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Editorial

Advanced Inorganic Semiconductor Materials

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1. Introduction

The information technology revolution has been based decisively on the development and application of inorganic semiconductors. Conventional devices utilize bulk semiconductors in which charge carriers are free to move in all three spatial directions. For example, silicon forms the basis of the vast majority of electronic devices, whilst compound semiconductors such as GaAs are used for many optoelectronic applications [1]. Recently, with the global boom in graphene research, more and more atomically thin 2D inorganic materials have gained significant interest [2–4]. Besides their promising applications in various ultrathin, transparent, and flexible nanodevices, 2D materials could also serve as one of the ideal models for establishing clear structure–property relationships in the field of solid-state physics and nanochemistry.

Despite the significant advances in the previous decade, both opportunities and challenges remain in this field. This SI consists of nine articles and two topical reviews, which highlight the most current research and ideas in inorganic semiconductors, from traditional to novel 2D semiconductor materials to 1D quantum dots. It captures the diversity of studies including experimental fabrication and characterization, as well as the electronic, electrical, magnetic, optoelectronic, and thermal properties of inorganic semiconductors.

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2. An Overview of Published Articles

This section provides a brief overview of the 11 contributions, organizing them into discreet subsections that include CQDs, 2D materials, germanium (Ge) on silicon (Si) avalanche photodiode, etc.

2.1. CQDs

In the article by Tian et al. (Contribution 1), the authors combine the microemulsion method with the microfluidic chip to prepare spherical QDSPs with regular shapes and high packing density. The small inter-dot distance enables QDSPs to have the following unique optical properties:

1. This self-assembled QDSP structure enables energy transfer between CQDs through fluorescence resonance energy transfer, resulting in a red shift in the steady-state fluorescence spectra of the SPs.
2. The dynamics of the energy transfer process of individual SPs are investigated by time-resolved fluorescence spectroscopy. The fast FRET process promotes the rapid energy transfer between excitons, resulting in the decay rate of PL intensity gradually increasing with the increase in energy, and the PL spectrum red shifts with time.
3. The non-radiative Auger recombination of CQDs is suppressed as FRET rates increase and potentially improve stability at high temperatures. Through short-chain ligand

exchange, higher packed SPs with better temperature-dependent optical stability are achieved, which can be attributed to the increased FRET rate and suppressed Auger recombination in the SPs with smaller dot spacing.

An CQD's self-assembled superparticle structure is an ideal platform for the research of multiparticle systems, and its novel FRET effect and temperature-insensitive fluorescence emission characteristics promote the development of new-type optoelectronic devices, such as photonic materials, solar cells, and optical sensors.

2.2. Two-dimensional Materials

In separate first-principles studies, the three articles by Jiang et al. (Contribution 2), Zhou et al. (Contribution 3), and Qiao et al. (Contribution 4) discuss the mechanical, electronic, magnetic, and optical properties of three typical 2D materials, i.e., adsorption of metal atoms on monolayer SiC, monolayer SnP_2S_6 and GeP_2S_6 under strain, as well as two doped 2D boron nitride polymorphs B_5N_6Al and B_5N_6C sheets. The results are summarized as follows.

1. Metal–atom-adsorbed SiC systems have potential applications in spintronic devices and solar energy conversion photovoltaic devices.
2. The strain is an effective band engineering scheme crucial for designing and developing next-generation nanoelectronic and optoelectronic devices.
3. Doping different atoms induces tunable electronic and magnetic properties in the 2D boron nitride sheets.

2.3. Ge on Si Avalanche Photodiode

In the article by Deeb et al. (Contribution 5), the planar structure of Ge on Si avalanche photodiode is designed. The dependences of the breakdown voltage, gain, bandwidth, responsivity, and quantum efficiency on the reverse bias voltage for different doping concentrations and thicknesses of the absorption and multiplication layers of the germanium on silicon avalanche photodiode are presented. The article presents simulation results, discussions, and analysis of design considerations. The dependence of the photodetectors' operating characteristics on the doping concentration for multiplication and absorption layers is revealed for the first time. Based on the analysis and simulation results, the optimal design for separate-absorption-charge-multiplication Ge on Si avalanche photodiode is proposed.

2.4. GaAs Quantum Dot

In the article by Dakhlaoui et al. (Contribution 6), the authors present the first detailed study of OACs produced by a Woods–Saxon-like spherical quantum dot containing a hydrogenic impurity at its center. They use a finite difference method to solve the Schrödinger equation within the framework of the effective mass approximation. First, they compute energy levels and probability densities for different parameters governing the confining potential. Then they calculate dipole matrix elements and energy differences and discuss their role in OACs. The findings demonstrate the important role of these parameters in tuning the OAC to enable blue or red shifts and alter its amplitude. The simulations provide a guided path to fabricate new optoelectronic devices by adjusting the confining potential shape.

2.5. Lead Halide Perovskites

The article by Junaid et al. (Contribution 7) reports the vibrational, structural, and elastic properties of mixed halide single crystals of $MA_xFA_{1-x}PbCl_3$ at room temperature by introducing the FA cation at the A-site of the perovskite crystal structure. Powder X-ray diffraction analysis confirms that its cubic crystal symmetry is similar to that of $MAPbCl_3$ and $FAPbCl_3$ with no secondary phases, indicating a successful synthesis of the $MA_xFA_{1-x}PbCl_3$ mixed halide single crystals. Structural analysis confirms that the FA substitution increases the lattice constant with increasing FA concentration. Raman spectroscopy provides insight into the vibrational modes, revealing the successful incorporation of the FA cation into the system. Brillouin spectroscopy is used to investigate the changes in the elastic properties induced via the FA substitution. A monotonic decrease in the sound velocity and the elastic constant suggests that the incorporation of large FA cations causes distortion within the inorganic framework, altering bond lengths and angles and ultimately resulting in decreased elastic constants. An analysis of the absorption coefficient reveals lower attenuation coefficients as the FA content increases, indicating reduced damping effects and internal friction. The current findings can facilitate the fundamental understanding of mixed lead chloride perovskite materials and pave the way for future investigations to exploit the unique properties of mixed halide perovskites for advanced optoelectronic applications.

2.6. Silver-Based Chalcogenide Semiconductors

The article by Wang et al. (Contribution 8) reports a facile mixture precursor hot-injection colloidal route to prepare $Ag_2Te_xS_{1-x}$ ternary QDs with tunable PL emissions from 950 nm to 1600 nm via alloying band gap engineering. As a proof-of-concept application, the $Ag_2Te_xS_{1-x}$ QDs-based near-infrared PD is fabricated via solution processes to explore their photoelectric properties. The ICP-OES results reveal the relationship between the compositions of the precursor and the samples, which is consistent with Vegard's equation. Alloying broadens the absorption spectrum and narrows the band gap of Ag_2S QDs. The UPS results demonstrate the energy band alignment of $Ag_2Te_{0.53}S_{0.47}$ QDs. The solution-processed $Ag_2Te_xS_{1-x}$ QD-based PD exhibits a photoresponse to 1350 nm illumination. With an applied voltage of 0.5 V, the specific detective is 0.91×10^{10} Jones and the responsivity is 0.48 mA/W. The PD maintains a stable response under multiple optical switching cycles, with a rise time of 2.11 s and a fall time of 1.04 s, which indicates excellent optoelectronic performance.

2.7. Thin-Film Transistors Featuring Ferroelectric HfO_2/$HfSe_2$ Stack

The article by Lu et al. (Contribution 9) investigates dual-mode synaptic plasticity in TFTs featuring an $HfSe_2$ channel, coupled with an OD-HfO_2 layer structure. In these transistors, the application of negative gate pulses results in a notable increase in the post-synaptic current, while positive pulses lead to a decrease. This distinctive response can be attributed to the dynamic interplay of charge interactions, significantly influenced by the ferroelectric characteristics of the OD-HfO_2 layer. The findings from this study highlight the capability of this particular TFT configuration to closely mirror the intricate functionalities of biological neurons, paving the way for advancements in bio-inspired computing technologies.

2.8. Inverse Opal Photonic Crystals

The review by Xiang et al. (Contribution 10) introduces the preparation methods of three-dimensional inverse opal photonic crystals, summarizes the principle of photocatalysis and the advantages of inverse opal photonic crystals in the field of photocatalysis, as well as the modification methods to further improve the efficiency of photocatalysis. Finally, the application progress in the fields of sewage purification, hydrogen production, and carbon dioxide decomposition is introduced.

2.9. Ohmic Contact Based on β-Ga_2O_3

The review by Zhang et al. (Contribution 11) summarizes the ohmic contact techniques developed in past years. First, the basic theory of metal–semiconductor contact is introduced. After that, the representative literature related to ohmic contact on β-Ga_2O_3 is summarized and analyzed, including the electrical property, the interface microstructure, the ohmic contact formation mechanism, and contact reliability. In addition, promising alternative schemes, including novel annealing techniques, and Au-free contact materials which are compatible with the CMOS process are expected and discussed. This review provides a theoretical basis understanding of ohmic contact on β-Ga_2O_3 devices, as well as the development trends of ohmic contact schemes.

3. Summary

In summary, this SI "Advanced Inorganic Semiconductor Materials" combines the latest achievements in the field of inorganic semiconductor materials, along with two reviews of previously obtained results. Inorganic semiconductors exhibit a wide range of new and unusual properties, which can be employed to fabricate improved and novel electronic and electro-optical devices.

With this SI published in the "Inorganics Materials" section, and further published as a book, the editors hope that the completeness and high quality of the contributions collected here receive the visibility and attention they deserve. These contributions would help readers to increase their knowledge in the field of inorganic semiconductor materials and be a new source of inspiration for novel, focused investigations, which we sincerely hope will contribute to the next edition of this SI "Advanced Inorganic Semiconductor Materials: 2nd Edition" [5].

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Abbreviations

The following abbreviations are used in this manuscript:

GaAs	gallium arsenide
2D	two-dimensional
SI	Special Issue
QDSP	quantum dot supraparticle
CQD	colloid quantum dot
SP	supraparticles
FRET	fluorescence resonance energy transfer
OAC	optical absorption coefficient
MA	$CH_3NH_3^+$, methylammonium
FA	$CH(NH_2)_2^+$, formamidinium
QD	quantum dot
PL	photoluminescence
PD	photodetector
ICP	inductively coupled plasma
OES	optical emission spectrometer
UPS	ultraviolet photoelectron spectroscopy
TFT	thin-film transistors
OD	oxygen-deficient

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