

NEWS & VIEWS

Open Access

Perovskite sensitized 2D photodiodes

Dong Li¹ and Anlian Pan¹✉

Abstract

A new type of perovskite sensitized programmable WSe₂ photodiode is constructed based on MAPbI₃/WSe₂ heterojunction, presenting flexible reconfigurable characteristics and prominent optoelectronic performances.

The emergence of two-dimensional semiconductors (2DSCs) provides a rich material foundation for the construction of new optoelectronic devices^{1,2}. Transition metal dichalcogenides (TMDs), as a representative, has been widely used in the construction of electrically tunable light emitting diodes (LEDs)³, gate-controlled p-n junction diodes⁴, and solar cells⁵. However, due to atomically thin geometry of monolayer TMDs, effectively tuning charge doping type and improving light absorption efficiency of them has always been a huge challenge, which greatly limits their application in high-performance optoelectronic devices⁶.

Electrostatic doping opens an effective way to regulate charge carriers in nanomaterials. Compared with traditional lattice doping with impurity atoms, electrostatic doping has been widely concerned and applied in low dimensional nanomaterials without introducing impurity atoms and degrading the intrinsic electronic properties of the nanoscale materials. For example, Lee et al.⁷ demonstrated a programmable device based on reversible solid-state doping of WSe₂. By manipulating silver ions in solid-state superior silver iodide (AgI), the carrier types of WSe₂ were adjusted to achieve reverse programming of transistors, diodes, photodiodes, and logic gates. Li et al.^{4,8} achieved high-performance reconfigurable p-n junctions and FET devices by precisely controlling the type of carriers in local floating gates, proving that electrostatic doping can effectively regulate the carrier type and density in TMDs.

One promising way to overcome the low light absorption efficiency of TMDCs is to integrate TMDs with organic dye molecules with high light absorption efficiency⁹. The hybrid lead halide perovskite (LHP), represented by Methylammonium lead iodide (CH₃NH₃PbI₃ or MAPbI₃), is a good choice as the building blocks of optoelectronic devices due to their high light absorption coefficients, long carrier diffusion lengths, strong defect tolerance, and tunable band structures. However, the “soft lattice” ionic LHPs is usually troubled by ion migration under voltage bias, resulting in poor material stability¹⁰ and large hysteresis in the voltage-dependent photocurrent¹¹. Although undesirable for stable operation of solar cell applications, the migration of positively or negatively charged ions could induce ion accumulation or ionic charge imbalance under applied electric fields¹², which can be potentially used to reversibly dope 2DSCs, thus to produce photodiodes.

In the regard, writing in this issue of *eLight*¹³, Xiangfeng Duan, Yu Huang, Dae Joon Kang, and colleagues report a method by exploiting ionic charge imbalance in LHPs to induce reversible doping in 2DSCs, achieving a perovskite sensitized programmable WSe₂ photodiode based on MAPbI₃/WSe₂ heterojunction with flexible reconfigurable characteristics and ultrahigh open circuit voltage. The device shows a switchable open circuit voltage up to 0.78 V and a high EQE of 84.3%. By integrating tunable graphene contacts, the photodiode performance can be further improved to achieve a highest open circuit voltage (V_{OC}) of 1.08 V and a maximum EQE of 91.3%, greatly exceeding those achieved previously in 2DSC lateral diodes.

In this work, the authors present a WSe₂/MAPbI₃ device, where the schematic view and working mechanism of

Correspondence: Anlian Pan (anlian.pan@hnu.edu.cn)

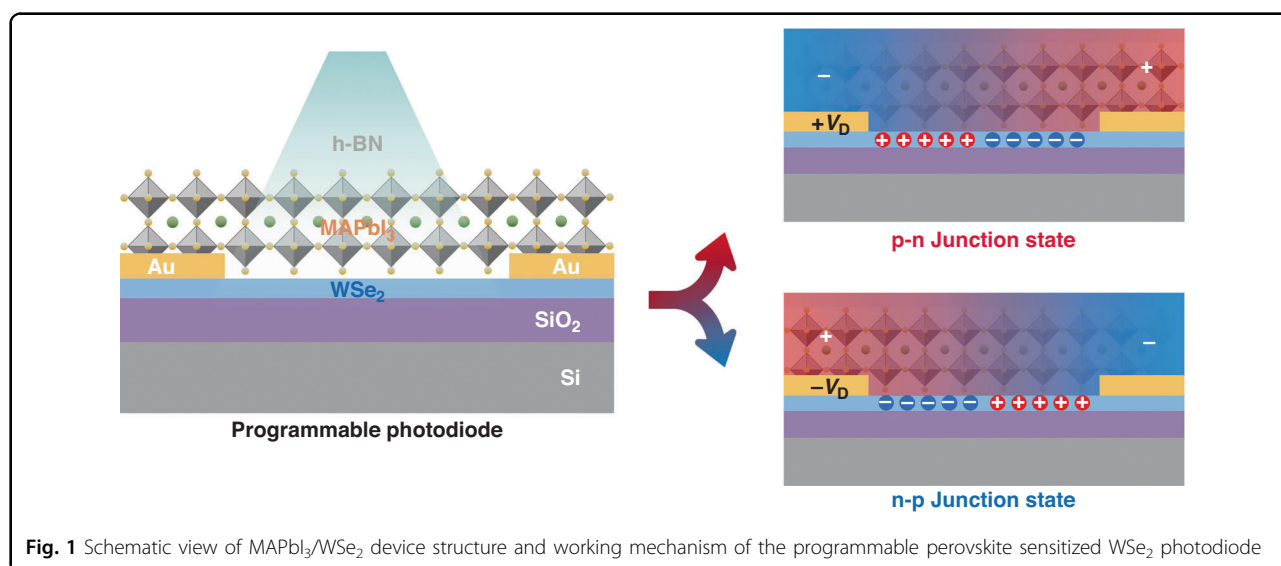
¹Key Laboratory for Micro-Nano Physics and Technology of Hunan Province, State Key Laboratory of Chemo/Biosensing and Chemometrics, Hunan Institute of Optoelectronic Integration, College of Materials Science and Engineering, Hunan University, Changsha, China

© The Author(s) 2023



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.





device are shown in Fig. 1. Under high temperature, ions in MAPbI₃ can be controlled by an external electric field for directional movement. After being frozen at low temperature, these migrated ions are solidified and form ion gates with specific electric field directions in MAPbI₃, thereby forming non-destructive and reversible electrostatic doping in nearby two-dimensional materials. Based on this working mechanism, the authors can perform controllable and reversible doping in WSe₂, achieving carrier inversion and p-n junction reconfiguration in the identical device.

Photodiode applications are further explored based on the programmed diode. Under 532-nm laser excitation (15 W/m²), the negatively poled photodiode delivered an V_{OC} of -0.78 V, and the identical photodiode showed a V_{OC} of $+0.75$ V after the positive lateral poling process. The results demonstrate that the p-n junctions can be reversibly programmed by the electrical poling process, which makes up the shortcomings of traditional silicon-based p-n junctions with fixed performances. Meanwhile, the extracted EQE of 84.3% at 532 nm represents the highest value achieved from lateral or sensitized 2D diode at zero bias voltage¹⁴. By integrating tunable graphene contacts, the photodiode performance can be further enhanced to a V_{OC} of 1.08 V and a maximum EQE of 91.3%. Such strong enhancement indicating that MAPbI₃ perovskite can serve as not only programmable ionic dopants but also the excellent optical absorber and highly efficient sensitization layer.

The unique design of MAPbI₃/WSe₂ device provides a new idea to fabricate high-performance programmable photodiodes. In addition, the combination of atomic thin 2D materials and ionic solids enables effective coupling between electronic transport and ionic transport, which may open up a new pathway for unconventional computing,

information storage systems, and programmable optoelectronic devices.

Published online: 06 June 2023

References

- Wang, S. Y. et al. Two-dimensional devices and integration towards the silicon lines. *Nat. Mater.* **21**, 1225–1239 (2022).
- Liu, C. Y. et al. Silicon/2D-material photodetectors: from near-infrared to mid-infrared. *Light Sci. Appl.* **10**, 123 (2021).
- Ross, J. S. et al. Electrically tunable excitonic light-emitting diodes based on monolayer WSe₂ p–n junctions. *Nat. Nanotechnol.* **9**, 268–272 (2014).
- Li, D. et al. Two-dimensional non-volatile programmable p–n junctions. *Nat. Nanotechnol.* **12**, 901–906 (2017).
- Pospischil, A., Furchi, M. M. & Mueller, T. Solar-energy conversion and light emission in an atomic monolayer p–n diode. *Nat. Nanotechnol.* **9**, 257–261 (2014).
- Komsa, H. P. et al. Two-dimensional transition metal dichalcogenides under electron irradiation: defect production and doping. *Phys. Rev. Lett.* **109**, 035503 (2012).
- Lee, S. J. et al. Programmable devices based on reversible solid-state doping of two-dimensional semiconductors with superionic silver iodide. *Nat. Electron.* **3**, 630–637 (2020).
- Sun, X. X. et al. Reconfigurable logic-in-memory architectures based on a two-dimensional van der Waals heterostructure device. *Nat. Electron.* **5**, 752–760 (2022).
- Yu, S. H. et al. Dye-sensitized MoS₂ photodetector with enhanced spectral photoresponse. *ACS Nano* **8**, 8285–8291 (2014).
- Xiao, Z. G. et al. Giant switchable photovoltaic effect in organometal trihalide perovskite devices. *Nat. Mater.* **14**, 193–198 (2015).
- Tan, S. et al. Steric impediment of ion migration contributes to improved operational stability of perovskite solar cells. *Adv. Mater.* **32**, 1906995 (2020).
- Jiang, J. Y. et al. Rational design of Al₂O₃/2D perovskite heterostructure dielectric for high performance MoS₂ phototransistors. *Nat. Commun.* **11**, 4266 (2020).
- Lee, S. J. et al. Lead halide perovskite sensitized WSe₂ photodiodes with ultrahigh open circuit voltages. *eLight* **3**, 8, <https://doi.org/10.1186/s43593-023-00040-8> (2023).
- Chen, P. et al. Approaching the intrinsic exciton physics limit in two-dimensional semiconductor diodes. *Nature* **599**, 404–410 (2021).

