Chemical Sensing by Band Modulation of a Black Phosphorus/Molybdenum Diselenide van der Waals Heterostructure

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Abstract
Van der Waals heterostructures based on two-dimensional (2D) materials have attracted considerable research interest in the past few years. In contrast to conventional heterostructures formed by covalent bonds that are generally associated with atomic/ionic inter-diffusion, the van der Waals heterostructure has an abrupt transition between the two materials and a sharp gradient of carrier concentration across the interface[1]. Their unique structural and physical properties have enabled new possibilities for a large array of novel devices and applications ranging from vertical tunneling transistors[2], barristors[3] to optoelectronic applications[4]. However, few have investigated their interaction with gaseous molecules and application as chemical or biological sensors.
In this work, we demonstrate a van der Waals heterostructure chemical sensor based on few-layered black phosphorus (BP) and molybdenum diselenide ($MoSe_2$) flakes. Due to the atomically thin nature of 2D materials, surface adsorption of gas molecules can effectively modulate the band alignment at the BP/$MoSe_2$ interface and, correspondingly, the electron transport characteristics of the device, making it a highly sensitive detector for chemical and physical adsorptions. Compared with sensors made of homogeneous nanomaterials on the same substrate, our device demonstrates a marked enhancement in detection limit and sensitivity by orders of magnitude for NO_2 detection. Kelvin probe force microscopy (KPFM) analysis confirms that the total built-in potential at the hetero-interface dramatically increases after exposure of NO_2 and provides direct evidence of the changes in band alignment due to NO_2 adsorption. Finite element model based on the quantitative KPFM results reveals that the modulation of barrier height in $MoSe_2$, which is induced by the modulation of both the total built-in potential and the ratio between majority carrier concentrations of both materials, is responsible for the enhanced sensitivity. Our work demonstrates the potential of van der Waals heterostructure as a fundamentally new platform for sensing applications and also provides insights into the interactions between gaseous molecules and 2D heterostructures.

References

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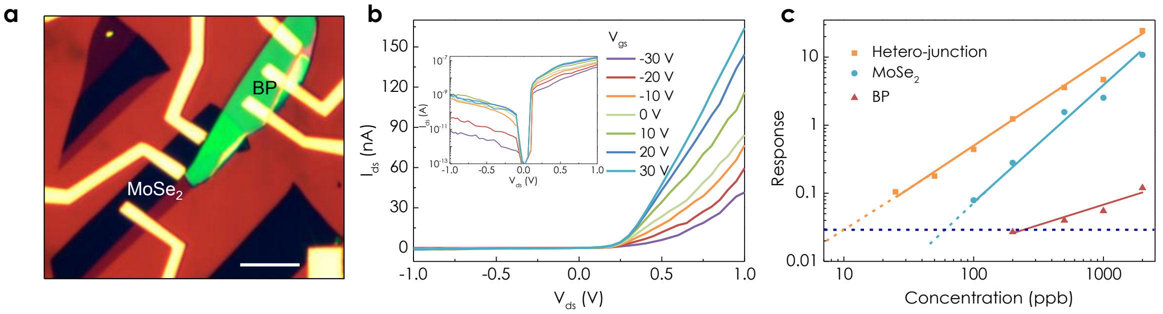
Figures



(a) Optical image of the fabricated device. The green flake is multi-layered BP, while the dark blue flakes are few-layered $MoSe_2$. Scale bar, 15 μm. (b) Gate tunable I-V characteristics of the BP/$MoSe_2$ hetero-junction. Inset: I-V characteristics under semilog scale. (c) Response of all three sensors as a function of gas concentration under logarithm scale. The intersection between each fitting line and the horizontal 3% SNR threshold (blue dashed line) corresponds to the detection limit of each sensor.