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Extreme Ultraviolet (EUV) Lithography VI

Obert R. Wood II
Eric M. Panning
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The CID Number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages.

Contents

Part One

- ix *Authors*
- xiii *Conference Committee*
- xvii *Introduction*

EUV RESIST EXTENDABILITY: JOINT SESSION WITH CONFERENCES 9422 AND 9425

- 9422 04 **Toward 10nm half-pitch in EUV lithography: results on resist screening and pattern collapse mitigation techniques** [9422-3]
- 9422 05 **Extending resolution limits of EUV resist materials** [9422-4]
- 9422 06 **Relationship between information and energy carried by extreme-ultraviolet photons: consideration from the viewpoint of sensitivity enhancement** [9422-5]

EUV RESIST MECHANISTIC STUDIES: JOINT SESSION WITH CONFERENCES 9422 AND 9425

- 9422 08 **Studying secondary electron behavior in EUV resists using experimentation and modeling** [9422-7]
- 9422 09 **Analysis of shot noise limitations due to absorption count in EUV resists** [9422-8]
- 9422 0A **Low-energy electron (0-100eV) interaction with resists using LEEM** [9422-9]

EUV SOURCE

- 9422 0B **Performance optimization of MOPA pre-pulse LPP light source (Invited Paper)** [9422-10]
- 9422 0C **Performance of one hundred watt HVM LPP-EUV source** [9422-11]
- 9422 0D **Considerations for a free-electron laser-based extreme-ultraviolet lithography program** [9422-12]
- 9422 0E **Sub-aperture EUV collector with dual-wavelength spectral purity filter** [9422-13]
- 9422 0F **High-radiance LPP source for mask-inspection application** [9422-14]
- 9422 0G **Optimum pre-pulsing and target geometry of LPP for efficient EUV and BEUV sources** [9422-15]

EUV MASK STRUCTURE

- 9422 OH **Magnetron sputtering for the production of EUV mask blanks** [9422-16]
- 9422 OI **Alternative materials for high numerical aperture extreme ultraviolet lithography mask stacks** [9422-17]
- 9422 OJ **Understanding EUV mask blank surface roughness induced LWR and associated roughness requirement** [9422-18]
- 9422 OK **Development and evaluation of interface-stabilized and reactive-sputtered oxide-capped multilayers for EUV lithography** [9422-19]

EUV RESISTS

- 9422 OL **Novel resist approaches to enable EUV lithography in high volume manufacturing and extensions to future nodes** [9422-20]
- 9422 OM **Understanding of stochastic noise** [9422-21]
- 9422 ON **Negative-tone imaging with EUV exposure for 14nm hp and beyond** [9422-22]
- 9422 OO **Acid generation mechanism in anion-bound chemically amplified resists used for extreme ultraviolet lithography** [9422-23]
- 9422 OP **Novel EUV resist development for sub-14nm half pitch** [9422-24]

EUV INTEGRATION

- 9422 OQ **Evaluating printability of buried native EUV mask phase defects through a modeling and simulation approach** [9422-96]
- 9422 OR **Towards production ready processing with a state-of-the-art EUV cluster** [9422-26]
- 9422 OS **EUV contact holes and pillars patterning** [9422-27]
- 9422 OT **EUV processing and characterization for BEOL** [9422-28]
- 9422 OU **Implementation of assist features in EUV lithography** [9422-29]
- 9422 OV **Optical proximity effects in 4-nm EUV lithography: a rigorous study using a new PSTD method** [9422-30]
- 9422 OW **Directed self assembly on resist-limited guiding patterns for hole grapho-epitaxy: Can DSA help lower EUV's source power requirements?** [9422-31]

MASK TOPOGRAPHY: JOINT SESSION WITH CONFERENCES 9422 AND 9426

- 9422 0X **Best focus shift mechanism for thick masks** [9422-32]
- 9422 0Y **Mitigation of image contrast loss due to mask-side non-telecentricity in an EUV scanner** [9422-33]
- 9422 0Z **EUV telecentricity and shadowing errors impact on process margins** [9422-34]

RESIST OUTGAS TESTING

- 9422 10 **Analysis of EUV resist outgassing depended on the dosage** [9422-35]
- 9422 11 **First results of outgas resist family test and correlation between outgas specifications and EUV resist development** [9422-36]
- 9422 12 **Collaborative work on reducing the intersite gaps in outgassing qualification** [9422-37]
- 9422 13 **Polarization resolved measurements with the new EUV ellipsometer of PTB** [9422-38]

EUV OPTICS AND MASK METROLOGY

- 9422 14 **Aberration estimation using EUV mask roughness** [9422-39]
- 9422 15 **A method of image-based aberration metrology for EUVL tools** [9422-40]
- 9422 16 **Correlation of actinic blank inspection and experimental phase defect printability on NXE3x00 EUV scanner** [9422-41]
- 9422 17 **Phase measurements of EUV mask defects** [9422-42]
- 9422 18 **Application of the transport of intensity equation to EUV multilayer defect analysis** [9422-43]

Part Two

EUV MASK INSPECTION

- 9422 19 **Actinic review of EUV masks: Status and recent results of the AIMS EUV system (Invited Paper)** [9422-44]
- 9422 1A **New ways of looking at masks with the SHARP EUV microscope** [9422-45]
- 9422 1B **SEMATECH produces defect-free EUV mask blanks: defect yield and immediate challenges** [9422-46]
- 9422 1C **Enhancing defect detection with Zernike phase contrast in EUV multilayer blank inspection** [9422-47]

- 9422 1D **Toward defect guard-banding of EUV exposures by full chip optical wafer inspection of EUV mask defect adders** [9422-48]
- 9422 1E **Application of differential phase contrast imaging to EUV mask inspection: a numerical study** [9422-49]

EUV EXTENSION

- 9422 1F **EUV lithography scanner for sub-8nm resolution (Invited Paper)** [9422-50]
- 9422 1G **EUV lithography optics for sub-9nm resolution** [9422-51]
- 9422 1H **Imaging performance of EUV lithography optics configuration for sub-9nm resolution** [9422-52]
- 9422 1I **EUV resolution enhancement techniques (RETs) for k_1 0.4 and below** [9422-53]
- 9422 1J **Extending shearing interferometry to high-NA for EUV optical testing** [9422-54]
- 9422 1K **Advanced coatings for next-generation lithography** [9422-55]

EUV MANUFACTURING

- 9422 1L **The patterning center of excellence (CoE): an evolving lithographic enablement model** [9422-56]
- 9422 1M **EUV mask cleans comparison of frontside and dual-sided concurrent cleaning** [9422-57]
- 9422 1N **Maintaining Moore's law: enabling cost-friendly dimensional scaling** [9422-58]
- 9422 1O **Multi-stack extreme-ultraviolet pellicle with out-of-band reduction** [9422-59]

EXPOSURE TOOLS

- 9422 1P **Performance overview and outlook of EUV lithography systems** [9422-60]
- 9422 1Q **Overlay and edge placement control strategies for the 7nm node using EUV and ArF lithography** [9422-61]
- 9422 1S **Evaluation of EUV resist performance using interference lithography** [9422-63]
- 9422 1T **An accurate method to determine the amount of out-of-band light in an EUV scanner** [9422-64]
- 9422 1U **EUV mask particle adders during scanner exposure** [9422-65]
- 9422 1V **Debris monitoring and minimization system for EUV sources** [9422-66]

9422 1W **Feasibility study on the impact of high-power EUV irradiation on key lithographic elements**
[9422-67]

POSTER SESSION

- 9422 1X **EUV patterning improvement toward high-volume manufacturing** [9422-25]
- 9422 1Y **Evaluation of rinse material and process for EUV lithography** [9422-69]
- 9422 1Z **Measurement of the phase defect size using scanning probe microscope and at-wavelength inspection tool** [9422-70]
- 9422 21 **Low-LER tin carboxylate photoresists using EUV** [9422-72]
- 9422 23 **Experimental validation of stochastic modeling for negative-tone develop EUV resists**
[9422-74]
- 9422 24 **Study of EUVL patterned mask inspection tool for half-pitch (hp) 16nm-11nm node** [9422-75]
- 9422 25 **Dependence of defect size and shape on detectability for EUV patterned mask inspection**
[9422-76]
- 9422 27 **Positive-tone EUV resists: complexes of platinum and palladium** [9422-78]
- 9422 28 **Test of an argon cusp plasma for tin LPP power scaling** [9422-79]
- 9422 29 **Analysis of distinct scattering of extreme ultraviolet phase and amplitude multilayer defects with an actinic dark-field microscope** [9422-80]
- 9422 2C **Improving process and system for EUV coat-develop track** [9422-83]
- 9422 2D **Effects of low-molecular weight resist components on dissolution behavior of chemically amplified resists for extreme ultraviolet lithography studied by quartz crystal microbalance**
[9422-84]
- 9422 2E **Evaluation of optical properties of EUV resist underlayer** [9422-85]
- 9422 2F **New approach to improve LER of EUV resist pattern by chemical and thermal treatment**
[9422-86]
- 9422 2H **Collector optic cleaning by in-situ hydrogen plasma** [9422-88]
- 9422 2I **Simulation study of the influence of PEB reaction rates on resist LER** [9422-90]
- 9422 2K **LPP light source for actinic HVM inspection applications** [9422-92]
- 9422 2L **Study of Dill's B parameter measurement of EUV resist** [9422-93]
- 9422 2M **Modeling of bi-spectral primary source for the EUV lithography** [9422-94]

- 9422 2O **Calibration of system errors in lateral shearing interferometer for EUV-wavefront metrology**
[9422-97]
- 9422 2P **Key components technology update of 100W HVM EUV source** [9422-98]
- 9422 2Q **13nm EUV free electron lasers for next generation photolithography: the critical importance of RF stability** [9422-99]

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Abe, Tamotsu, 0C, 2P
Abe, Tsukasa, 1Z
Abhari, Reza S., 2K
Abreau, F., 2K
Ahn, Chang-Nam, 0M
Ahn, Jin-Ho, 1O, 2E
Aloni, Shaul, 09
Amano, Tsuyoshi, 1Z, 24, 25
Antohe, Alin O., 1B
Arnold, John C., 0T
Asai, Masaya, 2C
Ashby, Paul D., 0L
Ashizawa, Noritaka, 0F
Ashworth, Dominic, 11, 12, 1E
Ayothi, Ramakrishnan, 0P, 11
Bahrenberg, Lukas, 29
Balachandran, Dave, 1B
Barletta, William A., 0D
Barouch, Eytan, 0V
Basavalingappa, Adarsh, 0Q
Beckers, Marcel, 1P
Beique, Genevieve, 0T
Benk, Markus P., 0J, 14, 15, 17, 1A, 1C
Berg, Robert, 12
Bespalov, V. G., 2M
Bhattachai, Suchit, 09, 21
Blackwell, James, 05
Bonam, Ravi, 1D
Boom, Herman, 1P
Böwering, Norbert, 0B
Boyle, John, 1M
Brainard, Robert L., 08, 21, 27
Brandstätter, Markus, 2K
Brandt, David C., 0B, 1P
Brown, Daniel J., 0B, 1P
Buitrago, Elizabeth, 04, 1S
Burkhardt, Martin, 0U, 0X, 1D
Capelli, Renzo, 19
Cardineau, Brian, 21
Chakraborty, Tonmoy, 11
Chang, Shu-Hao, 1T
Chao, Weilun, 09, 1C
Chauhan, V., 0Z
Chen, Alek C., 0M
Chen, Jack J. H., 0Y, 1T
Chen, Norman, 1T
Cheong, Lin Lee, 0T, 1M
Chi, Cheng, 0W
Chien, Shang-Chieh, 1T
Chou, Hsiang-Yu, 1T
Chuang, Frank, 1P
Chun, Jun Sung, 0L, 11, 1L
Chung, Chia-Chun, 0Y, 1T
Civay, D., 0Z
Claus, Rene A., 14, 17
Colburn, Matthew, 0R, 0T
Corliss, Daniel, 0R, 1D, 1M
Crispo, Gary, 1D
Cummings, Kevin, 0L, 11, 1B, 1E
Curry, John, 0K
Dai, Fengzhao, 2O
Danylyuk, Serhiy, 29
de Jong, Arjen T., 1V
Delancey, Robert, 1D
Del Re, Ryan, 21, 27
Demmerle, Wolfgang, 0Q, 23
Denbeaux, Gregory, 08, 0Q
de Peuter, Koen, 1P
de Ruijter, Chris, 1P
De Simone, Danilo, 0S, 23
Donoghue, Alexander P., 1A, 1C
Dunstan, Wayne J., 0B
Earley, William, 08
Eckstein, Hans-Christoph, 0E
Ekinci, Yasin, 04, 1S, 21, 27
Elg, Daniel T., 2H
Elizarov, V. V., 2M
Erdmann, Andreas, 18
Ershov, Alex, 0B
Evanschitzky, Peter, 18
Fallica, Roberto, 04
Fan, Yu-Jen, 0L, 11, 12
Farrar, Nigel R., 0B, 1P
Feigl, Torsten, 0E
Felix, Nelson, 0R, 0T
Fiedler, Tobias, 0E
Finders, Jo, 1P
Fischer, Andreas, 13
Fomenkov, Igor, 0B
Foubert, Philippe, 1X
Fournier, Gary, 0K
Freedman, Daniel, 21, 27
Frei, Marcel, 2Q
Fritsche, Bodo, 2Q
Fujii, Shinya, 06
Fujimori, Toru, 0N, 10, 12
Fujisawa, Tomohisa, 0P
Fumar-Pici, Anita, 0M

Gallagher, E., 16
 Gambino, Nadia, 2K
 Gao, Weimin, 23
 Garetto, Anthony, 19
 Geelen, D., 0A
 Gilmer, David, 0H
 Goethals, Anne-Marie, 1X
 Goldberg, Kenneth A., 0J, 0Q, 14, 15, 17, 1A, 1C
 Goodwin, Frank, 0H, 1B, 1E
 Goto, Takahiro, 0N
 Graham, Matthew, 0B
 Grantham, Steven, 0K
 Gräupner, Paul, 1H
 Grishkanich, A. S., 2M
 Gronlund, Keith, 1I
 Grzeskowiak, Steven, 08
 Guha Neogi, T., 0Z
 Gullikson, Eric M., 0J
 Gupta, Rachit, 0U
 Halle, Scott D., 1D
 Hamieh, Bassem, 0T
 Han, Eungnak, 05
 Hanna, Michael, 1Q
 Hansen, Steve, 1I
 Harada, Tetsuo, 10, 2L
 Harlson, Shane, 05
 Harned, Noreen, 0B, 1P
 Harris-Jones, Jenah, 0Q
 Harumoto, Masahiko, 2C
 Hassanein, Ahmed, 0G
 Hatakeyama, Masahiro, 24
 He, Long, 1B
 Hellweg, Dirk, 19
 Hendrickx, Eric, 15, 23
 Herbert, Stefan, 29
 Herbol, Henry, 08, 0Q
 Hetzer, David, 0R
 Hill, Shannon, 0K, 12
 Hiltbrunner, Carmen, 2Q
 Hira, Yudai, 0R
 Hirano, Ryoichi, 24, 25
 Hishiro, Yoshi, 0P
 Hoefnagels, R., 1S
 Hofmann, Oskar, 29
 Hong, Seongchul, 2E
 Hori, Masafumi, 0P
 Hori, Tsukasa, 0C, 2P
 Hoshiko, Kenji, 0P
 Hosler, Erik R., 0D, 0Z
 Hotalen, Jodi, 27
 Howell, Rafael, 1I
 Hsu, Stephen, 1I
 Huang, Roger, 1P
 Huang, Tao-Ming, 1T
 Hudgins, Duane, 2K
 Huli, Lior, 0R
 Hyun, Yoonsuk, 0S, 1U
 Iida, Susumu, 24, 25
 Inoue, Soichi, 10, 12, 1W
 Itani, Toshiro, 06, 1Y
 Jang, Il-Yong, 0Q
 Jen, Shih-Hui, 1I
 Jia, Jianjun, 1I
 Jiang, Fan, 0U, 0W
 Jilisen, René T. M., 1V
 Jindal, Vibhu, 0Q, 19
 Johnson, David G., 1A, 1C
 Johnson, Richard, 0R
 Jonckheere, R., 16
 Jung, Mi-Rim, 0M
 Juschkin, Larissa, 29
 Kaiser, N., 1K
 Kaiser, Winfried, 1G, 1H
 Kamohara, Itaru, 23
 Kaneyama, Koji, 2C
 Karimata, Kenichi, 24
 Karumuri, Anil, 0H, 1B
 Kasama, Kunihiro, 0F
 Kascheev, S. V., 2M
 Kawakami, Shinichiro, 1X
 Kawasuji, Yasufumi, 0C, 2P
 Kearney, Patrick, 0H, 0I, 1B
 Keens, Simon, 2Q
 Kelly, Chris, 08
 Kikuchi, Yukiko, 10, 12
 Kim, Guk-Jin, 1O
 Kim, In-Seon, 1O
 Kim, Jinsoo, 1U
 Kim, Jung Hwan, 2E
 Kim, Jung Sik, 2E
 Kim, Kyuyoung, 1U
 Kim, Seo-Min, 0M, 0S, 1U
 Kim, Young-Sik, 0M, 1U
 Kimoto, Takakazu, 0P
 Kimura, Toru, 0P
 Kindt, Louis, 1M
 Kinoshita, Hiroo, 10, 2L
 Klostermann, Ulrich, 23
 Kneer, Bernhard, 1G, 1H
 Koay, Chiew-seng, 0R
 Kobayashi, Kazuo, 0O
 Koch, Markus, 19
 Kodama, Takeshi, 0C, 2P
 Komuro, Yoshitaka, 0O
 Koo, Sunyoung, 1U
 Kool, Ron, 0B, 1P
 Kops, Margarete, 0F
 Kops, Ralf, 0F
 Kozawa, Takahiro, 06, 0O, 2D
 Kriese, Michael, 0K
 Krysak, Marie, 05
 Kulmala, Tero S., 04
 Kumar, Aditya, 0I
 Kuwahara, Yuhei, 1X
 Kwak, Nohjung, 1U
 Kwon, Won-Taik, 0M
 Lai, Kafai, 0W
 Lallement, Romain, 0T
 Laubis, Christian, 0E, 0I, 13
 Lebert, Rainer, 29

Lee, Hojune, 0H
 Lee, Jae Uk, 2E
 Lee, Seung Min, 2E
 Lee, Sung-Gyu, 1O
 Leeson, Michael, 05
 Leitel, Robert, 0E
 Leonhard, Dusty, 1M
 Levinson, Zac, 15
 Li, Jie, 2O
 Liang, Ted, 1C
 Liehr, Michael, 1L
 Lim, Chang-Moon, 0M, 0S, 1U
 Lin, Martin, 1P
 Lin, Yen-Chih, 12
 Liu, Chi-Chun, 0W
 Liu, Hua-Yu, 1I
 Lok, Sjoerd, 1P
 Loosen, Peter, 29
 Lu, Yen-Cheng, 0Y, 1T
 Lucas, Kevin, 23
 Lucatoro, Thomas, 0K, 12
 Luong, Vu, 0I
 Ma, Yuansheng, 0W
 Magnusson, Krister, 19
 Mallik, Arindam, 1N
 Mallmann, Jörg, 1P
 Mangat, Pawitter J. S., 0D, 0I, 15
 Marokkey, Sajan, 0Q
 Maruyama, Ken, 1I
 Maryasov, Aleksey, 29
 Matsumoto, Hiroie, 0R
 Matsumoto, Yoko, 2L
 Matsunaga, Koichi, 1X
 Matsuura, Yuriko, 2F
 Matthews, Ken, 0L
 McGeoch, Malcolm W., 28
 Megens, Henry, 1Q
 Meiling, Hans, 0B, 1P
 Meli, Luciana, 0R, 1D
 Mellman, Joerg, 0W
 Mercha, Abdelkarim, 1N
 Mertens, Guido, 0F
 Metz, Andrew, 0R
 Migura, Sascha, 1F, 1G, 1H
 Mikami, Shinji, 1W
 Minegishi, Shinya, 10, 12
 Minnaert, Arthur, 1P
 Mitsuyasu, Masaki, 2D
 Miyagi, Tadashi, 2C
 Miyakawa, Ryan, 1C, 1J
 Mizoguchi, Hakaru, 0C, 2P
 Mochi, Iacopo, 0Q
 Momota, Makoto, 0N
 Montgomery, Cecilia, 0L, 11
 Montgomery, Warren, 1L
 Mulkens, Jan, 1Q
 Murakami, Takeshi, 24
 Nafus, Kathleen, 1X
 Nagahara, Tatsuro, 2F
 Nagai, Tomoki, 0P
 Nagano, Akihisa, 0F
 Nakagawa, Hisashi, 0P
 Nakamura, Kiyotada, 0F
 Nakarai, Hiroaki, 0C, 2P
 Narasimhan, Amrit, 08
 Naruoka, Takehiko, 0P, 11
 Naujok, P., 1K
 Naulleau, Patrick P., 09, 14, 17, 1C, 1J, 2I
 Neisser, Mark, 08, 0L, 11, 21, 27
 Neumann, Jens Timo, 1G, 1H
 Neureuther, Andrew R., 09, 14, 17, 1C, 2I
 Ngai, Tat, 0H
 Nihashi, Wataru, 0N
 Nowak, Krzysztof M., 0C
 Ocola, Leonidas E., 08
 Oh, Hye-Keun, 1O
 Ohomori, Katsumi, 0O
 Okamoto, Takeshi, 2P
 Okazaki, Shinji, 0C, 2P
 Panici, Gianluca A., 2H
 Park, Jin-Goo, 1O
 Park, Sarohan, 0S
 Pasarelli, James, 21, 27
 Patil, Suraj, 0I
 Pauer, Hagen, 0E
 Peeters, Rudy, 1P
 Perlitz, Sascha, 19
 Perske, Marco, 0E
 Peters, Jan Hendrik, 19
 Petrillo, Karen, 0R
 Philipsen, Vicky, 0I, 15
 Pieczulewski, Charles, 2C
 Pirati, Alberto, 0B, 1P
 Pistor, Thomas V., 0Q
 Platonov, Yuriy, 0K
 Pollentier, Ivan, 12
 Popadic, Milos, 1P
 Preil, Moshe E., 0D
 Pritchard, D., 0Z
 Purvis, Michael, 0B
 Rafac, Rob, 0B
 Raghunathan, Ananthan, 0U, 0W, 0X
 Raghunathan, Sudharshanan, 0I, 15
 Rankin, Jed, 1M
 Riggs, Daniel, 0B
 Rispens, G., 1S
 Risse, Stefan, 0E
 Robinson, Chris, 0R, 1M
 Rodriguez, Jim, 0K
 Rokitski, Slava, 0B
 Rollinger, Bob, 2K
 Ronse, Kurt, 1N
 Rösch, Matthias, 1H
 Ruzic, D. N., 2H
 Ryckaert, Julien, 1N
 Saito, Takashi, 0R
 Saitou, Takashi, 0C, 2P
 Sanders, Alexander, 2K
 Sandstrom, Rick, 0B
 Santillan, Julius Joseph, 06

Santos, Bárbara, 0F
 Sasami, Takeshi, 10, 12
 Saulnier, Nicole, 0R, 0T
 Schafgans, Alexander A., 0B, 1P
 Schleicher, Philipp, 0E
 Schmöller, Thomas, 23
 Scholze, Frank, 0E, 0I, 13
 Schröder, Sven, 0E
 Seisyan, R. P., 2M
 Sekiguchi, Atsushi, 2L
 Sekito, Takashi, 2F
 Shih, Chih-Tsung, 0Y, 1T
 Shiobara, Eishi, 10, 12, 1W
 Shirai, Takahiro, 0F
 Shiraiishi, Yutaka, 0C, 2P
 Shiratani, Motohiro, 0P
 Sizyuk, Tatyana, 0G
 Slotboom, Daan, 1Q
 Smith, Bruce W., 15
 Smith, Daniel, 1P
 Smith, L., 0Z
 Soltwisch, Victor, 0I, 13
 Song, Hyun Min, 2E
 Sortland, Miriam, 21, 27
 Soumagne, Georg, 0C
 Srivastava, Shailendra N., 2H
 Srivats, Bharath, 0B
 Stadelhoff, Christian, 13
 Steinkopf, Ralf, 0E
 Stoeldraijer, Judon, 1P
 Stokes, Harold, 2C
 Sun, Kyu-Tae, 0M
 Sun, Lei, 0T
 Takagi, Isamu, 10, 12, 1W
 Takagi, N., 16
 Tanaka, Hiroshi, 0C, 2P
 Tanaka, Hiroyuki, 1W
 Tang, Feng, 2O
 Tao, Yezheng, 0B
 Tao, Zheng, 0S
 Tarrío, Charles, 0K, 12
 Tempeler, Jenny, 29
 Teramoto, Yusuke, 0F
 Terao, Kenji, 24
 Thean, Aaron, 1N
 Thete, A., 0A
 Thouroude, Yan, 2C
 Tittnich, Michael, 1L
 Torres, J. Andres, 0U, 0W
 Tromp, R. M., 0A
 Trost, Marcus, 0E
 Tsubaki, Hideaki, 0N
 Tsuchihashi, Toru, 0N
 Tsugama, N., 1S
 Tünnermann, A., 1K
 Turley, Christina, 1M
 Ullrich, Albrecht, 13
 Upadhyaya, Mihir, 0Q
 Vaenkatesan, Vidya, 1Q
 Valente, Sean, 0L
 Valentin, Chris, 1F
 van de Kerkhof, Mark, 1V
 Vandenberghe, Geert, 0S, 23
 Van den Heuvel, D., 16
 van der Molen, S. J., 0A
 van Es, Roderik, 1P
 van Ingen Schenau, Koen, 1F, 1H
 van Noordenburg, Martijn, 1P
 van Putten, Arnold, 1V
 van Schoot, Jan, 1F, 1G
 van Setten, Eelco, 1P
 Vaschenko, Georgiy, 0B
 Vemareddy, Kaushik, 1D
 Verduijn, Erik, 0I, 15
 Verkest, Diederik, 1N
 Verspaget, C., 1S
 Vo, Tuan, 0H
 Vockenhuber, Michaela, 04, 21, 27
 von Wezyk, Alexander, 0F
 Wagner, Christian, 0B, 1P
 Waller, Laura, 14, 17
 Wang, Wenhui, 0T
 Wang, Xiangzhao, 2O
 Wang, Yow-Gwo, 17, 1C
 Watanabe, Hidehiro, 16, 24, 25
 Watanabe, Takeo, 10, 2L
 Watanabe, Yukio, 0C, 2P
 Wei, Hannah, 1Q
 Weiss, Markus R., 19
 Wisehart, Liam, 0B
 Wojdyla, Antoine, 14, 15, 17, 1A, 1C
 Wood, Obert R., II, 0D, 0I, 15
 Word, James, 0U
 Wu, Feibin, 2O
 Wu, Jui-Ching, 1T
 Wu, Shun-Der, 1T
 Wuister, S., 0A
 Xu, Dongbo, 18
 Xu, Yongan, 0T, 0W
 Yabuta, Hironobu, 0F
 Yamada, Tsuyoshi, 0C
 Yamamoto, Hiroki, 0O, 2D
 Yamamoto, Kazuma, 1Y
 Yamamoto, Kazuma, 2F
 Yamazaki, Taku, 0C, 2P
 Yan, Pei-yang, 0J
 Yanagida, Tatsuya, 0C
 Yen, Anthony, 0Y, 1T
 Yeung, Michael, 0V
 Yildirim, O., 1S
 Yoshikawa, Shoji, 24
 Yu, Shinn-Sheng, 0Y, 1T
 Yulin, S., 1K
 Yum, Jung, 0H
 Zeitner, Uwe, 0E
 Zhang, Guojing, 0J
 Zhevlakov, A. P., 2M
 Zhou, Xibin, 1E
 Zimmermann, Jörg, 1I
 Zoldesi, Carmen, 1P

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Robert L. Brainard, College of Nanoscale Science and Engineering (United States)
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- 3 EUV Resist Mechanistic Studies: Joint Session with Conferences 9422 and 9425
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Clifford L. Henderson, Georgia Institute of Technology (United States)
- 4 EUV Source
Moshe E. Preil, GLOBALFOUNDRIES Inc. (United States)
Emily E. Gallagher, IMEC (Belgium)
- 5 EUV Mask Structure
Frank Goodwin, SEMATECH Inc. (United States)
Hidehiro Watanabe, EUVL Infrastructure Development Center, Inc. (Japan)
- 6 EUV Resists
Thomas I. Wallow, Brion Technologies, Inc. (United States)
Anna Lio, Intel Corporation (United States)

- 7 EUV Integration
Patrick P. Naulleau, Lawrence Berkeley National Laboratory
(United States)
Anthony Yen, Taiwan Semiconductor Manufacturing Company, Ltd.
(Taiwan)
- 8 Mask Topography: Joint Session with Conferences 9422 and 9426
Ted Liang, Intel Corporation (United States)
Tsai-Sheng Gau, Taiwan Semiconductor Manufacturing Company
Ltd. (Taiwan)
- 9 Resist Outgas Testing
Kurt G. Ronse, IMEC (Belgium)
Michael J. Lercel, SEMATECH Inc. (United States)
- 10 EUV Optics and Mask Metrology
Christopher S. Ngai, Applied Materials, Inc. (United States)
Jan Hendrik Peters, Carl Zeiss SMS GmbH (Germany)
- 11 EUV Mask Inspection
Naoya Hayashi, Dai Nippon Printing Company, Ltd. (Japan)
Bryan S. Kasprowitz, Photronics, Inc. (United States)
- 12 EUV Extension
Jim N. Wiley, ASML US, Inc. (United States)
Pawitter J. Mangat, GLOBALFOUNDRIES Inc. (United States)
- 13 EUV Manufacturing
Sang Hun Lee, Intel Corporation (United States)
Gregory R. McIntyre, IMEC (Belgium)
- 14 Exposure Tools
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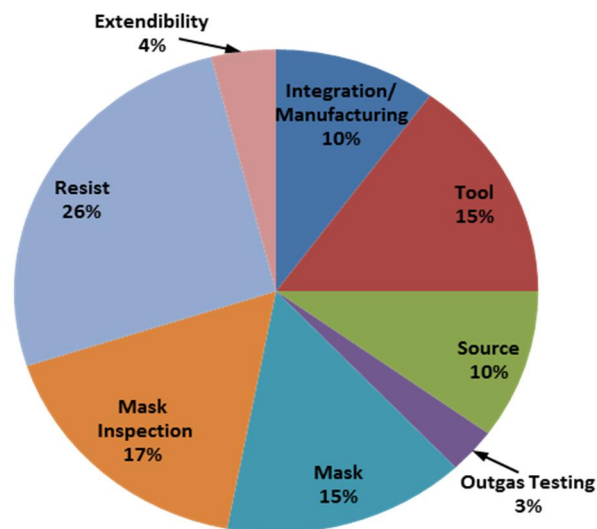
Introduction

The chairs of the Extreme Ultraviolet (EUV) Lithography VI Conference would like to thank the program committee, the session chairs, the presenters, and the attendees for a successful 2015 meeting at SPIE Advanced Lithography in San Jose, California. The number of conference oral talks this year was nearly identical to last year's number indicating that the interest in EUV lithography technology remains high. Peak session attendance at the keynote joint session topped 750. Key topics included EUV scanner and source performance, mask blank defectivity and actinic blank review, CAR and non-CAR resist status, EUV pellicle development, and EUV extendibility beyond the 7 nm technology node.

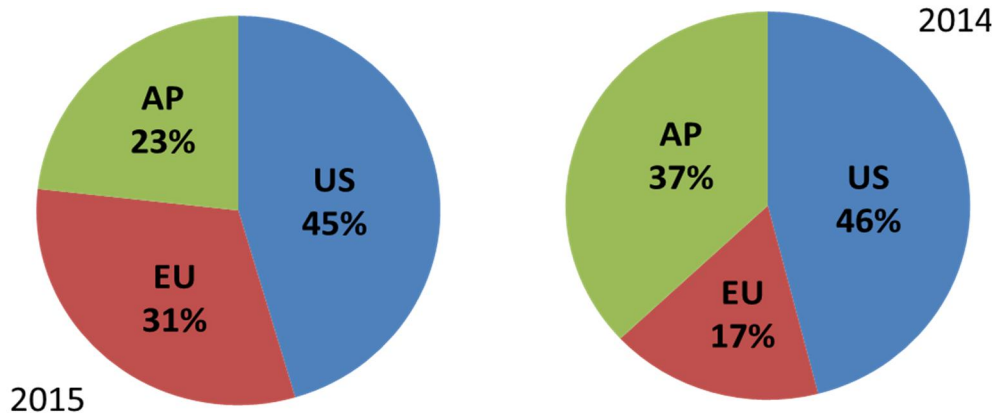
The EUV conference received 99 abstract submissions in 2015, of which 67 were accepted for oral presentation, 30 were accepted for presentation in the poster session, and 2 were withdrawn. The number of abstract submissions was ~25% lower than last year, perhaps because EUV technology is getting closer to HVM introduction. The 2015 SPIE Advanced Lithography Symposium attendance totaled 2,320, very nearly the same as 2014's count of 2,360. The average attendance at the EUV conference was 282 per session and the peak attendance in the keynote session was 752. The average attendance number was down slightly from the 2014 number of 332 but the keynote session attendance number was significantly higher than the 2014 number of 629.

Attendance by session is presented in Table 1.

Session	Count
Keynote	752
Resist Extendibility (Joint with 9425)	322
Resist Mechanistic Studies (Joint with 9425)	197
Source	317
Mask Structure	125
Resist	262
Integration	328
Mask Topography (Joint with 9426)	246
Resist Outgas Testing	85
Optics & Mask Metrology	161
Mask Inspection	166
Extension	315
Manufacturing	184
Exposure Tools	484



Submissions by region for 2015 and 2014 are shown in Figure 2.



2015 Conference Highlights

Scanners

ASML reported that 8 NXE:3300B scanners have been shipped to customers and 6 are already exposing wafers, that more than 600 wafers per day have been exposed on four scanners and more than 1000 wafers per day have been exposed in a 24 hour period with a NXE:3300B scanner at TSMC¹. The current collector lifetime is > 3 months and the average availability on an NXE:3300B scanner at TSMC is current 55%. ASML also provided the following preliminary imaging performance data for NXE:3300B scanners: 22 nm resolution for dense lines and spaces with full-wafer CDU = 1.0 nm, dedicated chuck overlay < 1.8 nm, matched machine overlay of < 3.5 nm, focus control < 12 nm, a 10x reduction in added particles per reticle pass (< 0.001).

Sources

At the 2015 Advance Etch Technology for Nanopatterning IV Conference, TSMC reported the achievement of 90 W at IF from a MOPA+PP LPP 3300B source (with an 80 W source configuration)². At the 2015 SPIE EUVL VI Conference, ASML-Cymer described the steady improvement in LPP source performance from 10 W at 1% conversion efficiency (CE) in 2011 to 30 W at 1.5% CE in Q2'12, to 50 W at 4.0% CE in Q3'12 and 80 W at 3.5% CE for 24 hours at TSMC, and 100+ W both in a custom system and in an in-house system at the ASML factory in Veldhoven in Q4'14³. These improvements in power were attributed to an evolution in the laser architecture, specifically to the addition of a pre-pulse to increase conversion efficiency and EUV emitting volume. ASML reported that 3 MOPA+PP 3300B sources (with 80 W source configuration) have delivered 110 W EUV of power for periods of one hour. At the 2015 SPIE EUVL VI conference, Gigaphoton described an LLP-EUV light

source with superconducting magnet debris mitigation that produced 130 W at 80 kHz rep-rate and 50% duty cycle for 130 minutes⁴.

Masks and Mask Metrology

SEMATECH reported that using ion beam sputter deposition of Mo/Si multilayer (ML) coatings at their Mask Blank Development Center in Albany New York, they have observed a 10% yield of ML-coated EUV mask blanks with 0 defects at 100 nm size and fewer than 5 defects at 80 nm size⁵. The final blank deposition run also resulted in 2 defect-free blanks (no defect adders > 54 nm in size). This result is the long awaited proof-of-concept that defect-free EUV mask blanks are possible! In a separate paper, SEMATECH reported that high quality Mo/Si ML coatings can be produced using commercially available PVD tools⁶. The Mo/Si coatings produced with the PVD tool had higher EUV reflectivity (68.4%) than those produced with an IBD tool (64%) and have already achieved comparable levels of added defects. Zeiss reported that their prototype AIMSTTM EUV system has achieved 2nd light and that the system is expected to be available for customers in Q4 of this year⁷. Zeiss went on to say that the measured imaging optics flare was ~1% and that the tool already exceeds the specs for 16 nm hp resolution. In a presentation by LBNL, the SHARP EUV microscope demonstrated 7.5 nm L/S resolution using a 0.625 NA zone plate lens. The SHARP tool should be able to mimic the imaging of anamorphic projection optics like those recently proposed by AMSL/Zeiss for use in higher-NA EUV scanners when using an elliptical zone plate lens⁸.

Resists

It was extremely gratifying to see a presentation by JSR showing that 13 nm half pitch (HP) lines and spaces (L/S) have been resolved by a new chemically amplified (CAR) resist patterned with the Berkeley 0.3 NA MET at 35.5 mJ/cm² dose⁹. This was an important result since progress in CAR resolution appeared to have been stalled for more than two years. Inpria reported that 13 nm HP L/S have been resolved by one of their Gen2 Platform metal-oxide materials also using the Berkeley 0.3 NA MET at 59 mJ/cm² dose¹⁰. Intel presented data for hybrid nanoparticle materials showing 2-3 weeks of shelf life and that the dose is also stable for 2 – 3 weeks¹¹. In a presentation at a satellite meeting on the day before the start of the EUVL VI Conference, ASML announced that witness plate outgas testing of CAR resist materials will no longer be required before use in an ASML NXE scanner¹². Given this relaxation of the outgas testing requirement, commercial resist suppliers should now be able to explore a wider range of PAG and quencher loadings than ever before possible leading to improved performance.

Manufacturing

SK Hynix reported that comparable yields of 2x DRAMs have been demonstrated with EUV single patterning and 193 nm immersion multiple patterning¹³. In a separate paper SK Hynix found that the particle adder rate in an NXE:3100 scanner is only 0 to 1 particle per day and that pellicle-less operation may be a better operational mode when the EUV source power exceeds > 300 Watts at intermediate focus¹⁴.

ASML-Brion described new pattern-placement-aware SMO application software that simultaneously minimizes pattern placement errors, enhances through-focus contrast and reduces the impact of stochastic effects¹⁵.

At the end of 2014, ASML reported the development of a full-size pellicle with 85% transmission and with excellent imaging performance. At 2015 SPIE Advanced Lithography, ASML announced that they will supply EUV pellicles to NXE customers and went on to describe a design for a removable and re-mountable pellicle that enables current pattern mask inspection tools to be used to inspect EUV patterned masks¹⁶.

Extendibility

ASML described the design of a EUV scanner with a 0.52 NA anamorphic half-field projection system¹⁷. The system's anamorphic 4x/8x design allows use of a conventional 6" mask and is expected to have a throughput of 150 wafers per hour when used with a 500 W source and a resist with 30 mJ/cm² sensitivity. In a companion paper by Zeiss, it was pointed out that the new anamorphic design has a central obscuration which blocks part of the 1st diffraction order and results in some contrast loss¹⁸. Zeiss also pointed out that the new system will require mirrors with extreme aspheric departures and tighter surface specs and a huge last mirror. In a third companion paper by Zeiss and ASML, the claim was made that Zeiss, ASML and Fraunhofer IISB all agree that the imaging differences between an isomorphic 8x system and an anamorphic 4x/8x system with a CRAO of 6° and NA > 0.5 are small¹⁹, e.g., the images of circular contact holes will become slightly elliptical at extreme out of focus positions and that anamorphic-aware OPC and SMO will be required. The authors claimed that the "benefits of the anamorphic high-NA system come without noticeable loss of image quality."

2016 Conference Call for Papers

In 2015, the first group of EUVL production tools was fielded and dramatic increases in EUV source power were achieved. In 2016, chip makers will be focused on driving EUVL technology toward meeting HVM productivity and yield targets for the 7 nm logic technology node. Nevertheless, a number of critical technology challenges remain, i.e., meeting productivity and availability targets for HVM, developing mature mask handling protocols, improving mask yield, inspection, review, and repair infrastructure, and simultaneously improving resist resolution, sensitivity and LER. Looking longer term, to meet patterning challenges beyond the 7 nm logic technology node, innovative approaches in EUV source, mask and imaging materials will be needed and developing much higher power sources will be essential.

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Eric M. Panning

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