

PROCEEDINGS OF SPIE

Metrology, Inspection, and Process Control for Microlithography XXXIII

Vladimir A. Ukraintsev
Ofer Adan
Editors

25–28 February 2019
San Jose, California, United States

Sponsored by
SPIE

Cosponsored by
Nova Measuring, Ltd. (United States)

Published by
SPIE

Volume 10959

Proceedings of SPIE 0277-786X, V. 10959

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Metrology, Inspection, and Process Control for Microlithography XXXIII, edited by
Vladimir A. Ukraintsev, Ofer Adan, Proc. of SPIE Vol. 10959, 1095901 © 2019
SPIE · CCC code: 0277-786X/19/\$18 · doi: 10.1117/12.2532423

Proc. of SPIE Vol. 10959 1095901-1

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:

Author(s), "Title of Paper," in *Metrology, Inspection, and Process Control for Microlithography XXXIII*, edited by Vladimir A. Ukraintsev, Ofer Adan, Proceedings of SPIE Vol. 10959 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)

ISBN: 9781510625655
ISBN: 9781510625662 (electronic)

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445

SPIE.org

Copyright © 2019, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/19/\$18.00.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

Publication of record for individual papers is online in the SPIE Digital Library.

**SPIE. DIGITAL
LIBRARY**

SPIDigitalLibrary.org

Paper Numbering: *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

Contents

ix	<i>Authors</i>
xv	<i>Conference Committee</i>
xix	<i>Introduction</i>

SESSION 1 KEYNOTE SESSION

10959 02	Tough road ahead for device overlay and edge placement error (Keynote Paper) [10959-1]
----------	-----------------------------------------------------------------------------------------------

SESSION 2 OVERLAY NEWS

10959 05	Overlay error investigation for metal containing resist (MCR) [10959-4]
10959 06	Process drift compensation by tunable wavelength homing in scatterometry-based overlay [10959-5]
10959 07	Measuring after etch overlay and characterizing tilt fingerprints in multi-tier 3D-NAND structures [10959-6]
10959 08	Standalone alignment technology enabling feed-forward compensation of on-product overlay errors [10959-7]

SESSION 3 CHALLENGES AND NEW METHODS

10959 0B	Image quality enhancement of a CD-SEM image using conditional generative adversarial networks [10959-10]
10959 0C	Statistical significance of STEM based metrology on advanced 3D transistor structures [10959-11]
10959 0D	Edge placement error measurement in lithography process with die to database algorithm [10959-12]

SESSION 4 INSPECTION I

10959 0F	Machine learning for predictive electrical performance using OCD [10959-14]
----------	------------------------------------------------------------------------------------

- 10959 OH **E-beam inspection of single exposure EUV direct print of M2 layer of N10 node test vehicle** [10959-16]
- 10959 OI **Gas-enhanced PFIB surface preparation enabled metrology and statistical analysis of 3D NAND devices** [10959-17]
- 10959 OJ **Development of standard samples with programmed defects for evaluation of pattern inspection tools** [10959-74]

SESSION 5 ADVANCES IN PHYSICAL CHARACTERIZATION

- 10959 OM **Quantitative tomography with subsurface scanning ultrasound resonance force microscopy** [10959-20]
- 10959 OO **Nano-scale molecular analysis of photo-resist films with massive cluster secondary ion mass spectrometry** [10959-22]

SESSION 6 LWR

- 10959 OP **Unbiased roughness measurements: subtracting out SEM effects, part 3** [10959-23]
- 10959 OQ **Linewidth and roughness measurement of SAOP by using FIB and Planer-TEM as reference metrology** [10959-24]
- 10959 OT **Roughness decomposition: an on-wafer methodology to discriminate mask, metrology, and shot noise contributions** [10959-27]

SESSION 7 NEW METHODS: STUDENT SESSION

- 10959 OU **Application of PSD for the extraction of programmed line roughness from SAXS** [10959-28]
- 10959 OV **Surface effects in simulations of scanning electron microscopy images** [10959-29]
- 10959 OX **Optical characterization of multi-NST nanowire test structures using Mueller matrix spectroscopic ellipsometry (MMSE) based scatterometry for sub 5nm nodes** [10959-31]
- 10959 OY **Tilted beam SEM, 3D metrology for industry (Karel Urbánek Best Student Paper Award)** [10959-32]

SESSION 8 MACHINE LEARNING

- 10959 0Z **Applications of machine learning at the limits of form-dependent scattering for defect metrology (Invited Paper)** [10959-33]
- 10959 10 **Engineering neural networks for improved defect detection and classification** [10959-34]
- 10959 11 **Using Gaussian process regression for efficient parameter reconstruction** [10959-35]
- 10959 12 **Deep learning's impact on contour extraction for design based metrology and design based inspection** [10959-36]
- 10959 13 **OPC model accuracy study using high volume contour based gauges and deep learning on memory device** [10959-37]

SESSION 9 SEM

- 10959 14 **What is prevalent CD-SEM's role in EUV era?** [10959-38]
- 10959 15 **High voltage CD-SEM based metrology for 3D-profile measurement using depth-correlated BSE signal** [10959-39]
- 10959 18 **FEM simulation for artificial generation of SEM pictures** [10959-42]

SESSION 10 SEM AND E-BEAM METROLOGY

- 10959 1A **Investigating process variability at ppm level using advanced massive eBeam CD metrology and contour analysis** [10959-44]
- 10959 1B **Depth measurement technique for extremely deep holes using back-scattered electron images with high voltage CD-SEM** [10959-45]
- 10959 1C **Evaluation of the accuracy and precision of STEM and EDS metrology on horizontal GAA nanowire devices** [10959-46]
- 10959 1D **High-resolution low-shrinkage CD metrology for EUV resist using high voltage CD-SEM** [10959-47]

SESSION 11 OVERLAY

- 10959 1E **Improved accuracy and robustness for advanced DRAM with tunable multi-wavelength imaging and scatterometry overlay metrology** [10959-48]

- 10959 1F **Edge placement error and line edge roughness** [10959-111]
- 10959 1G **Color mixing in overlay metrology for greater accuracy and robustness** [10959-50]
- 10959 1H **Smart implant-layer overlay metrology to enable fab cycle time reduction** [10959-51]
- 10959 1I **Intra-field stress impact on global wafer deformation** [10959-52]

SESSION 12 DESIGN INTERACTIONS WITH METROLOGY: JOINT SESSION WITH CONFERENCES 10959 AND 10962

- 10959 1J **AI: from deep learning to in-memory computing (Keynote Paper)** [10959-53]
- 10959 1L **3D optical proximity model optimization using inline 3DSEM metrology** [10959-55]

SESSION 13 PROCESS CONTROL

- 10959 1M **Contour based metrology: getting more from a SEM image** [10959-56]
- 10959 1N **Scatterometry and AFM measurement combination for area selective deposition process characterization** [10959-57]
- 10959 1O **Localized power spectral density analysis on atomic force microscopy images for advanced patterning applications** [10959-58]
- 10959 1P **Focus budget improvement using optimized wafer edge settings** [10959-59]
- 10959 1Q **New approach for APC and measurement sampler interaction in a complex process mix logic fab** [10959-60]

SESSION 14 INSPECTION II

- 10959 1R **Multiple beam inspection (MBI) for 7nm node and beyond: technologies and applications** [10959-61]
- 10959 1V **Process window discovery methodology for extreme ultraviolet (EUV) lithography** [10959-65]

SESSION 15 OPTICAL METROLOGY AND LATE NEWS

- 10959 1X **Spectroscopic reflectometry in the extreme ultraviolet for critical dimension metrology** [10959-68]

- 10959 1Y **Visualization of 3D structure of semiconductor devices by "Dig and See" using GFIS-SIM** [10959-69]
- 10959 1Z **Influence of sidewall perturbations of CD-SEM line roughness metrology** [10959-67]
- 10959 20 **Deep learning nanometrology of line edge roughness** [10959-109]
- 10959 21 **Novel method to achieve CD modeling in the presence of higher diffraction orders** [10959-110]

POSTER SESSION

- 10959 22 **Application of aberration corrected low voltage SEM for metrology** [10959-70]
- 10959 23 **An optimized parameter guidance system for line/space CD metrology** [10959-71]
- 10959 24 **Metrology of 3D NAND in electron micrographs by scale space snakes** [10959-72]
- 10959 27 **Measurement system of film structure by interferometry and ellipsometry** [10959-76]
- 10959 28 **Process monitoring and control with tunable wavelength overlay coupled with simulation-to-measurement analysis** [10959-77]
- 10959 29 **Parallel active cantilever AFM tool for high-throughput inspection and metrology** [10959-79]
- 10959 2A **Detection of particle defect components on silicon wafer with laser induced breakdown spectroscopy combined laser cleaning technology** [10959-81]
- 10959 2B **Accurate vertical sidewall measurement by a metrological tilting-AFM for reference metrology of line edge roughness** [10959-82]
- 10959 2C **Casual modeling of yield** [10959-83]
- 10959 2E **First results from the Large Dynamic Range Atomic Force Microscope for overlay metrology** [10959-85]
- 10959 2F **CD and OCD sampling scheme optimization for HVM environment** [10959-86]
- 10959 2G **Deep learning's impact on pattern matching for design based metrology and design based inspection** [10959-87]
- 10959 2I **Study on a feasibility of dark-field illumination for the near-field microscope** [10959-89]
- 10959 2K **Enhanced wafer overlay residuals control; deep sub-nanometer at sub-millimeter lateral resolution** [10959-91]

- 10959 2L **Area-framing optical defect review under optical resolution using multi-NA dark-field microscopy images** [10959-92]
- 10959 2M **YieldStar uDBO overlay metrology in Samsung D1y DRAM volume production** [10959-93]
- 10959 2N **New method removing SEM image noise to characterize CD and LWR** [10959-94]
- 10959 2O **Alignment sampling by thorough run-to-run simulation** [10959-95]
- 10959 2P **Overlay run-to-run control based on device structure measured overlay in DRAM HVM** [10959-96]
- 10959 2Q **Analysis and modelling of patterned wafer nano-topography using multiple linear regression on design GDS and silicon PWG data** [10959-97]
- 10959 2S **Macro CDSEM 2D metrology supporting advanced DRAM patterning** [10959-99]
- 10959 2T **Intra-field alignment for overlay feed-forward simulation with sampling optimization** [10959-101]
- 10959 2U **In-depth analysis and research of additional components of the uncertainty budget using the finite element method** [10959-102]
- 10959 2V **Characterization of STEM alignments and their automation** [10959-103]
- 10959 2W **Analyze line roughness sources using power spectral density (PSD)** [10959-104]
- 10959 2X **A diffraction-based overlay model based on FDTD method** [10959-105]
- 10959 2Y **Verification and analysis of FEM for measurement of temperature distribution through the multilayer wall** [10959-106]
- 10959 2Z **Denoising line edge roughness measurement using hidden Markov models** [10959-112]
- 10959 30 **Defect learning with predictive sampling for process improvement** [10959-113]
- 10959 31 **First demonstration of a 331-beam SEM** [10959-114]

Authors

Numbers in the index correspond to the last two digits of the seven-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first five 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.

Adiga, Umesh, 0l, 24
Adolf, A., 31
Aerts, Silvia, 2V
Ahmad, Ahmad, 29
Alkoken, R., 2S
Amit, Eran, 1E
Anberg, Doug, 1l
Ando, Satoshi, 08
Arjavac, Jason, 24
Atkins, Phillip R., 21
Avedisian, Brett, 0l
Bahrenberg, Lukas, 1X
Barla, Kathy, 0C, 1C
Barnes, Bryan M., 0Z
Bar-On, T., 2S
Bellah, Md. Motasim, 06, 28
BenDavid, Nir, 06, 28
Bérard-Bergery, Sébastien, 0Y
Besacier, Maxime, 0U, 0Y
Beylier, Charlotte, 1M
Bhattacharyya, Kaustuve, 02, 1G
Biedrzycki, Mark, 0l
Birnstein, Norman, 2O
Bizen, Daisuke, 1D
Blancquaert, Yoann, 0U
Bonam, Ravi, 10
Borisov, Sergei, 1Z
Boullart, Werner, 0C, 1C
Bouyssou, Régis, 1M
Bozkurt, Murat, 1G
Brose, Sascha, 1X
Brouzet, V., 2Q
Buhl, Stefan, 2F
Bunday, Benjamin D., 1Z
Burger, Sven, 11
Byun, Jin-Moo, 2M
Canga, Eren, 2K
Chagoya-Garzon, Alexandre, 1M
Chang, Hsien-Hung, 21
Chang, Jan-Hau, 21
Chang, Ken, 1G
Chang, Nick Weihan, 21
Charley, Anne-Laure, 0F, 1N, 1O
Chen, Aiden, 1R
Chen, Kai-Hsiung, 1G
Chen, Xiaomei, 2A
Cheng, Zh. H., 22
Chiu, Afu, 2P
Chiu, Chu-Han, 21
Choi, Ahlin, 1E, 2F
Choi, Byoung-Il, 13
Choi, DongSub, 1E
Choi, Jaeseung, 13
Chou, Kevin, 1R
Chu, Hsiao Lun, 2P
Clarke, James, 0l
Cohen, Avi, 2K
Constantoudis, Vassilios, 1F, 20, 2Z
Cramer, Jillian, 0C
Cross, Andrew, 1V
Danylyuk, Serhiy, 1X
Das, Sayantan, 0F, 0H
Decaunes, J., 1Q
Decoster, Stefan, 0Q
Demirer, Onur, 05
den Boef, Arie, 1G
Deng, Shaoren, 1N, 1O
Desmoulin, S., 1A
Dezauzier, Christophe, 1M
Diebold, Alain C., 0X
Dillen, Harm, 2W
Diller, Timothy, 2N
Dmitriev, Vladimir, 2K
Dohi, H., 22
Dong, Lisong, 2X
Dou, Shuyang, 2G
Dror, Chen, 06, 28
Ducoté, J., 1M
Duvdevani-Bar, S., 2S
Eberle, A. L., 31
Ebert, Martin, 1R
Eller, Michael J., 0O
Enomoto, Masashi, 2N
Erey, Georg, 1P
Fang, Wei, 23, 2W
Feng, Mu, 13
Fillinger, Laurent, 0M
Foltynski, Bartosz, 2M
Frachel, Michael, 1P
Freitag, Martin, 2T
Fritz, H., 31
Frommhold, Andreas, 0T
Gao, Kun, 06, 28
Gao, Linfei, 06
Gao, Xindong, 06, 28
Gardin, Christian, 1A, 1M
Ger, Avron, 0F, 1N
Gergaud, Patrice, 0U

Gershtein, L., 2S
 Ghafoori, Moein, 1X
 Giannatou, Eva, 20
 Glabisch, Sven, 1X
 Gogolides, Evangelos, 1F, 20, 2Z
 Golotsvan, Anna, 1E
 Gonda, Satoshi, 2B
 Goosen, Maikel, 2W
 Gorhad, Kujan, 2K
 Gosali, Benny, 1G
 Goto, Yasunori, 1S
 Gottipati, Abhishek, 06, 28
 Gourgon, Cécile, 0Y
 Gredy, V., 2Q
 Groeger, Philip, 1P, 2F
 Gronheid, Roel, 0S
 Grouwstra, Cedric, 2M
 Grzela, Grzegorz, 2M
 Gu, Yajun, 1I
 Guhlemann, Steffen, 2F, 2O
 Guliyev, Elshad, 29
 Guñjahn, Karsten, 06, 28
 Ha, Hyeon-Jun, 2M
 Habets, Boris, 1P, 2O, 2P, 2T
 Hagen, C. W., 0V
 Hagger, Jack, 24
 Hajaj, Eitan, 1E, 28
 Hajjahmadi, Reza, 1G
 Hakala, Chris, 1C
 Halder, Sandip, 0F, 0H, 1V
 Hamaguchi, Akira, 1B
 Hammerschmidt, Martin, 1I
 Han, Sang-Jun, 07, 1E
 Han, Woojun, 2I
 Hand, Sean, 1L
 Hao, Xueli, 06, 28
 Hashizume, Tomihiro, 1Y
 Hasibi, Faegheh, 1H
 Hayashi, S., 22
 Hazart, Jérôme, 0Y
 Henn, Mark-Alexander, 0Z
 Hermans, Jan, 1I
 Herrera, Pedro, 06, 28
 Herzel, Eitan, 1E
 Higashibata, Satomi, 0S
 Hirai, Akiko, 2B
 Hirose, K., 22
 Holz, Mathias, 29
 Hong, Minhyung, 1E
 Horikawa, I., 2S
 Hou, Xisen, 0O
 Hou, Zhenyu, 13
 Hsu, Hsiao-Lin, 2P, 2T
 Hu, Kwang-Young, 2M
 Hu, Xuerang, 1R
 Huang, Foster, 2P
 Huang, Guo-Tsai, 1G
 Huang, Shang-Chieh, 0D
 Huisman, Thomas J., 2W
 Hung, Joey, 0F, 1N
 Hunsche, S., 1A
 Hwang, Jong-Hyun, 2M
 Ida, Chihiro, 1B
 Iida, Susumu, 0J
 Ikota, Masami, 0Q, 1Y
 Illiberi, Andrea, 1N, 1O
 Ishikawa, Jun, 08
 Ishikawa, Masayoshi, 12, 2G
 Ivanov, Tzvetan, 29
 Izawa, Masayuki, 12, 2G
 Jang, Won-Jae, 2M
 Javaheri, Narjes, 1G
 Jeon, Sanghuck, 1E
 Jeon, Se-Ra, 2M
 Jeong, Junhee, 2L
 Ji, Rongyi, 2A
 Johannesen, Hayley, 0C, 1C
 Joo, K.-N., 27
 Joung, Tony, 06, 28
 Kai, Ding, 2O
 Kal, Subhadeep, 0X
 Kämmer, N., 31
 Kang, Daekwon, 13
 Karssenberg, Jaap, 07
 Karvtsov, Angela, 1L
 Kaufmann, N., 31
 Kawada, Hiroki, 0Q
 Kazumi, H., 22
 Keller, Nick, 0X
 Kenslea, Anne, 0C, 1C
 Kern, Robert, 2N
 Kessar, M., 2Q
 Keyvani, S., 2E
 Kiers, T., 1A
 Kim, Cheolkyun, 13
 Kim, Gilbert, 13
 Kim, Hwi, 2L
 Kim, Jaisoon, 2I
 Kim, Jang-Sun, 2M
 Kim, Jun-Yeob, 07
 Kim, Mingyu, 2F
 Kim, Seop, 2F
 Kim, Wan-Soo, 2F
 Kim, Young-Seok, 13
 Kizu, Ryosuke, 2B
 Klebanov, G., 2S
 Klein, Dana, 1E
 Ko, Sung-woo, 13
 Kobayashi, Shinji, 2N
 Kontoyiannis, Ioannis, 2Z
 Korde, Madhulika, 0X
 Koret, Roy, 0F, 1N
 Kris, R., 2S
 Krishnan, Shankar, 2I
 Kruit, P., 0V
 Kuiper, S., 2E
 Kwakman, Laurens, 0C, 1C
 Lam, Auguste, 1H

Lamonds, Lucas, 1P
 Lancee, Remco, 2M
 Lang, Jun, 13
 Lariviere, Stephane, 1V
 Larrañaga, Maialen, 1H
 Lazzarino, Frederic, 0Q, 1O
 Le Cunff, D., 2Q
 Lecarpentier, L., 1Q
 Ledoux, Micah, 0I
 Lee, Brian, 23
 Lee, Dohwa, 1E
 Lee, Dong-Hak, 07
 Lee, Dong-Young, 07, 1E, 2F
 Lee, Hong-Goo, 07, 1E, 2F
 Lee, Ho-Se, 29
 Lee, Jeongpyo, 1E
 Lee, JeonKyu, 13
 Lee, Jieun, 1E
 Lee, Julie, 30
 Lee, Jun Ho, 2L
 Lee, Jungtae, 1E
 Lee, Liequan, 21
 Lee, Sell, 13
 Lee, Seongjae, 1E
 Lee, Yungi, 2I
 Le-Gratiet, B., 1A, 1M, 1Q, 2Q
 Lemaire, P., 2Q
 Leray, Philippe, 05, 0F, 0H, 1N, 1O, 1V, 2K, 2W
 Levi, Shimon, 1L
 Levy, S., 2S
 Li, Guannan, 2A
 Li, Mingqi, 0O
 Li, Waikin, 05
 Li, Weihua, 06, 28
 Lin, John, 1G
 Lin, Yung-Hsiang, 2I
 Liu, Lituo, 2A
 Liu, Meng, 13
 Liu, Rex H., 2O, 2P, 2T
 Liu, Xuedong, 1R
 Liu, Zephyr, 1E
 Lomtscher, Patrick, 2O, 2P, 2T
 Loosen, Peter, 1X
 Lorusso, Gian Francesco, 0P, 0Q, 0T, 2O
 Lung, Hsiang-Lan, 1J
 Ma, Eric, 1R
 Ma, Ling, 2X
 Maas, Ruben, 2W
 Maassen, Martijn, 1R
 Macht, Lukasz, 2M
 Mack, Chris A., 0P, 1Z
 Maes, Jan Willem, 1N, 1O
 Mani, Antonio, 1V
 Mao, Ming, 05
 Marciano, Tal, 1E
 Marcuccilli, Gino, 30
 Maruyama, Kotaro, 0D, 0H
 Mathew, B., 2S
 Mathijssen, Simon, 1G
 Matsubara, Shinichi, 1Y
 McDaniel, Tony, 2N
 Mei, Hao, 06, 1E, 28
 Mermet, O., 1A
 Mertens, Hans, 0C, 1C
 Michels, Robert, 1X
 Midoh, Yoshihiro, 0B
 Mileham, Jeffrey, 1I
 Mill, A., 1Q
 Milléquant, Matthieu, 1M
 Milo, Renan, 06, 28
 Miroku, H., 2S
 Misumi, Ichiko, 2B
 Mizutani, Shinji, 0H
 Mizutani, Shunsuke, 1D
 Momonoi, Yoshinori, 14, 1D
 Morita, Masahiro, 08
 Mosden, Aelan, 0X
 Moussa, Alain, 1N, 1O
 Muehle, Alexander, 1P, 2O
 Muelders, Thomas, 1L
 Müller, I., 31
 Nagai, Satoshi, 05
 Nagai, Takamitsu, 0J
 Nagayoshi, Hiroyuki, 08
 Naipak, Victoria, 06, 28
 Nakamae, Koji, 0B
 Nelson, Dan, 24
 Neyezhmakov, Pavel, 2Y
 Nguyen, Duy Duc, 18
 Ninomiya, Taku, 15
 Nishihata, Takahiro, 1B
 Noifeld, E., 2S
 Nooitgedagt, Tjitte, 07
 Noot, Marc, 1G, 2M
 Novak, O., 2S
 Oberai, Assad A., 10
 Oh, Hangyeong, 2I
 Oh, Nang-Lyeom, 07
 Ohta, Hiroya, 15
 Orf, Bryan, 1P
 Osaki, Mayuka, 1B
 Osborne, Jason, 1L
 Ostrovsky, Alain, 1M
 Otten, Ronald, 1I
 Ouchi, Masanori, 2G
 Owen, David, 1I
 Pai, Shyh-Shii, 2I
 Paolillo, Sara, 1O
 Papagorgiou, Harria, 20
 Papavieros, George, 1F, 20, 2Z
 Park, Chan-Ha, 07, 13, 1E, 2F
 Park, Chris, 2L
 Park, DeNeil, 06, 28
 Park, Jongcheon, 13
 Park, Shin-Woong, 2L
 Pastol, Anne, 1H
 Pastur, S., 2S
 Patel, Dhruv, 10

Patterson, Oliver D., 1R
 Pereira, Cheryl, 0X
 Peters, J., 2E
 Petroni, Paolo, 1M
 Prentice, C., 1A
 Prokopov, Alexander, 2Y
 Pu, Lingling, 23, 2W
 Qin, Nan, 2N
 Ramanathan, Vidya, 06, 28
 Rangelow, Ivo W., 29
 Rathore, D., 2S
 Reay, Thomas, 2N
 Reche, Jérôme, 0U
 Ren, Alex, 2O
 Ren, Weiming, 1R
 Reum, Alexander, 29
 Reuter, Christoph, 29
 Riedesel, C., 31
 Rispens, Gijsbert, 0T
 Robinson, John C., 1E
 Roller, Justin, 24
 Rue, Chad, 0I
 Rutigliani, Vito, 0T, 20
 Sadeghian, Hamed, 0M
 Sah, Kaushik, 1V
 Saib, Mohamed, 0F, 1N, 1O
 Sakakibara, Makoto, 1D
 Sakimura, Shigetoshi, 12, 2G
 Saltoun, Lilach, 1E
 Salvador, Dave, 30
 Sato, Yoshishige, 0D
 Saville, Barry, 30
 Sawamura, Junpei, 08
 Schelcher, Guillaume, 0F
 Schiavone, Patrick, 18, 1M
 Schiffelers, Guido, 0T
 Schneider, Philipp-Immanuel, 1I
 Schwarzband, Ishai, 1L, 2S
 Schweikert, Emile A., 0O
 Sendelbach, Matthew, 0F
 Serwy, Roger, 2N
 Setoguchi, Katsumi, 14
 Shahrjerdy, Mir, 07
 Shiba, Yuji, 08
 Shibazaki, Yuichi, 08
 Shichi, Hiroyasu, 1Y
 Shimoda, Ryo, 0H
 Shimura, Satoru, 2N
 Shindo, Hiroyuki, 12, 2G
 Shinoda, Shinichi, 12, 2G
 Siew, Yong Kong, 0C, 1C
 Silver, Richard M., 0Z
 Sim, Hakyong, 13
 Simmons, Mark, 13
 Singh, Amandev, 1I
 Singh, Subodh, 1I
 Sinitsina, Vera, 1Z
 Skliarov, Vladimir, 2U, 2Y
 Soco, Aileen, 07
 Sohda, Yasunari, 15
 Sommer, E., 2S
 Son, Hyung-Sub, 2M
 Song, Sonyong, 08
 Stock, Hans-Jurgen, 1L
 Stollenwerk, Jochen, 1X
 Strauss, Michael, 0C, 1C, 1N, 24
 Su, Eason, 1G
 Sufrin, Yael, 2K
 Sun, Wei, 15
 Sungauer, Elodie, 0Y
 Suzuki, Makoto, 14, 1D
 Suzuki, Masaru, 05
 Suzuki, Yusaku, 1B
 Takahashi, Satoru, 0Q
 Takamasu, Kiyoshi, 0Q
 Tanaka, Maki, 1B
 Tanaka, Sayuri, 08
 Tanaka, Yusuke, 05
 Tang, P., 1A
 Tanimoto, Sayaka, 1Y
 Tel, W., 1A
 Thrun, Xavier, 1P
 Tien, D., 1A
 Tilson, Ashley, 24, 2V
 Tobayas, Matan, 1L
 Tolle, Ian, 30
 Tortai, Jean-Herve, 18
 Tottewitz, Steven, 2P, 2T
 Toyoda, Yasutaka, 12, 2G
 Trefonas, Peter, 0O
 Tsai, Li-Shiuan, 21
 Tseng, Sheng-Yang, 21
 Turovets, Igor, 0F, 1N
 Uchiyama, Takayuki, 0J
 Valade, Charles, 0Y
 Van den Heuvel, Dieter, 05, 1V
 van der Meijden, Vidar, 2M
 van Dijk, Leon, 1H, 1I
 van Es, Maarten H., 0M
 van Haren, Richard, 1H, 1I
 van Kessel, L., 0V
 van Leest, Arno, 07
 Van Roey, Frieda, 0P, 0T, 20
 Verkhoturov, Stanislav V., 0O
 Volfman, Alon Alexander, 28
 Volkovich, Roie, 1E
 Wang, Cathy, 1G
 Wang, F., 1A
 Wang, Fei, 1R
 Wang, Lei, 13
 Wang, Meng, 06, 28
 Wang, Teng, 23, 2W
 Wang, Y., 1A
 Wang, Zhigang, 14
 Warrick, Scott, 2C
 Wei, Yayi, 2X
 Weintraub, Jeffrey, 2C
 Willekers, R., 2E

Witvoet, G., 2E
Wong, Cheuk Wun, 06, 28
Woodworth, Gabriel, 1N
Wu, Chun-Sheng, 21
Xu, Buqing, 2X
Xu, Ming, 23
Yahiro, Takehisa, 08
Yamaguchi, Satoru, 14
Yamamoto, Takuma, 1B
Yamazaki, Yuichiro, 0D, 0H
Yang, Cheng Hao, 2T
Yang, Dongyue, 06, 28
Yaziv, Tal, 06, 28
Yen, Chi-Fu, 21
Yin, Weihua, 1R
Yohanan, Raviv, 28
Yong, Poh-Boon, 30
Yoo, Gyun, 13
You, Byeong Geon, 2L
Yu, Chun Chi, 2T
Yu, Xiaoya, 2A
Yumiba, Ryo, 12, 2G
Yun, Y. H., 27
Zagaris, Antonios, 1G
Zeidler, D., 31
Zhao, Nan, 23
Zhao, Qian, 13
Zhao, Yiqiong, 13
Zheng, Yunan, 13
Zhou, Hui, 0Z
Zhou, Wayne, 1E
Zhou, Weihu, 2A
Zhou, Wentian, 23
Zhou, Yue, 06, 28
Zou, Xiongfeng, 2X
Zschiedrich, Lin, 11

Conference Committee

Symposium Chair

Will Conley, Cymer, an ASML Company (United States)

Symposium Co-chair

Kafai Lai, IBM Thomas J. Watson Research Center (United States)

Conference Chair

Vladimir A. Ukraintsev, Qorvo Corporation (United States)

Conference Co-chair

Ofer Adan, Applied Materials Israel, Ltd. (Israel)

Conference Program Committee

John A. Allgair, BRIDG (United States)

Masafumi Asano, Tokyo Electron Ltd. (Japan)

Benjamin D. Bunday, Abeam Technologies, Inc. (United States)

Jason P. Cain, Advanced Micro Devices, Inc. (United States)

Xiaomeng Chen, Taiwan Semiconductor Manufacturing
Company Ltd. (Taiwan)

Hugo Cramer, ASML Netherlands B.V. (Netherlands)

Timothy F. Crimmins, Intel Corporation (United States)

Shunsuke Koshihara, Hitachi High-Technologies Corporation (Japan)

Yi-Sha Ku, Industrial Technology Research Institute (Taiwan)

Byoung-Ho Lee, SK hynix, Inc. (Korea, Republic of)

Philippe Leray, IMEC (Belgium)

Narender Rana, Western Digital Corporation (United States)

Christopher J. Raymond, Nanometrics Inc. (United States)

John C. Robinson, KLA Corporation (United States)

Martha I. Sanchez, IBM Research - Almaden (United States)

Matthew J. Sendelbach, Nova Measuring Instruments Inc.
(United States)

Richard Silver, National Institute of Standards and Technology
(United States)

Eric Solecky, GLOBALFOUNDRIES Inc. (United States)

Alexander Starikov, I&I Consulting (United States)

Alok Vaid, GLOBALFOUNDRIES Inc. (United States)

Session Chairs

- 1 Keynote Session
Martha I. Sanchez, IBM Research - Almaden (United States)
Ofer Adan, Applied Materials Israel, Ltd. (Israel)
- 2 Overlay News
Alexander Starikov, I&I Consulting (United States)
Christopher J. Raymond, Nanometrics Inc. (United States)
- 3 Challenges and New Methods
Shunsuke Koshihara, Hitachi High-Technologies Corporation (Japan)
Christopher J. Raymond, Nanometrics Inc. (United States)
- 4 Inspection I
Timothy F. Crimmins, Intel Corporation (United States)
Byoung-Ho Lee, SK Hynix, Inc. (Korea, Republic of)
- 5 Advances in Physical Characterization
Richard M. Silver, National Institute of Standards and Technology
(United States)
Hugo Cramer, ASML Netherlands B.V. (Netherlands)
- 6 LWR
John C. Robinson, KLA Corporation (United States)
Matthew J. Sendelbach, Nova Measuring Instruments Inc.
(United States)
- 7 New Methods: Student Session
Timothy F. Crimmins, Intel Corporation (United States)
Matthew J. Sendelbach, Nova Measuring Instruments Inc.
(United States)
- 8 Machine Learning
Masafumi Asano, Tokyo Electron Ltd. (Japan)
Benjamin D. Bunday, Abeam Technologies, Inc. (United States)
- 9 SEM
Benjamin D. Bunday, Abeam Technologies, Inc. (United States)
Shunsuke Koshihara, Hitachi High-Technologies Corporation (Japan)
- 10 SEM and e-Beam Metrology
Christopher J. Raymond, Nanometrics Inc. (United States)
Philippe Leray, IMEC (Belgium)

- 11 Overlay
Hugo Cramer, ASML Netherlands B.V. (Netherlands)
John C. Robinson, KLA Corporation (United States)

- 12 Design Interactions with Metrology: Joint Session with Conferences
10959 and 10962
John A. Allgair, BRIDG (United States)
Ryoung-Han R. Kim, IMEC (Belgium)

- 13 Process Control
Philippe Leray, IMEC (Belgium)
Alexander Starikov, I&I Consulting (United States)

- 14 Inspection II
Masafumi Asano, Tokyo Electron Ltd. (Japan)
Xiaomeng Chen, Taiwan Semiconductor Manufacturing
Company Ltd. (Taiwan)

- 15 Optical Metrology and Late News
Ofer Adan, Applied Materials Israel, Ltd. (Israel)
John C. Robinson, KLA Corporation (United States)

Introduction

The Metrology, Inspection, and Process Control for Microlithography XXXIII conference started with metrology challenges of state of the art silicon based quantum devices. While quantum devices are all about entanglement, quantum was not the only entanglement in the conference. Edge Placement Error (EPE) metrology approaches were presented to address the entanglement between metrology and inspection, and within metrology the entanglement of CD uniformity, roughness, 3D, pattern placement, and overlay errors. Various approaches were presented; from an all in one solution to a heterogeneous fleets of different perspectives of metrology and inspection to novel technologies, fused by artificial intelligence. Artificial intelligence was also studied from the metrological challenges raised by the new devices enabling it. CPU's, GPU's, and TPU's and future solutions all reviewed in invited tutorials you can read about in these Proceedings. As technology nodes shrink and structures become more complex, many novel technologies were introduced, and workhorse ones were improved.

Hopefully these Proceedings become a reference and foundation for future work. This comes with a bigger hope that the readers come back, and submit a paper telling others of novel achievements, and sharing interesting results of scientific merit to keep fueling the conference audience interest.

Dear readers,

Looking forward to seeing your submissions, presented next year on the podium, or interacting with the audience next to your poster.

Thank you.

**Vladimir A. Ukraintsev
Ofer Adan**

