# Material Technologies and Applications to Optics, Structures, Components, and Sub-Systems II

Matthias Krödel Joseph L. Robichaud William A. Goodman Editors

10–13 August 2015 San Diego, California, United States

Sponsored and Published by SPIE

Volume 9574

Proceedings of SPIE 0277-786X, V. 9574

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

Material Technologies and Applications to Optics, Structures, Components, and Sub-Systems II, edited by Matthias Krödel, Joseph L. Robichaud, William A. Goodman, Proc. of SPIE Vol. 9574, 957401 © 2015 SPIE · CCC code: 0277-786X/15/\$18 · doi: 10.1117/12.2208520

Proc. of SPIE Vol. 9574 957401-1

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 Material Technologies and Applications to Optics, Structures, Components, and Sub-Systems II, edited by Matthias Krödel, Joseph L. Robichaud, William A. Goodman, Proceedings of SPIE Vol. 9574 (SPIE, Bellingham, WA, 2015) Article CID Number.

ISSN: 0277-786X ISBN: 9781628417401

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. 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

**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

- v Authors
- vii Conference Committee
- ix Introduction

### SESSION 1 METAL MATERIALS I

9574 02	Design and manufacturing considerations for 0.25-1.5 meter beryllium telescopes for current and future space missions [9574-1]
9574 03	New decade of shaped beryllium blanks [9574-2]
9574 04	Design and manufacturing considerations for high-performance gimbals used for land, sea, air, and space [9574-3]
9574 05	Fabrication of stable lightweight Be-38AI optics and optical support structures [9574-4]
9574 06	Application and testing of additive manufacturing for mirrors and precision structures [9574-5]
SESSION 2	METAL MATERIALS II
9574 07	Structured surfaces on metal optics [9574-6]
9574 08	Physical and mechanical properties of LoVAR: a new lightweight particle-reinforced Fe-36Ni alloy [9574-7]
9574 09	Advanced thermal control for spacecraft applications [9574-8]
SESSION 3	CERAMIC MATERIALS I
9574 OC	Low-stress silicon cladding made by pulsed-ion-assisted evaporation [9574-11]
SESSION 4	CERAMIC MATERIALS II
9574 OD	Trade study of all-SiC lightweight primary mirror and metering structures for spaceborne telescope (Invited Paper) [9574-12]
9574 OE	T300HoneySiC: a new near-zero CTE molded C/SiC material [9574-13]

9574 OF	Recent development of fabrication of extreme light-weighted ceramic mirrors [9574-14]
9574 OG	Extreme stable and complex structures for opto-mechanical applications [9574-15]
SESSION 5	GLASS MATERIALS
9574 OI	Homogeneity of material and optical properties in HEM grown sapphire [9574-17]
9574 OJ	Strength of Zerodur <sup>®</sup> for mirror applications [9574-18]
9574 OK	Low temperature GRISM direct bonding [9574-19]
9574 OL	Polymers with customizable optical and rheological properties based on an epoxy acrylate based host-guest system [9574-20]
9574 OM	Low-strain laser-based solder joining of mounted lenses [9574-21]
SESSION 6	INNOVATIVE METROLOGY CONCEPTS
9574 ON	State-of-the-art cryogenic CTE measurements of ultra-low thermal expansion materials (Invited Paper) [9574-22]
9574 00	Next generation dilatometer for highest accuracy thermal expansion measurement of ZERODUR® [9574-23]
	POSTER SESSION
9574 OS	Focus tunable device actuator based on ionic polymer metal composite [9574-27]

## 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.

Acreman, Martyn, 06 Ait-Zaid, Sonia, OJ Bae, Jong-In, OD Beckert, Erik, OM Béhar-Lafenêtre, S., OJ Benkenstein, Tino, OK Burkhardt, Diana, OM Burkhardt, Thomas, OM Calvert, Jeff, 02 Campbell, Jeffrey, 03 Clune, Jason, 08 Cornillon, Laurence, 0J Eberhardt, Ramona, 07, 0M Ehrhardt, Sascha, OK Engel, Axel, 00 Fischer, Peter, 00 Gebhardt, Andreas, 07 Ghasemi Nejhad, Mehrdad N., 0E Gleißner, U., OL Goodman, William A., 0E Grabowski, Kevin, OK Hanemann, T., OL Hardesty, Robert, 05, 09 Harnisch, Gerd, OK Hartung, Johannes, 07 Hashiguchi, Don H., 03 Heberling, Jody, 03 Hibbard, D., Ol Ho, Joseph, 02 Hobmaier, J., OL Hornaff, Marcel, 0M Jedamzik, Ralf, 00 Kalkowski, Gerhard, OK Kamm, Andreas, 0M Kinast, Jan, 07 Krödel, Matthias, OF, OG Kunisch, Clemens, 00 Lee, Haeng-Bok, OD Michel, Robert, 08 Middelmann, Thomas, ON Morales, Amanda, 03 Myatt, Ray, 04, 06 Parker, Kelsey, 05, 09 Redd, Lafe, 04 Risse, Stefan, 07, OK Rogers, Brady, 02 Ruzan, Jeff, 02 Sayer, Aaron, 03 Schmidt, Erik, OM

Schödel, René, ON Sellers, Del, 04 Sheikh, David A., 0C Soose, Claus Peter, OF Stahr, Frank, OF Steinkopf, Ralf, 07 Stephenson, Timothy, 08 Stout, M., OI Su, Guo-Dung J., OS Suk, Jin-Young, OD Sweeney, Michael, 02, 04, 06 Tarrant, Andrew, 08 Thompson, Mike, 06 Tricker, David, 08 Tünnermann, Andreas, OM Uchida, Dave, 04 Vettese, Tom, 02, 04, 06 Wächter, Daniel, OF Walkov, Alexander, ON Warren, Mark, 02 Welson, Darren, OE Westenberger, Gerhard, 00 Westerhoff, Thomas, 00 Wright, Stan, OE Zauner, Christoph, 0G Zeitner, Uwe, OK Zhang, Yi-Wei, OS

## **Conference Committee**

Program Track Chair

H. Philip Stahl, NASA Marshall Space Flight Center (United States)

#### **Conference** Chairs

Matthias Krödel, ECM GmbH (Germany) Joseph L. Robichaud, L-3 Communications SSG (United States) William A. Goodman, Trex Enterprises Corporation (United States)

#### Conference Program Committee

Shyam S. Bayya, U.S. Naval Research Laboratory (United States) **A. Marcel Bluth**, ATK Aerospace Structures (United States) Nathan Carlie, SCHOTT North America, Inc. (United States) Vince M. Cowan, Air Force Research Laboratory (United States) Hans-Peter Dumm, Air Force Research Laboratory (United States) Richard A. Haber, Rutgers, The State University of New Jersey (United States) Haeng Bok Lee, Agency for Defense Development (Korea, Republic of) **Robert Michel**, Materion Brush Beryllium & Composites (United States) **Ted Mooney**, Harris Corporation (United States) Takao Nakagawa, Japan Aerospace Exploration Agency (Japan) Tsuyoshi Ozaki, Composites Research and Development Company, Ltd. (Japan) John W. Pepi, L-3 Communications SSG-Tinsley (United States) Margie F. Pinnell, University of Dayton (United States) Stefan Risse, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany) Michael N. Sweeney, General Dynamics-Global Imaging Technologies (United States) David B. Witkin, The Aerospace Corporation (United States)

#### Session Chairs

- 1 Metal Materials I **Robert Michel**, Materion Brush Beryllium & Composites (United States)
- 2 Metal Materials II **Robert Michel**, Materion Brush Beryllium & Composites (United States)

- 3 Ceramic Materials I Joseph L. Robichaud, L-3 Communications SSG (United States)
- 4 Ceramic Materials II William A. Goodman, Trex Enterprises Corporation (United States)
- 5 Glass Materials **Ted Mooney**, Harris Corporation (United States)
- 6 Innovative Metrology Concepts
  Matthias Krödel, ECM Engineered Ceramic Materials GmbH (Germany)

## Introduction

This is the second volume of the Material Technologies and Application to Optics, Structures, Components and Subsystems. These proceedings have expanded upon our legacy volumes on Optical Materials and Structures to include other topics related to subsystems, components, and assemblies made of different materials like metals, ceramics, and glass. In addition, we have also added a session on high accuracy material testing.

In this volume you will find interesting contributions of different material technologies:

- Metal materials like Be, AlBe
- Ceramic Materials like SiC, HB-Cesic, and T300HoneySic
- Low-expansion ceramics and glasses like Zerodur
- Gradient index refractive materials

In addition to the material papers, you will also find information about a broad band of applications already implemented in current programs or R&D projects.

We have done our best to collect papers about novel technologies and applications from an international community. We hope that you will find this volume exciting and educational.

> Matthias Krödel Joseph L. Robichaud William A. Goodman