

PROCEEDINGS OF SPIE

# ***Fiber Optic Sensors and Applications X***

**Eric Udd  
Gary Pickrell  
Henry H. Du  
Jerry J. Benterou  
Xudong Fan  
Alexis Mendez  
Stephen J. Mihailov  
Anbo Wang  
Hai Xiao**  
*Editors*

**2–3 May 2013  
Baltimore, Maryland, United States**

*Sponsored and Published by*  
SPIE

**Volume 8722**

Proceedings of SPIE 0277-786X, V. 8722

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

Fiber Optic Sensors and Applications X, edited by Eric Udd, Gary Pickrell, Henry H. Du, Jerry J. Benterou, Xudong Fan, Alexis Mendez, Stephen J. Mihailov, Anbo Wang, Hai Xiao, Proc. of SPIE Vol. 8722, 872201  
© 2013 SPIE · CCC code: 0277-786X/13/\$18 · doi: 10.1117/12.2031903

Proc. of SPIE Vol. 8722 872201-1

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 *Fiber Optic Sensors and Applications X*, edited by Eric Udd, Gary Pickrell, Henry H. Du, Jerry J. Benterou, Xudong Fan, Alexis Mendez, Stephen J. Mihailov, Anbo Wang, Hai Xiao, Proceedings of SPIE Vol. 8722 (SPIE, Bellingham, WA, 2013) Article CID Number.

ISSN: 0277-786X  
ISBN: 9780819495136

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 © 2013, 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/13/\$18.00.

Printed in the United States of America.

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

**SPIE**   
Digital Library

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

---

**Paper Numbering:** Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent 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. Numbers in the index correspond to the last two digits of the six-digit CID Number.

# Contents

vii	<i>Conference Committee</i>
ix	<i>Introduction</i>

---

## FIBER BRAGG GRATING SENSORS I

---

- 8722 02 **A personal review of 25 years of fiber grating sensor development (Invited Paper)** [8722-1]  
E. Udd, Columbia Gorge Research (United States)
- 8722 04 **Fiber Bragg grating sensing of detonation and shock experiments at Los Alamos National Laboratory (Invited Paper)** [8722-3]  
G. Rodriguez, R. L. Sandberg, S. I. Jackson, D. M. Dattelbaum, S. W. Vincent, Q. McCulloch, R. M. Martinez, S. M. Gilbertson, Los Alamos National Lab. (United States); E. Udd, Columbia Gorge Research (United States)
- 8722 05 **Development of high speed fiber grating sensor solutions for measuring velocity, position, pressure and temperature (Invited Paper)** [8722-4]  
E. Udd, Columbia Gorge Research (United States); J. Benterou, Lawrence Livermore National Lab. (United States)

---

## FIBER BRAGG GRATING SENSORS II

---

- 8722 06 **Analysis, compensation, and correction of temperature effects on FBG strain sensors (Invited Paper)** [8722-5]  
T. C. Haber, S. Ferguson, D. Guthrie, T. W. Graver, B. J. Soller, Micron Optics, Inc. (United States); A. Mendez, MCH Engineering LLC (United States)
- 8722 07 **Nondestructive inspection of CFRP adhesively bonded joints using embedded FBG sensors** [8722-6]  
S. Webb, P. Shin, K. Peters, North Carolina State Univ. (United States); R. Selfridge, S. Schultz, Brigham Young Univ. (United States)
- 8722 08 **Study of distributed fiber-optic laser-ultrasound generation based on ghost-mode of tilted fiber Bragg gratings** [8722-7]  
J. Tian, Q. Zhang, M. Han, Univ. of Nebraska-Lincoln (United States)
- 8722 09 **Engine test for wavelength-multiplexed fiber Bragg grating temperature sensor** [8722-8]  
L. Yu, D. Y. Wang, Y. Wang, C. M. Collins, W. C. Schneck III, J. M. Bailey, W. F. O'Brien, A. Wang, Virginia Polytechnic Institute and State Univ. (United States)

---

## DISTRIBUTED SENSING

---

- 8722 0D **High resolution, high sensitivity, dynamic distributed structural monitoring using optical frequency domain reflectometry (Invited Paper)** [8722-13]  
S. T. Kreger, A. K. Sang, N. Garg, J. Michel, Luna Innovations Inc. (United States)
- 8722 0E **Fully-distributed fiber-optic high temperature sensing based on stimulated Brillouin scattering** [8722-14]  
J. Wang, D. Hu, D. Y. Wang, A. Wang, Virginia Polytechnic Institute and State Univ. (United States)
- 8722 0F **Novel optical fibers for Brillouin-based distributed sensing** [8722-15]  
P. D. Dragic, Univ. of Illinois at Urbana-Champaign (United States); J. Ballato, S. Morris, A. Evert, Clemson Univ. (United States); R. R. Rice, Dreamcatchers Consulting (United States); T. Hawkins, Clemson Univ. (United States)

---

## PHYSICAL AND CHEMICAL SENSORS I

---

- 8722 0I **Effect of irradiation symmetry of CO<sub>2</sub> laser on mode coupling in long-period gratings inscribed in photonic crystal fiber** [8722-18]  
F. Tian, Stevens Institute of Technology (United States); J. Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); B. Zou, K. S. Chiang, City Univ. of Hong Kong (Hong Kong, China); H. Du, Stevens Institute of Technology (United States)
- 8722 0J **Compact, fiber-based, fast-light enhanced optical gyroscope** [8722-19]  
C. A. Christensen, A. Zavriyev, MagiQ Technologies, Inc. (United States); M. Bashkansky, U.S. Naval Research Lab. (United States); A. C. Beal, MagiQ Technologies, Inc. (United States)
- 8722 0K **Impact time measurement by using the fiber optic sensor in the pendulum ball collision** [8722-20]  
J. Lee, Andong National Univ. (Korea, Republic of); A. F. Vakakis, L. A. Bergman, Univ. of Illinois at Urbana-Champaign (United States)

---

## PHYSICAL AND CHEMICAL SENSORS II

---

- 8722 0N **Temperature sensing in high voltage transmission lines using fiber Bragg grating and free-space-optics** [8722-24]  
C. Floridia, J. B. Rosolem, A. A. Leonardi, C. A. Hortencio, CpqD Foundation (Brazil); R. F. Fonseca, R. O. C. Moreira, G. C. L. Souza, A. L. Melo, C. A. M. Nascimento, CEMIG (Brazil)
- 8722 0O **Single fiber Bragg grating for the measurement of liquid level and temperature** [8722-25]  
K. Srimannarayana, D. Sengupta, M. Sai Shankar, National Institute of Technology, Warangal (India)

8722 OP **Design and sensing research of the stepped metal film on optical fiber** [8722-26]  
Y. Gao, Luoyang Ship Material Research Institute (China) and Ocean Univ. of China (China); W. Cheng, W. Guo, Luoyang Ship Material Research Institute (China); S. Zhang, Luoyang Ship Material Research Institute (China) and Ocean Univ. of China (China); Y. Fu, L. Yu, Ocean Univ. of China (China)

8722 OQ **Escherichia coli biosensors for environmental, food industry, and biological warfare agent detection** [8722-27]  
R. C. S. B. Allil, Brazilian Army Technological Ctr. (Brazil) and Univ. Federal do Rio de Janeiro (Brazil); M. M. Werneck, J. L. da Silva-Neto, Brazilian Army Technological Ctr. (Brazil); M. A. L. Miguel, Univ. Federal do Rio de Janeiro (Brazil); D. M. C. Rodrigues, Brazilian Army Technological Ctr. (Brazil); G. L. Wandermur, Brazilian Army Technological Ctr. (Brazil) and Univ. Federal do Rio de Janeiro (Brazil); D. C. Rambauske, Univ. Federal do Rio de Janeiro (Brazil)

---

#### PHOTONIC MICRODEVICES/MICROSTRUCTURES FOR SENSING

---

8722 OR **Fiber optic refractive index sensor based on  $\pi$ -phase shifted fiber Bragg grating fabricated on etched side-hole fiber** [8722-28]  
Q. Zhang, L. Hu, J. Tian, N. J. Ianno, M. Han, Univ. of Nebraska-Lincoln (United States)

8722 OS **Integration of thin films with fiber micro-structures for sensing applications** [8722-29]  
M. Yang, M. Wang, G. Zhang, Wuhan Univ. of Technology (China)

8722 OT **A hybrid plasmonic whispering gallery mode sensor for single bionanoparticle detection** [8722-30]  
S. Holler, Fordham Univ. (United States); V. R. Dantham, Polytechnic Institute of New York Univ. (United States); V. Kolchenko, New York City College of Technology (United States); Z. Wan, Hunter College (United States); S. Arnold, Polytechnic Institute of New York Univ. (United States)

8722 OU **Novel compact architecture for high-resolution sensing with plasmonic gratings in conical mounting** [8722-31]  
G. Ruffato, Univ. degli Studi di Padova (Italy), Veneto Nanotech s.c.p.a. (Italy), and Istituto Nazionale per la Fisica della Materia, CNR (Italy); E. Pasqualotto, Univ. degli Studi di Padova (Italy); A. Sonato, Univ. degli Studi di Padova (Italy) and Veneto Nanotech s.c.p.a. (Italy); G. Zacco, Veneto Nanotech s.c.p.a. (Italy) and Istituto Nazionale per la Fisica della Materia, CNR (Italy); D. Silvestri, M. Dettin, M. Morpurgo, A. De Toni, Univ. degli Studi di Padova (Italy); F. Romanato, Univ. degli Studi di Padova (Italy), Veneto Nanotech s.c.p.a. (Italy), and Istituto Nazionale per la Fisica della Materia, CNR (Italy)

8722 OV **Multiplexed detection of aquaculture fungicides using a pump-free optofluidic SERS microsystem** [8722-32]  
S. H. Yazdi, I. M. White, Univ. of Maryland, College Park (United States)

**POSTER SESSION**

---

- 8722 0Y **A process for co-molding a visible-wavelength photonic crystal and microfluidic channel for biosensing applications** [8722-34]  
M. Srungarapu, C. E. Snyder, A. Kadiyala, B. Hamza, Y. Liu, J. M. Dawson, West Virginia Univ. (United States)

*Author Index*

# Conference Committee

## *Symposium Chair*

**Kenneth R. Israel**, Major General (USAF Retired) (United States)

## *Symposium Cochair*

**David A. Whelan**, Boeing Defense, Space, and Security (United States)

## *Conference Chairs*

**Eric Udd**, Columbia Gorge Research (United States)

**Gary Pickrell**, Virginia Polytechnic Institute and State University  
(United States)

**Henry H. Du**, Stevens Institute of Technology (United States)

## *Conference Cochairs*

**Jerry J. Benterou**, Lawrence Livermore National Laboratory  
(United States)

**Xudong Fan**, University of Michigan (United States)

**Alexis Mendez**, MCH Engineering LLC (United States)

**Stephen J. Mihailov**, Communications Research Center Canada  
(Canada)

**Anbo Wang**, Virginia Polytechnic Institute and State University  
(United States)

**Hai Xiao**, Missouri University of Science and Technology  
(United States)

## *Conference Program Committee*

**Christopher S. Baldwin**, Aither Engineering, Inc. (United States)

**Ole Bang**, Technical University of Denmark (Denmark)

**Eric A. Bergles**, BaySpec Inc. (United States)

**Jeff Bush**, Optiphase, Inc. (United States)

**Kevin Peng Chen**, University of Pittsburgh (United States)

**Brian Culshaw**, University of Strathclyde (United Kingdom)

**Abdessama Elyamani**, Northrop Grumman Navigation Systems  
(United States)

**Yoel Fink**, Massachusetts Institute of Technology (United States)

**Eric Lee Goldner**, US Sensor Systems, Inc. (United States)

**Tom W. Graver**, Micron Optics, Inc. (United States)

**Ming Han**, University of Nebraska-Lincoln (United States)

**Hajime Haneda**, National Institute for Materials Science (Japan)

**Kazuo Hotate**, The University of Tokyo (Japan)  
**Jiri Kanka**, Institute of Photonics and Electronics of the ASCR, v.v.i.  
(Czech Republic)  
**Victor I. Kopp**, Chiral Photonics, Inc. (United States)  
**Katerina Krebber**, Bundesanstalt für Materialforschung und -prüfung  
(Germany)  
**Steven T. Kreger**, Luna Innovations Inc. (United States)  
**David A. Krohn**, Light Wave Venture Consulting, LLC (United States)  
**Paul Lefebvre**, LxDATA (Canada)  
**Thomas D. Monte**, KVH Industries, Inc. (United States)  
**Glen A. Sanders**, Honeywell Technology (United States)  
**Dennis J. Trevor**, OFS Laboratories (United States)  
**Xingwei Wang**, University of Massachusetts Lowell (United States)  
**Reinhardt Willsch**, Institut für Photonische Technologien e.V.  
(Germany)  
**Younan Xia**, Georgia Institute of Technology (United States)  
**Hai Xiao**, Missouri University of Science and Technology (United States)

#### *Session Chairs*

- 1 Fiber Bragg Grating Sensors I  
**Brian Soller**, Micron Optics, Inc. (United States)
- 2 Fiber Bragg Grating Sensors II  
**Eric Udd**, Columbia Gorge Research (United States)
- 3 Fiber Bragg Grating Sensors III  
**Gary Pickrell**, Virginia Polytechnic Institute and State University  
(United States)
- 4 Distributed Sensing  
**Ming Han**, University of Nebraska-Lincoln (United States)
- 5 Physical and Chemical Sensors I  
**Eric Udd**, Columbia Gorge Research (United States)
- 6 Physical and Chemical Sensors II  
**Jerry J. Benterou**, Lawrence Livermore National Laboratory  
(United States)
- 7 Photonic Microdevices/Microstructures for Sensing  
**Jerry J. Benterou**, Lawrence Livermore National Laboratory  
(United States)



## Introduction

*Fiber Optic Sensors and Applications X* continues with a tradition of SPIE sponsored fiber optic sensor conferences that started with the *Fiber Optic and Laser Sensor* series of conferences in 1983 that were in part derived on still earlier conferences including *Laser Inertial Rotation Sensors* in 1978 with several fiber optic gyro papers and several other fiber and integrated optic conferences that contained sessions on fiber sensors. This history now spans 35 years with many types of fiber optic sensors. Often a particular type of fiber sensor was highlighted in the conference, and in the case of these proceedings, an effort was made to collect papers that would serve to celebrate 25 years of fiber grating sensor development. As with every anniversary of technology, an exact beginning is sometimes hard to define. In this case, early effort in approximately the 1987 to 1988 time frame were used as the starting point, as the first commercially available fiber gratings began to appear and organizations almost immediately began to apply them to sensor applications.

Several invited papers describe various applications of fiber grating sensor technology and it is hoped in some sense that these provide a brief history of the technology as well as some directions for the future.

Other papers contained in this volume are directed toward other applications and there are several that involve biomedical and biochemical sensing.

**Eric Udd  
Gary Pickrell  
Henry H. Du**

