High-performance reconstructive spectrometers with van der Waals junctions

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1. Main text

Conventional spectrometers rely on bulk optical components such as gratings or filters to separate colors from one another, and therefore cannot be miniaturized without sacrificing their performance. Recently, a new class of ‘ultra-miniaturized reconstructive spectrometers’ has emerged that overcomes this limitation by not requiring that colors be separated prior to detection [1]. Instead, such spectrometers combine the spectral sensitivity and photodetection in a single component element whose spectral responsivity can be electrically modulated. A computational algorithm is then used to reconstruct the spectral content of unknown input light from variations in the photocurrent as the applied modulation signal is swept. Nanometer-level spectral resolutions are possible even though the footprint of the device is on the order of a few tens of micrometers.

Layered 2D materials are ideal candidates for producing such miniaturized spectrometers. They exhibit strong light-matter interaction, and their bandgap can be modulated (e.g. via the Stark effect), leading to an electrically-tunable optical response [3]. Moreover, they naturally possess dangling-bonds-free surfaces, and can be assembled in van der Waals (vdW) structures without taking into consideration lattice mismatch. This allows us to engineer the energy band alignment at the heterostructure interface by choosing the appropriate combination of materials.

Previously, we reported a miniaturized spectrometer based on a locally-gated vdW junction between MoS_2 and WSe_2, operating in the spectral range of 400 – 850 nm [2]. Here, we further simplify the device architecture while simultaneously extending its operating range to cover both the visible and NIR [4]: we construct a simple vdW heterostructure diode using multilayer MoS_2, which possesses a relatively wide bandgap of 1.2 eV, and multilayer black phosphorus (BP), whose bandgap is only 0.3 eV (Fig 1a, b). The resulting vdW junction exhibits an efficient modulation of band alignment between staggered-gap and broken-gap, which changes the character of charge carrier transport from thermionic emission to band-to-band tunneling, merely by controlling the source-to-drain bias voltage (V_{DS}), without requiring gate modulation. The modulation of optical responsivity observed is sufficient to reconstruct spectra with nm-scale peak accuracy in both the visible and NIR (Fig 1c–f).

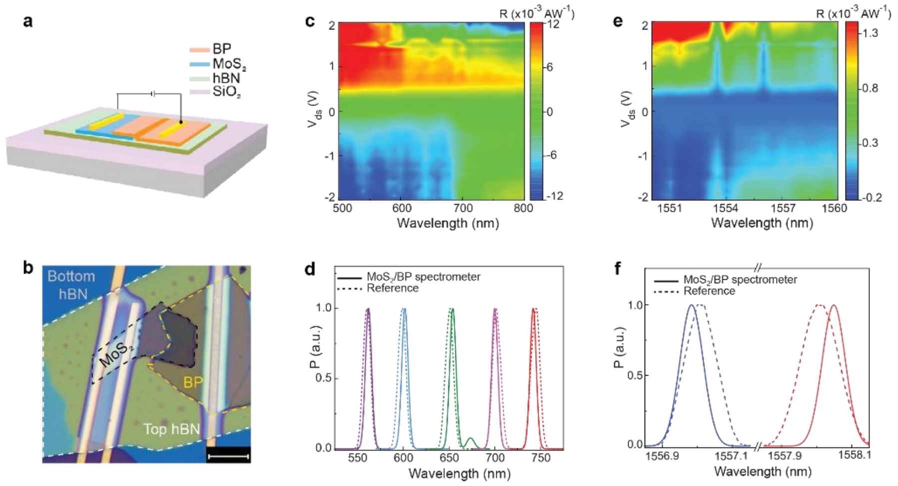

Fig. 1. **a** Schematic of the vdW junction computational spectrometer. **b** The fabricated MoS2/BP vdW diode seen under an optical microscope. To protect the device, the heterostructure is encapsulated with hBN on either side. Scale bar 10 μm. **c** Responsivity as a function of wavelength and applied V_{DS} in the visible range. **d** Comparison of reconstructed and reference spectra in the visible range. **e** and **f** Responsivity matrix and benchmarking of reconstructed spectra in the NIR region.

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3. References

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