Black phosphorus-based van der Waals heterostructures for mid-infrared light-emission applications

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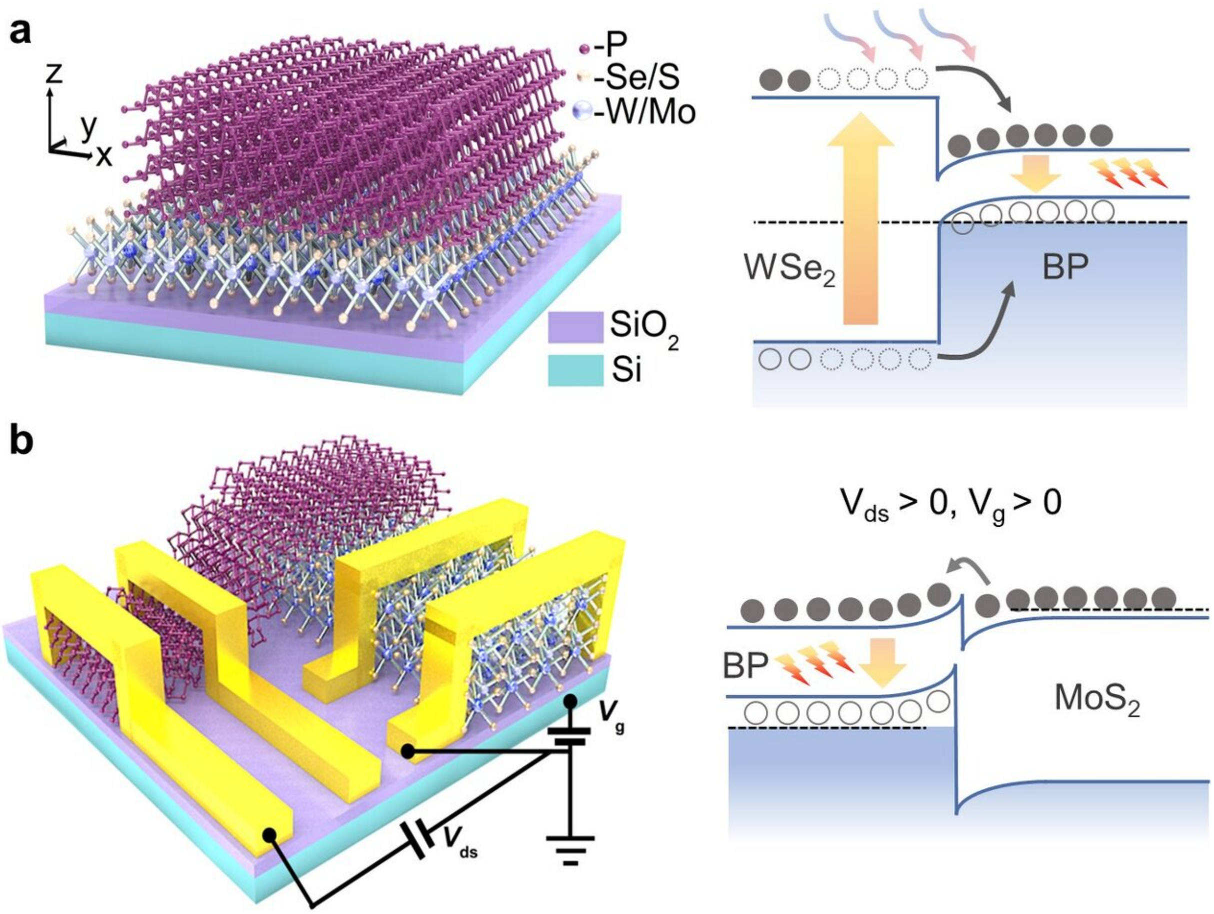

a, Schematic diagram of the BP-WSe2 heterostructure. Under the excitation of light, the electron and hole pairs in WSe2 can be efficiently transmitted to BP, thereby enhancing its MIR photoluminescence. b, Schematic diagram of the BP-MoS2 heterojunction diode. Under a positive bias voltage between BP and

MoS2, the electrons on the conduction band of MoS2 can overcome the barrier, enter into the conduction band of BP, and recombine with abundant holes in BP. Thereby electroluminescence is achieved Credit: Xinrong Zong, Huamin Hu, Gang Ouyang, Jingwei Wang, Run Shi, Le Zhang, Qingsheng Zeng, Chao Zhu, Shouheng Chen, Chun Cheng, Bing Wang, Han Zhang, Zheng Liu, Wei Huang, Taihong Wang, Lin Wang and Xiaolong Chen

Researchers have realized optically and electrically driven mid-infrared (MIR) light-emitting devices in a simple but novel van der Waals (vdW) heterostructure constructed from thin-film black phosphorus (BP) and transition-metal dichalcogenides (TMDC). This work suggests that vdW heterostructure is a promising platform for mid-infrared research and applications.

MIR spectra have been widely used for thermal imaging, molecule characterizations, and communications. Among MIR technologies, MIR light-emitting diodes (LED) show advantages of narrow linewidth, low power consumption, and portability. Since the discovery of thin-film BP in 2014, it has received much attention due to its unique properties, such as in-plane anisotropy, high carrier mobility, and tunable band gap, etc., making BP a promising material for applications in electronics and optoelectronics.

BP has a thickness-dependent (0.3-2 eV) bandgap, and the bandgap size can be further tuned through introducing external electric field or chemical doping. Because of these reasons, thin-film BP has been regarded as a star MIR material. Previous research mainly focused on the luminescence properties of monolayer and few-layer BP flakes (with layer number 7 layers) shows remarkable photoluminescence properties in MIR region.

In a report for the journal *Light: Science & Applications*, researchers proposed a novel vdW heterostructure for MIR light-emission applications, built from BP and TMDC (such as WSe_2 and MoS_2). According to the DFT calculation, the BP-WSe_2 heterostructure forms a type-I band alignment. Hence, the electron and hole pairs in the monolayer WSe_2 can be efficiently transported into the narrow-bandgap BP, thereby enhancing the MIR photoluminescence of thin-film BP. An enhancement factor ~200% was achieved in the 5nm-thick BP-WSe_2 heterostructure.

On the other hand, the BP-MoS_2 heterostructure forms a type-II band alignment. A natural PN junction is formed at the interface between p-type BP and n-type MoS_2. When a positive voltage bias is applied between BP and MoS_2 (Vds > 0), electrons in the conduction band of MoS_2 can cross the barrier and enter into the conduction band of BP. At the same time, the majority of holes are blocked at the interface inside BP due to the large Schottky barrier of the valence band. As a result, an efficient MIR electroluminescence is achieved in the BP-MoS_2 heterostructure.

The BP-TMDC vdW heterostructures have many advantages, such as a simple fabrication process, high efficiency, and good compatibility with silicon technology. Hence, this technology provides a promising platform for investigating silicon-2-D hybrid optoelectronic systems.

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