

Chapter 5

Conclusion

1. A combination technique of interferometric phase shifting and off-axis illumination was detailed. The experimental and theoretical results agreed well, and showed that the proposed technique could improve the resolution by 30% for line/space patterns. The issue of image contrast degradation introduced by two-beam imaging could be addressed by the satisfaction of the following two conditions:

Amplitude Condition *The peak intensity of the transmitted pattern must be equal to the minimum intensity of the reflected pattern.*

Phase Condition *The phase difference between R and T images must be π , i.e. the images must be in the opposite phase.*

and the image contrast could achieve the maximum 100% value.

Since in the proposed arrangement no beam splitter was placed between the mask and the projection lens, optical aberrations could not cause such serious problems as in the original phase shifting setup.

2. Resolution improvement of 52% was demonstrated experimentally using a single on-axis hole by means of an annular aperture. Simulation and experimental evaluation of the imaging of extended hole arrays and other feature types is necessary for a detailed final conclusion. On the other hand, experiments should follow the trend of optical microlithography and shrink the wavelength to 248 nm. Preliminary experiments performed at 248 nm show that the main issues that have to be solved are:

- pulse to pulse instability of excimer lasers,
- vibration sensitivity of the system,
- efficient focal position alignment.

3. The three-dimensional aerial image of an on-axis contact hole was calculated and optimized using a wave optics model by means of a coated objective. The optimum obstruction ratio was found to be $\epsilon=0.3$. In addition to the results of a scalar wave optics model, a microlithographic simulation tool Solid-C was used to calculate the aerial image of contact hole arrays. It was shown that an appropriate coated objective could enhance the *DOF* by a factor of 1.5 to 2. The focus-exposure process window becomes significantly larger, even if the designed feature size on the resist is below the theoretical Rayleigh limit.
4. The aerial image of an on-axis point-like source was calculated using a scalar wave optics model when a birefringent plate was inserted between the projection lens and the wafer. The plate shifts the foci created by the ordinary and the extraordinary rays to different amounts. The distance between these images can be controlled by the thickness of the plate, and strongly depends on the refractive index. Since aberrations proportional to the thickness of the plate cause undesirable distortions, the application of a thin but strongly birefringent material is a better candidate than using a slightly birefringent but thick plate.
5. A novel multiple imaging technique based on the application of a Fabry-Perot etalon was demonstrated. The distance and the amplitude ratio between the adjacent images could be controlled by the separation and the reflectivity of the etalon mirrors, respectively. The depth of focus and resolution were improved by a factor of 4 and 1.6 using an on-axis point-like source.
6. It was shown theoretically that a Fabry-Perot etalon placed between the mask and the projection lens can be considered as a spatial filter that transmits certain spatial Fourier components of the mask pattern, while blocking others. Based on this analogy, the proposed multiple imaging technique could be simulated by means of an appropriate pupil-plane filter.
7. The point spread function of the optical system was calculated using Prolith/2 and compared with the experimental results.
8. Spatial coherence of the optical system was optimized for contact hole arrays. The optimum value was found to be $\sigma=0.28$.
9. The aerial images of extended mask patterns (off-set contact hole arrays and line/space patterns) were evaluated experimentally and theoretically. Light loss, pitch sensitivity and increased intensity side lobes introduced by the filter were

also evaluated and effective methods were proposed to minimize their undesirable effects.