# Advances in Terahertz Biomedical Imaging and Spectroscopy

Kirill I. Zaytsev Dmitry S. Ponomarev Maksim Skorobogatiy Editors

22–27 January 2022 San Francisco, California, United States

20–24 February 2022 ONLINE

Sponsored and Published by SPIE

Volume 11975

Proceedings of SPIE, 1605-7422, V. 11975

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

Advances in Terahertz Biomedical Imaging and Spectroscopy, edited by Kirill I. Zaytsev, Dmitry S. Ponomarev, Maksim Skorobogatiy, Proc. of SPIE Vol. 11975, 1197501 · © 2022 SPIE · 1605-7422 · doi: 10.1117/12.2634786

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 Advances in Terahertz Biomedical Imaging and Spectroscopy, edited by Kirill I. Zaytsev, Dmitry S. Ponomarev, Maksim Skorobogatiy, Proc. of SPIE 11975, Seven-digit Article CID Number (DD/MM/YYYY); (DOI URL).

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

ISBN: 9781510648210 ISBN: 9781510648227 (electronic)

Published by **SPIE** P.O. Box 10, Bellingham, Washington 98227-0010 USA Telephone +1 360 676 3290 (Pacific Time) SPIE.org Copyright © 2022 Society of Photo-Optical Instrumentation Engineers (SPIE).

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 fees. To obtain permission to use and share articles in this volume, visit Copyright Clearance Center 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.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

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



**Paper Numbering:** A unique citation identifier (CID) number is assigned to each article in the Proceedings of SPIE 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 Conference Committee

### SESSION 1 EMERGING TOOLS AND METHODS OF THZ BIOPHOTONICS

- 11975 02 Biomedical applications of terahertz technology (Keynote Paper) [11975-1]
- 11975 03 Graphene-based plasma-wave devices for terahertz applications (Invited Paper) [11975-3]

### SESSION 2 THZ-WAVE INTERACTIONS WITH TISSUES AND LIQUIDS

- 11975 04 Effects of high intensity non-ionizing pulses of terahertz radiation on human skin fibroblasts (Invited Paper) [11975-17]
- 11975 05Terahertz multi-dimensional imaging for nanoparticle-assisted therapeutics (Invited Paper)<br/>[11975-18]
- 11975 06 Implementation of a coplanar-waveguide chip for the measurement of EM wave absorption spectrum of SARS-Cov-2 virus (Invited Paper) [11975-22]

### **Conference Committee**

### Symposium Chairs

Jennifer K. Barton, The University of Arizona (United States) Wolfgang Drexler, Medizinische University Wien (Austria)

### Program Track Chairs

Ammasi Periasamy, University of Virginia (United States) Daniel L. Farkas, University of Southern California (United States) and SMI (United States)

### Conference Chairs

Kirill I. Zaytsev, A. M. Prokhorov General Physics Institute of the RAS (Russian Federation)

Dmitry S. Ponomarev, Institute of ultra-high frequency semiconductor electronics of the Russian Academy of sciences. (Russian Federation) Maksim Skorobogatiy, Polytechnique Montréal (Canada)

### Conference Program Committee

Enrique Castro-Camus, Centro de Investigaciones en Óptica, A.C. (Mexico) Olga P. Cherkasova, Institute of Laser Physics of the SB RAS (Russian Federation) Irina N. Dolganova, Bauman Moscow State Technical University (Russian Federation) Yury V. Kistenev, National Research Tomsk State University (Russian Federation) Vladimir N. Kurlov, Institute of Solid State Physics RAS (Russian Federation) Andrea G. Markelz, University at Buffalo (United States) Hiroaki Minamide, RIKEN (Japan) Roberto Morandotti, Institut National de la Recherche Scientifique (Canada) Taiichi Otsuji, Tohoku University (Japan) Marco Peccianti, University of Sussex (United Kingdom) Igor V. Reshetov, I.M. Sechenov First Moscow State Medical University (Russian Federation) Alexander P. Shkurinov, M. V. Lomonosov Moscow State University (Russian Federation) Michael S. Shur, Rensselaer Polytechnic Institute (United States) Chi-Kuang Sun, National Taiwan University (Taiwan)

Peter S. Timashev, I.M. Sechenov First Moscow State Medical University (Russian Federation)

Tsuneyuki Ozaki, Institut National de la Recherche Scientifique (Canada)
Valery V. Tuchin, Saratov State University (Russian Federation)
Vincent P. Wallace, The University of Western Australia (Australia)
Anna N. Yaroslavsky, University of Massachusetts Lowell (United States)
Elena S. Zhukova, Moscow Institute of Physics and Technology (Russian Federation)