Front Matter: Volume 9544
Metamaterials, Metadevices, and Metasystems 2015

Nader Engheta
Mikhail A. Noginov
Nikolay I. Zheludev
Editors

9–13 August 2015
San Diego, California, United States

Sponsored and Published by
SPIE

Volume 9544
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:


ISSN: 0277-786X
ISSN: 1996-756X (electronic)
ISBN: 9781628417104

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 © 2015, 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/15/$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
SPIEDigitalLibrary.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 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.
- The CID Number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages.
# Contents

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>vii</td>
<td>Authors</td>
</tr>
<tr>
<td>ix</td>
<td>Conference Committee</td>
</tr>
</tbody>
</table>

## NANOSCIENCE + ENGINEERING PLENARY SESSION

| 9544 03 | Nano-bio-optomechanics: nanoaperture tweezers probe single nanoparticles, proteins, and their interactions (Plenary Paper) [9544-501] |

## ACTIVE METAMATERIALS I

| 9544 0D | Coherent effects in nonlinear metamaterial-based devices (Invited Paper) [9544-8] |

## HYPERBOLIC METAMATERIALS II

| 9544 17 | Mid-infrared hyperbolic metamaterial based on graphene-dielectric multilayers (Invited Paper) [9544-36] |
| 9544 18 | LCR model for hyperbolic metamaterials [9544-37] |
| 9544 19 | Optical mode confinement in three-dimensional Al/SiO$_2$ nanocavities with hyperbolic dispersion [9544-39] |

## MID INFRARED AND THERMAL

| 9544 1D | Design and analysis of chevrons shaped split ring resonator in the mid-infrared region [9544-43] |
| 9544 1F | Experimental verification of classical electromagnetically induced transparency in conductors [9544-45] |

## MANIPULATING LIGHT WITH METAMATERIALS

| 9544 1J | Multi-foci metalens for spin and orbital angular momentum interaction [9544-49] |
| 9544 1K | Birefringence modulation of thermally driven metal nanograting [9544-50] |

## METADEVICES AND METASYSTEMS I

| 9544 1O | Design and analysis of near perfect metamaterial reflector in visible range [9544-54] |
The silicon photomultiplier as a metasystem with designed electronics as metadevice for a new receiver-emitter in visible light communications [9544-55]

METADEVICES AND METASYSTEMS II

Design theory of thin film hyperbolic metamaterial colimators [9544-59]

RANDOMNESS AND FLUCTUATIONS

Giant field fluctuations in dielectric metamaterial and Raman sensor [9544-64]
A non-Monte Carlo approach to analyzing 1D Anderson localization in dispersive metamaterials [9544-67]

METASURFACES I

Vertical split-ring resonators for plasmon coupling, sensing and metasurface (Invited Paper) [9544-69]
Cascaded metasurfaces for broadband antenna isolation [9544-70]
Anisotropic impedance surfaces for enhanced antenna isolation [9544-71]

NOVEL PHENOMENA AND METHODS

Metamaterial models of curved spacetime [9544-86]
Electron beam excitation of a CSRR loaded waveguide for Cherenkov radiation [9544-87]
Infra-red spectral microscopy of standing-wave resonances in single metal-dielectric-metal thin-film cavity [9544-88]

LOW-FREQUENCY MATERIALS

Polarization and angle dependent transmission through microwave metamaterials in the Ku frequency band [9544-92]
Extraordinary terahertz transmission through electrically small particles [9544-93]
<table>
<thead>
<tr>
<th>Poster ID</th>
<th>Title</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>9544 2R</td>
<td>Hybrid plasmonic nanosandwich structures</td>
<td>[9544-95]</td>
</tr>
<tr>
<td>9544 2S</td>
<td>Adjustment characteristics in terahertz transmission through a split ring resonator-based metamaterial</td>
<td>[9544-96]</td>
</tr>
<tr>
<td>9544 2V</td>
<td>Shaping the light distribution of strongly focused systems for efficient excitation of optical nano-circuits</td>
<td>[9544-99]</td>
</tr>
<tr>
<td>9544 2W</td>
<td>Quantum toroidal moments of nanohelix eigenstates</td>
<td>[9544-100]</td>
</tr>
<tr>
<td>9544 2X</td>
<td>Mie resonance in the arrays of dielectric rods in air</td>
<td>[9544-101]</td>
</tr>
</tbody>
</table>

Proc. of SPIE Vol. 9544  954401-5
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.

Afanas’ev, Konstantin N., 1Y
Alt-El-Aoud, Yassine, 1F
Akyurtlu, Aklim, 1F
ALShareef, Mohammed R., 2P
Alsheheri, Soad, 2R
Bacco, Carla, 19
Bie, Yehua, 2S
Boginskaya, Irina A., 1Y
Budashov, Igor A., 1Y
Castañeda, L. F., 1P
Castaño, J. F., 1P
Chang, You-Chia, 17
Chen, Wei Ting, 23
Cleary, Justin W., 2M
Couture, Paul A., 2O
Dalal, Reena, 2X
Encinosa, Mario, 2W
Fiddy, Michael A., 18, 1T
Friedman, Jerry, 24
Fullager, Daniel B., 1T
Ginn, James C., 2M
Gordon, Reuven, 03
Gutierrez, R. M., 1P
Harshbarger, Derek, 24
Hernandez, A. I., 1P
Hirschmugl, Carol, 2M
Hrabar, Silvia, 2V
Hsu, Wei-Lun, 23
Huang, Kun, 1J
Huang, Yao-Wei, 23
Ishii, Miho, 1K
Ivanov, Andrey V., 1Y
Iwami, Kentaro, 1K
Jablonski, Allan, 24
Kalra, Yogita, 2X
Kelly, Priscilla, 19
Khalilzadeh-Rezaie, Farnood, 2M
Kildishev, Alexander V., 17
Kissel, Glen J., 21
Kumar, A., 1D
Kurochkin, Ilya N., 1Y
Kussow, Adil-Gerali, 1F
Kuznetsova, Lyuba, 19
Lagarkova, Andrey N., 1Y
Lakhtakia, Akhlesh, 2K
Lee, David A., 2O
Letizia, Rosa, 2L
Liao, Chun Yen, 23
Liu, Ai Qun, 23
Liu, Chang-Hua, 17
Liu, Che-Hung, 17
Luo, Jun, 2S
Mackay, Tom G., 2K
Marder, Seth R., 17
Malin, Mohammed, 2R
Mehmood, M. Q., 1J
Mei, Shengtao, 1J
Miraglia, Joseph A., 24, 25
Musselman, Randall L., 2O
Nagasaki, Hideaki, 1K
Nandan, N., 1D
Narimanov, Evgenii E., 17
Nath, Janardan, 2M
Norr, Theodore B., 17
Okorn, Boris, 2V
Panjwani, Deep, 2M
Perea, Robert E., 2M
Pinchuk, Anatoly O., 2O
Qiu, Cheng-Wei, 1J
Ramahi, Omar, 2P
Rosenbury, C. A., 18
Ryzhikov, Ilya A., 1Y
Saboktakin, Marjan, 2R
Saini, T. S., 1D
Salandrino, Alessandro, 0D
Sancho-Parramon, Jordi, 2V
Sang, Honghui, 2S
Sarychev, Andrey K., 1Y
Scott, Robert, 24
Shankhwar, Nishant, 1O
Sharples, Emlyn, 2L
Shelton, David J., 2M
Shimura, Takashi, 1K
Shrekenhamer, David, 24, 25
Sievenpiper, Daniel F., 24, 25
Sinha, Ravindra Kumar, 1D, 1O, 2X
Smith, Evan M., 2M
Sun, Greg, 23
Tsai, Din Ping, 23
Tsai, Wei-Yi, 23
Umeda, Naohiro, 1K
Vedral, James L., 2O
Williamson, Johnny, 2W
Wu, Pin Chieh, 23
Xie, Changsheng, 2S
Yesiltas, Mehmet, 2M
Zhang, Siyuan, 17
Zhang, Xinyu, 2S
Zheludev, Nikolay I., 23
Zhong, Zhaohui, 17
Conference Committee

Symposium Chairs

Satoshi Kawata, Osaka University (Japan)
Manijeh Razeghi, Northwestern University (United States)

Symposium Co-chairs

David L. Andrews, University of East Anglia (United Kingdom)
James G. Grote, Air Force Research Laboratory (United States)

Conference Chairs

Nader Engheta, University of Pennsylvania (United States)
Mikhail A. Noginov, Norfolk State University (United States)
Nikolay I. Zheludev, University of Southampton (United Kingdom) and Nanyang Technological University (Singapore)

Conference Program Committee

Andrea Alù, The University of Texas at Austin (United States)
David L. Andrews, University of East Anglia (United Kingdom)
Pierre Berini, University of Ottawa (Canada)
Alexandra Boltasseva, Purdue University (United States)
Igal Brener, Sandia National Laboratories (United States)
Mark Brongersma, Stanford University (United States)
Che Ting Chan, Hong Kong University of Science and Technology (Hong Kong, China)
Hongsheng Chen, Zhejiang University (China)
Jennifer A. Dionne, Stanford University (United States)
Harald W. Giessen, Universität Stuttgart (Germany)
Yuri S. Kivshar, The Australian National University (Australia)
Jacob B. Khurgin, Johns Hopkins University (United States)
Uriel Levy, The Hebrew University of Jerusalem (Israel)
Natalia M. Litchinitser, University at Buffalo (United States)
Martin W. McCall, Imperial College London (United Kingdom)
Albert Polman, FOM Institute for Atomic and Molecular Physics (Netherlands)
Gennady B. Shvets, The University of Texas at Austin (United States)
David R. Smith, Duke University (United States)
Costas M. Soukoulis, Iowa State University (United States)
Mark I. Stockman, Georgia State University (United States)
Philippe Tassin, Chalmers University of Technology (Sweden)
Sergei Tretyakov, Aalto University School of Science and Technology (Finland)
Din Ping Tsai, National Taiwan University (Taiwan)
Augustine M. Urbas, Air Force Research Laboratory (United States)
Martin Wegener, Karlsruher Institut für Technologie (Germany)
Xiang Zhang, University of California, Berkeley (United States)

Session Chairs

NanoScience + Engineering Plenary Session
Satoshi Kawata, Osaka University (Japan)
David L. Andrews, University of East Anglia (United Kingdom)

1 Toroids and Vortices
Mikhail A. Noginov, Norfolk State University (United States)

2 Active Metamaterials I
Philippe Tassin, Chalmers University of Technology (Sweden)

3 Active Metamaterials II
Zubin Jacob, University of Alberta (Canada)

4 Control of Physical Phenomena with Metamaterials
Mikhail Lapine, University of Technology, Sydney (Australia)

5 Hyperbolic Metamaterials I
Luca Alloatti, Massachusetts Institute of Technology (United States)

6 Atomic Scale Metamaterials
Natalia M. Litchinitser, University at Buffalo (United States)

7 Dielectric and Semiconductor Metamaterials
Adil-Gerai Kussow, University of Massachusetts Lowell (United States)

8 Hyperbolic Metamaterials II
Adil-Gerai Kussow, University of Massachusetts Lowell (United States)

9 Mid Infrared and Thermal
Viktor A. Podolskiy, University of Massachusetts Lowell (United States)

10 Manipulating Light with Metamaterials
Joshua D. Caldwell, U.S. Naval Research Laboratory (United States)

11 Metadevices and Metasystems I
Ertugrul Cubukcu, University of Pennsylvania (United States)

12 Metadevices and Metasystems II
Alberto Piqué, U.S. Naval Research Laboratory (United States)
13 Randomness and Fluctuations  
Zhaozhu Li, The College of William & Mary (United States)

14 Metasurfaces I  
Andrey K. Sarychev, Institute for Theoretical and Applied Electrodynamics (Russian Federation)

15 Metasurfaces II  
Mayer A. Landau, Air Force Research Laboratory (United States)

16 Metasurfaces III  
Arseniy I. Kuznetsov, A*STAR - Data Storage Institute (Singapore)

17 Novel Phenomena and Methods  
Xingjie Ni, University of California, Berkeley (United States)

18 Low-Frequency Materials  
David Wilkowski, Nanyang Technological University (Singapore)