple centre settings; for the altPSM case the partial coherence was held at 0.3σ .

The obscuration range chosen for investigation was between 6% and 20% in 2% increments. A subset of this data is shown in the following sections to show the trends of the data. The lenses manufactured for 193nm microsteppers using a similar lens design used a value of 10% [3].

3.1 130nm 1:1 line space:

The graphs in figure 4 below show the NILS versus defocus for the dense lines imaged with a binary mask and different partial coherence values. As can be seen the higher obscuration gives slightly lower NILS values at best focus but slightly higher NILS at higher defocus settings. This effect is most pronounced in cases where the light is most coherent (lower sigma values.)

Figure 4. NILS vs. defocus for 130nm 1:1 features at multiple partial coherence settings.

3.2 130nm 1:5 line space:

Figure 5 shows the trend for an isolated feature imaged with a binary mask and multiple partial coherence settings. In this case the obscuration has a much greater effect upon the image quality. The more coherent the light sources the larger effect that the obscuration has. This is likely to be due to the larger amount of zero order light, used to image isolated features, that is blocked by the larger obscuration. This can be seen in the diffraction plot in figure 6. As the illumination source becomes less coherent the obscuration has decreasing effect upon the signal. However, even in the least coherent cases a higher obscuration causes a weakening of the signal at the majority of focus settings studied.

Figure 5. NILS vs. defocus for 130nm 1:5 features at multiple partial coherence settings.

Figure 6. Distribution of diffraction orders for 130nm 1:5 isolated line with 6% and 18% obscuration.

It is interesting to consider the NILS for the different obscurations through a series of pitches for an individual linewidth. As the linewidth becomes increasingly isolated the number of orders of light combining, either destructively or constructively, increases. The left hand graph in figure 7 shows the NILS at best focus as the pitch is varies from 260nm (1:1 duty cycle) to 1430nm (1:10) for conventional illumination with a partial coherence of 0.7. As can be seen at the smallest pitch there is no great difference in signal between the three obscurations shown, however at the larger pitches the larger obscuration has a much lower NILS. The reason for this being the much larger amount of the zero order light that is being blocked as can be seen in figure 8. Another interesting feature in the graphs is the dip in NILS at the 390nm pitch (1:2 duty cycle), this is due to the relative lack of overlap taking place between the zero and first order

rays that are used to compose this image. Below this pitch there is much greater overlap and above it additional orders of light are captured in the pupil plane.

Figure 7. NIS vs. pitch for 130nm line with conventional illumination (LHS) and off-axis illumination (RHS) at zero focus.

130nm CD, 0.7s, 18% obscuration, 0.25 waves

Figure 8. Distribution of diffraction orders for 130nm 1:1 on left and 1:5 on the right with 18% obscuration

The use of off-axis illumination, in this case a quadropole, does not seem to be greatly effected by the use of different obscurations as can be seen in figure 9. This is likely to be due to the zero order light being used as one of the diffracted orders. This is further seen in the graph on the right side of figure 9 where the different obscuration has little effect even as the line becomes increasingly isolated and many more diffracted orders of light are gathered.

Figure 9. NILS vs. focus for 130nm (1:1) line:space using quadropole illumination at multiple central partial coherence and a radial partial coherence of 0.15.

3.3 130nm 1:2.2 contacts:

130nm contacts on a pitch of 420nm using a binary mask were studied and the results are shown in figure 10. The obscuration seems to have very little effect upon the image formation with almost no difference seen. This is likely to be due to the fact that the pitch is semi-dense, so the intensity of the higher order signals is not greatly different to that of the zero order so the difference in intensity of the zero order from the obscuration change has lesser effect than for dense or isolated features.

Figure 10. NILS vs. defocus for 130nm contacts at 420nm (1:2.2) pitch at multiple partial coherence settings.

3.4 130nm 1:1 and 1:5 line/space with altPSM:

When using an altPSM mask it is normal to use a low partial coherence, i.e. a more coherent source. A typical setting would be of the order of 0.3 [4,5]. For a dense pattern the NILS values are significantly higher than those achieved for the partial coherence using a conventional binary mask throughout all focus settings studied as can be seen in figure 11. Modifying the obscuration also has much less effect upon the signal than in the case of a binary mask. The most likely reason for this is the ‘dark edge’ effect from the PSM defining the separate features and any ‘halo’ effect being outweighed by the clearer edge definition. If we consider the case for an isolated line, we can see in figure 11 that when compared to the binary mask the NILS is not appreciably higher for the PSM than it was for the dense line, however it has less decrease in NILS as the defocus setting increases. At best focus the obscuration has a major effect upon the NILS as it did for the binary mask. This is due to the larger amount of zero order light that is removed by the larger obscuration as can be seen in figure 12.

Figure 11. NILS vs. defocus for 130nm line/space at 1:1 and 1:5 duty cycles using altPSM.

Figure 12. Distribution of diffraction orders for 130nm 1:1 on left and 1:5 on the right with 18% obscuration and a phase-shift mask.

4. CONCLUSION

The simulation work shown here indicates that for the case of dense line/space features a higher obscuration does indeed give a slightly higher signal to use for both binary and altPSM masks. However, the increased obscuration has a much greater detrimental effect upon more isolated features such as the 1:5 duty cycle studied here. Indeed where an isolated feature is imaged using an altPSM mask the increased obscuration may lead to an inability to image the desired feature. In the case of this lens design, using an obscuration of the order of 12% is a good compromise in that it helps to eliminate any possible 'halo' effects but will not have a greatly negative effect upon imaging isolated features when using an altPSM mask. The obscuration chosen and used in this lens was 12%.

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