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Two-Dimensional Material-Based Negative Differential Resistance Device with High Peak-to- Valley Current Ratio for Multi-Valued Logic Circuits

Authors : Kwan-Ho Kim, Jin-Hong Park

Abstract : The multi-valued logic (MVL) circuits, which can handle more than two logic states, are one of the promising solutions to overcome the bit density limitations of conventional binary logic systems. Recently, tunneling devices such as Esaki diode and resonant tunneling diode (RTD) have been extensively explored to construct the MVL circuits. These tunneling devices present a negative differential resistance (NDR) phenomenon in which a current decreases as a voltage increases in a specific applied voltage region. Due to this non-monotonic current behavior, the tunneling devices have more than two threshold voltages, consequently enabling construction of MVL circuits. Recently, the emergence of two dimensional (2D) van der Waals (vdW) crystals has opened up the possibility to fabricate such tunneling devices easily. Owing to the defect-free surface of the 2D crystals, a very abrupt junction interface could be formed through a simple stacking process, which subsequently allowed the implementation of a high-performance tunneling device. Here, we report a vdW heterostructure based tunneling device with multiple threshold voltages, which was fabricated with black phosphorus (BP) and hafnium diselenide ($HfSe_2$). First, we exfoliated BP on the SiO_2 substrate and then transferred $HfSe_2$ on BP using dry transfer method. The BP and $HfSe_2$ form type-Ⅲ heterojunction so that the highly doped n+/p+ interface can be easily implemented without additional electrical or chemical doping process. Owing to high natural doping at the junction, record high peak to valley ratio (PVCR) of 16 was observed to the best our knowledge in 2D materials based NDR device. Furthermore, based on this, we first demonstrate the feasibility of the ternary latch by connecting two multi-threshold voltage devices in series.

Keywords : two dimensional van der Waals crystal, multi-valued logic, negative differential resistnace, tunneling device
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