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Modeling of Optical Images of Semiconductor Structures with Large Numerical Aperture Lenses

Chi-Min Yuan and Andrzej J. Strojwas
Department of Electrical and Computer Engineering
Carnegie Mellon University, Pittsburgh, PA 15213 USA

Abstract

A simulator which calculates optical images of typical semiconductor structures on wafers has been developed. The simulator differs from other optical image simulators in that instead of approximating the light scattering solutions with the scalar model, it solves the Maxwell's equations rigorously using the "wave-guide" model[1,2,3]. Many commercial schemes employed to generate optical images of the structures can be modeled. In this paper, we focus on studying the effects of the numerical apertures (NA's) of the objective lens used by conventional full field microscopes. The pros and cons of using lenses with different NA's can be analyzed with the simulation results, which can further aid process engineers to improve the accuracy of optical measurements.

Summary

Optical methods play an important role in VLSI manufacturing process diagnosis. Examples include Nomarski scanning in defect control, full field imaging or confocal scanning for critical dimension measurement, and various scanning schemes for mask-to-wafer alignment. These optical methods surpass electrical and SEM measurements in that the optical methods are independent of the conductivity of the layer of interest and that the measurements can be performed efficiently and nondestructively. However, optical methods have several drawbacks such as interference effect, polarization effect, and improper choice of NA's. Therefore, we are motivated to model various optical methods employed in VLSI processes in order to gain more insight into these methods and improve their reliability.

The structure of the simulator is illustrated in Fig.1. It allows the user to enter the wavelength used for the measurement and the topography of the structure to be imaged. The topography can have arbitrary shape, and is regarded as a grating-like structure which repeats itself many times. A single line or groove structure can be modeled as part of a grating with large enough period so that neighboring structures do not interfere with one another. The wave-guide model, which solves the Maxwell's equations numerically, is used to calculate the reflected and transmitted light patterns for both the TE and TM polarizations. These patterns will be examined by the energy conservation checker and the reciprocity theorem checker to ensure that the answers obtained are self-consistent. For a relatively experienced user, the optimum period of the topography grating can easily be chosen in the first run so that there is no need to go through the verification loop. Then, the optical configuration, such as the objective NA, is entered to the simulator and the Fourier optics[2] is used to model various optical schemes. These schemes include full field, dark and bright field scanning, confocal scanning, Nomarski scanning, and various alignment schemes utilized by commercial steppers. Different optical images can be obtained for the same structure depending on the specific scheme used.

In this work, we studied the effect of large NA lens on the optical images. Simulations of the images from large NA lens can be performed efficiently by separating the illumination and the topography components and employing the backward substitution technique[3]. In Fig.2, full field images of three different structures under different illumination conditions are simulated. These structures are 0.5 μm-deep oxide groove, 0.5 μm-deep 45°-tapered oxide groove, and 0.4 μm-deep oxide groove covered with nonplanar photoresist. In Figs.2(a)-(c), coherent illumination is used with collecting NA = 0.6. The edges of the structures can always be discerned by locating two darkest lines, but the interference fringes may sometimes cause confusion. In Figs.2(d)-(f), Kohler illumination is assumed with objective NA = 0.4 and collecting NA = 0.6. This optical arrangement with the widely used 2/3 objective-collecting ratio, known as the coherence factor, yields clear images without interference fringes. Kohler illumination with the same coherence factor is used in Figs.2(g)-(i) but with objective NA = 0.6 and collecting NA = 0.9. The images at the edges begin to degrade due to the large illumination angle. Finally, very high NA (0.95) is used in Figs.2(j)-(l) for objective and collecting lenses. The images from the TE illumination have interference fringes at the edges which makes the signal analysis difficult, while these fringes do not appear in the TM illumination. Note that for coherent illumination, the images are almost independent of the illumination polarization. However, the difference starts to appear when large NA lenses are used, and the images obtained from the TM polarization are always weaker but smoother than those from the TE polarization. Also note that for structures coated with nonplanar photoresist, the images are drastically influenced by the photoresist profiles. This problem occurs commonly in mask-to-wafer alignment, and most of the stepper manufacturers have discarded this type of bright field detection method. With the above simulation results, it has been demonstrated that lenses with different NA's can have drastic effects on the detected images and these effects can be identified using the simulator.

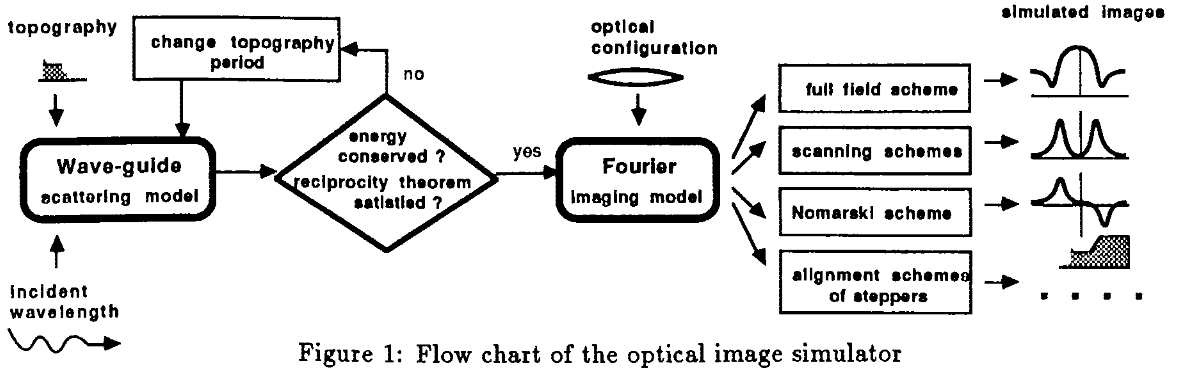

Figure 1: Flow chart of the optical image simulator

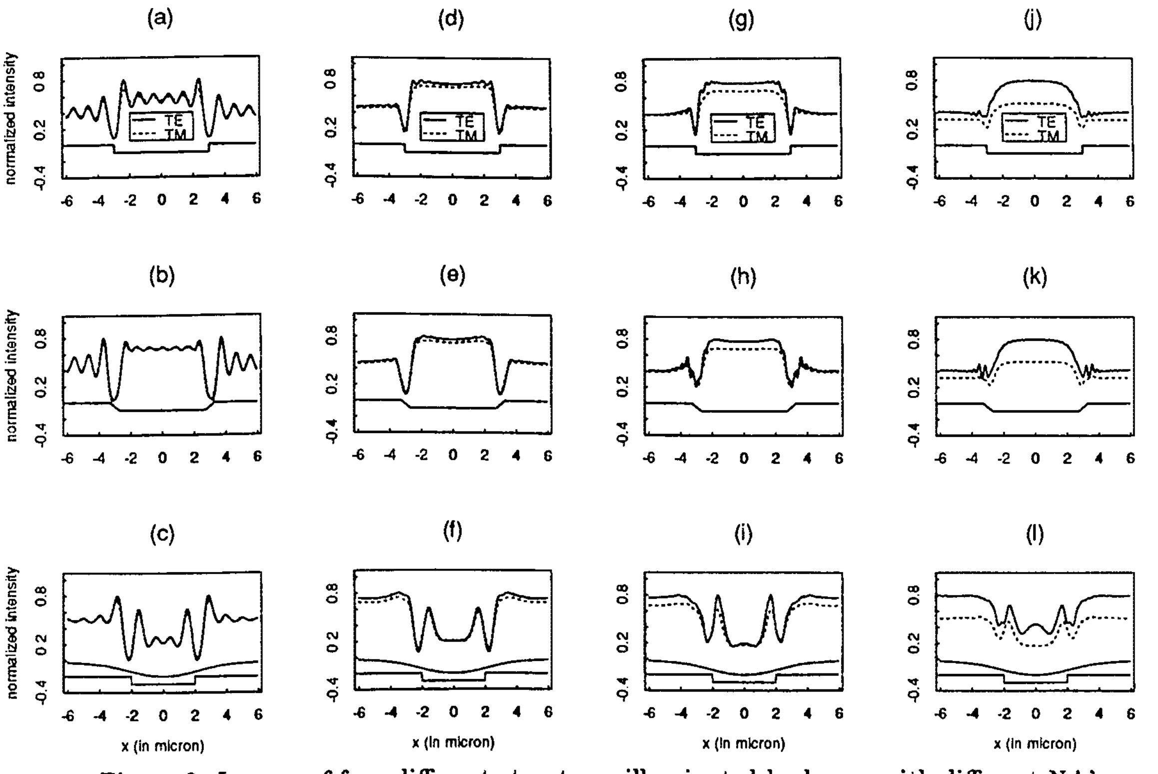

Figure 2: Images of four different structures illuminated by lenses with different NA's

References

1. D. Nyyssonen, "Theory of optical edge detection and imaging of thick layers", JOSA vol.72, p.1425, Oct. 1982
2. C. P. Kirk, "Theoretical models for the optical alignment of wafer steppers", SPIE vol.772, p.134, 1987
3. C. Yuan, J. Shaw, W. Hopewell, "Modeling of optical alignment images for semiconductor structures", SPIE Microlithography conf., San Jose, CA 1989