

2nd Canterbury Conference on OCT with Emphasis on Broadband Optical Sources

Adrian Podoleanu

Ole Bang

Editors

6–8 September 2017

Canterbury, United Kingdom

Organized by

Applied Optics Group, School of Physical Sciences, University of Kent (United Kingdom)

NKT Photonics (Denmark)

Technical University of Denmark (Denmark)

Published by

SPIE

Volume 10591

Proceedings of SPIE, 1605-7422, V. 10591

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

2nd Canterbury Conference on OCT with Emphasis on Broadband Optical Sources,
edited by Adrian Podoleanu, Ole Bang, Proc. of SPIE Vol. 10591, 1059101
© 2018 SPIE · CCC code: 1605-7422/18/\$18 · doi: 10.1117/12.2314878

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 *2nd Canterbury Conference on OCT with Emphasis on Broadband Optical Sources*, edited by Adrian Podoleanu, Ole Bang, Proceedings of SPIE Vol. 10591 (SPIE, Bellingham, WA, 2018) Seven-digit Article CID Number.

ISSN: 1605-7422
ISSN: 2410-9045 (electronic)

ISBN: 9781510616745
ISBN: 9781510616752 (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 © 2018, 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 1605-7422/18/\$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. 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*
- xiii *Introduction*
- xv *Conference Sponsorship and Support*

OCT IN OPHTHALMOLOGY

- 10591 02 **New clinical opportunities for retinal vascular imaging: adaptive optics to OCT angiography (Invited Paper)** [10591-50]
- 10591 03 **Subretinal hyper-reflective material seen on optical coherence tomography as a biomarker for disease monitoring in age-related macular degeneration** [10591-44]
- 10591 04 **Supercontinuum ultra-high resolution line-field OCT; experimental spectrograph comparison and comparison with current clinical OCT systems by the imaging of a human cornea** [10591-43]
- 10591 05 **Use of a supercontinuum white light in evaluating the spectral sensitivity of the pupil light reflex** [10591-41]
- 10591 06 **Superpixel guided active contour segmentation of retinal layers in OCT volumes** [10591-21]

OCT ANGIOGRAPHY, MICROSCOPY, AND ENDOSCOPY

- 10591 07 **OCT-based angiography in real time with hand-held probe** [10591-6]
- 10591 08 **Assessing embryo development using swept source optical coherence tomography** [10591-26]
- 10591 09 **Tissue imaging using full field optical coherence microscopy with short multimode fiber probe (Invited Paper)** [10591-3]
- 10591 0A **Towards an ultra-thin medical endoscope: multimode fibre as a wide-field image transferring medium** [10591-34]

NOISE IN SUPERCONTINUUM

- 10591 0B **Low-noise supercontinuum sources based on all-normal dispersion fibers: exploring their prospects and limitations (Invited Paper)** [10591-47]

10591 OC **Noise study of all-normal dispersion supercontinuum sources for potential application in optical coherence tomography [10591-32]**

ADDRESSING THE BROADBAND CHALLENGE

10591 OD **Resolution dependence on phase extraction by the Hilbert transform in phase calibrated and dispersion compensated ultrahigh resolution spectrometer-based OCT [10591-20]**

MULTIMODAL APPROACHES

10591 OE **Phase sensitive optical coherence microscopy for photothermal imaging of gold nanorods [10591-39]**

10591 OF **Photonic compressive sensing enabled data efficient time stretch optical coherence tomography [10591-31]**

NONDESTRUCTIVE TESTING AND ART CONSERVATION

10591 OG **(Full field) optical coherence tomography and applications [10591-45]**

10591 OH **Impact of absorption in the top layer of a two layer sample on spectroscopic spectral domain interferometry of the bottom layer [10591-12]**

OCT IN DENTISTRY

10591 OI **Investigation of firing temperature variation in ovens for ceramic-fused-to-metal dental prostheses using swept source optical coherence tomography [10591-11]**

10591 OJ **OCT investigation of dental lesions [10591-36]**

10591 OK **New ways of combating demineralization: link between classic and allopathic medicine [10591-7]**

10591 OL **OCT aspects of dental hard tissue changes induced by excessive occlusal forces [10591-35]**

10591 OM **Dental impression technique using optoelectronic devices [10591-8]**

CONDITIONING THE SIGNAL

10591 ON **Swept source optical coherence tomography of objects with arbitrary reflectivity profiles [10591-28]**

10591 OO **Coherence and diffraction limited resolution in microscopic OCT by a unified approach for the correction of dispersion and aberrations [10591-48]**

- 10591 OP **Fast detection of vascular plaque in optical coherence tomography images using a reduced feature set** [10591-29]
- 10591 OQ **Phase estimation for global defocus correction in optical coherence tomography** [10591-46]
- 10591 OR **Increasing signal-to-noise ratio of swept-source optical coherence tomography by oversampling in k-space** [10591-27]
- 10591 OS **Reduction of measurement errors in OCT scanning** [10591-13]
- 10591 OT **Long axial imaging range using conventional swept source lasers in optical coherence tomography via re-circulation loops** [10591-14]

MASTER SLAVE OCT

- 10591 OU **From master slave interferometry to complex master slave interferometry: theoretical work (Invited Paper)** [10591-49]

RANDOM LASERS AND SWEEP SOURCES

- 10591 OV **Optimisation of a polygon mirror-based spectral filter for swept source optical coherence tomography (SS-OCT)** [10591-30]
- 10591 OW **Stable supercontinuum source based on random lasing** [10591-24]

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.

Abe, Hiroyuki, 09
Agemy, Steven, 02
Ahrens, M., 0O
Bai, Fangliang, 06
Bang, Ole, 0C, 0D, 0Q
Barua, Souman, 0M
Bradu, Adrian, 08, 0A, 0D, 0I, 0M, 0T, 0U
Buchroithner, Boris, 0G
Carroll, Joseph, 02
Caujolle, S., 08
Cernat, R., 08
Chin, Catherine, 05
Chui, Toco, 02
Dobre, George, 0E, 0V
Dubra, Alfredo, 02
Duma, Virgil-Florin, 0I, 0M, 0V
Đuriš, Miroslav, 0A
Engelholm, R. D., 0C
Eto, Kai, 09
Everson, Michael, 0V
Fernando, Namal, 0N, 0R
Feuchter, Thomas, 08, 0D, 0H, 0U
Feurer, Thomas, 0B
Fleischhauer, F., 0H
Gabor, Alin Gabriel, 0M
Garcia, Patricia, 02
Gelikonov, Grigory V., 07
Gelikonov, Valentine M., 07
Gibson, Stuart J., 06
Gonzalo, I. B., 0C
Goto, Tetsuhiro, 09
Griffin, D., 08
Hanneschläger, Günther, 0G
Heidt, Alexander M., 0B
Heise, Bettina, 0G
Hewko, Mark, 0P
Hillmann, D., 0O
Hu, Yong, 0E
Hughes, Michael, 0A
Hüftmann, G., 0O
Idorași, Laura, 0K
Israelsen, Niels M., 0D, 0Q
Jackson, David A., 0T
Jensen, Mikkel, 0Q
Katta, M., 03
König, P., 0O
Kordi, Behzad, 0N, 0R
Krawitz, Brian, 02
Ksenofontov, Sergey Yu., 07
Kurotani, Reiko, 09
Lall, Gurprit S., 05
Lawman, Samuel, 04
Lee, H. B., 03
Leick, Lasse, 05, 0H, 0U
Leiss-Holzinger, Elisabeth, 0G
Lu, L., 03
Ma, Rui, 0W
Madden, Peter W., 04
Maria, Michael, 0D, 0U
Marques, Manuel J., 06, 08
Mason, Sharon, 04
Mercuț, Răzvan, 0J
Mercuț, Veronica, 0J, 0L
Mezgebo, Biniyam, 0N, 0R
Mididoddi, Chaitanya K., 0F
Mo, Shelley, 02
Moiseev, Alexander A., 07
Morel, E. N., 0S
Münter, Michael, 0O
Nagib, Karim, 0N, 0R
Negruțiu, Meda-Lavinia, 0I, 0K, 0M
Nishidate, Izumi, 09
Ocana Macias, Mariano, 0P
Ogodescu, Alexandru, 0K
Ong, B. B., 03
Osiac, Eugen, 0J, 0L
Patel, N., 03
Pinhas, Alexander, 02
Podoleanu, Adrian Gh., 05, 06, 08, 0A, 0D, 0E,
0H, 0I, 0K, 0M, 0Q, 0T, 0U
Popescu, Sanda Mihaela, 0J, 0L
Prakash, Ammu, 0P
Prylepa, Andrii, 0G
Rajendram, R., 0H
Rao, Yun Jiang, 0W
Rivet, Sylvain, 0U
Robinson, G., 08
Romano, Vito, 04
Romînu, Mihai, 0I
Rosen, Richard, 02
Sallese, M., 0S
Sato, Manabu, 09
Schulz-Hildebrandt, H., 0O
Scriciu, Monica, 0J, 0L
Scripsema, Nicole, 02
Secoșan, Sandra Andreea, 0K
Shen, Yao-Chun, 04
Sherif, Sherif S., 0N, 0P, 0R

Silvestri, G., 08
Sinescu, Cosmin, 0I, 0K, 0M
Sowa, Michael, 0P
Spahr, H., 0O
Stan, Adrian Tudor, 0K
Tabla, P. M., 0S
Tărăță, Daniela, 0L
Terpelov, Dmitry A., 07
Thakur, Rahul, 0R
Todor, Raluca, 0I
Topala, Florin Ionel, 0I, 0M
Torga, J. R., 0S
Vătu, Mihaela, 0J
Wang, Chao, 0F
Weitz, Rishard, 02
Williams, Bryan M., 04
Wu, Han, 0W
Yvon, C., 03
Zaharia, Cristian, 0K, 0M
Zakri, R., 03
Zeng, Xiong, 0W
Zhang, Wei Li, 0W
Zheng, Yalin, 04

Conference Committee

Conference Chairs

Adrian Podoleanu, University of Kent (United Kingdom)
Ole Bang, Technical University of Denmark (Denmark)

Local Executive Committee

Adrian Bradu, University of Kent (United Kingdom)
George M. Dobre, University of Kent (United Kingdom)
Michael Hughes, Imperial College London (United Kingdom)

Local Support Committee

Magalie Bondu, NKT Photonics (Denmark) and University of Kent (United Kingdom)
Caroline Catherine Chin, NKT Photonics (Denmark) and University of Kent (United Kingdom)
Sophie Caujolle, NKT Photonics (Denmark) and University of Kent (United Kingdom)
Michael Everson, University of Kent (United Kingdom)
Thomas Feuchter, NKT Photonics (Denmark)
Felix T. Fleischhauer, NKT Photonics (Denmark) and University of Kent (United Kingdom)
Yong Hu, University of Kent (United Kingdom)
Peter Lee, University of Kent (United Kingdom)
Lasse Leick, NKT Photonics (Denmark)
Michael Maria, NKT Photonics (Denmark) and University of Kent (United Kingdom)
Manuel Jorge Marques, University of Kent (United Kingdom)
Peter Moselund, NKT Photonics (Denmark)
Ranjan Rajendram, Moorfields Eye Hospital (United Kingdom)
John B Schofield, Maidstone Tunbridge Wells NHS Trust (United Kingdom)

International Advisory Committee

Adrian Podoleanu, University of Kent (United Kingdom)
Ole Bang, Technical University of Denmark (Denmark)
John Clowes, NKT Photonics (Denmark)
John Dudley, Université de Franche-Comte (France)
Grigory Gelikonov, Institute of Applied Physics (Russian Federation)
Rainer Leitgeb, Medizinische Universität Wien (Austria)

Michael Leitner, Thorlabs (Germany)
Xingde Li, The Johns Hopkins University (United States)
David D. Sampson, The University of Western Australia (Australia)
Manabu Sato, Yamagata University (Japan)
Kevin Tsia, The University of Hong Kong (Hong Kong China)
Frederique Vanholsbeeck, The University of Auckland (New Zealand)
Maciej Wojtkowski, Polish Academy of Sciences (Poland)
Daniel Woods, Michelson Diagnostic (United Kingdom)
Hao F. Zhang, Northwestern University (United States)

OSA Student Chapter at the University of Kent

Magalie Bondu, NKT Photonics (Denmark) and University of Kent
(United Kingdom)
Sophie Caujolle, NKT Photonics (Denmark) and University of Kent
(United Kingdom)
Samuel Edeagu, University of Kent (United Kingdom)
Michael Everson, University of Kent (United Kingdom)
Felix T. Fleischhauer, NKT Photonics (Denmark) and University of Kent
(United Kingdom)
Yong Hu, University of Kent (United Kingdom)
Chaitanya K. Mididoddi, University of Kent (United Kingdom)

Session Chairs

- 1 OCT in Ophthalmology I
Adrian Podoleanu, University of Kent (United Kingdom)
- 2 OCT in Ophthalmology II
Richard Rosen, New York Eye and Ear Infirmary (United States)
- 3 OCT Angiography, Microscopy, and Endoscopy
Haida Liang, Nottingham Trent University (United Kingdom)
- 4 Noise in Supercontinuum
Patrick Bowen, NKT Photonics (Denmark)
- 5 Industry Forum I
Adrian Podoleanu, University of Kent (United Kingdom)
- 6 Addressing the Broadband Challenge
David D. Sampson, The University of Western Australia (Australia)
- 7 Multimodal Approaches
Frederique Vanholsbeeck, The University of Auckland (New Zealand)

- 8 Nondestructive Testing and Art Conservation
Michael Hughes, Imperial College London (United Kingdom)
- 9 OCT in Dentistry
Grigory Gelikonov, Institute of Applied Physics (Russian Federation)
- 10 Conditioning the Signal
Adrian Podoleanu, University of Kent (United Kingdom)
- 11 Master Slave OCT
Yun-Jiang Rao, University of Electronic Science and Technology of
China (China)
- 12 Industry Forum II
Adrian Bradu, University of Kent (United Kingdom)
- 13 Random Lasers and Swept Sources
George M. Dobre, University of Kent (United Kingdom)

Introduction

Welcome to the proceedings from the 2nd Canterbury Conference on Optical Coherence Tomography with Emphasis on Broadband Optical Sources (2CCOCT), held 6-8 September 2017 at the University of Kent, Canterbury, UK.

This marks the second international conference that the University of Kent has organized on OCT. In 2017, the researchers in OCT celebrated 20 years since here, in the University of Kent, the first in-vivo en-face OCT image of the human retina was produced, and 19 years since the OCT/SLO instrument was invented within the Applied Optics Group. This represented the combination of the new (OCT) and old technology (scanning laser ophthalmoscopy, SLO) for imaging the back of the eye, in one instrument, that as a concept, the OCT/SLO instrument has since known a wide spread in different facets.

The University of Kent welcomed participants from Argentina, Australia, Austria, Canada, China, Denmark, France, Germany, Japan, New Zealand, Romania, Russia, UK, and USA, well-respected professionals in their fields—academia, health, higher education and industry. The university also welcomed several participants whose career paths crossed through the Applied Optics Group.

The conference was organised around the 3rd Network event of the European Industrial Doctoral School, "Ultrawide Bandwidth Photonics Devices, Sources and Applications" (UBAPHODESA, 607627, 2014-2018), supported by the Marie Curie Action, European Commission. The European Industrial Doctoral School has educated five early-stage researchers (ESRs), who spent 18 months at the Applied Optics Group, University of Kent, and then 18 months at NKT Photonics (Denmark), complemented by short stages at the associated partners: Institute of Ophthalmology of the University College London, Northwick Park Hospital (NPH) London, Optos Plc-Scotland, Technical University of Denmark, and Northwestern University (United States).

During the three-day conference, the ESRs presented their achievements after their three years of PhD training in an industrial setting, on optical coherence tomography (OCT), photoacoustics, supercontinuum lasers, and their clinical and industrial applications.

The organisers are grateful for the support of the Marie Curie training site, as well as of the companies, NKT Denmark, Superlum (Ireland), Santec (Japan), and Thorlabs (Germany).

With their support and with that of contributors from so many countries, this event that initially aimed to be a local network gathering has become a truly international conference.

The organisers acknowledge the support of SPIE. The papers in this conference proceedings volume will be published on the SPIE Digital Library and will be visible worldwide – as are the papers from the *1st Canterbury Workshop in Optical Coherence Tomography and Adaptive Optics*, SPIE Volume 7138 (2008). The other major society for this community, The Optical Society, was present at the conference with its Student Chapter at the University of Kent. Its chapter sponsored the best oral presentation of an ESR.

Adrian Podoleanu
Ole Bang

Conference Sponsorship and Support

Organized by

Applied Optics Group, School of Physical Sciences, University of Kent
(United Kingdom)

NKT Photonics (Denmark)

Technical University of Denmark (Denmark)

Sponsored by

European Commissions, Marie Curie European Industrial Doctorate School,
Ultrawide Bandwidth Photonics Devices, Sources and Applications,
(UBAPHODESA, 607627, 2014-2018), University of Kent (United Kingdom)

NKT Photonics (Denmark)

EPSRC Image-Guided Therapies UK Network+ (United Kingdom)

OSA Student Chapter, University of Kent (United Kingdom)

NKT Photonics (Denmark)

Superlum (Ireland)

Santec (Japan)

Thorlabs (Germany)

University of Kent (United Kingdom)

