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EDITORIAL

The Future of Lithography Will Be Curvy!

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In this volume of JM^3, the third part of a Special Section on Curvilinear Masks has been published. Distributed among all three parts are 13 technical papers, as well as an editorial by the guest editors, Leo Pang (D2S) and Danping Peng (Siemens EDA), that provides a useful guide to this special section. With many submissions to this special section, there is clearly interest in the topic of curvilinear masks! This heightened interest in masks with curvy features can be traced to early work on inverse lithography technology (ILT), where computed solutions contained curvy features. Moreover, data showed that better process windows were obtained using truly curvy features rather than Manhattan approximations to optimal computed solutions.

For many years, the superior performance of curvy layouts seemed to be mostly of academic interest, because implementation was not seen as practical. In particular, very long write times were required to pattern curvy features on masks using vector shaped-beam (VSB) mask writers and common writing strategies. This situation changed significantly with the introduction of multibeam mask writers, as well as the development of new writing strategies that made it practical to write curvy features using VSB tools (as least for optical masks) while maintaining the quality of on-wafer patterning. The contributions of multibeam mask writers and writing strategies using VSB tools are discussed in several of the papers in the Special Section on Curvilinear Masks.

Soon after multibeam mask writers became available it was realized that the ability to manufacture masks with curvy features required more than new mask writers and writing strategies. Much infrastructure for mask-making needed to be adapted for making curvy patterns. To begin, a method was needed to describe curvy features without creating massively large data files. The rectangles that make up Manhattan patterns are easily described – length, width, and location. Describing curvy features is more complex. This led to the creation of the MULTIGON data format, described in the paper by Hu et al. in Part 1 of the Special Section on Curvilinear Masks.

The transition from Manhattan geometries to curvy ones is bringing a leap in complexity. The geometry of rectangles is elementary, while the Bezier curve and spline descriptors of the MULTIGON format are much more sophisticated mathematically. Even the concept of "critical dimension" needs to be reconsidered. The dimension of a rectangular feature is intuitively understood to be the narrow width, with some additional consideration given at times to the shorter side – the "line ends." It is far from intuitively obvious what the dimension of a curvy feature is. In one of his own contributions to the Special Section on Curvilinear Masks, Guest Editor Leo Pang proposes a definition of the dimension of a curvy feature. I encourage the readers of JM^3 to give thoughtful consideration to Dr. Pang's proposal. Should it pass scrutiny, it would be a useful metric going forward.

Perhaps even less obvious is what should be the definition of line-edge roughness (LER) for curvy features. For calculating the LER of long lines, feature edges are referenced to straight lines that are parallel to the intended feature. What the reference should be for curvy features is less clear, particularly at low spatial frequencies. This is reminiscent of the early confusion over what constitutes the critical dimension of a long rectangular feature and what is low-frequency line-width roughness (LWR).

The use of curvy features is an example of how advanced lithography continues to be a dynamic field. Many aspects of lithographic technology are affected when curvy features are introduced, requiring solutions to numerous new problems. This can even be true for mature lithographic technologies, such as dry optical lithography, since ILT has the potential to extend the capability of older tool sets. For advanced high-NA EUV lithography, problems associated with curvy features will need to be solved in parallel with learning about other aspects of this new technology. For example, the resolution of high-NA EUV lithography will necessitate very small sub-resolution assist features, to ensure that they do not print. Capable e-beam resists, exposure tools, writing strategies, etch processes, and metrology will be needed to support the patterning of these very small features, and solutions will need to take into account some of the subtle aspects of anamorphic imaging. It appears that there are still plenty of interesting problems for lithographers to solve!