Journal of
Micro/Nanolithography,
MEMS, and MOEMS

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Kafai Lai, Andreas Erdmann, "Extending VLSI and Alternative Technology with Optical and Complementary Lithography," *J. Micro/Nanolith. MEMS MOEMS* **15**(2), 021201 (2016), doi: 10.1117/1.JMM.15.2.021201.

Extending VLSI and Alternative Technology with Optical and Complementary Lithography

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Although significant progress has been made in extreme ultraviolet (EUV) lithography, optical lithography is expected to continue as the primary lithographic technology for manufacturing over the next several years. Extension of water-based immersion lithography to below 20 nm half-pitch (10 nm logic node) requires the use of innovative resolution enhancement techniques, solutions to complexities introduced by hyper-NA optics, and extensive use of double or multiple sequential exposure and patterning techniques, and even complementary use of optical lithography with nontraditional techniques. In addition to resolution, very tight process (and overlay) control and high-quality photomasks are also necessary. The successful use of optics to provide viable working solutions for these device nodes will require fundamental integration of all aspects of the patterning process. Accurate physical models, especially for the efficient modeling of 3D-mask effect and their impact on optical proximity correction (OPC) and inverse lithography (IL) are indispensable. For 14 nm and beyond, early design technology co-optimization is necessary to ensure the patterning solution can enable design for products.

This special section contains six papers that cover a wide spectrum of innovations that collectively extend optical lithography. The paper by Xiaoqing Xu et al. describes an approach for the evaluation of middle-of-line and other critical layouts in terms of multiple patterning lithography constraints. Yield-aware mask/color assignment as another important aspect of multiple patterning is discussed by Yukihide Kohira et al. They describe the use of special cost functions and optimization methods to identify tri-color layouts, which are tolerant to overlay errors. The paper by Masato Shibuya et al. resumes the discussion of different radiometric corrections that appear in imaging theory for photolithography. The theoretical considerations on this important topic are validated by experimental data. Several other papers address the increasingly important correct modeling of mask 3D effects. The manuscript of Michael Lam et al. describes several aspects of the modeling of non-Manhattan shaped corners and the integration of a developed modeling approach is integrated into a full-chip 3D mask simulation methodology. These papers on algorithmic aspects of mask 3D modeling are completed by a paper by Krishnaparvathy Puthankovilakam et al. on direct experimental investigations of the intensity and the phase of the light, which is transmitted through photomask, and by an article by Andreas Erdmann et al. on the analysis of phase effects and mask-induced focus shifts in DUV and EUV-lithography.

We hope you enjoy the collection of articles in this special section, and any feedback or suggestions are welcome.

Kafai Lai received his doctorate degree from the University of Texas at Austin in electrical engineering. Since then he has been working on lithography R&D and currently in the IBM Research Division. He has worked on optical imaging modeling and lens characterization, exposure tooling analysis, OPC/RET development, source mask optimization and design technology co-optimization and most recently directed self-assembly lithography. He is also the chair of the 2012-2015 SPIE Optical Microlithography Conference and has been a member of the technical program committee. He has been teaching various short courses in many lithography conferences worldwide since 2005. He has also been the symposium chair for the CSTIC conference in Shanghai since 2009. Moreover, he serves as an editor for *Proceedings of SPIE, Proceedings of IEEE, ECS Transactions*, the *Journal of Advanced Optical Technologies* and others, we well as a guest editor for JM3 special sections for the previous two years. Based on his pioneering work in extending optical lithography and source mask optimization, he was appointed Fellow of SPIE and Fellow of OSA, as well as a senior member of IEEE.

Andreas Erdmann is the head of the Lithography Simulation Group at the Fraunhofer IISB. His fields of research include simulation of optical lithography, computational electrodynamics, microelectronic process technology, and modern optics. He contributed to the development of several advanced lithography simulators, including the development and research lithography simulator Dr.LiTHO. Since 2007, he has been a lecturer at Erlangen University and a mentor at Erlangen Graduate School SAOT. He is also the chair of the 2014-2017 SPIE Optical Microlithography Conference and has been a member of the technical program committee. He is a Fellow of SPIE.