PROCEEDINGS OF SPIE

SPIDigitalLibrary.org/conference-proceedings-of-spie

Front Matter: Volume 6581

, "Front Matter: Volume 6581," Proc. SPIE 6581, Metamaterials II, 658101 (29 May 2007); doi: 10.1117/12.747047

SPIE.

Event: International Congress on Optics and Optoelectronics, 2007, Prague, Czech Republic

PROCEEDINGS OF SPIE

Metamaterials II

Vladimir Kuzmiak
Peter Markos
Tomasz Szoplik
Editors

16–18 April 2007
Prague, Czech Republic

Sponsored by
SPIE Europe

Cooperating Organizations
SPIE Czech Republic Chapter
COST
ESF—European Science Foundation (France)
Czech and Slovak Society for Photonics
ePIXnet (Belgium)
Fyzikální Ústav (Czech Republic)
Meta Morphose (United Kingdom)
NEMO—Network of Excellence in Micro-Optics (Belgium)
PhOREMOST
SPIE Poland Chapter

Published by
SPIE

Proceedings of SPIE, 0277-786X, v. 6581

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

The papers included 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. The papers published in these proceedings 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 this book:

Author(s), "Title of Paper," in *Metamaterials II*, edited by Vladimir Kuzmiak, Peter Markos, Tomasz Szoplik, Proceedings of SPIE Vol. 6581 (SPIE, Bellingham, WA, 2007) Article CID Number.

ISSN 0277-786X

ISBN 9780819467096

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 © 2007, The 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 <http://www.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/07/\$18.00.

Printed in the United States of America.

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

SPIDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- 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 complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

Contents

- vii Conference Committee
- ix Introduction
- xi *Liquid crystalline nonlinear optical metamaterials with low-loss tunable negative-zero-positive refractive indices (Plenary Paper) [6587-203]*
I. C. Khoo, A. Diaz, D.-H. Kwon, D. H. Warner, Pennsylvania State Univ. (USA)

NEGATIVE INDEX MATERIALS

- 6581 03 **Magnetic response and negative refractive index of metamaterials (Invited Paper)** [6581-01]
Th. Koschny, Iowa State Univ. (USA) and Institute of Electronic Structure and Laser—FORTH (Greece); J. Zhou, Iowa State Univ. (USA); C. M. Soukoulis, Iowa State Univ. (USA), Institute of Electronic Structure and Laser—FORTH (Greece), and Univ. of Crete (Greece)
- 6581 04 **General relativity in electrical engineering (Invited Paper)** [6581-02]
U. Leonhardt, T. G. Philbin, Univ. of St. Andrews (United Kingdom)
- 6581 05 **A simple recipe for negatively refracting metamaterials via homogenization** [6581-03]
T. G. Mackay, Univ. of Edinburgh (United Kingdom); A. Lakhtakia, Pennsylvania State Univ. (USA)
- 6581 06 **Binary-nanoparticle left-handed metamaterial for optical frequencies** [6581-04]
A. A. Zharov, R. E. Noskov, Institute for Physics of Microstructures (Russia)

NOVEL CONCEPTS IN METAMATERIALS

- 6581 07 **New properties of light in metamaterials (Invited Paper)** [6581-27]
S. Fan, J. Shin, J.-T. Shen, Stanford Univ. (USA)
- 6581 08 **Metamaterials driven by gain and special configurations (Invited Paper)** [6581-05]
A. D. Boardman, N. King, Univ. of Salford (United Kingdom); Yu. Rapoport, Taras Shevchenko Kyiv National Univ. (Ukraine)
- 6581 0A **Metamaterial phenomenons via uniform motion** [6581-07]
T. G. Mackay, Univ. of Edinburgh (United Kingdom); A. Lakhtakia, Pennsylvania State Univ. (USA)
- 6581 0B **Detuning conditions for negative dielectric in optical metamaterials** [6581-08]
S. V. Kartalopoulos, The Univ. of Oklahoma (USA)
- 6581 0C **Formation of glass-metal metamaterials via reactive diffusion: a model** [6581-09]
V. Zhurikhina, A. Lipovskii, St.-Petersburg State Polytechnic Univ. (Russia); Y. Kaganovskii, Bar-Ilan Univ. (Israel)

PLASMONICS

6581 OE **Directive emission from a single subwavelength aperture in a periodically corrugated silver film** [6581-11]
F. Capolino, Univ. of Siena (Italy) and Univ. of Houston (USA); R. Qiang, D. R. Jackson, J. Chen, Univ. of Houston (USA)

6581 OG **Metal-dielectric composite optical structures with novel dynamic tunable localized surface-plasmonic effects** [6581-13]
Y. Feng, M. Willatzen, N. L. Andersen, Univ. of Southern Denmark (Denmark)

TUNABLE AND NONLINEAR METAMATERIALS

6581 OM **Surface lattice solitons: analytical solutions** [6581-18]
Y. Kominis, A. Papadopoulos, I. Tsopeles, S. Droulias, National Technical Univ. of Athens (Greece); N. Efremidis, Univ. of Crete (Greece) and National Technical Univ. of Athens (Greece); G. Papazisimos, K. Hizanidis, National Technical Univ. of Athens (Greece)

6581 ON **Nonlinear surface waves in a left handed material (LHM) and super lattices (LANS) wave-guide structure** [6581-19]
H. M. Mousa, Al Azhar Univ. (Palestinian Authority); M. M. Shabat, Max-Planck-Institut für Physik komplexer Systeme (Germany)

6581 OO **Optically tunable photonic crystals used as devices for the THz range** [6581-20]
F. Kadlec, P. Kužel, Institute of Physics (Czech Republic)

DEVICE APPLICATIONS OF METAMATERIALS

6581 OP **Terahertz metamaterials for active, tunable, and dynamic devices (Invited Paper)** [6581-21]
N. I. Landy, Boston College (USA); H.-T. Chen, J. F. O'Hara, Los Alamos National Lab. (USA); J. M. O. Zide, A. C. Gossard, Univ. of California, Santa Barbara (USA); C. Highstrete, M. Lee, Sandia National Labs. (USA); A. J. Taylor, Los Alamos National Lab. (USA); R. D. Averitt, Boston Univ. (USA); W. J. Padilla, Boston College (USA)

6581 OQ **Metamaterials as complex dielectrics in the design of a new class of integrated circuits** [6581-22]
A. Toscano, L. Vegni, F. Bilotti, S. E. Lauro, Univ. of Roma Tre (Italy)

6581 OR **Bidimensional phase-varying metamaterial for steering beam antenna** [6581-23]
A. Ourir, S. N. Burokur, A. de Lustrac, Univ. Paris-Sud, UMR 8622, CNRS (France)

6581 OS **Faraday effect enhancement in metal-dielectric plasmonic systems** [6581-24]
V. I. Belotelov, A.M. Prokhorov General Physics Institute (Russia) and M.V. Lomonosov Moscow State Univ. (Russia); L. L. Doskolovich, Image Processing Systems Institute (Russia); V. A. Kotov, A.M. Prokhorov General Physics Institute (Russia); E. A. Bezus, D. A. Bykov, Image Processing Systems Institute (Russia); A. K. Zvezdin, A.M. Prokhorov General Physics Institute (Russia)

- 6581 OT **Birefringence of nanoporous alumina: experiment vs. theory** [6581-25]
A. A. Lutich, Institute of Molecular and Atomic Physics (Belarus); M. B. Danailov, Synchrotron, Trieste (Italy); S. Volchek, V. A. Yakovtseva, V. A. Sokol, Belarusian State Univ. of Informatics and Electronics (Belarus); S. V. Gaponenko, Institute of Molecular and Atomic Physics (Belarus)
- 6581 OU **Two-photon polymerization and applications in plasmonics** [6581-26]
S. Passinger, Laser Zentrum Hannover e.V. (Germany); A. Stepanov, Laser Zentrum Hannover e.V. (Germany) and Kazan Physical-Technical Institute (Russia); A. Evlyukhin, Vladimir State Univ. (Russia); C. Reinhardt, R. Kiyan, B. Chichkov, Laser Zentrum Hannover e.V. (Germany)

MODELLING METAMATERIALS

- 6581 OV **Analysis of resonant responses of split ring resonators using conformal mapping techniques** [6581-30]
S. G. McMeekin, Glasgow Caledonian Univ. (United Kingdom); A. Z. Khokhar, B. Lahiri, R. M. De La Rue, N. P. Johnson, Univ. of Glasgow (United Kingdom)
- 6581 OW **Dispersion effects in light pulses refracted from right- to left-handed media** [6581-31]
J. Pniewski, T. Szoplik, Univ. of Warsaw (Poland); M. Scalora, Charles M. Bowden Research Ctr. (USA)
- 6581 OX **Modeling of photonic crystal waveguide structures** [6581-29]
I. Richter, P. Kwiecien, M. Šišnor, A. Haiduk, Czech Technical Univ. in Prague (Czech Republic)
- 6581 OY **Numerical modeling of pseudo-isotropic negative refractive index media** [6581-32]
T.-C. Yang, Y.-H. Yang, National Tsing Hua Univ. (Taiwan); T.-J. Yen, National Tsing Hua Univ. (Taiwan) and National Nano Device Labs. (Taiwan)
- 6581 OZ **Electromagnetic waves in absorbing uniaxial metamaterials** [6581-33]
E. Starodubtsev, Gomel State Technical Univ. (Belarus)
- 6581 10 **Filtering properties of the LHM-RHM layered structures** [6581-34]
K. Król, J. Pniewski, R. Kotyński, Warsaw Univ. (Poland)
- 6581 11 **Diffraction analysis of photonic metamaterials using a transmission line formulation** [6581-28]
N. Dabidian, Amirkabir Univ. of Technology (Iran); M. Shahabadi, Univ. of Tehran (Iran); A. Tavakoli, Amirkabir Univ. of Technology (Iran)
- 6581 12 **Photonic band structure of one-dimensional aperiodic superlattices composed of negative refraction metamaterials** [6581-36]
M. H. Tyc, W. Salejda, A. Klauzer-Kruszyna, K. Tarnowski, Wrocław Univ. of Technology (Poland)
- 6581 13 **Propagation of polarized light through superlattices composed of left- and right-handed materials** [6581-37]
K. Tarnowski, W. Salejda, M. H. Tyc, A. Klauzer-Kruszyna, Wrocław Univ. of Technology (Poland)

- 6581 14 **Self-similar non-Bragg band gaps in fractal metamaterial multilayers** [6581-38]
J. A. Monsoriu, Univ. Politcnica de Valencia (Spain); R. A. Depine, Univ. de Buenos Aires
(Argentina); E. Silvestre, P. Andrs, Univ. de Valencia (Spain)

Author Index

Conference Committee

Symposium Chairs

Pavel Tománek, Brno University of Technology (Czech Republic)
Miroslav Hrabovský, Palacký University (Czech Republic)
Hugo Thienpont, Vrije Universiteit Belgium (Belgium)

Symposium Honorary Chair

Karel Jungwirth, Institute of Physics (Czech Republic)

Conference Chairs

Vladimir Kuzmiak, Institute of Radio Engineering and Electronics (Czech Republic)
Peter Markos, Institute of Physics (Slovak Republic)
Tomasz Szoplik, University of Warsaw (Poland)

Program Committee

Roel G. Baets, Universiteit Gent (Belgium)
Jiri Ctyroky, Institute of Radio Engineering and Electronics (Czech Republic)
F. Javier Garcia de Abajo, Consejo Superior de Investigaciones Científicas (Spain)
Nigel P. Johnson, University of Glasgow (United Kingdom)
Maria Kafesaki, Institute of Electronic Structure and Laser of the Foundation for Research and Technology—Hellas (Greece)
Yuri S. Kivshar, The Australian National University (Australia)
Didier Lippens, Université des Sciences et Technologies de Lille (France)
Ekmel Ozbay, Bilkent University (Turkey)
Vladimir M. Shalaev, Purdue University (USA)
David R. Smith, Duke University (USA)
Costas M. Soukoulis, Iowa State University (USA), Institute of Electronic Structure and Laser—FORTH (Greece), and University of Crete (Greece)
Martin Wegener, Forschungszentrum Karlsruhe (Germany)
Nikolay I. Zheludev, University of Southampton (United Kingdom)

Session Chairs

- 1 Negative Index Materials
Peter Markos, Institute of Physics (Slovak Republic)

- 2 Novel Concepts in Metamaterials
Vladimir Kuzmiak, Institute of Radio Engineering and Electronics (Czech Republic)
- 3 Plasmonics
Tomasz Szoplik, University of Warsaw (Poland)
- 4 Metamaterials: Toward the Visible Range
John B. Pendry, Imperial College London (United Kingdom)
- 5 Tunable and Nonlinear Metamaterials
Willie J. Padilla, Boston College (USA)
- 6 Device Applications of Metamaterials
Nigel P. Johnson, University of Glasgow (United Kingdom)
- 7 Modelling Metamaterials
Jiri Ctyroky, Institute of Radio Engineering and Electronics (Czech Republic)

Introduction

Today, metamaterials attract great attention due not only to the cutting-edge research on invisibility cloaks and the superlensing devices exceeding the diffraction limit, but also due to the developing technologies that will likely transform optics' common applications and will affect the techniques developed by the next generation of engineers.

In contrast to conventional materials, metamaterials offer new and unique features that are extremely attractive for commercial applications such as antennas. The next generation of hand-held devices is believed to be the leader in major technological breakthroughs.

This second symposium in a series of conferences on metamaterials provided an updated overview of recent activities in this field including:

- recent advances in scaling metamaterials with artificial magnetic response toward optical frequencies;
- novel concepts beyond the limits of the classical concepts;
- recent achievements in plasmonics and microwave technology in the investigation of tunable and nonlinear metamaterials;
- device applications and progress in modeling of metamaterials.

This conference was one of nine conferences held at the SPIE Congress on Optics and Optoelectronics organized in Prague by the SPIE Czech Chapter and SPIE Europe, and it was designed to bring together leading scientists to create an important regional forum addressing the most important developments in the field of photonics.

As chairs of this meeting, we would like to express our thanks to all those participants who contributed through their presentations and to the programme committee members.

Vladimir Kuzmiak
Peter Markos
Tomasz Szoplik