Computational Lithography: Exhausting Optical System Limits through Intensive Optimization

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The historical dimension scaling of semiconductor manufacturing has, until recent years, been primarily driven by the reduction of wavelength used in the dimension-limiting photolithography process. This process is at the core of the industries ability to effectively mass-produce semiconductor electronics. In recent years, wavelength-scaling has failed to keep up with the pace of the industry's guiding light, that being Moore's law, which can be paraphrased as a doubling of density every two years. The 193nm-wavelength technology continues to be the only production-ready solution delivering the required scaling, but it must maintain its cost-effectiveness in how it is achieving its device scalability.

To keep with the required scaling pace, without wavelength-scaling, the industry turned to pre-correction of optical effects through modification of the photo-mask. These techniques are generally known as Optical Proximity Correction (OPC), which are continually evolving and standard practice in production solutions. These techniques typically adjust fragments of polygon shapes on the photo-mask, using print-target shapes as a starting point, as well as adding extra non-printing "assist features" through rule or model based techniques. The evolution of these OPC methods will be briefly discussed.

The industry is now reaching the limits of traditional OPC, and has begun utilizing a combination of processing and computational techniques to keep pushing the minimum dimension scaling at pace. These include; double exposure, double patterning, and a new generation of intensive optimization techniques.

In this presentation, the motivation for using intensive optimization techniques in optical lithography will be explained. Limitations in human intuition, the impossibility of exhaustive or integer searches, and the inability of conventional techniques to sufficient handle advanced objectives or constraints, are all typical reasons for employing intensive optimization.

These techniques employ state-of-the-art optimization on many more degrees of freedom than that taken into account during OPC. The typical OPC limitations of conventional illumination and print-target starting designs are removed and the system is optimized as a whole, to not only image the required target structures, but to ensure maximum stability of the process through the expected variation of the conditions during exposure. This system optimization manipulates both the exposure illumination and the photo-mask, during a technique that we call Source-Mask-Optimization (SMO)[1,2]. Figure 1 shows the typical flow of the SMO method; input target is provided, optimizer determines the shapes of both the mask and the source to produce an on-wafer image with maximized process stability, which is then delivered on wafer (shown here as an SEM image).

Finding an SMO solution can involve various steps of increasing algorithmic complexity and computation effort. These steps are a mix of local and global optimization methods that attempt to achieve the sufficiently global optimum solution for lithographic printability. This talk will discuss these steps and the challenges of bringing together advanced techniques in an SMO solution.

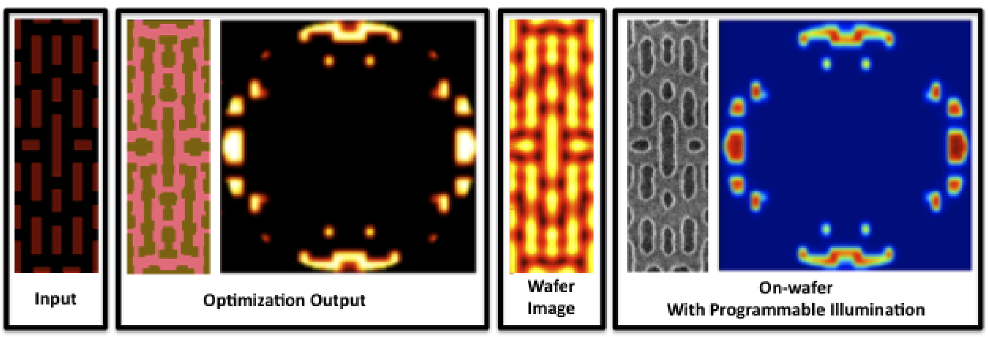

Figure 1: Ins and outs of SMO: Black boxes from left to right show the stages of SMO; first input target is provided, then optimizer determines the shapes of both the mask and the source to then produce an on-wafer image with maximized process stability, which finally delivered on wafer (shown here as an SEM image).

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1 Rosenbluth, A. E., *et al.*, “Optimum mask and source patterns to print a given shape,” Journal of Microlithography, Microfabrication, and Microsystems 1(1), 13–30 (2002).

2 David Melville *et al*, “Demonstrating the benefits of source-mask optimization and enabling technologies through experiment and simulations”, Proc. SPIE 7640, 764006 (2010)