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SPECIAL ISSUE: Optical Gain Materials towards Enhanced Light-Matter Interactions

Advanced optical gain materials keep on giving

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In the past few decades, there has been a long-standing pursuit to exploring emergent materials with robust optical gain and superior light-matter interacting properties for the development of photonic and optoelectronic devices including but not limited to micro-lasers, single photon emitters, light-emitting-diodes, photo-detectors and so on. Pioneering efforts have been devoted to advanced optical gain materials, covering from classical II-VI/III-V semiconductors, emergent two-dimensional semiconducting materials, organic dyes to halide perovskites, which hold great promise for optimizing the device performance and expanding the frontier photonics/optoelectronics. Meanwhile, the scientific and engineering challenges, forging these materials into powerful tools for fundamental sciences and industrial technologies, still remain. The rapid evolution of this area necessitates a highlight of the recent advances and challenges, which is the aim of this timely themed issue on "Optical Gain Materials towards Enhanced Light-Matter Interactions" organized by *Science China Materials*. This highlight was partly motivated by a symposium organized during the 10th International Conferences on Materials for Advanced Technologies (ICMAT 2019) held in Singapore, co-chaired by all the guest editors.

The wide applicability of optical gain materials highly depends on the intrinsic crystalline and optical quality, and cannot be separated from advanced fabrication techniques. The review by Liu *et al.* [1] concentrates on the recent studies of various growth methods in halide perovskite semiconductors. Especially, Chen *et al.* [2] propose the continuous-flow fabrication of doped perovskite nanocrystals in a microfluidic reactor, which enables efficient physical mixing of the precursor ions in the confined micro-channels with stable and closed environment towards high-quality synthesis. Controlled growth of plasmonic heterostructures with a specific composition, morphology, size, and structural symmetry, as well as their optical-related applications are covered by Wang *et al.* [3]. The progress report by Xiao *et al.* [4] provides a comprehensive summary of colloidal crystals spheres self-assembly into periodic patterns for optical applications. For typical third-generation semiconductors, Liu *et al.* [5] overview the development on the design and growth of GaN-based laser diodes.

With advanced optical gain materials and well-designed structures, novel optical and photonic properties resulting from enhanced light-matter interactions can be expected. From a basic scientific perspective, Chen *et al.* [6] highlight the booming GaAs-based nanowires, especially in the aspect of optical properties and lasing, towards potential infrared laser in integrated optoelectronics. In specific researches, the article by Wang *et al.* [7] realizes the plasmon-enhanced second-harmonic generation up to 617.7-fold in asymmetric Ag@CdSe hetero-nanorods, enabling high-resolution detection in the biological sensing. An ultrafast formation (<100 fs) of dihydrogen defects in YH_xO_y, which is responsible for the transparent-to-opaque photochromic transition with the state stability strongly dependent on the concentration of oxygen, is presented by Cao *et al.* [8] by using excited-state density functional theory simulation. In the contribution by Pan *et al.* [9], the strong optical anisotropy of deep-ultraviolet fluorooxoborates with designed possible anionic groups is systematically analyzed to check the influence on birefringence towards developing novel nonlinear optical crystals. Another strategy to enrich the understanding of ideal nonlinear optical crystals, theoretical modeling and simulation, is reported by Lin *et al.* [10], covering seven potential structures in the deep-ultraviolet region predicted for the first time. For two-dimensional GeS na-

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noflakes exfoliated experimentally, Jiang *et al.* [11] observe conspicuous saturated absorption and reverse saturated absorption effects as the incident light are parallel to armchair and zigzag directions of GeS, respectively, revealing the considerable potential for polarization-tunable switching. Moreover, Peng *et al.* [12] utilize the magneto-photoluminescence measurement to directly reveal the dark exciton in $CsPbBr_3$ perovskite crystals; Xing *et al.* [13] report the light-induced phase transition and photochromism in two-dimensional $Cs_2PbCl_2I_2$ perovskite crystals, where the newly generated $CsPbI_3$ exhibits a higher stability than the pure cousin. These two papers promote the understanding of halide perovskite-based optoelectronics.

Photonic and optoelectronic applications of advanced optical gain materials, such as miniaturized laser, light-emitting diodes, solar cell, photodetectors, and optical switching, are of intense interest. The continuous-wave pumped laser in semiconductor quantum dots is detailed in the progress report by Zhong *et al.* [14]. Another contribution by Zhao *et al.* [15] stresses the organic crystal/Ag nanowire heterostructures and their applications in Boolean logic unit, which paves a hopeful approach into sub-wavelength photonic circuitry. To improve the perovskite solar cell performance, Cheng *et al.* [16] theoretically predict $PbCl_2$ as a promising candidate for buffer layer in the typical $CH_3NH_3PbI_3/TiO_2$ solar cell structure due to proper bandgap alignment, small lattice mismatch and excellent surface passivation. An extra emphasis by Xing *et al.* [17] is placed on the high-quality lead-free double perovskites, $Cs_2AgBiBr_6$, as the active region in the solar cell with large grain size (~0.5 μm) and tolerable efficiency (~1.11%), providing a meaningful guide towards high-efficient non-toxic photovoltaic devices. Furthermore, the applications of van der Waals heterostructures based on two-dimensional layered materials with unique performance are accentuated. A Bi_2Se_3/WSe_2 photodetector investigated by Zhai *et al.* [18] shows a high detectivity (2.2×10^{10} Jones) and a high responsivity (3 A W^{-1}) excited by the 1456 nm near-infrared source owing to the broken-gap tunneling heterostructure. A MoS_2/NbS_2 transistor with NbS_2 as the contact electrodes demonstrates a high field-effect mobility (15 $cm^2\ V^{-1}\ s^{-1}$) and a high current on-off ratio (1.8×10^7) and another photodetector with the same structure reveals a high responsivity (1.27 A W^{-1}), where the enhanced performance originates from the successful direct epitaxy reported by Gong *et al.* [19]. A $In_2Se_3/SnSe_2$ photodetector in the work of Yao *et al.* [20] exhibits an ultralow dark current (6.3 pA), a high detectivity (8.8×10^{11} Jones), a high signal-to-noise ($>3\times10^4$) as well as the capability of integration on flexible substrates, where the depletion near the interface and type-II alignment can efficiently suppress the dark current and separate the photo-generated carriers. Finally a CdS/BP photodetector proposed by Li *et al.* [21] possesses a record high responsivity up to 9.2×10^5 A W^{-1} at a low bias voltage of 1.0 V benefiting from the large light absorption efficiency of CdS.

In summary, this special issue presents some exciting studies that give a flavor of the fascinating scientific and technological developments being carried out in the advanced optical gain materials and related enhanced light-matter interactions in these systems. Particularly, fabrication, photophysics together with optoelectronic device based on these emergent materials are comprehensively discussed. Finally, we would like to thank the editorial team of *Science China Materials* for providing the opportunity to edit this special issue. We also sincerely thank all the authors for their outstanding contributions and the referees for their valuable comments that help to improve the articles in this special issue.

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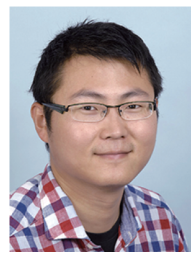

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