Optical Materials EXPRESS

Physics of Complex Photonic Media and Metamaterials: feature issue introduction

ALEX KRASNOK,[1,2] VIKTORIIA BABICHEVA,[3] AND CARSTEN ROCKSTUHL[4]

[1] *Department of Electrical and Computer Engineering, Florida International University, Miami, FL, USA*
[2] *Knight Foundation School of Computing and Information Sciences, Florida International University, Miami, FL, USA*
[3] *Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, NM, USA*
[4] *Institute of Nanotechnology, Institute of Theoretical Solid State Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany*

Abstract: We introduce the *Optical Materials Express* feature issue on the Physics of Complex Photonic Media and Metamaterials. This issue comprises a collection of nine manuscripts on the development, characterization, control, and applications of complex photonic media and metamaterials, including but not limited to metagratings, chiral metamirrors, diamond nanopillars, rotating metamaterials, and networks of random lasers.

1. Introduction

This collection of research articles in the *Optical Materials Express* feature issue offers a comprehensive exploration of the physics of complex photonic media and metamaterials. The papers present intriguing advancements, focusing on their unique properties and potential applications. Research on closed-form analytical design of metagratings, wave propagation in left- and right-handed media, high-Q Fano resonances in diamond nanopillars, and others embody the issue's core theme. A central focus is the role of symmetry and asymmetry, evident in studies about negative refraction in time-dependent media and momentum conservation in time-varying media. Meanwhile, practical applications of metamaterials are underscored through work on rotating metamaterials, moiré effects in coupled atomic arrays, and networks of random lasers. This research points to the future of efficient and innovative technologies with implications across fields like communication, sensing, computing, and encryption. The feature issue highlights the interdisciplinary nature of complex photonic media and metamaterials, offering insight and sparking new research directions.

2. Feature issue summary

2.1. Metasurface and metagrating design

A significant portion of the work featured in this issue deals with innovative designs and applications of metasurfaces and metagratings. Tan *et al.* [1] provide an analytical study on a beamforming reflective metagrating that requires a relatively low number of meta-atoms, opening doors for high-efficiency wide-angle beam deflections. Such a theoretical approach can potentially simplify the design of complex metasurface and metagrating structures. The efficiency of their theoretical model was corroborated by numerical simulations of metagratings composed of microstrip capacitor structures. Moreover, Hu *et al.* [2] introduce a novel chiral metamirror for circularly polarized waves. Their work reveals the limitations of traditional chiral metamirrors and proposes a new approach with a broad range of applications. They utilize a unique construction of asymmetry unit cells to create a dual-band spin-selection flips THz chiral metamirror, demonstrating the exciting capabilities of metamirrors in controlling the

#500975 https://doi.org/10.1364/OME.500975
Journal © 2023 Received 19 Jul 2023; published 1 Aug 2023

Optical Materials EXPRESS

chiral characteristics of reflected waves. This research could improve biosensors and electronic devices, broadening their operational bandwidth. Rana and Dalarsson's study [3] explores TEM-wave propagation within a coaxial waveguide composed of impedance-matched RHM and LHM media. They designed two permittivity and permeability profiles: abrupt and linear RHM-LHM transitions. Through precise solutions to Maxwell's equations and simulations, they demonstrated the expected properties of RHM-LHM structures, modeled smooth material transitions, and validated the abrupt transition as a limiting case.

2.2. Nanophotonic structures and time-varying media

Another group of studies delves into exploring nanophotonic structures and time-varying media. Bonino and Angelini [4] demonstrate the utility of diamond-based meta-surfaces as nanophotonic platforms. They leverage the high sensitivity and linearity of a nanostructured diamond surface as a refractive index sensor, demonstrating excellent control over light propagation at the nanoscale. Fano-like resonances with a high Q-factor, excited by plane waves, were shown to be achievable, thereby increasing potential applications in the field of nonlinear optics and photonics. Lasri and Sirota [5] propose a temporal analog of negative refraction using time-dependent media. They reveal a stark contrast from the spatial case, introducing simultaneous positive and negative refraction, which paves the way for unprecedented control over wave dynamics in photonic media. Further, Ortega-Gomez *et al.*'s [6] invited tutorial on the conservation of momentum in time-varying media provides a comprehensive review, unraveling the implications of Noether's theorem for the electromagnetic field. The insights gained from this study will prove vital to future developments in understanding and manipulating the electromagnetic properties of time-varying media.

2.3. Applications and future directions

The final segment of the feature issue focuses on applications and future challenges in complex photonic media and metamaterials. Geva and Steinberg's research [7] into the electrodynamics of slowly rotating metamaterials reveals the potential for applications in non-reciprocal dynamics and optical gyroscopes while also pointing towards connections to number theory problems. Dams *et al.*'s exploration [8] of moiré effects in strongly coupled atomic arrays uncovers potential applications in optical sensors and light traps. They demonstrate how these effects can control and enhance the density of optical states, opening up exciting possibilities for photonics. Lastly, Consoli *et al.*'s invited paper [9] on networks of random lasers provides a compelling perspective on photonics neural networks. They discuss the challenges, advancements, and future directions in developing photonic networks of random lasers. With their unique spectral characteristics, such networks offer the potential for advancements in various fields, including image recognition and encryption.

3. Conclusion

The papers in this feature issue offer a snapshot of the current state of research into complex photonic media and metamaterials. They underscore the potential for breakthroughs in fields as diverse as communications, computing, sensing, and encryption while highlighting areas where further research is needed. These contributions undoubtedly pave the way for future innovation and understanding in the physics of complex photonic media and metamaterials.

We aspire that this special issue provides a relevant, contemporary survey of the sphere of optical phase change materials and devices, kindling further scientific exploration and technological advancements in this domain. We are profoundly thankful to every author and reviewer for their invaluable input. Furthermore, we sincerely thank Dr. Stavroula Foteinopoulou for her invaluable support of this feature issue and the diligent Optica team for their remarkable efforts throughout the evaluation and production stages.

Optical Materials EXPRESS

References

1. Z. Tan, J. Yi, S. Wang, X. Chen, and S. N. Burokur, "Closed-form analytical design of a beamforming reflective metagrating with a relatively low number of meta-atoms," Opt. Mater. Express **13**(3), 624 (2023).
2. R. Hu, G. Chen, X. Huang, B. Zhang, K. Du, C. Zhou, T. Wang, W. Zhu, and S. Wang, "Dual-band flexible THz metamirror for spin-selective flips," Opt. Mater. Express **13**(4), 925 (2023).
3. B. Rana and M. Dalarsson, "TEM-wave propagation over an impedance-matched periodic RHM to LHM transition in a coaxial waveguide," Opt. Mater. Express **13**(4), 1118 (2023).
4. V. Bonino and A. Angelini, "High-Q Fano resonances in diamond nanopillars," Opt. Mater. Express **13**(4), 1110 (2023).
5. O. Lasri and L. Sirota, "Temporal negative refraction [Invited]," Opt. Mater. Express **13**(5), 1401 (2023).
6. A. Ortega-Gomez, M. Lobet, J. E. Vázquez-Lozano, and I. Liberal, "Tutorial on the conservation of momentum in photonic time-varying media [Invited]," Opt. Mater. Express **13**(6), 1598 (2023).
7. T. Geva and B. Z. Steinberg, "Rest-frame analysis of rotating metamaterials, gyroscopes, and century-old problems in number theory [Invited]," Opt. Mater. Express **13**(7), 1870 (2023).
8. D. Dams, D. Beutel, X. Garcia-Santiago, C. Rockstuhl, and R. Alaee, "Moiré flat bands in strongly coupled atomic arrays," Opt. Mater. Express **13**(7), 2003 (2023).
9. A. Consoli, N. Caselli, and C. López, "Networks of random lasers: current perspective and future challenges [Invited]," Opt. Mater. Express **13**(4), 1060 (2023).