Introduction Vol. 8, No. 9 | 1 Sep 2018 | OPTICAL MATERIALS EXPRESS 2967
Optical Materials EXPRESS

Feature issue introduction: Optical Phase Change Materials

RICHARD HAGLUND,[1] DANIEL HEWAK,[2] SHRIRAM RAMANATHAN,[3] AND JUEJUN HU[4]

[1]*Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235-1807, USA*
[2]*Optoelectronics Research Center, University of Southampton, University Road, Southampton SO17 1BJ, United Kingdom*
[3]*Department of Materials Engineering, Purdue University, 701 West Stadium Avenue, West Lafayette, IN, 47907-2045 USA*
[4]*Department of Materials Science and Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA*
**richard.haglund@vanderbilt.edu*

Abstract: This *Optical Materials Express* feature issue presents a collection of twelve papers clustered around the general topic of optical phase-change materials. While the scientific study of phase-change materials has a long history, interest in these materials for optical as well as electronic applications has risen sharply in the last decade, and is now the subject of intense world-wide research efforts. In this set of feature papers, topics range from basic materials studies to applications of phase-change materials in metasurfaces, sensing, integrated optics, silicon photonics and polarization switching.

1. Introduction

Solid-solid phase transitions have long occupied a place among the most fundamental and challenging themes in condensed-matter science, while simultaneously holding out the promise of opportunities in materials-based electronic and optical technologies. During the past decade, interest has been growing in the optical science and engineering communities in phase-change materials (PCMs) because of their clear relevance to opportunities for optical modulation and switching when electrical or optical excitation can be used to initiate the phase transformation. The phase transitions of interest include both alterations in electronic structure that lead to insulator- or semiconductor-to-metal transitions, and structural phase transitions between crystal classes or between glassy and crystalline phases. For optical applications, the appeal of the most common PCMs is the large change in optical constants that can be achieved either by the IMT or SPT; these large changes in the dielectric environment adjacent to the PCMs can then be used to drive specific optical functionalities.

2. Summary of papers in the feature issue

This special issue presents a spectrum of current research in phase-change materials motivated by ways in which PCMs can be used to achieve specific optical functionalities. Although most of the papers in the special issue address applications in optical modulation or switching, optically induced phase changes can also be used to pattern or structure materials to achieve a desired functionality, as shown in a paper describing a laser-induced vitrification process that alters local refractive-index profiles in a controlled way [1]. Phase-change materials can also be created by conventional materials synthesis techniques to create optically reconfigurable materials, demonstrated here by graphene-oxide doping of polyvinylidene fluoride (PVDF) to achieve optically switchable piezoelectric behavior [2].

The bulk of the papers in the special issue describe the use of the two most widely used PCMs currently under consideration in research – germanium-antimony-tellurium (GST) glasses and vanadium dioxide (VO_2) – for specific technological applications. Two papers describe the use of vanadium dioxide to create surfaces that exhibit wavelength selectivity.

#342967 https://doi.org/10.1364/OME.8.002967
Journal © 2018 Received 21 Aug 2018; published 31 Aug 2018

Optical Materials EXPRESS

Highly textured VO_2 nanostructures, synthesized by oxidation of electron-beam deposited metallic vanadium films, exhibit selective reflectivity in the infrared [3]. A thermally tunable heterostructure incorporating a layer of VO_2 in a multilayer configuration is employed to create near-perfect infrared absorption without the need for either a Fabry-Perot cavity or nanostructuring [4].

The theme of reconfigurable devices using phase-change materials is developed in a trio of papers that use GST as the phase-changing medium. Nanophotonic integrated circuits incorporating GST-on-silicon hybrid structures create a platform that is both non-volatile and continuously reprogrammable, demonstrated in the form of an optical switch with a 33 dB extinction ratio [5]. A reconfigurable near-infrared metasurface based on $Ge_2Sb_2Te_5$ glass is described that exhibits a 7:1 on-off ratio independent of polarization at 1.55 μm; the design of the metasurface is enabled by coupling a genetic algorithm optimizer to standard electromagnetic solver software [6]. A novel route to optically controlled switching in integrated photonics can also be achieved by evanescent-field coupling, in this case between GST and the confined mode in a Si_3N_4 waveguide [7].

Opening a view into possible use of PCMs for multi-wavelength infrared emitters and sensors, $Ge_2Sb_2Te_5$ glass is used to provide active, polarization controlled switching of thermionic metal-insulator-metal plasmonic emitters [8]. The obverse application is adumbrated in the demonstration of a tunable surface for infrared absorption spectroscopy, based on uniform field enhancement in a dielectric-metal structure that incorporates VO_2 thin film as the modulating element [9].

Two papers deal with more general questions of the materials physics of PCMs. One is a study of the effect of hafnium doping on a VO_2 thin films in the monoclinic (M) phase, showing control of the hysteresis width in the thermally induced phase transition, a transition to the VO_2(B) phase at high doping levels, and a possible application for control of thermal radiation properties of these films [10]. A modified Maxwell Garnett model, based on an asymmetric effective-medium theory, is considered as a way to treat electromagnetic hysteresis in VO_2 using only a few input parameters to generate a phenomenological description of the phase transformation, in a formalism that can possibly be extended to other kinds of PCMs [11].

The feature issue concludes with a review of phase-change materials in the major types of silicon photonic devices using thermo-optic, electro-optic and all-optical methods for inducing the phase transformation [12]. The review makes it clear that although many of the papers in this feature issue demonstrate the effects of phase-changing materials by thermal cycling through the phase transition, a full range of thermal, optical and electrical excitations can be used to enlarge the palette of possible applications.

The variety of perspectives on optical phase-change materials exhibited here no doubt will point the way to a wide range of future applications that capitalize on way PCMs can alter the dielectric environment of materials and structures to achieve both non-volatile switching and latching as well provide high-speed modulation of photonic devices.

Acknowledgments

The editors are grateful to all of the authors who contributed papers for this feature issue; to all the reviewers who graciously accepted the responsibility for assessing and commenting on the submissions in a timely manner; and to the *Optical Materials Express* editorial staff who supported the submission, review and publication process.

References

1. M. Kang, L. Sisken, J. Cook, C. Blanco, M. C. Richardson, I. Mingareev, and K. Richardson, "Refractive-index patterning of infrared glass ceramics through laser-induced vitrification [Invited]," Opt. Mater. Express **8**(9), 2722–2733 (2018).

Optical Materials EXPRESS

2. Y. A. Barnakov, O. Paul, A. Joaquim, A. Falconer, R. Mu, V. Y. Barnakov, D. Dikin, V. P. Petranovskii, A. Zavalin, A. Ueda, and F. Williams, "Light-intensity-induced phase transitions in graphene oxide-doped polyvinylidene fluoride," Opt. Mater. Express **8**(9), 2579–2585 (2018).
3. M. E. Uslu, I. B. Misirlioglu, and K. Sendur, "Selective IR response of highly textured, phase-change VO_2 nanostructures obtained via oxidation of electron beam-deposited metallic V films," Opt. Mater. Express **8**(8), 2035–2049 (2018).
4. Z. Liu, B. Banar, S. Butun, H. Kocer, K. Wang, J. Scheuer, J. Wu, and K. Aydin, "Dynamic infrared thin-film absorbers with tunable absorption level based on VO_2 phase transition," Opt. Mater. Express **8**(8), 2151–2158 (2018).
5. J. Zheng, A. Khanolkar, P. Xu, S. Colburn, S. Deshmukh, J. Myers, J. Frantz, E. Pop, J. Hendrickson, J. Doylend, N. Boechler, and A. Majumdar, "GST-on-silicon hybrid nanophotonic integrated circuits: a non-volatile quasi-continuously reprogrammable platform," Opt. Mater. Express **8**(6), 1551–1561 (2018).
6. A. V. Pogrebnyakdov, J. A. Bossard, J. P. Turpin, J. D. Musgraves, H. J. Shin, C. Rivero-Baleine, N. Podraza, K. A. Richardson, D. H. Werner, and T. S. Mayer, "Reconfigurable near-IR metasurface based on $Ge_2Sb_2Te_5$ phase-change material," Opt. Mater. Express **8**(8), 2264–2275 (2018).
7. C. Rios, M. Stegmaier, Z. Cheng, N. Youngblood, C. D. Wright, W. H. P. Pernice, and H. Bhaskaran, "Controlled switching of phase-change materials by evanescent-field coupling in integrated photonics [Invited]," Opt. Mater. Express **8**(9), 2455–2470 (2018).
8. Y. Qu, Q. Li, L. Cai, and M. Qiu, "Polarization switching of thermal emissions based on plasmonic structures incorporating phase-changing material $Ge_2Sb_2Te_5$," Opt. Mater. Express **8**(8), 2312–2320 (2018).
9. G. Bakan, S. Ayas, and A. Dana, "Tunable enhanced infrared absorption spectroscopy surfaces based on thin VO_2 films," Opt. Mater. Express **8**(8), 2190–2196 (2018).
10. T. Huang, T. Kang, Y. Li, J. Li, L. Deng, and L. Bi, "Metal-insulator phase transition in Hf-doped VO_2(M) thin films: a study on the structural, electrical, optical and infrared radiation properties," Opt. Mater. Express **8**(8), 2300–2311 (2018).
11. J. D. Frame, N. G. Green, and X. Fang, "Modified Maxwell Garnett model for hysteresis in phase-change materials," Opt. Mater. Express **8**(7), 1988–1996 (2018).
12. K. J. Miller, R. F. Haglund, Jr., and S. M. Weiss, "Optical phase-change materials in integrated silicon photonic devices: review," Opt. Mater. Express **8**(8), 2415–2429 (2018).