

# PROCEEDINGS OF SPIE

## ***Modeling Aspects in Optical Metrology V***

**Bernd Bodermann**

**Karsten Frenner**

**Richard M. Silver**

*Editors*

**23–25 June 2015**

**Munich, Germany**

*Sponsored by*

SPIE

*Cooperating Organisations*

European Optical Society

German Scientific Laser Society (Wissenschaftliche Gesellschaft  
Lasertechnik e.V.)

*Published by*

SPIE

**Volume 9526**

Proceedings of SPIE 0277-786X, V. 9526

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

Modeling Aspects in Optical Metrology V, edited by Bernd Bodermann, Karsten Frenner, Richard M. Silver,  
Proc. of SPIE Vol. 9526, 952601 · © 2015 SPIE · CCC code: 0277-786X/15/\$18 · doi: 10.1117/12.2197968

The papers included 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. The papers published in these proceedings 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 this book:

Author(s), "Title of Paper," in *Modeling Aspects in Optical Metrology V*, edited by Bernd Bodermann, Karsten Frenner, Richard M. Silver, Proceedings of SPIE Vol. 9526 (SPIE, Bellingham, WA, 2015) Article CID Number.

ISSN: 0277-786X  
ISBN: 9781628416862

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 © 2015, 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](http://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/15/\$18.00.

Printed in the United States of America.

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



[SPIEDigitalLibrary.org](http://SPIEDigitalLibrary.org)

---

**Paper Numbering:** Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print. Papers are published as they are submitted and meet publication criteria. A unique citation identifier (CID) number is assigned to each article at the time of the first 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, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four 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. The complete citation is used on the first page, and an abbreviated version on subsequent pages.

# Contents

vii	Authors
ix	Conference Committee

---

## SESSION 1 SCATTEROMETRY I

---

- 9526 05 **Enlarging applicability domain of the C method with piecewise linear parameterization: gratings of deep and smooth profiles (Invited Paper)** [9526-1]
- 9526 06 **Specialized scatterometry methods for two types of gratings with distinct groove profiles** [9526-2]
- 9526 07 **Spatial mode projection for side-wall angle measurements** [9526-3]

---

## SESSION 2 INTERFEROMETRY AND PHASE I

---

- 9526 08 **Phase error analysis and compensation in fringe projection profilometry (Invited Paper)** [9526-4]
- 9526 09 **Signal simulation method for homodyne multiple target interferometers using short coherence length laser sources** [9526-8]
- 9526 0A **Metrological characterization of a large aperture Fizeau for x-ray mirrors measurement** [9526-7]
- 9526 0C **A way for measuring the relationship between DM surface and wave-front aberrations in a beam rotate-90° laser system** [9526-9]

---

## SESSION 3 RADIOMETRY AND PHOTOMETRY

---

- 9526 0D **Optical detectors based on thermoelastic effect in crystalline quartz (Invited Paper)** [9526-10]
- 9526 0F **Numerical modeling and uncertainty analysis of light emitting diodes for photometric measurements** [9526-11]

---

## SESSION 4 OPTICAL SYSTEMS

---

- 9526 0G **Horizontal geometrical reaction time model for two-beam nacelle LiDARs** [9526-14]
- 9526 0H **Investigation vignetting beams in optoelectronic autocollimation angle measurement system** [9526-15]

- 9526 0I **Transferring the Rb+ hyperfine-structure stability to a Fabry-Perot resonator used as a frequency standard for astronomical spectrographs** [9526-19]
- 9526 0K **Wide-aperture laser beam measurement using transmission diffuser: errors modeling** [9526-18]
- 9526 0L **Application of the ARMA model in distributed fiber vibration sensing system** [9526-16]

---

**SESSION 5 STOCHASTIC SCATTERING AND NANOPARTICLES**

---

- 9526 0M **Simulating the coherent light propagation in a random scattering materials using the perturbation expansion (Invited Paper)** [9526-20]
- 9526 0N **The optical properties of tropospheric soot aggregates determined with the DDA (Discrete Dipole Approximation) method** [9526-21]
- 9526 0O **Detection of fast flying nanoparticles by light scattering over a large volume** [9526-23]
- 9526 0P **Nonspherical nanoparticles characterization by partially depolarized dynamic light scattering** [9526-22]

---

**SESSION 6 OPTICAL MATERIAL PARAMETERS AND THIN FILMS**

---

- 9526 0Q **Nondestructive measurement of two-dimensional refractive index profiles by deflectometry (Invited Paper)** [9526-24]
- 9526 0R **Problems in thin film thickness measurement resolved: improvements of the fast Fourier transform analysis and consideration of the numerical aperture of microscope headers and collimators** [9526-25]

---

**SESSION 7 SCATTEROMETRY II**

---

- 9526 0S **Methods for optical modeling and cross-checking in ellipsometry and scatterometry (Invited Paper)** [9526-27]
- 9526 0U **The statistical inverse problem of scatterometry: Bayesian inference and the effect of different priors** [9526-29]
- 9526 0V **The effect of systematic errors on the hybridization of optical critical dimension measurements** [9526-30]

---

**SESSION 8 MICROSCOPY AND IMAGING**

---

- 9526 0W **Simulation of light in-coupling through an aperture probe to investigate light propagation in a thin layer for opto-electronic application** [9526-33]

- 9526 0X **Effect of wavefront aberrations on a focused plenoptic imaging system: a wave optics simulation approach** [9526-34]
- 9526 0Y **Total variation iterative constraint algorithm for limited-angle tomographic reconstruction of non-piecewise-constant structures** [9526-35]
- 9526 0Z **A cascaded plasmonic superlens for near field imaging with magnification** [9526-36]

---

**SESSION 9 INTERFEROMETRY AND PHASE II**

---

- 9526 10 **Calibration of the amplification coefficient in interference microscopy by means of a wavelength standard (Invited Paper)** [9526-37]
- 9526 11 **In-line digital holography with double knife edge** [9526-38]
- 9526 12 **Fourier analysis of quadratic phase interferograms** [9526-39]
- 9526 13 **Phase retrieval based on diffraction element array with single far field** [9526-40]
- 9526 14 **Dynamic stitching interferometric testing for large optical plane** [9526-41]

---

**SESSION 10 MUELLER POLARIMETRY**

---

- 9526 16 **Snapshot polarimeter based on the conical refraction phenomenon** [9526-46]
- 9526 17 **Measurement errors induced by axis tilt of biplates in dual-rotating compensator Mueller matrix ellipsometers** [9526-43]
- 9526 19 **Correction of depolarization effect in Mueller matrix ellipsometry with polar decomposition method** [9526-45]
- 9526 1A **Parallel aligned liquid crystal on silicon display based optical set-up for the generation of polarization spatial distributions** [9526-47]

---

**POSTER SESSION**

---

- 9526 1B **A novel autocollimating method for measuring the focal distances** [9526-48]
- 9526 1C **Modelling of microcracks image treated with fluorescent dye** [9526-49]
- 9526 1D **High-angle light scattering to determine the optical fiber core** [9526-51]
- 9526 1E **Research of the use of autoreflection scheme to measure the error of the optical elements in space telescope's relative position** [9526-52]
- 9526 1F **Modeling and analysis of the solar concentrator in photovoltaic systems** [9526-53]

- 9526 1G **In situ estimate of duty cycle of surface-relief holographic gratings during development by measuring TM/TE diffraction efficiency ratio** [9526-54]
- 9526 1H **Investigation of a mathematical model of the system of electro-optical sensors for monitoring nonlinear surfaces** [9526-55]
- 9526 1I **Using quaternions to control assembly and adjustment mirror-prism optical systems** [9526-56]
- 9526 1L **Maximum power point search method for photovoltaic panels which uses a light sensor in the conditions of real shading and temperature** [9526-59]
- 9526 1M **The study of the structural stability of the spiral laser beams propagation through inhomogeneous phase medium** [9526-60]
- 9526 1N **Simulation and analysis of lightweight space mirror design** [9526-62]
- 9526 1O **Propagation invariant laser beams for optical metrology applications** [9526-63]
- 9526 1Q **Determination of refractive index by Moiré deflectometry** [9526-26]

# 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.

Abbas, Mohammed, 0F	Juhasz, G., 0S
Abdula, Polina A., 1N	Kalkanjiiev, Todor K., 16
Agocs, E., 0S	Khan, Mohammed Z. U., 0F
Ahmadi, Mohammad, 1Q	Konyakhin, Igor A., 0H, 1E, 1H
Al-Hadhrami, Luai M., 0F	Kozma, P., 0S
Ao, Ming-Wu, 0C, 13	Kraszewski, Maciej, 0M
Bär, Markus, 0U	Krauze, W., 0Y
Barnes, Bryan M., 0V	Kühmstedt, Peter, 08
Bäumer, S., 0O	Kujawińska, M., 0Y
Beuth, Thorsten, 09, 0G	Kumar, N., 0S
Beverage, Jake, 10	Lashmanov, Oleg U., 1C
Bittkau, Karsten, 0W	Leger, James R., 0Q
Bodermann, Bernd, 0S, 0U	Lehnen, Stephan, 0W
Bräuer-Burchardt, Christian, 08	Levin, Alexander D., 0P
Campos, Juan, 11, 16, 1A	Li, Lifeng, 05, 1G
Cao, Zhao, 0W	Li, Weiqi, 17, 19
Carius, Reinhard, 0W	Lin, Di, 0Q
Casillas-Rodríguez, Francisco J., 12	Liu, Shiyuan, 17, 19
Chelbanov, V. P., 0D	Lizana, Angel, 16, 1A
Chen, Xiuguo, 17, 19	Lohner, T., 0S
Cisotto, L., 07	Madanipour, Khosro, 1Q
de Groot, Peter, 10	Major, C., 0S
Deutz, A., 0O	Makowski, P., 0Y
Dong, Lizhi, 0C, 13	Márquez, Andrés, 1A
Endres, J., 0S	Marshall, Richard J., 0X
Ermes, Markus, 0W	Martínez, Jose Luis, 1A
Ershov, Alexandr G., 1B	Matsak, Ivan S., 0K
Estévez, Irene, 16, 1A	Meah, Chris J., 0X
Ezhova, Kseniia, 1E, 1I	Molev, Fedor, 1E
Fodor, B., 0S	Mompert, Jordi, 16
Fox, Maik, 09, 0G	Mora-González, Miguel, 12
Freijo Martín, Idoia, 0A	Moreno, Ignacio, 1A
Frenner, Karsten, 0Z	Mroczka, Janusz, 1F, 1L
Fried, M., 0S	Muñoz-Maciel, Jesús, 12
Fries, T., 0R	Muzychenko, Yana B, 1M
Fu, Liwei, 0Z	Nador, J., 0S
Glebov, Victor, 1C	Neutov, Mikhail Y., 1N
Gross, Hermann, 0U	Notni, Gunther, 08
Grupetta, Stephen, 0X	Osten, Wolfgang, 0Z
Gu, Honggang, 17, 19	Ostrowski, Mariusz, 1L
Heidenreich, Sebastian, 0U	Peinado, Alba, 16, 1A
Henn, Mark-Alexander, 0V	Peña-Lecona, Francisco G., 12
Holzhüter, Hanno, 0I	Peng, HeKuo, 0L
Houta, F., 0R	Pereira, S. F., 07, 0S
Huke, Philipp, 0I	Petrik, P., 0S
Iemmi, Claudio, 11, 16	Petrochenko, Andrew V., 1H
Ishanin, G. G., 0D	Pettazzi, F., 0O
Javadianvarjovi, Soheila, 1Q	Plachta, Kamil, 1F
Jiang, Hao, 17, 19	Pluciński, Jerzy, 0M

Qi, Te, 14  
Quinten, M., 0R  
Ramirez, Claudio, 11, 1A  
Reiners, Ansgar, 0I  
Sakhariyanova, Aigany M., 0H  
Schau, Philipp, 0Z  
Shen, Biyao, 1G  
Shmyt'kova, Ekaterina A., 0P  
Silver, Richard M., 0V  
Skorupski, Krzysztof, 0N  
Smekhov, Andrey, 0H  
Soskind, M., 1O  
Soskind, Y. G., 1O  
Stork, Wilhelm, 09, 0G  
Strąkowski, Marcin R., 0M  
Streck, Andreas, 09  
Styles, Iain B., 0X  
Świrniak, Grzegorz, 1D  
Tan, Yi, 0C  
Tolstoba, Nadezhda D., 1N  
Trojanowski, Michał, 0M  
Turola, Massimo, 0X  
Turpin, Alex, 16  
Urbach, H. P., 07, 0S  
van der Donck, J., 0O  
Vannoni, Maurizio, 0A  
Wang, Shuai, 0C, 13  
Wu, Hongyan, 0L  
Wu, Xin, 14  
Wurm, Matthias, 0U  
Xu, Bing, 13  
Xu, Haiyan, 0L  
Xu, Xihong, 05  
Yang, Lin, 06  
Yang, Ping, 0C, 13  
Yu, Yingjie, 14  
Zeng, Lijiang, 1G  
Zhang, Chuanwei, 17, 19  
Zhang, Linna, 14  
Zhang, Nien Fan, 0V  
Zheng, Xuejie, 1A  
Zhou, Hui, 0V  
Zhu, Yan, 07  
Zinchik, Alexander A., 1M  
Zverev, Victor, 1I

# Conference Committee

## Symposium Chairs

**Wolfgang Osten**, Institut für Technische Optik (Germany)  
**Gunther Notni**, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)  
**Andrew John Moore**, Heriot-Watt University (United Kingdom)

## Conference Chair

**Bernd Bodermann**, Physikalisch-Technische Bundesanstalt (Germany)

## Conference Co-chairs

**Karsten Frenner**, Institut für Technische Optik (Germany)  
**Richard M. Silver**, National Institute of Standards and Technology (United States)

## Conference Programme Committee

**Markus Bär**, Physikalisch-Technische Bundesanstalt (Germany)  
**Jörg Bischoff**, Osires Optical Engineering (Germany)  
**Harald Bosse**, Physikalisch-Technische Bundesanstalt (Germany)  
**Sven Burger**, Konrad-Zuse-Zentrum für Informationstechnik (Germany)  
**Peter Evanschitzky**, Fraunhofer-Institut für Integrierte Systeme und Bauelementetechnologie IISB (Germany)  
**Christian Hafner**, ETH Zürich (Switzerland)  
**Wolfgang Holzapfel**, DR. JOHANNES HEIDENHAIN GmbH (Germany)  
**Bernd H. Kleemann**, Carl Zeiss AG (Germany)  
**Wolfgang Osten**, Institut für Technische Optik (Germany)  
**Andreas Rathsfeld**, Weierstrass-Institut für Angewandte Analysis und Stochastik (Germany)  
**Thomas Scherübl**, Carl Zeiss SMS GmbH (Germany)  
**Patrick Schiavone**, Aselta Nanographics (France)  
**Irwan D. Setija**, ASML Netherlands B.V. (Netherlands)  
**Michael Totzeck**, Carl Zeiss AG (Germany)  
**Jari Turunen**, University of Eastern Finland (Finland)  
**Frank Wyrowski**, Friedrich-Schiller-Universität Jena (Germany)

## Session Chairs

- 1 Scatterometry I  
**Sven Burger**, JCMwave GmbH (Germany)

- 2 Interferometry and Phase I  
**Bernd Bodermann**, Physikalisch-Technische Bundesanstalt (Germany)  
**Christof Pruss**, Institut für Technische Optik (Germany)
- 3 Radiometry and Photometry  
**Liwei Fu**, Universität Stuttgart (Germany)
- 4 Optical Systems  
**Wolfgang Holzapfel**, DR. JOHANNES HEIDENHAIN GmbH (Germany)
- 5 Stochastic Scattering and Nanoparticles  
**Egbert Buhr**, Physikalisch-Technische Bundesanstalt (Germany)
- 6 Optical Material Parameters and Thin Films  
**Michael Schulz**, Physikalisch-Technische Bundesanstalt (Germany)
- 7 Scatterometry II  
**Bernd Bodermann**, Physikalisch-Technische Bundesanstalt (Germany)
- 8 Microscopy and Imaging  
**Karsten Frenner**, Institut für Technische Optik (Germany)
- 9 Interferometry and Phase II  
**Wolfgang Osten**, Institut für Technische Optik (Germany)
- 10 Mueller Polarimetry  
**Peter Petrik**, Research Institute for Technical Physics and Materials Science (Hungary)