PROCEEDINGS OF SPIE

SPIDigitalLibrary.org/conference-proceedings-of-spie

Front Matter: Volume 11296

, "Front Matter: Volume 11296," Proc. SPIE 11296, Optical, Opto-Atomic, and Entanglement-Enhanced Precision Metrology II, 1129601 (19 March 2020); doi: 10.1117/12.2570051

SPIE.

Event: SPIE OPTO, 2020, San Francisco, California, United States

PROCEEDINGS OF SPIE

Optical, Opto-Atomic, and Entanglement-Enhanced Precision Metrology II

**Selim M. Shahriar
Jacob Scheuer**
Editors

**1–6 February 2020
San Francisco, California, United States**

Sponsored and Published by
SPIE

Volume 11296

Proceedings of SPIE 0277-786X, V. 11296

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

Optical, Opto-Atomic, and Entanglement-Enhanced Precision Metrology II, edited by Selim M. Shahriar,
Jacob Scheuer, Proc. of SPIE Vol. 11296, 1129601 · © 2020 SPIE
CCC code: 0277-786X/20/\$21 · doi: 10.1117/12.2570051

Proc. of SPIE Vol. 11296 1129601-1

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 *Optical, Opto-Atomic, and Entanglement-Enhanced Precision Metrology II*, edited by Selim M. Shahriar, Jacob Scheuer, Proceedings of SPIE Vol. 11296 (SPIE, Bellingham, WA, 2020) Seven-digit Article CID Number.

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

ISBN: 9781510633551
ISBN: 9781510633568 (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 © 2020, 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 \$21.00 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/20/\$21.00.

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

vii *Authors*
ix *Conference Committee*

QUANTUM SENSING, SPIN SQUEEZING, AND RELATED TECHNOLOGIES I

11296 05 **Spectroscopic sensing enhanced by quantum molecular coherence and by plasmonic nanoantennas (Invited Paper)** [11296-4]

ATOMIC CLOCKS, ATOMIC INTERFEROMETERS, AND ENABLING TECHNOLOGIES I

11296 07 **Decoherence and dynamics in continuous 3D-cooled atom interferometry (Invited Paper)** [11296-20]

11296 08 **Measurements of the dipole moments of cesium Rydberg-ground molecules (Invited Paper)** [11296-21]

11296 09 **Progress of a compact microwave clock based on atoms cooled with a diffractive optic (Invited Paper)** [11296-22]

QUANTUM SENSING, SPIN SQUEEZING, AND RELATED TECHNOLOGIES II

11296 0C **Quantum-enhanced sensing in the real world: multiple parameters & fault tolerance (Invited Paper)** [11296-5]

11296 0F **Measuring the time tunneling particles spend in the barrier (Invited Paper)** [11296-8]

QUANTUM SENSING, SPIN SQUEEZING, AND RELATED TECHNOLOGIES III

11296 0H **Implementation of polarization-based truncated SU (1,1) interferometer in hot Rb vapor (Invited Paper)** [11296-11]

QUANTUM SENSING, SPIN SQUEEZING, AND RELATED TECHNOLOGIES IV

11296 0L **Polarization dichroic mirrors for quantum optics with atomic ensembles (Invited Paper)** [11296-16]

11296 0M **Imaging in time of non-classical ultrafast signals with high temporal resolution (Invited Paper)**
[11296-17]

ATOMIC CLOCKS, ATOMIC INTERFEROMETERS, AND ENABLING TECHNOLOGIES III

11296 0W **A compact and reliable 780nm laser for atom cooling on-board a 6U CubeSat** [11296-33]

QUANTUM SENSING, SPIN SQUEEZING, AND RELATED TECHNOLOGIES VI

11296 18 **Advanced Hamiltonian engineering in spin ensembles for enhanced sensing and control (Invited Paper)** [11296-45]

NEW LASER TECHNOLOGIES FOR PRECISION METROLOGY AND SENSING

11296 1C **High power, high wall-plug efficiency, high reliability, continuous-wave operation quantum cascade lasers at Center for Quantum Devices (Invited Paper)** [11296-48]

ATOMIC CLOCKS, ATOMIC INTERFEROMETERS, AND ENABLING TECHNOLOGIES V

11296 1H **Advances in strontium optical lattice clocks at NIM (Invited Paper)** [11296-58]

ATOMIC CLOCKS, ATOMIC INTERFEROMETERS, AND ENABLING TECHNOLOGIES VI

11296 1M **Atomic clocks for space: basic physics research at The Aerospace Corporation (Invited Paper)**
[11296-63]

11296 1N **Vector curvature sensor based on a single fiber Bragg grating (Invited Paper)** [11296-64]

ATOMIC METROLOGY: NEW DIRECTIONS

11296 1O **Atomic flux circuits (Invited Paper)** [11296-65]

11296 1R **Sensing gravity by holding atoms for 20 seconds (Invited Paper)** [11296-68]

FIBER OPTICS SENSING, METROLOGY, AND RELATED TECHNOLOGIES

- 11296 1X **A 1800-km optical fiber link for metrology, geodesy, and clock comparison** [11296-70]
- 11296 1Y **High-resolution optical phase demodulation and all-fiber resonance cavities with dynamic population Bragg gratings recorded in Ytterbium-doped fibers at 1064 nm** [11296-71]
- 11296 20 **Nonlinear optical effects in the acetylene filled micro-structured fibers with Maxwell distribution of relaxation rates** [11296-73]

FREQUENCY COMBS

- 11296 2A **High-resolution direct optical frequency comb Raman spectroscopy of single ions: from atomic fine structures to rotational spectra of molecular ions (Invited Paper)** [11296-83]

TESTS OF FUNDAMENTAL PHYSICS II

- 11296 2H **Direct semiconductor diode laser system for an optical lattice clock based on neutral strontium for future tests of fundamental physics in space (Invited Paper)** [11296-95]

GRAVITATIONAL WAVE DETECTION AND RELATED TECHNOLOGIES

- 11296 2K **Advanced quantum-enhanced metrology for gravitational-wave detection (Invited Paper)** [11296-86]
- 11296 2M **Application of optical frequency comb in LISA space laser interferometry (Invited Paper)** [11296-88]

SLOW AND FAST LIGHT IN CAVITIES, RESONATORS, AND WAVEGUIDES

- 11296 2O **Front induced transitions in slow light and dispersive waveguides** [11296-102]
- 11296 2S **Dispersion engineering in distributed Brillouin dynamic sensing with spectrum engineering (Invited Paper)** [11296-106]

GYROSCOPES AND PRECISION ROTATION SENSING I

- 11296 3I **Hafele and Keating on a chip: Sagnac interferometry with a single clock (Invited Paper)** [11296-109]

GYROSCOPES AND PRECISION ROTATION SENSING III

11296 39 **Controlling the anharmonicity of a time-orbiting potential trap (Invited Paper)** [11296-116]

PRECISION MAGNETOMETRY AND ENABLING TECHNOLOGIES

11296 3C **Microfabricated magnetometers for imaging and communication (Invited Paper)** [11296-119]

INTEGRATED/CHIP SCALE SENSING AND RELATED TECHNOLOGIES I

11296 3D **Enhanced dissipative sensing in a microresonator with multimode input (theory) (Invited Paper)**
[11296-120]

INTEGRATED/CHIP SCALE SENSING AND RELATED TECHNOLOGIES II

11296 3L **Microwave photonic processing with spatial-spectral holographic materials (Invited Paper)**
[11296-128]

INTEGRATED/CHIP SCALE SENSING AND RELATED TECHNOLOGIES III

11296 3Q **Enhanced dissipative sensing in a microresonator with multimode input (experiment)**
[11296-158]

OPTICAL METROLOGY: NEW DEVELOPMENTS II

11296 3W **Tunable geometries from a sparse quantum spin network (Invited Paper)** [11296-138]

QUANTUM INFORMATION PROCESSING AND RELATED TECHNOLOGIES II

11296 46 **Towards variable strength measurements of non-local observables (Invited Paper)** [11296-148]

QUANTUM INFORMATION PROCESSING AND RELATED TECHNOLOGIES III

11296 4B **Experimental realization of robust weak measurements (Invited Paper)** [11296-157]

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.

Aguilar, E., 1Y	Eich, Manfred, 2O
Aiello, Roberto, 1X	Elvin, Rachel, 09
Al Maruf, Rubayet, 0L	Fancher, Charles T., 07
Alem, Orang, 3C	Fang, Zhanjun, 1H
Ambrosini, Roberto, 1X	Farfurnik, D., 18
Anderson, Paul, 0L	Farries, Mark, 0W
Arnold, Aidan S., 09	Feng, Cheng, 2S
Atkocius, Vilius, 3I	Fernholz, Thomas, 3I
Avella, Alessio, 4B	Ferretti, Hugo, 46
Baba, Toshihiko, 2O	Flannery, Jeremy, 0L
Babbitt, Wm. Randall, 3L	Foxon, Bethany, 3I
Bai, Jingxu, 08	Fridman, Moti, 0M
Bai, Suying, 08	Friedman, Ori, 0M
Bajcsy, Michal, 0L	Gaafar, Mahmoud A., 2O
Bar-Gill, N., 18	Genov, G., 18
Bashkansky, Mark, 07	Genovese, Marco, 4B
Ben'Attar, K. I. O., 18	Gentile, Fabio, 3I
Ben-Shalom, Y., 18	Gerginov, Marja, 3C
Bentsen, Gregory S., 3W	Gerginov, Vladislav, 3C
Berl, S., 39	Gramegna, Marco, 4B
Bianco, Giuseppe, 1X	Griffin, Paul F., 09
Black, Adam T., 07	Grudinin, Ivan, 2M
Bonsma-Fisher, Kent, 46	Guo, Ying, 1N
Bopp, Douglas G., 1O	Hashizume, Tomohiro, 3W
Bortolotti, Claudio, 1X	Hernandez, E., 1Y, 2O
Bregazzi, Alan, 09	Hoth, Gregory W., 09
Brodutch, Aharon, 46	Huang, M., 1M
Buyskikh, Anton S., 3W	Hudson, A., 1M
Calonico, Davide, 1X	Hughes, Jeremy, 3C
Camparo, J., 1M	Hummon, Matthew T., 1O
Cao, Shiyang, 1H	Jaffe, Matt, 1R
Casillas, N., 2O	Jammi, Sindhu, 3I
Clark, Logan W., 1R	Jelesko, F., 18
Clivati, Cecilia, 1X	Jia, Suotang, 08
Cohen, Eliahu, 0M, 4B	Jiang, Weiguo, 1N
Daley, Andrew J., 3W	Johnson, Jamie, 3I
Danilishin, Stefan L., 2K	Keliehor, Brendan, 09
Datta, Animesh, 0C	Kitching, John, 1O
Davis, Emily J., 3W	Klein, Avi, 0M
De Natale, Paolo, 1X	Knappe, Svenja, 3C
de Souza, M. A., 4B	Korenko, Branislav, 3C
Degiovanni, Ivo P., 4B	Kristensen, Sofus L., 1R
Devani, Diviya, 0W	Krzyzewski, Sean, 3C
Diaz, J., 2O	Kwolek, Jonathan M., 07
Di Sarno, Valentina, 1X	Le, Khoa, 1O
Drewnsen, M., 2A	Legg, Thomas, 0W
Driskell, T., 1M	Levi, Filippo, 1X
Duadi, Hamootal, 0M	Lewis, Ben, 09
Dziewior, Jan, 4B	Li, Linfeng, 3C

Li, Tianchu, 1H	Taylor, Ellyse, 1O
Li, Ye, 1H	Tham, Weng-Kian, 46
Lin, Baiken, 1H	Tinto, Massimo, 2M
Lin, Yige, 1H	Vaidman, Lev, 4B
Lu, Bingkun, 1H	Vinckier, Quentin, 2M
Luo, Z., 39	Wang, Qiang, 1H
Lupu-Gladstein, Noah, 46	Warren, Zachary, 1M
Maccaferri, Giuseppe, 1X	Welch, Matthew, 0W
Maddaloni, Pasquale, 1X	Williams, Jason R., 2H
Maddox, Stephen, 0W	Wright, Michael, 09
Meir, Sara, 0M	Xu, Victoria, 1R
Meng, Fei, 1H	Yang, Tao, 1H
Moan, E., 39	Yoon, Taehyun, 0L
Monahan, D., 1M	Yu, Nan, 2H, 2M
Müller, Holger, 1R	Zhang, Yundong, 1N
Mura, Alberto, 1X	Zhao, Jianming, 08
Nanni, Mauro, 1X	Zhu, Fuxing, 1N
Negusini, Monia, 1X	
Novikova, Irina, 0H	
Ocegueda, M., 20	
Panda, Cristian D., 1R	
Pang, Ou Teen Arthur, 46	
Perini, Federico, 1X	
Petrov, Alexander Yu., 2O	
Piacentini, Fabrizio, 4B	
Pomponio, Marco, 3C	
Poulios, Konstantinos, 3I	
Prajapati, Nikunj, 0H	
Qi, Kaiyue, 1N	
Qu, Yanchen, 1N	
Rajagopal, Sreekul Raj, 3D, 3Q	
Razeghi, Manijeh, 1C	
Rebufello, Enrico, 4B	
Retzker, A., 18	
Ricci, Roberto, 1X	
Rieländer, Daniel, 2M	
Riis, Erling, 09	
Roma, Mauro, 1X	
Romanov, Gleb, 3C	
Rosenberger, A. T., 3D, 3Q	
Sackett, C. A., 39	
Santamaria Amato, Luigi, 1X	
Schima, Susan, 1O	
Schkolnik, Vladimir, 2H	
Schleier-Smith, Monika H., 3W	
Schneider, Thomas, 2S	
Semnani, Behrooz, 0L	
Shahal, Shir, 0M	
Shutov, Anton D., 05	
Shutova, Mariia, 05	
Sibony, Inbar, 0M	
Siciliani de Cumis, Mario, 1X	
Sokolov, Alexei V., 05	
Spierings, David C., 0F	
Stagni, Matteo, 1X	
Steinberg, Aephraim M., 0F, 46	
Stepanov, S., 1Y, 20	
Su, Huaiyin, 1N	
Sun, Zhen, 1H	
Tampellini, Anna, 1X	

Conference Committee

Symposium Chairs

Sailing He, KTH Royal Institute of Technology (Sweden) and Zhejiang University (China)
Yasuhiro Koike, Keio University (Japan)

Symposium Co-chairs

Connie J. Chang-Hasnaian, University of California, Berkeley (United States)
Graham T. Reed, Optoelectronics Research Centre, University of Southampton (United Kingdom)

Program Track Chair

David L. Andrews, University of East Anglia (United Kingdom)

Conference Chairs

Selim M. Shahriar, Northwestern University (United States)
Jacob Scheuer, Tel Aviv University (Israel)

Conference Program Committee

Nancy Aggarwal, Northwestern University (United States)
Angelo Bassi, Università degli Studi di Trieste (Italy)
Robert W. Boyd, University of Ottawa (Canada) and University of Rochester (United States)
Danielle A. Braje, MIT Lincoln Laboratory (United States)
John H. Burke, Defense Advanced Research Projects Agency (United States)
Eliahu Cohen, Bar-Ilan University (Israel)
Brian D'Urso, Montana State University (United States)
Andrew Geraci, Northwestern University (United States)
John C. Howell, The Hebrew University of Jerusalem (Israel)
Jacob B. Khurgin, Johns Hopkins University (United States)
Jaewan Kim, Korea Institute for Advanced Study (Korea, Republic of)
John E. Kitching, National Institute of Standards and Technology (United States)
Timothy Kovachy, Northwestern University (United States)
Uriel Levy, The Hebrew University of Jerusalem (Israel)
Frank A. Narducci, Naval Postgraduate School (United States)
Irina Novikova, William & Mary (United States)

Gour S. Pati, Delaware State University (United States)
Stefania Residori, L'Institut de Physique de Nice (France)
Monika H. Schleier-Smith, Stanford University (United States)
David D. Smith, NASA Marshall Space Flight Center (United States)
Misha Sumetsky, Aston University (United Kingdom)
Renu Tripathi, Delaware State University (United States)
Sharon M. Weiss, Vanderbilt University (United States)
Yanhong Xiao, Fudan University (China)
Avinoam Zadok, Bar-Ilan University (Israel)

Session Chairs

- 1 Quantum Sensing, Spin Squeezing, and Related Technologies I
William J. Munro, NTT Basic Research Laboratories (Japan)
- 2 Quantum Sensing, Spin Squeezing, and Related Technologies II
Mehul Malik, Heriot-Watt University (United Kingdom)
- 3 Quantum Sensing, Spin Squeezing, and Related Technologies III
Robert Fickler, Tampere University (Finland)
- 4 Quantum Sensing, Spin Squeezing, and Related Technologies IV
Irina Novikova, William & Mary (United States)
- 5 Atomic Clocks, Atomic Interferometers, and Enabling Technologies I
Gour S. Pati, Delaware State University (United States)
- 6 Atomic Clocks, Atomic Interferometers, and Enabling Technologies II
Renu Tripathi, Delaware State University (United States)
- 7 Atomic Clocks, Atomic Interferometers, and Enabling Technologies III
May Eun Yeon Kim, National Institute of Standards and Technology
 (United States)
- 8 Atomic Clocks, Atomic Interferometers, and Enabling Technologies IV
Malcolm Boshier, Los Alamos National Laboratory (United States)
- 9 Quantum Sensing, Spin Squeezing, and Related Technologies V
Avi Pe'er, Bar-Ilan University (Israel)
- 10 Quantum Sensing, Spin Squeezing, and Related Technologies VI
Robert Compton, Honeywell (Canada)
- 11 New Laser Technologies for Precision Metrology and Sensing
Nancy Aggarwal, Northwestern University (United States)

- 12 Optomechanics and Force Detection I
Tejas Deshpande, Northwestern University (United States)
- 13 Atomic Clocks, Atomic Interferometers, and Enabling Technologies V
Shimon Kolkowitz, University of Wisconsin-Madison (United States)
- 14 Atomic Clocks, Atomic Interferometers, and Enabling Technologies VI
Tim Kovachy, Northwestern University (United States)
- 15 Atomic Metrology: New Directions
Hui Cao, Yale University (United States)
- 16 Fiber Optics Sensing, Metrology, and Related Technologies
Alex M. Kuzmich, University of Michigan (United States)
- 17 Optomechanics and Force Detection II
Jean-Pierre Zendri, Istituto Nazionale di Fisica Nucleare (Italy)
- 18 Frequency Combs
Nan Yu, Jet Propulsion Laboratory (United States)
- 19 Gravitational Wave Detection and Related Technologies
Sougato Bose, University College London (United Kingdom)
- 20 Tests of Fundamental Physics I
Gadi Afek, Yale University (United States)
- 21 Tests of Fundamental Physics II
Natasha Sachdev, University of Michigan (United States)
- 22 Quantum Information Processing and Related Technologies I
Alexander O. Sushkov, Boston University (United States)
- 23 Slow and Fast Light in Cavities, Resonators, and Waveguides
Kerry J. Vahala, Caltech (United States)
- 24 Gyroscopes and Precision Rotation Sensing I
Misha Sumetsky, Aston University (United Kingdom)
- 25 Gyroscopes and Precision Rotation Sensing II
Michel J. F. Digonnet, Stanford University (United States)
- 26 Gyroscopes and Precision Rotation Sensing III
Frank A. Narducci, Naval Postgraduate School (United States)
- 27 Precision Magnetometry and Enabling Technologies

He Wang, The Aerospace Corporation (United States)

- 28 Integrated/Chip Scale Sensing and Related Technologies I
John E. Kitching, National Institute of Standards and Technology
(United States)
- 29 Integrated/Chip Scale Sensing and Related Technologies II
Albert T. Rosenberger, Oklahoma State University (United States)
- 30 Integrated/Chip Scale Sensing and Related Technologies III
Jacob B. Khurgin, Johns Hopkins University (United States)
- 31 Optical Metrology: New Developments I
Uriel Levy, The Hebrew University of Jerusalem (Israel)
- 32 Optical Metrology: New Developments II
Selim Shahriar, Northwestern University (United States)
- 33 Optical Metrology: New Developments III
Gregory Bentsen, Princeton University (United States)
- 34 Quantum Information Processing and Related Technologies II
Eliahu Cohen, Bar-Ilan University (Israel)
- 35 Quantum Information Processing and Related Technologies III
Sharon Shwartz, Bar-Ilan University (Israel)