

PROCEEDINGS OF SPIE

Broadband Access Communication Technologies XI

Benjamin B. Dingel
Katsutoshi Tsukamoto
Spiros Mikroulis
Editors

31 January–1 February 2017
San Francisco, California, United States

Sponsored by
SPIE

Cosponsored by
Corning Incorporated (United States)
NTT Electronics Corporation (Japan)

Published by
SPIE

Volume 10128

Proceedings of SPIE 0277-786X, V. 10128

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

Broadband Access Communication Technologies XI, edited by Benjamin B. Dingel,
Katsutoshi Tsukamoto, Spiros Mikroulis, Proc. of SPIE Vol. 10128, 1012801
© 2017 SPIE · CCC code: 0277-786X/17/\$18 · doi: 10.1117/12.2275082

Proc. of SPIE Vol. 10128 1012801-1

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 *Broadband Access Communication Technologies XI*, edited by Benjamin B. Dingel, Katsutoshi Tsukamoto, Spiros Mikroulis, Proceedings of SPIE Vol. 10128 (SPIE, Bellingham, WA, 2017) Seven-digit Article CID Number.

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

ISBN: 9781510606975
ISBN: 9781510606982 (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 © 2017, 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/17/\$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

- v *Authors*
- vii *Conference Committee*
- ix *Introduction*

OPTO PLENARY SESSION

- 10128 02 **LiFi: transforming fibre into wireless (Plenary Paper)** [10128-202]

OPTICAL COMMUNICATIONS PLENARY SESSION: JOINT SESSION WITH CONFERENCES 10128, 10129, 10130, AND 10131

- 10128 03 **Integrated microwave photonics: a key enabling technology for radio-over-fiber (Invited Paper)** [10128-1]

SPECIAL WORKSHOP ON OPTICAL WIRELESS AND INTEGRATED PHOTONICS TECHNOLOGIES FOR DATA CENTERS: JOINT SESSION WITH CONFERENCES 10128 AND 10131

- 10128 04 **FireFly: reconfigurable optical wireless networking data centers (Invited Paper)** [10128-2]

SILICON PHOTONICS AND ALTERNATIVE TECHNOLOGIES FOR DATA CENTERS AND SHORT HAULS: JOINT SESSION WITH CONFERENCES 10128, 10129, 10130, AND 10131

- 10128 05 **MEMS-based beam-steerable free-space optical communication link for reconfigurable wireless data center** [10128-3]

MILLIMETER-WAVE COMPONENTS AND TECHNOLOGIES AND 5G RADIO-OVER-FIBER (ROF) SYSTEMS FOR ACCESS

- 10128 06 **Radio over optical waveguide system-on-wafer for massive delivery capacity 5G MIMO access networks (Invited Paper)** [10128-4]

- 10128 07 **High-responsivity 100GHz waveguide UTC-photodetector** [10128-5]

- 10128 08 **Millimeter- and terahertz-wave over fiber technologies for high-speed communication and non-telecom applications (Invited Paper)** [10128-6]

- 10128 09 **Array-antenna-electrode electro-optic modulators for millimeter-wave radio-over-fiber systems** [10128-7]

MILLIMETER-WAVE TECHNOLOGIES AND ADVANCED MIMO ROF SYSTEMS

- 10128 0A **Enabling technologies for millimeter-wave radio-over-fiber systems in next generation heterogeneous mobile access networks (Invited Paper)** [10128-8]
- 10128 0B **Coexistence and transmission of multiple radios over seamless fiber-wireless systems (Invited Paper)** [10128-9]
- 10128 0C **802.11ac WLAN MIMO radio-over-fiber distributed antenna system for in-building networks based on multicore fiber** [10128-10]
- 10128 0D **Bidirectional MIMO and SISO 3GPP LTE-advanced fronthaul architectures based on multicore fiber (Invited Paper)** [10128-11]

ADVANCED RADIO-OVER FIBER SYSTEMS FOR ACCESS

- 10128 0E **Integration of power over fiber on RoF systems in different scenarios (Invited Paper)** [10128-12]
- 10128 0F **High-voltage optical power delivery using a light-wave-modulation method** [10128-13]
- 10128 0G **Distribution of multiband THz wireless signals over fibre (Invited Paper)** [10128-14]
- 10128 0I **High-throughput and low-latency 60GHz small-cell network architectures over radio-over-fiber technologies (Invited Paper)** [10128-16]

POSTER SESSION

- 10128 0K **Secure positioning technique based on the encrypted visible light map** [10128-18]
- 10128 0L **A comparative study of optical concentrators for visible light communications** [10128-19]
- 10128 0M **High-power InGaAs/InP MUTC photodetector modules for RF photonics links and ROF** [10128-20]

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.

Akahane, Kouichi, 07, 0F
Aya, Hironori, 09
Beling, Andreas, 0M
Binh, Le N., 06
Campbell, Jenna, 0M
Chang, Gee-kung, 0A
Cheng, Lin, 0A
Cho, Hyunwoo, 0A
Chun, Hyunchoe, 0L
Collins, Stephen, 0L
Contreras, P., 0E
Das, S. R., 04
Deng, Peng, 05
Estrella, Steven, 0M
Faulkner, Grahame, 0L
Fice, Martyn, 0G
Gomez, Ariel, 0L
Gonzalez-Guerrero, Luis, 0G
Guidotti, Daniel, 0A
Gupta, H., 04
Haas, Harald, 02
Hay, Kenneth, 0M
Iezekiel, Stavros, 03
Ikeda, Takashi, 09
Inoue, Toshiyuki, 09
Islim, Mohamed Sufyan, 02
Johansson, Leif, 0M
Jung, G., 0K
Kalfas, G., 0I
Kanno, Atsushi, 07, 08, 0B, 0F
Kavehrad, Mohsen, 04, 05
Kawanishi, Tetsuya, 07, 0B
Kobayashi, Atsushi, 0F
Lee, Y. U., 0K
Li, Quinglong, 0M
Llorente, Roberto, 0C, 0D
Longtin, J., 04
López-Cardona, J. D., 0E
Lou, Yan, 05
Lu, Feng, 0A
Maertz, Brian, 0M
Manousiadis, Pavlos P., 0L
Mashanovitch, Milan, 0M
Matsukawa, Yuuki, 09
Matsumoto, Atsushi, 07, 0F
Miliou, A., 0I
Mitsolidou, C., 0I
Montero, D. S., 0E
Morant, Maria, 0C, 0D
Mulyawan, Rahmat, 0L
Murata, Hiroshi, 09
O'Brien, Dominic, 0L
Okamura, Yasuyuki, 09
Pinzón, P. J., 0E
Pleros, N., 0I
Rajbhandari, Sujjan, 0L
Renaud, Cyril, 0G
Renner, Daniel, 0M
Samuel, Ifor D. W., 0L
Seeds, Alywn, 0G
Sekar, V., 04
Shams, Haymen, 0G
Shen, Shuyi, 0A
Sun, Keye, 0M
Takai, Hiroshi, 0F
Tapetado, A., 0E
Tien Dat, Pham, 0B
Tsiokos, D., 0I
Turnbull, Graham A., 0L
Umezawa, Toshimasa, 07, 0F
Vagionas, C., 0I
Vázquez, C., 0E
Vithanage, Dimali A., 0L
Wang, Jing, 0A
Xu, Mu, 0A
Yamamoto, Naakatsu, 07, 0B, 0F
Yan, Yan, 0A
Yang, Zhen, 0G
Yin, Liang, 02
Yu, Jianjun, 0A
Zhang, Junwen, 0A

Conference Committee

Symposium Chairs

Jean-Emmanuel Broquin, IMEP-LAHC (France)
Shibin Jiang, AdValue Photonics, Inc. (United States)

Symposium Co-chairs

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

Program Track Chair

Benjamin B. Dingel, Nasfine Photonics, Inc. (United States)

Conference Chairs

Benjamin B. Dingel, Nasfine Photonics, Inc. (United States)
Katsutoshi Tsukamoto, Osaka Institute of Technology (Japan)
Spiros Mikroulis, Huawei Technologies Duesseldorf GmbH (Germany)

Conference Program Committee

Frank Deicke, Fraunhofer-Institut für Photonische Mikrosysteme
(Germany)
Harald Haas, The University of Edinburgh (United Kingdom)
Mohsen Kavehrad, The Pennsylvania State University (United States)
Nicholas Madamopoulos, The City College of New York
(United States)
Ken-ichi Sato, Nagoya University (Japan)
Atul K. Srivastava, NEL America, Inc. (United States)

Session Chairs

- 1 Optical Communications Plenary Session: Joint Session with
Conferences 10128, 10129, 10130, and 10131
Benjamin B. Dingel, Nasfine Photonics, Inc. (United States)
Xiang Zhou, Google (United States)

- 2 Special Workshop on Optical Wireless and Integrated Photonics Technologies for Data Centers: Joint Session with Conferences 10128 and 10131
Atul K. Srivastava, NEL America, Inc. (United States)
Guifang Li, CREOL, The College of Optics and Photonics, University of Central Florida (United States)
- 3 Special Workshop on Advanced Optical Fibers and Amplifiers for SDM and Data Centers: Joint Session with Conferences 10129, 10130, and 10131
Guifang Li, CREOL, The College of Optics and Photonics, University of Central Florida (United States)
Atul K. Srivastava, NEL America, Inc. (United States)
- 4 Silicon Photonics and Alternative Technologies for Data Centers and Short Hauls: Joint Session with Conferences 10128, 10129, 10130, and 10131
Youichi Akasaka, Fujitsu Network Communications Inc. (United States)
Benjamin B. Dingel, Nasfine Photonics, Inc. (United States)
- 5 Millimeter-Wave Components and Technologies and 5G Radio-Over-Fiber (RoF) Systems for Access
Katsutoshi Tsukamoto, Osaka Institute of Technology (Japan)
Spiros Mikroulis, Huawei Technologies Duesseldorf GmbH (Germany)
- 6 Millimeter-Wave Technologies and Advanced MIMO RoF Systems
Katsutoshi Tsukamoto, Osaka Institute of Technology (Japan)
Le Binh, Huawei Technologies Duesseldorf GmbH (Germany)
- 7 Advanced Radio-Over Fiber Systems for Access
Roberto Llorente Sáez, Universidad Politècnica de València (Spain)

Introduction

Welcome to the proceedings from the Photonics West OPTO 2017 conference on Broadband Access Communication Technologies XI.

This year we added a new conference chair, Dr. Spiros Mikroulis from Huawei Technologies at European Research Center in Munich, Germany. Dr. Mikroulis was formerly with the Univ. College London, UK.

We continued our tradition in providing multiple-joint-sessions to cut across different areas at these conferences. These excellent joint sessions are made possible through the cooperation and leadership of all the four conference chairs involved. We are very grateful to these conference chairs coming from:

Broadband Access Communication Technologies (Conference 10128),
Optical Metro Networks and Short-Haul Systems IX (Conference 10129),
Next Generation Optical Communication: Components, Sub-Systems, and
Systems VI (Conference 10130), and
Next-Generation Optical Networks for Data Centers and Short-Reach Links IV
(Conference 10131).

We introduced a new Best Student Paper Award selected from the pool of student papers who submit to any of the four different conferences mentioned above. The awards were sponsored by Corning Inc. and NEL America and carry a \$500 prize. We encourage students to submit papers for next year 2018.

Lastly, we thank the speakers and authors of all invited and contributed papers, as well as the technical program committee members for their valuable efforts. We appreciate the great assistance of the SPIE staff that make this conference strong and successful.

Benjamin B. Dingel
Katsutoshi Tsukamoto
Spiros Mikroulis

