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Editorial overview

Photonics of 2D materials

The emergence of graphene and graphene-like two dimensional (2D) materials has attracted a strong interest from the photonics community in recent decade. Apart from zero-gap graphene, insulating hexagonal boron nitride and semiconducting transition metal dichalcogenides and phosphorene/black phosphorus are being intensively investigated because of their fascinating photonic and optoelectronic properties. Compared to traditional bulk photonic materials such as Gallium Arsenide (GaAs) and Silicon (Si), 2D materials exhibit many unique properties important for device applications in nanophotonics. Firstly, quantum confinement in the direction perpendicular to 2D plane leads to novel electronic and optical features that are distinctively different from their bulk counterparts. Secondly, their surfaces are naturally passivated without any dangling bonds making them readily compatible for integration with photonic structures such as waveguides and cavities. It is also possible to construct vertical hetero-structures by using different 2D materials, without considering lattice mismatch issues that are common in bulk semiconductors. This is because the 2D layers with different lattice constants in heterostructures are only weakly bounded by van der Waals force. Thirdly, despite being atomically thin, many 2D materials interact very strongly with light.

This special Issue focuses on the most recent advances in the field of optics, photonics and optoelectronics of 2D materials. This issue has 43 papers, covering light emitting diodes and lasers, non-linear optics and ultrafast optical phenomena, photodetectors and photovoltaic devices, optical modulators, plasmonics, 2D based terahertz devices and applications of 2D materials in communications, imaging, and sensing as well as in various other optoelectronic devices and their applications.

It includes four invited review articles. C. Anfuso et al. summarized recent applications of Atomic Force Microscopy (AFM) to 2D materials. In particular, the review focuses on the properties of 2D materials with regards to nanomechanics, nanoelectromechanics, nanoelectrics, nanospectroscopy and nanoelectrochemistry. The explanations of how to characterize these properties using AFM techniques are also supplemented with recent examples from the literature. K. Wu et al. reviewed nonlinear photonics of several 2D materials including topological insulators, transition metal dichalcogenides and black phosphorus. They summarized the current specifications from these 2D material-based mode locked and *Q*-switched lasers. This review also offers new insights for researchers on ultrafast photonics based on 2D materials. J. Lu et al. present a comprehensive review on recent research investigations on 2D materials such as graphene and transition metal dichalcogenides using THz spectroscopy. The review also includes characterization of electron transport of graphene at equilibrium state and transient behavior at non-equilibrium state. This review would provide researchers a comprehensive understanding of fundamental THz properties of 2D materials. K. Zhang summarized THz photodetectors with different physical working mechanism and introduced the state-of-the-art THz photodetectors based on various promising 2D materials, such as graphene, transition metal dichalcogenides, black phosphorus and topological insulators. A brief discussion on the remaining challenges and a perspective of the 2D materials based THz photodetectors highlighted the promising THz applications of 2D materials.

P. Yan et al. employed ultrathin quartz plate-based multilayer molybdenum disulfide (MoS_2) by chemical vapor deposition as a saturable absorber to demonstrate it as an effective mode locker for ultrafast photonics. X. Ma et al. investigated the influences of rare earth element Eu^{3+} doping on the photoelectric characteristics of MoS_2 films deposited on p-Si substrates using vapor deposition method, and show that the Eu^{3+} doped MoS_2 films can be used to fabricate high efficiency luminescent and optoelectronic devices. M. Shah et al. theoretically investigated intensity-dependent optical nonlinearity in graphene-aided D-microfibers. This study may open new opportunities towards next-generation all fiber graphene nonlinear optical devices by tuning the chemical potential of graphene and varying radial distance and radii of the D-microfiber. Z. Cai et al. report diode-pumped Q-switched Pr:YLF lasers at deep red regime using a few-layer Bi_2Se_3 saturable absorber, revealing its potential as a saturable absorber for visible solid-state lasers. B. Guo et al. demonstrate versatile soliton pulses in a passively mode-locked fiber laser with a WS_2-deposited microfiber, and demonstrates that such devices have high optical nonlinearity for studying a wide variety of nonlinear soliton phenomena. W. Liu reported fabrication of saturable absorber by magnetron sputtering of WS_2 and Au films on tapered fiber. The heat elimination and damage threshold can be improved for WS_2 saturable absorber with evanescent field interaction. Q. Song et al. reported WS_2 & graphene oxide based saturable absorber for passively Q-switched mode-locked Nd:$GdTaO_4$ lasers, and proposed that a mixed WS_2-GO saturable absorber could be suitable for solid state lasers. L. Li et al. present a stable Q-switched Er-doped fiber laser with WS_2-based saturable absorber. Their experimental results show that the WS_2/PVA saturable absorber can work as a promising *Q*-switching device for high power fiber lasers. M. Liu et al. synthesized black phosphorus quantum dots (BPQDs) by using a liquid exfoliation method that combined probe sonication and bath sonication. The authors demonstrated saturable absorption of BPQDs at 1.55 μm suggesting that BPQDs could be an attractive nonlinear optical material for applications in the field of nonlinear optics. H. Wu et al. synthesized uniform SnS and SnS_2 QDs *via* a convenient and facile ultrasonic method. Their work demonstrates the potential of SnS and SnS_2 QDs for optical and electronic applications.

The 43 articles in this special issue are merely representative of the research work in the growing and flourishing field of 2D materials in photonics. This special issue tries to address a wide range of cutting-edge advances based on 2D materials, from graphene, topological insulator,

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transition metal dichalcogenides to black phosphorus and 2D-material-based QDs. A significant number of papers in this issue has been devoted to the investigation of light–matter interaction in 2D materials, including nonlinear optics, ultrafast relaxation, THz photonics, nonlinear Kerr effect, luminescent, optoelectronic, optical modulation and their applications for saturable absorber, modulator, emitter, THz detector and so on. The special issue therefore gives the readers a broad perspective of the cutting edge advancements of 2D material photonics.

Acknowledgments

We would like to thank Professor Min Qiu for the opportunity to publish this special section, and Professor Qing Yang and Optics Communication staff for their great support during the preparation process. We also appreciate great efforts from the reviewers who offered detailed and important reviews and suggestions to improve the manuscripts submitted to this issue, leading to its high quality. Lastly, we feel very grateful to all the authors for their excellent contributions to this special issue. We anticipate that all the papers will provide readers with a wider and better knowledge about the recent developments in the photonics of 2D materials.

Han Zhang is a distinguished Professor of Photonics at Shenzhen University, China. He received B.S. degree from Wuhan University (2006) and Ph.D. degree from Nanyang Technological University (2011). He is the winner of the National Thousand Talents Program for Distinguished Young Scholars, a government endowed professorship, and the National Science Fund for Excellent Young Scholars and the New Century Excellent Talent Award, MOE, China. His current research is focused on ultrafast and nonlinear photonics of 2-D materials. He has published more than 100 papers with more than 11,000 total citations and an H-index of 51. He is also the director of Shenzhen Key Laboratory of Two-Dimensional Materials and Devices/Shenzhen Engineering Laboratory of Phosphorene and Optoelectronics, an Associate Editor of OSA Photonics Research, Editorial Board Member of Scientific Reports.

Dr. Junzhuan Wang is an Associate Professor in School of Electronic Science and Engineering, Nanjing University, China. She got her Ph.D. in Applied Physics, Nanjing University in 2008 and joined the National Laboratory of Solid State Microstructures, Nanjing University. From 2009 to 2011 she was in LPICM, Ecole Polytechnique/CNRS as a visiting scholar. Dr. Wang's research focuses on the semiconductor nanomaterials for photonic devices and color sensors (such as ELDs, photovoltaic solar cells, lithium battery cells and RGB photodetectors). She has published around 30 peer reviewed papers, including in Nature Communications, Advanced Materials, NanoLetters and Advanced Optical Materials.

Dr. Tawfique Hasan is a Reader in Nanomaterials Engineering at the Cambridge Graphene Centre, Cambridge University. He is also the Deputy Director for Teaching and Training in EPSRC Funded Centre for Doctoral Training in Graphene Technology.

Dr. Hasan has pioneered a number of application areas in graphene and 2-dimensional materials, including inkjet printable graphene inks, ultrafast lasers using graphene polymer composites, flexible smart windows and high speed printable highly conductive graphene inks using commercial graphics printers. His current research focuses on formulation of functional 0D, 1D and 2D nanomaterial and hybrid material ink systems for a wide range of low-cost, printable and flexible photonic, (opto)electronic, energy devices and sensing, in particular, distributed sensor networks for real time environmental monitoring.

Dr. Hasan has >110 peer-reviewed journal articles with >11,000 citations and an H-index of 34. He spun out two start-ups on 2D materials, one of which was recently acquired.

Qiaoliang Bao received his B.A. (2000) and M.E. (2003) degrees in Materials Science and Engineering from Wuhan University of Technology (China). He obtained his Ph.D. degree (2007) in Materials Physics and Chemistry from Wuhan University (China). He worked as postdoctoral fellow at Nanyang Technological University and National University of Singapore from 2007 to 2012. He is currently appointed as tenured associated professor at Department of Materials Science and Engineering, Monash University. His research interests include synthesis and optical characterization of two-dimensional materials as well as their incorporation into photonic and optoelectronic devices. He has authored or co-authored more than 130 refereed journal articles with more than 10,000 total citations and an H-index of 46.

Dr. Bao is the guest editor of special issues in Optical Communications and IEEE Journal of Selected Topics of Quantum Electronics (JSTQE). He received Discovery Early Career Researcher Award (2012) and Future Fellowship (2015) given by Australian Research Council, Award of Thousand Young Talents Program (2012, China), Larkins Fellowship (2012) given by Monash University, First Runner-up of Scopus Young Researcher of the Year Award (2013, Australia), Young Tall Poppy Science Awards (2015) given by Australian Institute of Policy and Science.

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