PROCEEDINGS OF SPIE

Next-Generation Optical Networks for Data Centers and Short-Reach Links IV

Atul K. Srivastava Editor

31 January–2 February 2017 San Francisco, California, United States

Sponsored by SPIE

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

Published by SPIE

Volume 10131

Proceedings of SPIE 0277-786X, V. 10131

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

Next-Generation Optical Networks for Data Centers and Short-Reach Links IV, edited by Atul K. Srivastava, Proc. of SPIE Vol. 10131, 1013101 · © 2017 SPIE CCC code: 0277-786X/17/\$18 · doi: 10.1117/12.2275092

Proc. of SPIE Vol. 10131 1013101-1

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 SPIEDigitalLibrary.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 Next-Generation Optical Networks for Data Centers and Short-Reach Links IV, edited by Atul K. Srivastava, Proceedings of SPIE Vol. 10131 (SPIE, Bellingham, WA, 2017) Seven-digit Article CID Number.

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

ISBN: 9781510607033 ISBN: 9781510607040 (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.



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

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

- 10131 03 Data center performance improvement using optical wireless links (Invited Paper) [10131-2]
- 10131 04 The role of integrated photonics in datacenter networks (Invited Paper) [10131-3]
- 10131 05 Toward exa-scale optical circuit switch interconnect networks for future datacenter/HPC (Invited Paper) [10131-4]

SPECIAL WORKSHOP ON ADVANCED OPTICAL FIBERS AND AMPLIFIERS FOR SDM AND DATA CENTERS: JOINT SESSION - 10129, 10130, AND 10131

10131 06 Universal fibers for data center applications (Invited Paper) [10131-5]

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

- 10131 07 Chip-scale Si-photonics optical transceiver for a photonics-electronics convergence system (Invited Paper) [10131-6]
- 10131 08 Silicon photonic switch technology for optical networks in telecom and datacom areas (Invited Paper) [10131-7]

ADVANCED SILICON PHOTONICS FOR METRO AND DATA CENTER NETWORKS: JOINT SESSION WITH CONFERENCES 10129 AND 10131

- 10131 09 Photonic integrated devices for high-capacity data-center interconnect (Invited Paper) [10131-8]
- 10131 0A Impairment mitigation in noncoherent optical transmission enabled with machine learning for intra-datacenter networks [10131-9]
- 10131 0B Cost-effective light-emission optical sub-assembly for datacenter networks (Invited Paper) [10131-10]
- 10131 0C Ge/SiGe for silicon photonics (Invited Paper) [10131-11]

100G TRANSMISSION TECHNOLOGIES FOR METRO AND DATA CENTER I: JOINT SESSION WITH CONFERENCES 10129 AND 10131

10131 OD Systems and technologies for high-speed inter-office/datacenter interface (Invited Paper) [10131-12] Optically amplified 100-gigabit ethernet (Invited Paper) [10131-13] 10131 OE 100G TRANSMISSION TECHNOLOGIES FOR METRO AND DATA CENTER II: JOINT SESSION WITH CONFERENCES 10129 AND 10131 10131 OF MPI investigation for 40G NRZ link with low-RL cable assemblies (Invited Paper) [10131-14] 10131 0G Recent standardization activities for client and networking optical transceivers and its future directions (Invited Paper) [10131-15] **POSTER SESSION** 10131 OH Model establishing and performance analysis of service stratum traffic in the integrated sensing network [10131-16]

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.

Adachi, K., OB Arnon, Shlomi, 03 Berdinskikh, Tatiana, OF Buscamante, Yesica R. R., 09 Chen, Xin, 06 Chiuchiarelli, Andrea, 09 Coleman, Doug, 06 de Carvalho, Luis H. H., 09 de Farias, Giovanni B., 09 Faysanyo, Pitak, OF Freitas, Alexandre P., 09 Fujikata, J., 07 Fukutoku, M., OD Ge, Zhiqun, OH Glick, Madeleine, 04 Gurreri, Michael, OF Hagihara, Y., 07 Hasegawa, Hiroshi, 0A Hurley, Jason E., 06 Ibusuki, Y., 07 Inoue, Takashi, 05 Ishii, Kiyo, 05 Ishikawa, Yasuhiko, OC Isono, Hideki, OG Ito, Keisuke, OA Kurata, K., 07 Kurihara, M., 07 Li, Ming-Jun, 06 Mori, Yojiro, OA Motta, Diogo de A., 09 Moura, Uiara C., 09 Nakahara, K., OB Nakamura, Shigeru, 08 Nakamura, T., 07 Nakanishi, A., OB Namiki, Shu, 05 Naoe, K., OB Nishizawa, H., OD Niwa, Masaki, 0A Ogura, I., 07 Reis, Jacklyn D., 09 Santana, Henrique F., 09 Satake, Toshiaki, OF Sato, Ken-ichi, OA Sone, Y., 0D Spiekman, Leo, OE Stone, Jeffery S., 06 Sun, Xiaohan, OH Suzuki, T., OB

Tajima, Akio, 08 Takeshita, Hitoshi, 08 Tamura, K. R., 0B Tanaka, S., 0B Thongdaeng, Rutsuda, 0F Ueda, Koh, 0A Wang, Ying, 0H Yamamoto, S., 0D Yanagimachi, Shigeyuki, 08 Yashiki, K., 07 Yoshimatsu, T., 0D Zakharian, Aramais R, 06 Zhang, Xiaolu, 0H Zhao, Xinqun, 0H

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 Chair

Atul K. Srivastava, NEL America, Inc. (United States)

Conference Program Committee

Philippe P Absil, IMEC (Belgium)
Kasyapa Balemarthy, OFS Optics (India)
Benjamin B. Dingel, Nasfine Photonics, Inc. (United States)
Mitchell H. Fields, Avago Technologies Ltd. (United States)
Hideki Isono, Fujitsu Ltd. (Japan)
Hai-Feng Liu, Intel Corporation (United States)
B. Jonathan Luff, Mellanox Technologies, Inc. (United States)
Takahiro Nakamura, Photonics Electronics Technology Research Association (Japan)
Jacklyn D. Reis, CPqD (Brazil)
Takashi Saida, NTT Photonics Laboratories (Japan)
Ivan Shubin, Oracle (United States)
Takashi Takemoto, Hitachi, Ltd. (Japan)

Session Chairs

 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) 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 Advanced Silicon Photonics for Metro and Data Center Networks: Joint Session with Conferences 10129 and 10131
 Philippe P. Absil, IMEC (Belgium) Jianjun Yu, ZTE USA (United States)
- 6 100G Transmission Technologies for Metro and Data Center I: Joint Session with Conferences 10129 and 10131
 Yuta Ueda, NTT Photonics Laboratories (Japan)
 Achyut K. Dutta, Banpil Photonics, Inc. (United States)
- 7 100G Transmission Technologies for Metro and Data Center II: Joint Session with Conferences 10129 and 10131
 Kiyo Ishii, National Institute of Advanced Industrial Science and Technology (Japan)