

PROCEEDINGS OF SPIE

Terahertz, RF, Millimeter, and Submillimeter-Wave Technology and Applications IX

Laurence P. Sadwick
Tianxin Yang
Editors

15–18 February 2016
San Francisco, California, United States

Sponsored by
SPIE

Cosponsored by
Hübner GmbH & Company KG (Germany)

Published by
SPIE

Volume 9747

Proceedings of SPIE 0277-786X, V. 9747

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

Terahertz, RF, Millimeter, and Submillimeter-Wave Technology and Applications IX,
edited by Laurence P. Sadwick, Tianxin Yang, Proc. of SPIE Vol. 9747, 974701
© 2016 SPIE · CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2239389

Proc. of SPIE Vol. 9747 974701-1

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 *Terahertz, RF, Millimeter, and Submillimeter-Wave Technology and Applications IX*, edited by Laurence P. Sadwick, Tianxin Yang, Proceedings of SPIE Vol. 9747 (SPIE, Bellingham, WA, 2016) Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)
ISBN: 9781628419825

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.



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 six-digit CID article numbering system structured as follows:

- 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.

Contents

vii	Authors
xi	Conference Committee

SESSION 1 THZ TECHNOLOGY I

- 9747 03 **Sub-wavelength nano-electrode structures to improve the performance of terahertz photomixers** [9747-2]
- 9747 04 **Simulation, fabrication, and measurement of a plasmonic-enhanced terahertz photoconductive antenna** [9747-9]

SESSION 2 THZ TECHNOLOGY II

- 9747 07 **Low-bias gate tunable terahertz plasmonic signatures in chemical vapour deposited graphene of varying grain size** [9747-6]
- 9747 09 **Thickness measurement of tablet coating using continuous-wave terahertz reflection spectroscopy** [9747-8]

SESSION 3 GHZ TECHNOLOGY

- 9747 0B **Use of optical speckle patterns for compressive sensing of RF signals in the GHz band** [9747-11]
- 9747 0C **Oxygen detection system consisting of a millimeter wave Fabry-Pérot resonator and an integrated SiGe front-end** [9747-14]
- 9747 0D **High-efficiency W-band hybrid integrated photoreceiver module using UTC-PD and pHEMT amplifier** [9747-12]
- 9747 0E **Optical resonators metrology using an RF-spectrum approach (Best Student Paper Award)** [9747-13]

SESSION 4 THZ SENSING AND DETECTION

- 9747 0F **Development of terahertz endoscopic system for cancer detection (Invited Paper)** [9747-15]
- 9747 0G **Characterizations of diffractive microlens in Nb₅N₆ microbolometers array for THz detection** [9747-16]

9747 OK **Fourier domain interferometry-based spotlight-mode synthetic-aperture optical imaging system for use from low-earth orbit** [9747-20]

SESSION 5 MATERIALS FOR THZ AND GHZ

9747 OM **Textured semiconductors for enhanced photoconductive terahertz emission** [9747-22]

9747 ON **Microfabrication of SU-8 Fresnel lenses for THz imaging** [9747-23]

9747 OO **Perfect absorber metamaterial for real time detection and recognition of micro-poisons in aqueous solutions and atmosphere using millimeter wavelength spectroscopy** [9747-24]

SESSION 6 THZ SPECTROSCOPY

9747 OP **Enhancement of water retention in UV-exposed fuel-cell proton exchange membranes studied using terahertz spectroscopy** [9747-25]

9747 OR **Dynamic measurements at THz frequencies with a fast rotary delay line** [9747-27]

9747 OS **Highly sensitive terahertz spectroscopy of residual pesticide using nano-antenna** [9747-28]

9747 OT **Pulsed THz spectroscopy of substance under disordered opaque cover** [9747-29]

SESSION 7 OPTICAL/OPTO-ELECTRONICS, THZ AND GHZ, AND NEW DEVELOPMENTS

9747 OU **Frequency measurement of THz waves by electro-optic sampling using Mach-Zehnder-modulator-based flat comb generator** [9747-30]

9747 OV **Advances in optoelectronic oscillators** [9747-31]

9747 OW **All-optical real-time data format conversion in FBG sensing network** [9747-32]

9747 OY **A novel method to produce swept laser source using wavelengths parallel swept optical loop** [9747-34]

9747 OZ **Piroxicam derivatives THz classification (Best Student Paper Award)** [9747-79]

SESSION 8 THZ SECURITY AND SENSING

9747 12 **Photoconductive antennas based on low temperature grown GaAs on silicon substrates for broadband terahertz generation and detection** [9747-37]

9747 13 **Electronic terahertz imaging for security applications (Invited Paper)** [9747-38]

9747 14 **Terahertz imaging of composite materials in reflection and transmission mode with a time-domain spectroscopy system** [9747-39]

SESSION 9 QUANTUM CASCADE AND OTHER LASER-BASED DEVELOPMENTS

- 9747 15 **Measuring intensity correlations of a THz quantum cascade laser around its threshold at sub-cycle timescales (Best Student Paper Award)** [9747-40]
- 9747 17 **Coherent THz light source based on photo-mixing with a UTC-PD and ASE-free tunable diode laser** [9747-42]
- 9747 18 **Highly efficient local-oscillator-free photonic microwave down-converters based on period-one nonlinear dynamics of semiconductor lasers (Best Student Paper Award)** [9747-43]
- 9747 19 **Hybrid polymer/InP dual DBR laser for 1.5 μm continuous-wave terahertz systems** [9747-44]

SESSION 10 THZ SOURCES AND ANTENNAS

- 9747 1B **Terahertz generation and detection using femtosecond mode-locked Yb-doped fiber laser** [9747-46]
- 9747 1E **Fast terahertz optoelectronic amplitude modulator based on plasmonic metamaterial antenna arrays and graphene** [9747-49]

SESSION 11 ELECTRIC/MAGNETIC AND RELATED MEASUREMENTS/SIMULATIONS

- 9747 1F **Atom-based RF electric field metrology above 100 GHz** [9747-50]
- 9747 1H **Electromagnetic modelling of a space-borne far-infrared interferometer** [9747-52]
- 9747 1I **Experimental demonstration of trapping waves with terahertz metamaterial absorbers on flexible polyimide films** [9747-53]
- 9747 1J **Broadband frequency-chirped terahertz-wave signal generation using periodically-poled lithium niobate for frequency-modulated continuous-wave radar application** [9747-54]

SESSION 12 DESIGN AND APPROACHES FOR OPTICS, THZ, RF, AND X-RAY APPLICATIONS

- 9747 1K **Multilayers for EUV, soft x-ray and x-ray optics (Invited Paper)** [9747-55]
- 9747 1L **Design and optimization of polymer ring resonator modulators for analog microwave photonic applications** [9747-56]
- 9747 1O **Coherent THz wave combiner composed of arrayed uni-traveling carrier photodiodes and planar lightwave circuit** [9747-59]
- 9747 1P **Novel fiber fused lens for advanced optical communication systems** [9747-60]

SESSION 13 NOVEL TESTING, DEVELOPMENT, MEASUREMENT, AND CHARACTERIZATION

- 9747 1T **RF beam transmission of x-band PAA system utilizing large-area, polymer-based true-time-delay module developed using imprinting and inkjet printing** [9747-64]

SESSION 14 DETECTORS AND SENSORS

- 9747 1V **Towards a fully packaged high-performance RF sensor featuring slotted photonic crystal waveguides** [9747-66]
- 9747 1X **High-power MUTC photodetectors for RF photonic links** [9747-68]
- 9747 1Y **THz dual-band metasurfaces** [9747-69]

SESSION 15 MODULATION

- 9747 20 **Experimental studies on WDM to TDM signal conversions using gigahertz electro-absorption modulators** [9747-71]

POSTER SESSION

- 9747 22 **Planar array antenna with director on indium phosphide substrate for 300GHz wireless link** [9747-73]

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.

- | | |
|-------------------------------------|------------------------------|
| Abdallah, Zeina, 0E | Gessner, Thomas, 0C |
| Abramovich, A., 0O | Giles, Robert H., 0F |
| Ade, Peter, 1H | Göbel, T., 19 |
| Akahane, K., 0D | Gordon, Joshua A., 1F |
| Alavi, Karim, 0F | Griffiths, Jonathan P., 1E |
| Balac, Stéphane, 0E | Grzelczak, Michal P., 0Z |
| Balocco, C., 0N | Guenther, Dustin, 1P |
| Bartholdt, R., 12 | Guerboukha, Hichem, 0R |
| Bauch, Andreas, 0C | Guo, L. Jay, 1T |
| Beck, Matthias, 15 | Haakestad, Magnus W., 14 |
| Beere, Harvey E., 07, 1E | Hackner, Angelika, 0C |
| Beigang, R., 12 | Hajji, M., 0N |
| Beling, Andreas, 1X | Hamazaki, Junichi, 1J |
| Benea Chelmus, Ileana Cristina, 15 | Hammler, J., 0N |
| Bergen, Mark H., 0M | Han, Sang-Pil, 1B |
| Bhat, Santoshkumar D., 0P | Happach, M., 19 |
| Bonzon, Christopher, 15 | Haruki, J., 1O |
| Boucher, Yann G., 0E | Hisatake, S., 1O |
| Bracken, Colm, 1H | Hofmann, Stephan, 07, 1E |
| Braeuninger-Weimer, Philipp, 07, 1E | Holloway, Christopher L., 1F |
| Brinker, W., 19 | Holzman, Jonathan F., 0M |
| Burford, Nathan, 04 | Hornsby, Amber, 1H |
| Chembo, Yanne K., 0V | Hosako, Iwao, 0U, 1J |
| Chen, J., 0G | Hosseinzadeh, Arash, 1L |
| Chen, Ray T., 1T, 1V | Hristovski, Ilija R., 0M |
| Chen, Xiangning, 1T | Huang, Qiushi, 1K |
| Chen, Zhi Ning, 03 | Hung, Yu-Han, 18 |
| Chesworth, Andrew A., 1P | Hwang, Sheng-Kwang, 18 |
| Chua, Soo Jin, 03 | Izasa, Naoto, 22 |
| Chum, Chan Choy, 03 | Jen, Alex K.-Y., 1V |
| Chung, Chi-Jui, 1V | Jeon, Min Yong, 1B |
| Collier, Christopher M., 0M | Jessop, David S., 07, 1E |
| Dash, Jyotirmayee, 09, 0P | Jiang, C. T., 0G |
| de Felipe, D., 19 | Johansson, Leif A., 1X |
| Degl'Innocenti, Riccardo, 1E | Joseph, Cecil S., 0F |
| DeRemer, Matt, 1P | Kamboj, Varun S., 07, 1E |
| Devi, Nirmala, 09, 0P | Kanaya, Haruichi, 22 |
| Ding, Jun, 1Y | Kaneko, Yuta, 0U |
| Donohoe, Anthony, 1H | Kang, L., 0G |
| Doradla, Pallavi, 0F | Kanno, Atsushi, 0D, 1J |
| El-Shenawee, Magda, 04 | Kasamatsu, Akifumi, 0U, 1J |
| Estrella, Steven, 1X | Katayama, Ikufumi, 0U |
| Faist, Jérôme, 15 | Kato, Kazutoshi, 1O, 22 |
| Fernandez, Arnaud, 0E | Katshima, K., 0D |
| Fukuoka, D., 17 | Kawanishi, T., 0D |
| Gaitzsch, Markus, 0C | Keil, N., 19 |
| Gallant, A. J., 0N | Kidambi, Piran R., 07 |
| Gao, Peirui, 20 | Kim, Giyoung, 0S |
| Ge, Chunfeng, 20 | Kim, Ji Su, 1B |

- Kim, Namje, 1B
 Kindness, Stephen J., 1E
 Kirigaya, Mayu, 0U
 Kissinger, Dietmar, 0C
 Kleinert, M., 19
 Klier, J., 12
 Klos, M., 12
 Kong, Moon Sik, 1B
 Krupa, Jeffrey D. A., 0M
 Kurth, Steffen, 0C
 Lampin, J.-F., 12
 Lee, Charles Y.-C., 1V
 Lee, Dong-Kyu, 0S
 Leite, Joseph, 1P
 Li, Qiaochu, 1T
 Lin, Guoping, 0V
 Lin, Hungyen, 1E
 Lin, Yuankun, 1Y
 Liu, Jinsong, 1I
 Liu, Shiyuan, 0W, 0Y
 Llopis, Olivier, 0E
 Lu, Ding, 03
 Luo, Jingdong, 1V
 Luo, Sha, 0W, 0Y
 Ma, Rui, 0W, 0Y
 Maissen, Curdin, 15
 Malinka, Wieslaw, 0Z
 Mangalgiri, Gauri, 0C
 Markov, Andrey, 0R
 Martinez, Armando, 1P
 Mashanovitch, Milan L., 1X
 Matinenghi, Romain, 0V
 Matsumoto, A., 0D
 Meinig, Marco, 0C
 Middlebrook, Christopher T., 1L
 Möhrle, M., 19
 Moon, Ki Won, 1B
 Morohashi, Isao, 0U
 Muro, K., 17
 Murphy, J. Anthony, 1H
 Nagatsuma, T., 1O
 Nasr, Ismail, 0C
 Nellen, S., 19
 Nelson, Robert L., 1V
 Nguimdo, Romain M., 0V
 Noda, K., 17
 Nowak, Kacper, 0Z
 Ochana, M., 0O
 Oda, Tomoki, 22
 Ogawa, Yoh, 1J
 O'Sullivan, Créidhe, 1H
 Pan, Y., 0N
 Pan, Zeyu, 1T
 Panday, Ashwin, 1T
 Pannell, Chris, 0K
 Park, Kyung Hyun, 1B
 Pascale, Enzo, 1H
 Pei, Y. F., 0G
 Pesala, Bala, 09, 0P
 Petermann, K., 19
 Plinska, Stanislawa, 0Z
 Plinski, Edward F., 0Z
 Prechtel, Ulrich, 0C
 Qu, Hang, 0R
 Rambabu, Gutru, 0P
 Rannow, Randy K., 1P
 Ray, Shaumik, 09, 0P
 Ren, Han, 1Y
 Ren, Yuan, 07, 1E
 Ritchie, David A., 07, 1E
 Rogers, John, 0K
 Rothschild, D., 0O
 Rozban, D., 0O
 Ruiz, Omar, 1P
 Sakamoto, Takahide, 0U
 Sakano, G., 1O
 Sakuma, K., 1O
 Saleh, Khaldoun, 0V
 Savini, Giorgio, 1H
 Scalari, Giacomo, 15
 Schell, M., 19
 Sefler, George A., 0B
 Sekine, Norihiko, 0U, 1J
 Seo, Minah, 0S
 Sešek, A., 13
 Shaw, T. Justin, 0B
 Sibik, Juraj, 07
 Simons, Matt T., 1F
 Singh, Angadjiit, 07
 Skorobogatiy, Maksim, 0R
 Sol, Christian W. O., 1E
 Son, Joo-Hiuk, 0S
 Sørgård, Trygve R., 14
 Sterczewski, Lukasz A., 0Z
 Stirling, Trevor J., 0M
 Subbaraman, Harish, 1T, 1V
 Sudiwala, Rashmi, 1H
 Sun, Mei, 03
 Szczesniak-Siega, Berenika, 0Z
 Szlachetko, Bogusław, 0Z
 Tanoto, Hendrix, 03
 Teng, Jinghua, 03
 Trofimov, V. A., 0T
 Trontelj, J., 13
 Tu, X. C., 0G
 Umezawa, T., 0D
 Valley, George C., 0B
 van Rheenen, Arthur D., 14
 Wan, C., 0G
 Wang, Kejia, 1I
 Wang, Wei, 1I
 Wang, Zhanshan, 1K
 Wang, Zhaoying, 0W, 0Y, 20
 Wecker, Julia, 0C
 Weigel, Robert, 0C
 Wu, P. H., 0G
 Wu, Qing Yang Steve, 03

Xiao, Long, 1E
Xiao, P., 0G
Xu, Ningning, 1Y
Xu, Xiaochuan, 1T
Yamamoto, Naokatsu, 0D, 1J
Yan, Hai, 1V
Yang, Tianxin, 0W, 0Y, 20
Yuan, Quan, 0W, 0Y
Zagursky, D. Yu., 0T
Zakharova, I. G., 0T
Zawadzki, C., 19
Zeitler, J. Axel, 07, 1E
Zeze, D., 0N
Zhang, Cheng, 1T
Zhang, Hualiang, 1Y
Zhang, Weili, 1Y
Zhang, Xingyu, 1T, 1V
Zhang, Zhong, 1K
Zhou, Mi, 1Y
Zou, Yi, 1T

Conference Committee

Symposium Chairs

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

Symposium Co-chairs

David L. Andrews, University of East Anglia (United Kingdom)
Alexei L. Glebov, OptiGrate Corporation (United States)

Program Track Chair

James G. Grote, Air Force Research Laboratory (United States)

Conference Chairs

Laurence P. Sadwick, InnoSys, Inc. (United States)
Tianxin Yang, Tianjin University (China)

Conference Program Committee

René Beigang, Technische Universität Kaiserslautern (Germany)
Jianji Dong, Huazhong University of Science and Technology (China)
Frank Ellrich, Fraunhofer-Institut für Physikalische Messtechnik
(Germany)
Robert H. Giles, University of Massachusetts Lowell (United States)
R. Jennifer Hwu, InnoSys, Inc. (United States)
Anthony Murphy, National University of Ireland, Maynooth (Ireland)
Créidhe O'Sullivan, National University of Ireland, Maynooth (Ireland)
Kyung Hyun Park, Electronics and Telecommunications Research
Institute (Korea, Republic of)
Alessia Portieri, TeraView Ltd. (United Kingdom)
Jinghua Teng, A*STAR Institute of Materials Research and Engineering
(Singapore)
Michael Weibel, Joint Research and Development, Inc.
(United States)
Jiangfeng Zhou, University of South Florida (United States)

Session Chairs

- 1 THz Technology I
Jiangfeng Zhou, University of South Florida (United States)
Laurence P. Sadwick, InnoSys, Inc. (United States)

- 2 THz Technology II
Karen Ke Lin, Institute of Materials Research and Engineering (IMRE)
(Singapore)
Tianxin Yang, Tianjin University (China)
- 3 GHz Technology
Laurence P. Sadwick, InnoSys, Inc. (United States)
R. Jennifer Hwu, InnoSys, Inc. (United States)
- 4 THz Sensing and Detection
Laurence P. Sadwick, InnoSys, Inc. (United States)
Frank Ellrich, Fraunhofer-Institut für Physikalische Messtechnik
(Germany)
- 5 Materials for THz and GHz
Tianxin Yang, Tianjin University (China)
Laurence P. Sadwick, InnoSys, Inc. (United States)
- 6 THz Spectroscopy
Anthony Donohoe, National University of Ireland, Maynooth (Ireland)
Laurence P. Sadwick, InnoSys, Inc. (United States)
- 7 Optical/Opto-Electronics, THz and GHz, and New Developments
René Beigang, Technische Universität Kaiserslautern (Germany)
Kyung Hyun Park, Electronics and Telecommunications Research Institute (Korea, Republic of)
- 8 THz Security and Sensing
René Beigang, Technische Universität Kaiserslautern (Germany)
Laurence P. Sadwick, InnoSys, Inc. (United States)
- 9 Quantum Cascade and Other Laser-based Developments
Robert H. Giles, University of Massachusetts Lowell (United States)
Laurence P. Sadwick, InnoSys, Inc. (United States)
- 10 THz Sources and Antennas
Tianxin Yang, Tianjin University (China)
Laurence P. Sadwick, InnoSys, Inc. (United States)
- 11 Electric/Magnetic and Related Measurements/Simulations
Tianxin Yang, Tianjin University (China)
Anthony Donohoe, National University of Ireland, Maynooth (Ireland)
- 12 Design and Approaches for Optics, THz, RF, and X-Ray Applications
Tianxin Yang, Tianjin University (China)
Jianji Dong, Huazhong University of Science and Technology (China)

- 13 Novel Testing, Development, Measurement, and Characterization
Tianxin Yang, Tianjin University (China)
Laurence P. Sadwick, InnoSys, Inc. (United States)
- 14 Detectors and Sensors
Karen Ke Lin, Institute of Materials Research and Engineering (IMRE)
(Singapore)
Frank Ellrich, Fraunhofer-Institut für Physikalische Messtechnik
(Germany)
- 15 Modulation
Laurence P. Sadwick, InnoSys, Inc. (United States)
Robert H. Giles, University of Massachusetts Lowell (United States)

