All-2D Ambipolar $ReSe_2$ Field-Effect Transistors for Logic Circuit Applications

Ko-Chun Lee
Shih-Hsien Yang, Yuan-Ming Chang, Che-Yi Lin, Feng-Shou Yang, Yung-Shang Sung, Takashi Taniguchi, Ching-Hwa Ho, Chen-Hsin Lien*, Yen-Fu Lin*

Institute of Electronics Engineering, National Tsing Hua University, Hsinchu, 30013, Taiwan

chlien@ee.nthu.edu.tw, yenfulin@nchu.edu.tw

Abstract

As various 2D materials have been synthesized, from semi-metal to insulator, the potential of 2D materials is extended wildly. Rhenium diselenide ($ReSe_2$), a kind of transition metal dichalcogenides (TMD), has a layer-number dependent bandgap ranging from 1.27 to 1.32 eV [1] for two-layers to ten-layers, is studied in this report. Due to the free of surface bonds and atomically flat surfaces, different 2D materials can form heterostructures without lattice mismatch by direct vertical stacking [2].

An optical microscope (OM) image of an all-2D $ReSe_2$ field-effect transistor (FET) is shown in **Fig. 1**a. The 2D channel material free of dangling bond surface is preserved by applying hBN as an insulator, which prevents surface roughness scattering. Moreover, traditional metal contacts replaced with graphene contact, which has excellent conductivity and tunable Fermi level characteristics, on 2D materials can avoid Fermi level pinning problem [3] and may improve device performance. **Figure 1b shows** the I_{ds}-V_{bg} for the $ReSe_2$ FET under various V_{ds} at different temperatures and shows clear ambipolar behaviour, which means the majority conduction carrier can be either electrons or holes and act as n-FET and p-FET. According to thermionic emission theory, the Schottky barrier height of the graphene contact can be derived from the curve fitting of Arrhenius plots and the derived results are shown in Fig. 1c. This tunability results in a much lower contact Schottky barrier height and clear ambipolarity in charge transport.

Inverters composed of the $ReSe_2$ FET and a resistor were fabricated to examine its circuit diagram and functions shown in **Fig. 2**a and 2b. The $ReSe_2$ FET operated in n- and p- FET conditions served as a put-down and -up device, respectively. Under the operation frequency of 10 Hz, it shows stable output levels and indicates a good potential for logic circuits with a single device.

References

[1] Z. Huan, et al., *Nano Research*, 8 (2015) 3651.
[2] Y. Tang, K. F. Mak, Nat. Nanotechnol., 12 (2017) 1121.
[3] C. Gong, et al., *Nano Lett*., 14 **(2014)** 1714.

Figures

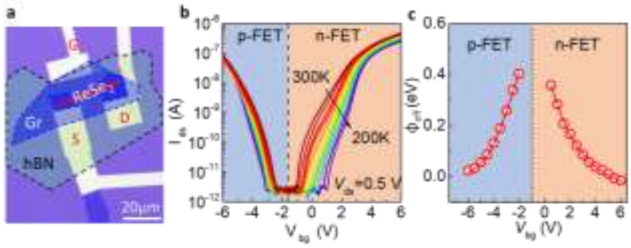

Figure 1: (a) OM image of a $ReSe_2$ FET. (b) Transfer characteristics at different temperatures of $ReSe_2$ FET. (c) Schottky barrier heights of graphene contact.

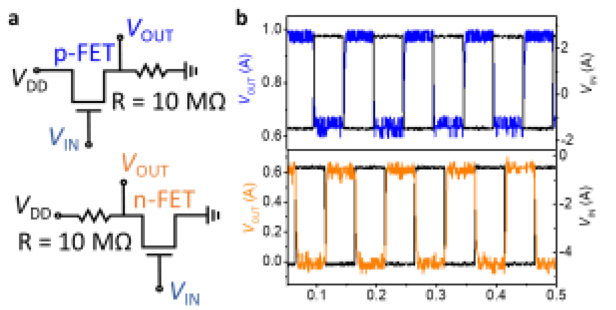

Figure 2: (a) The schematic and (b) V_{OUT}/V_{IN} versus time at the frequency = 10 Hz of the inverter circuit with the $ReSe_2$ FET operated in n- and p- FET conditions.