

PROCEEDINGS OF SPIE

Smart Structures and NDE for Energy Systems and Industry 4.0

Norbert G. Meyendorf
Kerrie Gath
Christopher Niezrecki
Editors

4–5 March 2019
Denver, Colorado, United States

Sponsored by
SPIE

Cosponsored by
OZ Optics, Ltd. (United States)
Polytec, Inc. (United States)

Cooperating Organizations
Jet Propulsion Laboratory (United States)
Colorado Photonics Industry Association (United States)

Published by
SPIE

Volume 10973

Proceedings of SPIE 0277-786X, V. 10973

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

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 SPIEDigitalLibrary.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 *Smart Structures and NDE for Energy Systems and Industry 4.0*, edited by Norbert G. Meyendorf, Kerrie Gath, Christopher Niezrecki, Proceedings of SPIE Vol. 10973 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

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

ISBN: 9781510626010
ISBN: 9781510626027 (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**
SPIEDigitalLibrary.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.

Conference Committee

Symposium Chairs

Tribikram Kundu, The University of Arizona (United States)
Gregory W. Reich, Air Force Research Laboratory (United States)

Symposium Co-chairs

Zoubeida Ounaies, The Pennsylvania State University (United States)
Hoon Sohn, KAIST (Korea, Republic of)

Conference Chair

Norbert G. Meyendorf, Iowa State University of Science and
Technology (United States)

Conference Co-chairs

Kerrie Gath, Ford Motor Company (United States)
Christopher Niezrecki, University of Massachusetts Lowell
(United States)

Conference Program Committee

Ali Abdul-Aziz, NASA Glenn Research Center (United States)
Steven R. Anton, Tennessee Technological University (United States)
Nicolas P. Avdelidis, Université Laval (Canada)
George Y. Baaklini, NASA Glenn Research Center (United States)
Leonard J. Bond, Iowa State University of Science and Technology
(United States)
Diann E. Brei, University of Michigan (United States)
Peter C. Chen, NASA Goddard Space Flight Center (United States)
Michael Dalichow, Quality Network Inc. (United States)
Marcelo Dapino, The Ohio State University (United States)
Dimitrios A. Exarchos, University of Ioannina (Greece)
Kevin M. Farinholt, Luna Innovations Inc. (United States)
Xiao-Yan Gong, Medical Implant Mechanics LLC (United States)
Steven F. Griffin, The Boeing Company (United States)
Peter Heilmann, arxes-tolina GmbH (Germany)
Manfred Johannes, South African Institute for Non-Destructive Testing
(South Africa)
Nancy L. Johnson, General Motors Company (United States)
Vassilios Kappatos, University of Southern Denmark (Denmark)

Michael Kroening, Pontifícia Universidade Católica do Rio de Janeiro (Brazil)

Jayanth N. Kudva, NextGen Aeronautics, Inc. (United States)

Amrita Kumar, Acellent Technologies, Inc. (United States)

Jay Lee, University of Cincinnati (United States)

Jung-Ryul Lee, KAIST (Korea, Republic of)

Donald J. Leo, The University of Georgia (United States)

Zheng Liu, The University of British Columbia Okanagan (Canada)

Theodore E. Matikas, University of Ioannina (Greece)

Geoffrey P. McKnight, HRL Laboratories, LLC (United States)

Tobias Melz, Fraunhofer-Institut für Betriebsfestigkeit und Systemzuverlässigkeit (Germany)

Michele Meo, University of Bath (United Kingdom)

Alexander Michaelis, Fraunhofer Institut für Keramische Technologien und Systeme IKTS (Germany)

Bernd Michel, Fraunhofer-Institut für Elektronische Nanosysteme (Germany)

Christopher Niezrecki, University of Massachusetts Lowell (United States)

Piotr Omenzetter, University of Aberdeen (United Kingdom)

Gyuhae Park, Chonnam National University (Korea, Republic of)

Kara J. Peters, North Carolina State University (United States)

W. Lance Richards, Armstrong Flight Research Center (United States)

Janet M. Sater, Institute for Defense Analyses (United States)

Stefano Starra, Università degli Studi dell'Aquila (Italy)

Tadeusz Stepinski, AGH University of Science and Technology (Poland)

Mark R. Woike, NASA Glenn Research Center (United States)

H. Felix Wu, U.S. Department of Energy (United States)

Dong-Jin Yoon, Korea Research Institute of Standards and Science (Korea, Republic of)

Lingyu Yu, University of South Carolina (United States)

Christian Wunderlich, Fraunhofer Institut für Keramische Technologien und Systeme IKTS (Germany)

Edward V. White, The Boeing Company (United States)

Session Chairs

- 1 Keynote Session I
Kerrie Gath, Ford Motor Company (United States)
- 2 The Internet of Things
Kerrie Gath, Ford Motor Company (United States)
- 3 New Applications for Smart Structures and Materials for Industry 4.0
Norbert G. Meyendorf, Iowa State University of Science and Technology (United States)

- 4 Industrial and Commercial Application of Smart Structures and Materials
Norbert G. Meyendorf, Iowa State University of Science and Technology (United States)
- 5 Keynote Session II
Norbert G. Meyendorf, Iowa State University of Science and Technology (United States)
- 6 Big Data, Data Management, Dataprocessing, and Datafusion I
Uchenna Anyaoha, The University of British Columbia Okanagan (Canada)
Norbert G. Meyendorf, Iowa State University of Science and Technology (United States)
- 7 Big Data, Data Management, Dataprocessing, and Datafusion II
Uchenna Anyaoha, The University of British Columbia Okanagan (Canada)
Norbert G. Meyendorf, Iowa State University of Science and Technology (United States)
- 8 NDE and SHM for Energy Systems
Christopher Niezrecki, University of Massachusetts Lowell (United States)
- 9 Sensors, Actuators, and Monitoring for Energy Systems
Christopher Niezrecki, University of Massachusetts Lowell (United States)