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

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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\(_2\) (V\(_{ds}\) > 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-TMD 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.

**More information:** Xinrong Zong et al, Black phosphorus-based van der Waals heterostructures for mid-infrared light-emission applications, *Light: Science & Applications* (2020). [DOI: 10.1038/s41377-020-00356-x](https://doi.org/10.1038/s41377-020-00356-x)

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