

Journal of  
**Micro/Nanolithography,  
MEMS, and MOEMS**

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# **Continuation of Scaling with Optical and Complementary Lithography**

Kafai Lai  
Andreas Erdmann

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### Kafai Lai

IBM Semiconductor R&D Center  
2070 Route 52  
Hopewell Junction, New York 12533, United States  
E-mail: [kafailai@us.ibm.com](mailto:kafailai@us.ibm.com)

### Andreas Erdmann

Fraunhofer Institute for Integrated Systems and Device Technology  
Schottkystr. 10  
Erlangen 91058, Germany  
E-mail: [andreas.erdmann@iisb.fraunhofer.de](mailto:andreas.erdmann@iisb.fraunhofer.de)

While EUV lithography is still maturing, 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 non-traditional 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. Recently material-based dimension scaling based on the use of creative solutions, such as “freezing” first resist in double patterning approach and the use of directed self-assembly in optically created guiding patterns, are getting strong momentum from both academia and industry as a low-cost alternative. For 14 nm and beyond, early design technology co-optimization is necessary to ensure the patterning solution can enable design for products. In summary, a holistic optimization of all lithography steps, including physical design optimization, is required to extend optical lithography for further dimension scaling down to the 7 nm node and maybe beyond. This special edition is intended for topics that are advancing the field of optical nano- and microlithography beyond the 14 nm technology node circuit scaling.

This special edition has six papers that cover a wide spectrum of innovations that collectively extend optical lithography. Yongchan Ban et al. describe layout decomposition method for self-aligned double patterning, while the paper from Bei

Yu et al. proposes a method for triple patterning using conflict graphs and end-cutting. The paper of Sikun Li et al. revisits the application of ring-shaped phase shift masks for *in situ* aberration measurements. On SMO area, the paper from Pei-Chun Liu et al. discusses SMO based on Abbe-PCA and Sylvester equation that accelerate algorithm when including three-dimensional resist profile effect. On the DFM/DTCO aspect, yet another paper by Bei Yu et al. focuses on design hot spot detection using a new accurate method based on PCA-SVM classifier with hierarchical data clustering. The paper from Kaushik et al. covers a cross-discipline study discussing sub-20 nm SoC design challenges while employing design technology co-optimization as a holistic approach to scaling. It should be a valuable reading for both designers and lithographers.

We hope you enjoy the collection of articles in this special edition, and any feedback and suggestions are welcomed.

**Kafai Lai** has been working on Optical Lithography R&D for 20 years and currently works in the IBM Research Division. He is also the chair of the 2012-2015 SPIE Optical Microlithography Conference and has been the chair of the CSTIC conference in Shanghai since 2009. He serves as the editor of several proceedings and journals from SPIE, IEEE, and ECS, including 2 JM3 special editions. He was appointed Fellow of SPIE and Fellow of OSA, as well as a senior member of IEEE.

**Andreas Erdmann** is head of the Fraunhofer IISB computational lithography and optics group and teaches as “Privatdozent” at the University of Erlangen. He has 20 years of experience in lithography and more than 160 scientific publications. He co-chairs SPIE conferences on optical microlithography and computational optics and is organizer of the International Fraunhofer Lithography Simulation Workshop. He contributed to the development of several advanced lithography simulators, including the development and research lithography simulator, Dr.LiTHO.