

PROCEEDINGS OF SPIE

Advanced Photon Counting Techniques IV

Mark A. Itzler
Joe C. Campbell
Editors

7–8 April 2010
Orlando, Florida, United States

Sponsored and Published by
SPIE

Volume 7681

Proceedings of SPIE, 0277-786X, v. 7681

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

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 *Advanced Photon Counting Techniques IV*, edited by Mark A. Itzler, Joe C. Campbell, Proceedings of SPIE Vol. 7681 (SPIE, Bellingham, WA, 2010) Article CID Number.

ISSN 0277-786X
ISBN 9780819481450

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 © 2010, 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/10/\$18.00.

Printed in the United States of America.

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

The logo for SPIE Digital Library features the word "SPIE" in a bold, sans-serif font above the words "Digital Library" in a similar font. To the right of the text is a stylized graphic consisting of three vertical bars of increasing height, resembling a bar chart or a signal waveform.

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 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>

SESSION 1 PHOTON COUNTING APPLICATIONS AND TECHNIQUES I

- 7681 02 **Functional diffuse reflectance spectroscopy at small source-detector distances based on fast-gated single-photon avalanche diodes (Invited Paper)** [7681-01]
D. Contini, A. Pifferi, Politecnico di Milano (Italy); L. Spinelli, Istituto di Fotonica e Nanotecnologie (Italy); A. Torricelli, Politecnico di Milano (Italy); R. Cubeddu, Politecnico di Milano (Italy), Istituto di Fotonica e Nanotecnologie (Italy), and ULTRAS-INFM-CNR (Italy); F. Martelli, G. Zaccanti, Univ. degli Studi di Firenze (Italy); A. Dalla Mora, A. Tosi, Politecnico di Milano (Italy); F. Zappa, S. Cova, Politecnico di Milano (Italy) and Micro Photon Devices (Italy)
- 7681 05 **Characterisation of photon counting systems at NPL** [7681-05]
E. Theocharous, J. Cheung, C. Chunnillal, National Physical Lab. (United Kingdom)

SESSION 2 PHOTON COUNTING APPLICATIONS AND TECHNIQUES II

- 7681 07 **A technology review of time-of-flight photon counting for advanced remote sensing (Invited Paper)** [7681-07]
R. A. Lamb, SELEX Galileo Ltd. (United Kingdom)
- 7681 08 **Anti-aliasing techniques in photon-counting depth imaging using GHz clock rates** [7681-08]
N. J. Krichel, A. McCarthy, R. J. Collins, G. S. Buller, Heriot-Watt Univ. (United Kingdom)
- 7681 09 **Cross strip microchannel plate imaging photon counters with high time resolution** [7681-09]
O. H. W. Siegmund, J. V. Vallerga, A. S. Tremsin, Univ. of California, Berkeley (United States); L. C. Stonehill, R. Shirey, M. W. Rabin, D. C. Thompson, Los Alamos National Lab. (United States)

SESSION 3 PHOTON COUNTING APPLICATIONS AND TECHNIQUES III

- 7681 0A **Photon counting detector for laser time transfer and optical navigation in space (Invited Paper)** [7681-10]
J. Blazej, I. Prochazka, J. Kodet, Czech Technical Univ. in Prague (Czech Republic)

SESSION 4 SUPERCONDUCTING SINGLE-PHOTON DETECTORS

7681 0D **Superconducting transition-edge sensors optimized for high-efficiency photon-number resolving detectors (Invited Paper)** [7681-13]

A. E. Lita, B. Calkins, L. A. Pellouchoud, National Institute of Standards and Technology (United States); A. J. Miller, Albion College (United States); S. Nam, National Institute of Standards and Technology (United States)

7681 0H **A superconducting nanowire single-photon detector system for single-photon source characterization** [7681-17]

C. R. Fitzpatrick, Heriot-Watt Univ. (United Kingdom) and National Physical Lab. (United Kingdom); C. M. Natarajan, R. E. Warburton, G. S. Buller, Heriot-Watt Univ. (United Kingdom); B. Baek, S. Nam, National Institute of Standards and Technology (United States); S. Miki, Z. Wang, M. Sasaki, National Institute of Information and Communications Technology (Japan); A. G. Sinclair, National Physical Lab. (United Kingdom); R. H. Hadfield, Heriot-Watt Univ. (United Kingdom)

SESSION 5 SINGLE-PHOTON SOURCES

7681 0I **Room-temperature single-photon sources: design, performance, and applications (Invited Paper)** [7681-18]

M. Barth, D. Höckel, L. Koch, S. Schietinger, T. Schröder, T. Aichele, O. Benson, Humboldt-Univ. zu Berlin (Germany)

SESSION 6 SINGLE-PHOTON AVALANCHE DIODES I

7681 0K **Simulations of avalanche breakdown statistics: probability and timing (Invited Paper)** [7681-20]

J. S. Ng, C. H. Tan, J. P. R. David, The Univ. of Sheffield (United Kingdom)

7681 0L **Photon-timing jitter dependence on the injection position in single-photon avalanche diodes** [7681-21]

M. Assanelli, A. Ingarciola, I. Rech, A. Gulinatti, M. Ghioni, Politecnico di Milano (Italy)

7681 0M **Planar silicon SPADs with improved photon detection efficiency** [7681-22]

A. Gulinatti, F. Panzeri, I. Rech, Politecnico di Milano (Italy); P. Maccagnani, IMM-CNR sezione di Bologna (Italy); M. Ghioni, S. D. Cova, Politecnico di Milano (Italy) and Micro-Photon-Devices (Italy)

SESSION 7 SINGLE-PHOTON AVALANCHE DIODES II

7681 0N **Progress towards photon counting between 1 μ m and 1.6 μ m using silicon with infrared absorbers (Invited Paper)** [7681-23]

A. P. Morrison, Univ. College Cork (Ireland) and Tyndall National Institute (Ireland); J. M. Hayes, Tyndall National Institute (Ireland); F. Gity, Univ. College Cork (Ireland) and Tyndall National Institute (Ireland); B. Corbett, Tyndall National Institute (Ireland)

- 7681 OP **Hybridization process for back-illuminated silicon Geiger-mode avalanche photodiode arrays** [7681-25]
D. R. Schuette, R. C. Westhoff, A. H. Loomis, D. J. Young, J. S. Ciampi, B. F. Aull, R. K. Reich, MIT Lincoln Lab. (United States)
- 7681 OQ **Antimonide-based Geiger-mode avalanche photodiodes for SWIR and MWIR photon counting (Invited Paper)** [7681-26]
E. K. Duerr, M. J. Manfra, M. A. Diagne, R. J. Bailey, J. J. Zayhowski, J. P. Donnelly, M. K. Connors, M. J. Grzesik, G. W. Turner, MIT Lincoln Lab. (United States)

SESSION 8 SINGLE-PHOTON AVALANCHE DIODES III

- 7681 OR **InGaAs/InP SPADs for near-infrared applications: device operating conditions and dedicated electronics (Invited Paper)** [7681-27]
A. Tosi, A. Dalla Mora, Politecnico di Milano (Italy); S. Tisa, Micro Photon Devices S.r.l. (Italy); F. Acerbi, Politecnico di Milano (Italy); F. Zappa, S. Cova, Politecnico di Milano (Italy) and Micro Photon Devices S.r.l. (Italy)
- 7681 OS **High-performance InGaAs/InP-based single-photon avalanche diode with reduced afterpulsing** [7681-28]
C. Hu, X. Zheng, J. C. Campbell, Univ. of Virginia (United States); B. M. Onat, X. Jiang, M. A. Itzler, Princeton Lightwave, Inc. (United States)
- 7681 OU **Bias-dependant jitter of InGaAs(P) single-photon detectors** [7681-30]
W. H. Farr, K. Birnbaum, Jet Propulsion Lab. (United States)

SESSION 9 SINGLE-PHOTON AVALANCHE DIODES IV

- 7681 OV **Single-photon detectors based on InP avalanche diodes: status and prospects** [7681-31]
M. A. Itzler, X. Jiang, M. Entwistle, B. M. Onat, K. Slomkowski, Princeton Lightwave, Inc. (United States)
- 7681 OW **Modeling negative feedback in single-photon avalanche diodes (Invited Paper)** [7681-32]
M. M. Hayat, D. A. Ramirez, The Univ. of New Mexico (United States); G. J. Rees, The Univ. of Sheffield (United Kingdom); M. A. Itzler, Princeton Lightwave, Inc. (United States)
- 7681 OX **High-gain and low-excess noise near-infrared single-photon avalanche detector arrays** [7681-33]
K. Linga, Y. Yevtukhov, B. Liang, Amplification Technologies, Inc. (United States)
- 7681 OY **Comparison of linear-mode avalanche photodiode lidar receivers for use at one-micron wavelength** [7681-34]
M. A. Krainak, X. Sun, G. Yang, NASA Goddard Space Flight Ctr. (United States); W. Lu, MEI Technologies (United States)
- 7681 OZ **2.23 GHz gating InGaAs/InP single-photon avalanche diode for quantum key distribution** [7681-35]
J. Zhang, P. Eraerds, N. Walenta, C. Barreiro, R. Thew, H. Zbinden, Univ. of Geneva (Switzerland)

7681 10

Iqueye: a single-photon counting very high-speed photometer for the ESO 3.5m NTT (Invited Paper) [7681-04]

C. Barbieri, Univ. degli Studi di Padova (Italy); G. Naletto, Univ. degli Studi di Padova (Italy) and CNR-IFN (Italy); I. Capraro, T. Occhipinti, Univ. degli Studi di Padova (Italy) and ADAPTICA (Italy); E. Verroi, Univ. degli Studi di Padova (Italy); P. Zoccarato, S. Gradari, Univ. degli Studi di Padova (Italy) and CISAS, Univ. degli Studi di Padova (Italy); M. Barbieri, INAF (Italy); C. Germana, Univ. degli Studi di Padova (Italy); L. Zampieri, E. Giro, INAF (Italy); V. Da Deppo, Univ. degli Studi di Padova (Italy) and CNR-IFN (Italy); A. Di Paola, INAF (Italy); C. Facchinetti, Agenzia Spaziale Italiana (Italy); P. Bolli, C. Pernechele, S. Billotta, G. Bonanno, M. Belluso, F. Messina, INAF (Italy); M. Zaccariotto, CISAS, Univ. degli Studi di Padova (Italy) and Univ. degli Studi di Padova (Italy)

Author Index

Conference Committee

Symposium Chair

Michael T. Eismann, Air Force Research Laboratory (United States)

Symposium Cochair

William Jeffrey, HRL Laboratories, LLC (United States)

Conference Chairs

Mark A. Itzler, Princeton Lightwave, Inc. (United States)

Joe C. Campbell, University of Virginia (United States)

Program Committee

Gerald S. Buller, Heriot-Watt University (United Kingdom)

Sergio D. Cova, Politecnico di Milano (Italy)

William H. Farr, Jet Propulsion Laboratory (United States)

Robert H. Hadfield, Heriot-Watt University (United Kingdom)

Majeed M. Hayat, The University of New Mexico (United States)

Michael A. Krainak, NASA Goddard Space Flight Center (United States)

Alan L. Migdall, National Institute of Standards and Technology (United States)

Simon Verghese, MIT Lincoln Laboratory (United States)

Michael Wahl, PicoQuant GmbH (Germany)

Hugo Zbinden, University of Geneva (Switzerland)

Session Chairs

- 1 Photon Counting Applications and Techniques I
Michael Wahl, PicoQuant GmbH (Germany)
- 2 Photon Counting Applications and Techniques II
Gerald S. Buller, Heriot-Watt University (United Kingdom)
- 3 Photon Counting Applications and Techniques III
Michael A. Krainak, NASA Goddard Space Flight Center (United States)
- 4 Superconducting Single-Photon Detectors
Robert H. Hadfield, Heriot-Watt University (United Kingdom)

- 5 Single-Photon Sources
William H. Farr, Jet Propulsion Laboratory (United States)
- 6 Single-Photon Avalanche Diodes I
Majeed M. Hayat, The University of New Mexico (United States)
- 7 Single-Photon Avalanche Diodes II
Joe C. Campbell, University of Virginia (United States)
- 8 Single-Photon Avalanche Diodes III
Mark A. Itzler, Princeton Lightwave, Inc. (United States)
- 9 Single-Photon Avalanche Diodes IV
Alberto Tosi, Politecnico di Milano (Italy)

Introduction

The conference on Advanced Photon Counting Techniques had a successful second year after transitioning to the SPIE Defense, Security, and Sensing Symposium in Orlando last year. This conference again exhibited strong relevance to applications and topics addressed by other conferences at this venue.

The two-day conference began with three sessions dedicated to the applications and techniques of photon counting. Two of the most prevalent applications of photon counting—viz., fluorescence techniques for biological systems, and single-photon time-of-flight measurements for three-dimensional imaging—were well-represented in these sessions. Additional sessions provided treatments of other areas of photon counting technology such as superconducting single-photon detectors and single-photon sources.

The second day of the conference was primarily dedicated to four sessions covering advances related to single-photon avalanche diodes (SPADs). Once again, talks in these sessions covered devices employing a variety of materials systems. Considerable progress was described for more established device technologies represented by Si and InP/InGaAs SPADs, and the use of more novel material systems included recent studies of antimonide-based SPADs for midwave infrared detection and silicon-based devices with infrared absorbers. Specific SPAD performance attributes such as afterpulsing and timing jitter were described in more focused studies, and the role of electronic circuits required for SPAD operation was also covered. Finally, several papers covering recent progress in the design of self-quenching SPADs for longer wavelength ($> 1 \mu\text{m}$) single-photon detection demonstrated the continued interest in this area.

The recent growth in the science, technology, and application of photon counting for advanced sensing has continued steadily over the last year. As the content of these Proceedings show, the SPIE annual conference on Advanced Photon Counting Techniques has established itself as an important event in this field.

Mark A. Itzler
Joe C. Campbell

