

PROCEEDINGS OF SPIE

Quantum Optics

Jürgen Stuhler
Andrew J. Shields
Editors

5–7 April 2016
Brussels, Belgium

Sponsored by
SPIE

Cosponsored by
B-PHOT—Brussels Photonics Team (Belgium)
Research Foundation Flanders (Belgium)
Visit Brussels (Belgium)

Cooperating Organisations
Photonics 21 (Germany)
EOS—European Optical Society (Germany)
KTN—the Knowledge Transfer Network (United Kingdom)
Graphene Flagship (Belgium)
Photonics Public Private Partnership (Belgium)

Published by
SPIE

Volume 9900

Proceedings of SPIE 0277-786X, V. 9900

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

Quantum Optics, edited by Jürgen Stuhler, Andrew J. Shields, Proc. of SPIE Vol. 9900
990001 · © 2016 SPIE · CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2244527

Proc. of SPIE Vol. 9900 990001-1

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 *Quantum Optics*, edited by Jürgen Stuhler, Andrew J. Shields, Proceedings of SPIE Vol. 9900 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)
ISBN: 9781510601451

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 © 2016, 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/16/\$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

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	<i>Authors</i>
vii	<i>Conference Committee</i>

ATOM SENSORS I

9900 03	Development of a strontium optical lattice clock for the SOC mission on the ISS (Best Student Paper Award) [9900-2]
9900 04	Development of compact cold-atom sensors for inertial navigation [9900-3]
9900 07	Towards rotation sensing with a single atomic clock [9900-6]
9900 08	MIGA: combining laser and matter wave interferometry for mass distribution monitoring and advanced geodesy [9900-7]

QUANTUM TECHNOLOGIES

9900 09	The UK National Quantum Technologies Hub in sensors and metrology (Keynote Paper) [9900-8]
---------	---

ATOM SENSORS II

9900 0F	Optical atomic magnetometry for magnetic induction tomography of the heart [9900-14]
---------	---

QUANTUM COMMUNICATIONS I

9900 0J	Satellite quantum communication towards GEO distances [9900-18]
9900 0K	Aerospace laser communications technology as enabler for worldwide quantum key distribution [9900-19]
9900 0L	Encoding M classical bits in the arrival time of dense-coded photons [9900-20]

QUANTUM COMMUNICATIONS II

9900 0N	Improving the coherence properties of solid-state spin ensembles via optimized dynamical decoupling [9900-23]
9900 0P	Demonstration of a coexistence scheme between polarization-entangled QKD and classical data channels [9900-25]

QT APPLICATIONS AND INSTRUMENTS I

- 9900 0S **Initialization and measurement of nitrogen-vacancy centers in diamond with plasmonic Purcell enhancement** [9900-28]
- 9900 0T **Coherent two-photon excitation of quantum dots** [9900-29]
- 9900 0U **Free-space single-photon transistor based on Rydberg interaction** [9900-30]

QUANTUM INFORMATION AND INSTRUMENTS

- 9900 12 **Quantum noise in energy-efficient slow light structures for optical computing: squeezed light from slow light** [9900-38]

POSTER SESSION

- 9900 17 **Modeling cavities exhibiting strong lateral confinement using open geometry Fourier modal method** [9900-43]
- 9900 1A **Maximizing the information gain of a single ion microscope using Bayes experimental design** [9900-47]
- 9900 1B **Feasibility of two-photon rotational spectroscopy on trapped HD⁺** [9900-48]
- 9900 1C **Orthogonal frequency division multiplexed quantum key distribution in the presence of Raman noise** [9900-49]
- 9900 1E **1THz synchronous tuning of two optical synthesizers** [9900-52]
- 9900 1G **Compact narrow linewidth diode laser modules for precision quantum optics experiments on board of sounding rockets** [9900-54]

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.

Aleksic, Slavisa, 0P
Amand, L., 08
Antoni-Micollier, L., 04
Arnold, A. S., 09
Bacco, Davide, 0J
Bahrani, Sima, 1C
Bar-Gill, Nir, 0N, 0S
Barrett, B., 04
Barwood, G., 03
Bason, Mark G., 07, 09
Battelier, B., 04
Beardsley, R. P., 09
Benkler, Erik, 1E
Benson, T. M., 09
Bertoldi, A., 08
Bianco, Giuseppe, 0J
Bishop, Thomas, 07
Bize, S., 03
Bongs, K., 03, 09
Bostock, H., 09
Bouyer, P., 04, 08
Bowtell, R. W., 09
Boyer, V., 09
Brookes, M. J., 09
Budker, D., 0N
Campion, R. P., 09
Canuel, B., 08
Chichet, L., 04
Constantin, Florin L., 1B
Cormier, E., 08
Cross, T., 09
Cruise, M. A., 09
Cumming, D. R. S., 09
Deans, Cameron, 0F
Dequal, Daniele, 0J
Dobrovitski, V. V., 0N
Erbert, Götz, 1G
Ertmer, W., 03
Fang, B., 08
Farfurnik, D., 0N
Fernholz, Thomas, 07, 09
Fouché, L., 04
Freearde, T., 09
Freise, A., 09
Fromhold, T. M., 09
Fuchs, Christian, 0K
Gaffet, S., 08
Gaiarin, Simone, 0J
Garraway, B. M., 09
Geiger, R., 08
Gentile, Fabio, 07
Gill, P., 03, 09
Gorniaczyk, Hannes, 0U
Gregersen, Niels, 17
Griffin, P. F., 09
Groot-Berning, Karin, 1A
Hackermuller, L., 09
Hamerly, Ryan, 12
Harms, J., 08
Hastie, J. E., 09
Häyrynen, Teppo, 17
He, W., 03
Hegazy, Salem F., 0L
Hempler, N., 09
Hensinger, W., 09
Hentschel, Michael, 0P
Hill, I. R., 03, 09
Himsworth, M., 09
Hipp, Florian, 0P
Hofferberth, Sebastian, 0U
Holleville, D., 03, 08
Holynski, M., 09
Huber, T., 0T
Hübel, Hannes, 0P
Hughes, J., 03, 09
Hush, Michael R., 07
Hussain, Sarah, 0F
Jacob, Georg, 1A
Jammi, Sindhu, 07
Jamshidi, Kambiz, 12
Jarmola, A., 0N
John, P., 09
Kaenders, W., 03
Kaushik, A., 09
Kock, B. O., 09
Kohfeldt, Anja, 1G
Krüger, P., 09
Kulosa, A., 03
Kürbis, Christian, 1G
Landragin, A., 04, 08
Lautier, J., 04
Lefèvre, G., 08
Lesanovsky, Igor V., 07
Le Targat, R., 03
Lhermite, J., 08
Li, X., 09
Lien, Y.-H., 09
Lisdat, Ch., 03

Lodewyck, J., 03
 Luceri, Vincenza, 0J
 Luvsandamdin, Erdenetsetseg, 1G
 Mabuchi, Hideo, 12
 Maclean, J. O., 09
 Maddox, S., 09
 Malcolm, G. P. A., 09
 Marmugi, Luca, 0F
 Marsh, J. H., 09
 Mas, Hèctor, 07
 Melén, Gwen, 0K
 Mellor, C. J., 09
 Mielec, N., 08
 Mirgorodskiy, Ivan, 0U
 Moll, Florian, 0K
 Morra, Ahmed E., 0L
 Napolitano, F., 04
 Nauerth, Sebastian, 0K
 Neuhaus, Rudolf, 1E
 Niggebaum, A., 09
 Nizamani, A. H., 09
 Novikov, S. V., 09
 Obayya, Salah S. A., 0L
 Origlia, S., 03
 Orucevic, F., 09
 Ostermann, L., 0T
 Ovchinnikov, Y., 03
 Paboeuf, D., 09
 Pandey, Saurabh, 07
 Paris-Mandoki, Asaf, 0U
 Parrotta, D. C., 09
 Pasquazi, A., 09
 Paul, D. J., 09
 Peccianti, M., 09
 Pelisson, S., 08
 Perea-Ortiz, M., 09
 Peters, Achim, 1G
 Petrov, P., 09
 Pham, L. M., 0N
 Plant, S., 09
 Poppe, Andreas, 0P
 Porte, H., 04
 Poschinger, Ulrich G., 1A
 Potter, E., 09
 Poullos, Konstantinos, 07
 Pramod, M. S., 03
 Predojević, A., 0T
 Prevedelli, M., 08
 Prilmüller, M., 0T
 Puppe, Thomas, 1E
 Pyragius, Tadas, 07
 Raab, Christoph, 1E
 Rapaport, Ronen, 0S
 Rasel, E.-M., 03
 Rau, Markus, 0K
 Razavi, Mohsen, 1C
 Renzoni, Ferruccio, 0F
 Riis, E., 09
 Riou, I., 08
 Ritsch, H., 0T
 Rodriguez Blanco, A., 09
 Rohde, Felix, 1E
 Rosenberg, Itamar, 0S
 Ruostekoski, J., 09
 Rushforth, A. W., 09
 Salehi, Jawad A., 1C
 Schiavon, M., 0J
 Schiemangk, Max, 1G
 Schiller, S., 03
 Schmidt, Christopher, 0K
 Schmidt-Kaler, Ferdinand, 1A
 Singer, Kilian, 1A
 Singh, Y., 03, 09
 Sinuco-Leon, G., 09
 Smith, L., 03
 Smith, P., 09
 Solomon, G. S., 0T
 Sorel, M., 09
 Stabrawa, A., 09
 Sterr, U., 03
 Stevenson, Robin, 07
 Stuhler, Jürgen, 03, 1E
 Świerad, D., 03
 Telle, Harald R., 1E
 Tomasin, M., 0J
 Tränkle, Günther, 1G
 Tresp, Christoph, 0U
 Tropper, A., 09
 Unterreitmayer, Reinhard, 1E
 Vallone, Giuseppe, 0J
 Vasilakis, Georgios, 07
 Vedovato, F., 0J
 Venon, B., 03
 Villoresi, Paolo, 0J
 Viswam, S., 03
 Vogl, Tobias, 0K
 Vogt, S., 03
 von Klitzing, Wolf, 07
 Walsworth, R. L., 0N
 Wang, Z. H., 0N
 Weihs, G., 0T
 Weinfurter, Harald, 0K
 Welch, N., 09
 Wicht, Andreas, 1G
 Wildman, R. D., 09
 Williams, R. A., 09
 Wolf, Sigal A., 0S
 Zach, Armin, 1E
 Zimmer, Christian, 0U

Conference Committee

Symposium Chairs

Francis Berghmans, Vrije Universiteit Brussel (Belgium)
Jürgen Popp, Leibniz-Institut für Photonische Technologien e.V.
(Germany)
Ronan Burgess, European Commission Photonics Unit (Belgium)
Peter Hartmann, SCHOTT, AG (Germany)

Honorary Symposium Chair

Hugo Thienpont, Vrije Universiteit Brussel (Belgium)

Conference Chairs

Jürgen Stuhler, TOPTICA Photonics AG (Germany)
Andrew J. Shields, Toshiba Research Europe Ltd. (United Kingdom)

Conference Program Committee

Christoph Becher, Universität des Saarlandes (Germany)
Oliver Benson, Humboldt-Universität zu Berlin (Germany)
Rainer Blatt, Leopold-Franzens-Universität Innsbruck (Austria)
Kai Bongs, The University of Birmingham (United Kingdom)
Philippe Bouyer, Institut d'Optique Graduate School LP2N (France)
and Muquans Bordeaux (France)
Michael Jetter, Universität Stuttgart (Germany)
Christian Kurtsiefer, National University of Singapore (Singapore)
Eugene S. Polzik, Niels Bohr Institute (Denmark)
Bruno Sanguinetti, id Quantique SA (Switzerland)

Session Chairs

- 1 Atom Sensors I
Kai Bongs, The University of Birmingham (United Kingdom)
- 2 Quantum Technologies
Jürgen Stuhler, TOPTICA Photonics AG (Germany)
- 3 Atom Sensors II
Ulrich Eismann, TOPTICA Photonics AG (Germany)
- 4 Quantum Communications I
Andrew J. Shields, Toshiba Research Europe Ltd. (United Kingdom)

- 5 Quantum Communications II
Martin Ward, Toshiba Research Europe Ltd. (United Kingdom)
- 6 QT Applications and Instruments I
Tara Liebisch, Universität Stuttgart (Germany)
- 7 QT Applications and Instruments II
Thomas Fernholz, The University of Nottingham (United Kingdom)
- 8 Quantum Information and Instruments
Ana Predojevic, University of Innsbruck (Austria)