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Gate-tunable Diode-like Current Rectification and Ambipolar Transport in Multilayer van der Waals $ReSe_2/WS_2$ p-n Heterojunctions

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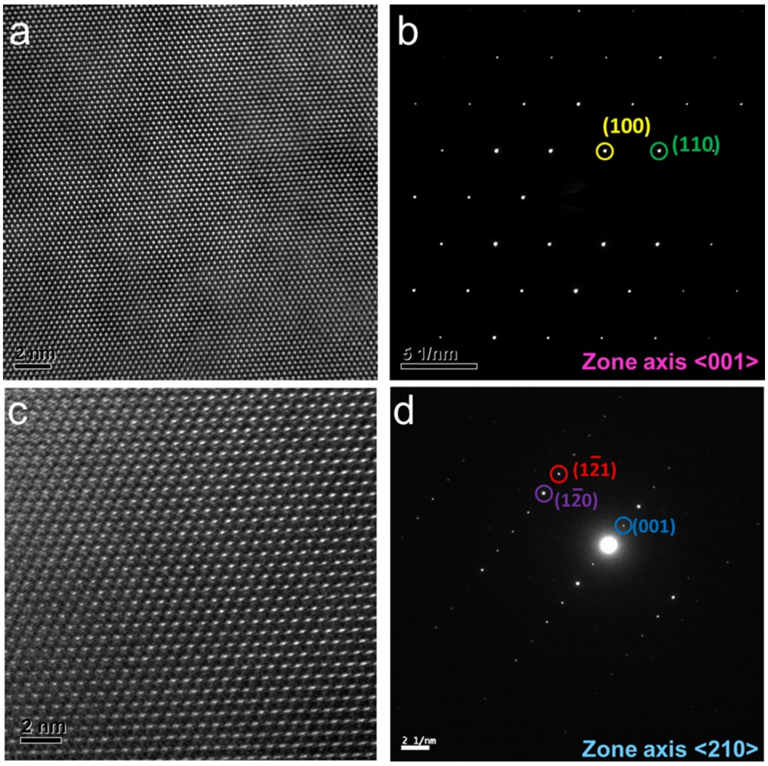

Figure S1 (a) TEM image of individual WS_2; (b) SAED pattern of the WS_2; (c) TEM image of individual $ReSe_2$; (d) SAED pattern of the $ReSe_2$.

The multi-layer WS_2 and the $ReSe_2$ 2D materials are obtained by micromechanical exfoliation and were transferred onto TEM grids with lacey support by poly (methyl methacrylate) (PMMA) transfer method in order to investigate their structure and crystal quality. The high resolution TEM (HRTEM) images (Figure S1a, c) show the hexagonal ring lattice in the WS_2 and the $ReSe_2$, indicating good single crystalline phase. The corresponding selected area electron diffraction (SAED) patterns of the single crystalline WS_2 and $ReSe_2$ nanosheet (Figure S1b,d) reveal orientation of WS_2 is along (001) zone axis belongs to a hexagonal crystal system and orientation of $ReSe_2$ is along (210) zone axis.

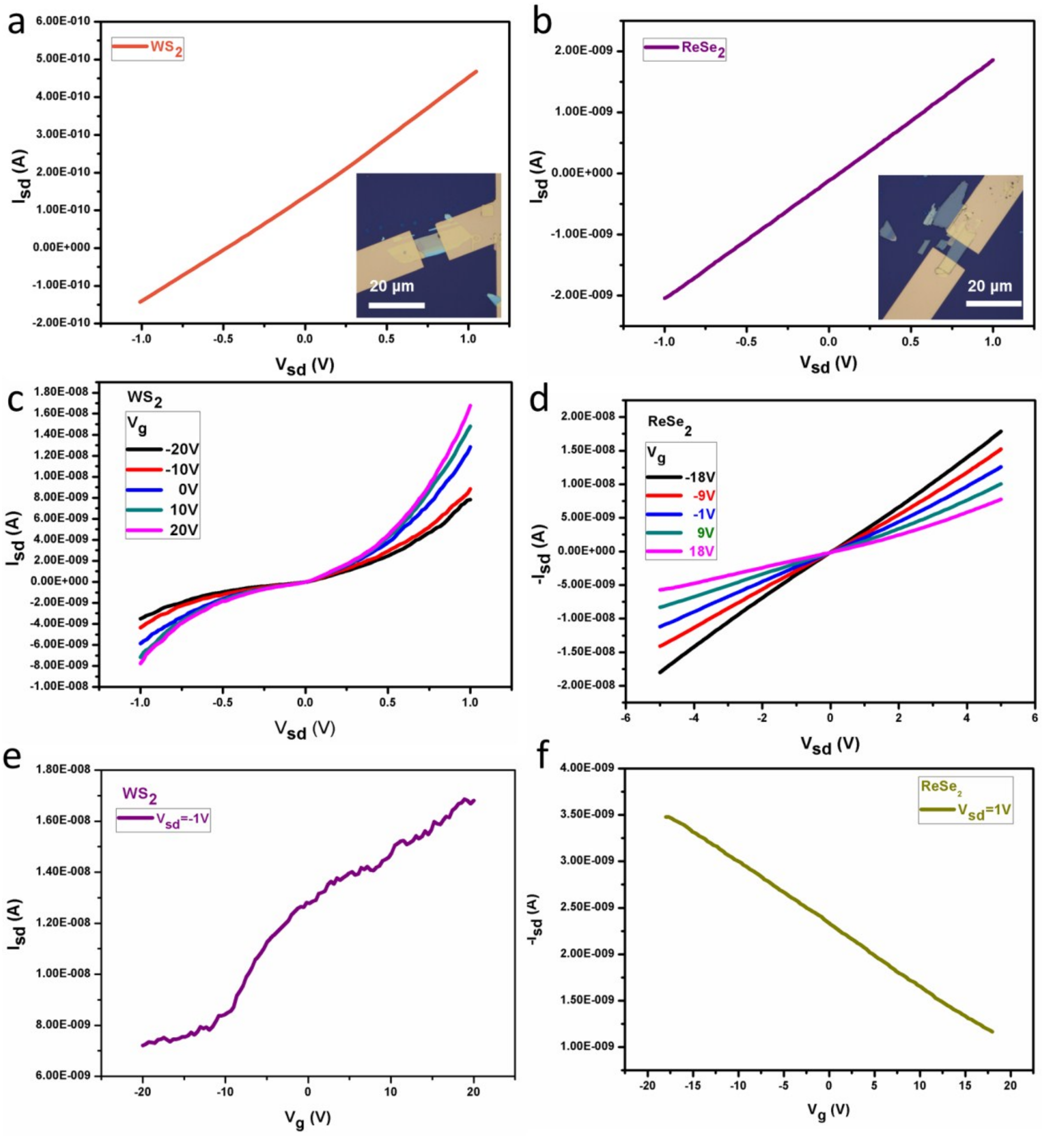

Figure S2 I_{sd}-V_{sd} characteristics of the individual (a) WS_2 multilayer and (b) $ReSe_2$ multilayer. Output characteristics of the individual (c)WS_2 multilayer and (d) $ReSe_2$ multilayer. Transfer characteristic of individual (e) WS_2 multilayer and (f) $ReSe_2$ multilayer.

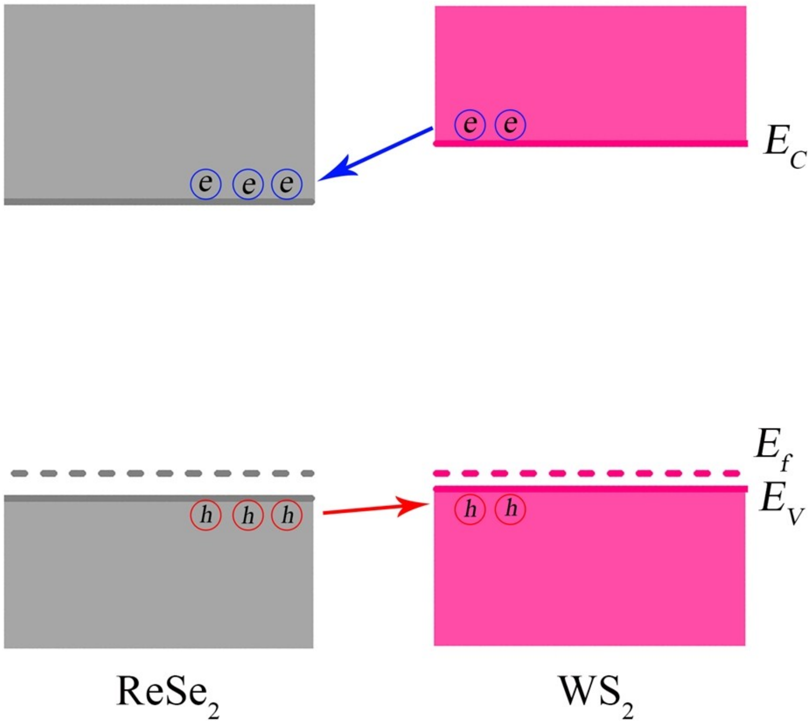

Figure S3. The band offset of type-II ReSe2-WS2 heterostructure in the Fermi level alignment.

Section A. Details of the $ReSe_2/WS_2$ heterojunctions Device Fabrication.

The $ReSe_2/WS_2$ heterojunctions were fabricated with transfer method. Both multilayer 2D $ReSe_2$ and WS_2 materials were first exfoliated mechanically and transferred onto two Si substrates coating 300nm-thick SiO_2 layer, respectively, from the WS_2 and $ReSe_2$ crystals. And then, a few drops of the self-regulating polymethyl methacrylate (PMMA) solution was spin coated onto $ReSe_2$ multilayer on Si substrates coating 300nm-thick SiO_2 layer by using rotating speed of 3000 r s−1 and baked at 180 °C for 2 min as a transfer medium, and the $ReSe_2$ multilayer were transferred onto another substrate with WS_2 multilayer to partly overlap with the WS_2 multilayer to form $ReSe_2/WS_2$ heterojunction sample, and finally the PMMA on $ReSe_2$ was removed by acetone.

Electrode patterns of the sample were fabricated by electron-beam lithography (SEM) using an SEM/focused ion beam system (Nava 200 NanoLab) at a voltage of 30 kV and a current of 1.5 nA. And then 8-nm-thick Cr layer followed 80-nm-thick Au layer was deposited by using electron beam evaporation in turn. Finally, well-defined source and drain electrodes were achieved by using the lift-off process with acetone/IPA.

The Raman measurements were conducted by a confocal laser Raman spectrometer (Renishaw Model inVia-Reflex) with He–Ne laser (532 nm) excitation. Samples were further characterized by AFM (Benyuan NanoInstruments Ltd. Model CSPM 5500A) to confirm the thickness of layers.