Editorial

Andreas Erdmann* and Masato Shibuya

Introduction to the special issue on optical lithography

DOI 10.1515/aot-2015-0039

Lithography is one of the most important process steps in the manufacturing of integrated electronic circuits for computers, mobile phones, tablets, digital home appliances and many other devices in daily use. Optical projection lithography employs a projection stepper or scanner to create images of designed patterns in a photosensitive layer on the top of silicon-wafers. The size of the smallest features in the pattern and the robustness of the image and pattern formation versus dose, focus and other impact factors determine the performance of fabricated integrated circuits.

Over many years the reduction of feature sizes and resulting performance improvements of integrated circuits were achieved by evolutionary developments of the imaging technology for projection scanners, especially by the use of smaller wavelengths and larger numerical apertures (NA). The evolution of wavelength and NA driven scaling stopped in 2007, when ASML and Nikon introduced ArF water immersion scanners with a wavelength of 193 nm and an NA of 1.35. Since then the progress of lithographic manufacturing technology is enabled by a holistic optimization of the complete lithographic imaging system and by new materials and processes: Increasingly aggressive optical proximity correction (OPC) of the mask and dedicated illumination schemes (source shapes) are applied to print pre-defined target patterns with a high fidelity. Extensive tool and process control mechanisms are introduced to improve the stability of the pattern formation. Various multi-patterning techniques are applied to create dense arrays of small features. The increase of mask complexity and additional process steps, which are required for multi-patterning, result in a significant increase of costs. Recent results on the combination of advanced imaging technology with smart materials like co-block polymers in directed self-assembly indicate alternative material-driven pathways for future scaling.

The small wavelength of extreme ultraviolet (EUV) lithography promises a revival of the wavelength and NA driven scaling. Recent news from the beginning of this year on the progress on EUV-sources and on the order of 15 ASML EUV lithography systems from an unnamed U.S. customer support expectations that EUV lithography will be used in manufacturing in near future. The success of EUV lithography depends also on the complete mask infrastructure (especially mask design, manufacturing, inspection and repair), on the availability of appropriate photoresists with high sensitivity, good resolution and low line-edge roughness, and on the extendibility of EUV systems towards larger numerical apertures.

This special issue of Advanced Optical Technologies extends a special issue of AOT from the year 2012 on ‘The next decade of optical lithography’. Experts from leading research organization and companies contribute review and research articles, which provide valuable insights in recent developments of DUV and EUV projection lithography for semiconductor fabrication.

Mark Neisser and Stefan Wurm from Sematech provide an update on the lithography challenges for a continuation of the scaling. They give an overview on the considered patterning technologies including extreme ultraviolet lithography (EUV), nanoimprint lithography (NIL), maskless lithography (ML2) and directed self-assembly (DSA). The status and key challenges of these technologies are summarized and compared to extensions of presently used multiple patterning.

The article ‘How to make lithography patterns print: The role of OPC and Pattern Layout’ by Peter de Bisschop from imec reviews state-of-the-art optical proximity correction (OPC). The in-depth discussion of models for the description of optical, photoresist and other effects is complemented by a comprehensive overview on computational and experimental methods for the model application and verification. Other important topics such as design restrictions, layout styles are discussed as well. The article

***Corresponding author: Andreas Erdmann,** Fraunhofer IISB-Technology simulation, Schottkystr. 10, Erlangen 91058, Germany, e-mail: andreas.erdmann@iisb.fraunhofer.de
Masato Shibuya: Optical Designing Laboratory, Faculty of Engineering, Department of Media and Image Technology, Tokyo Polytechnic University, 1583 Iiyama, Atsugi-shi, Kanagawa 243-0297, Japan

www.degruyter.com/aot

provides a plenty of useful information for the practical implementation and application of OPC flows and comes with an extensive list of references for further reading.

The application of many important control schemes, which are needed for advanced semiconductor lithography today, is reviewed in the article of Tomoyuki Matsuyama from Nikon on 'Exposure tool control for advanced semiconductor lithography'. He describes how the geometry and spatial coherence of the illumination and the pupil wavefront of the projection lens are controlled and manipulated in Nikon scanners. Computational methods are combined with different tool options to improve the uniformity and the overlay accuracy of the print results.

The article of Hakaru Mizoguchi and his co-authors from Gigaphoton 'Performance of one hundred watt HVM LPP-EUV Source' describes the latest results of their company to provide an alternative to the EUV sources of Cymer for EUV lithography. Interesting insights to the development of EUV sources and on the very latest status of EUV sources are given. Several key components of these sources such as the pre-pulse technique, debris mitigation and filters for out-of-band radiation are explained.

Takahiro Kozawa from Osaka University reviews 'Resist material options for extreme ultraviolet lithography' with special emphasize on chemically amplified photoresist. He describes the trade-off relationship between sensitivity, resolution and line-edge roughness (LER) of the photoresist. Several strategies to improve the photoresist performance by increasing the resist absorption, the quantum efficiency of acid generation, and the effective reaction radius for deprotection and by control of the dissolution mechanisms are discussed.

A review of the historical development of EUV technology in Japan is presented by Hiroo Kinoshita and his colleagues from the Center for Extreme Ultraviolet Lithography at the University of Hyogo. The article 'Development of Element Technologies for EUVL' highlights the design of aspherical mirror systems, the application of an interference exposure system for photoresist characterization, and important recent developments on actinic mask inspection tools using a coherent scatterometry microscope.

The Talbot effect offers interesting options for the cost-effective lithographic patterning of periodic structures. In the article 'Focus tolerance influenced by source size in Talbot lithography' Takashi Sato and his team from Toshiba discuss the impact of the spatial coherence on the contrast and process windows of Talbot images. Several guidelines for the choice of the most appropriate illumination options for mask aligners are derived.

The research article 'Flat-field anastigmatic mirror objective for high-magnification extreme ultraviolet microscopy' of Mitsunori Toyoda from the Tohoku University describes the design of a novel EUV optics, which consists of a Schwarzschild optics and a concave mirror. The smart design procedure is based on the aberration theory and confirmed by ray tracing simulations of the imaging performance. It provides diffraction limited images with a magnification of 1500. The proposed optics offers new possibilities for mask inspection and applications of EUV technology beyond lithography.

Andreas Erdmann
Fraunhofer IISB-Technology simulation,
Schottkystr. 10, Erlangen 91058, Germany,
andreas.erdmann@iisb.fraunhofer.de

Andreas Erdmann received his PhD degree from the Friedrich-Schiller-University of Jena, Germany. In 1995 he joined the Fraunhofer Institute ISiT, where he started his activities in the field of lithography simulation. Since 1999 he is head of the Lithography Simulation Group at 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. He presented more than 150 talks at international conferences including 22 invited and key-note talks and published more than 200 publications in scientific journals and conference proceedings. Since 2007 he is lecturer at Erlangen university, mentor at the Erlangen Graduate School of Advanced Optical Technologies.

Masato Shibuya
Optical Designing Laboratory, Faculty of
Engineering, Department of Media and
Image Technology, Tokyo Polytechnic
University, 1583 Iiyama, Atsugi-shi,
Kanagawa 243-0297, Japan

Masato Shibuya graduated from Tokyo Institute of Technology TIT in 1977 with a master's degree in physics and joined Nikon Corporation. He has been designing space and lithography optics and studying resolution enhancement technology, and he has invented a phase shifting mask. Also he has been studying fundamentals of lens optics such as the sine condition in the presence of spherical aberration. He received his PhD from the University of Tokyo in 1996. He joined Tokyo Polytechnic University in 2001 and has been a professor in the Department of Media and Image Technology, Faculty of Engineering. His research interests includes fundamental lens optics, optical lithography, and 3-D display. He received the 2011 'Outstanding Optical and Quantum Electronics Achievement Award' (Takuma Award) for his invention of PSM from Japanese Society of Applied Physics (JSAP). He is a fellow of JSAP and a fellow of SPIE.