Ambipolar characteristics based on complementary MoS_2 and WSe_2 field-effect transistor

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Recently, semiconducting two-dimensional (2D) transition metal dichalcogenide (TMD) material-based field-effect transistors (FETs) were studied actively to overcome the short channel effects (SCEs), which are fundamental issues in scaling of logic transistors for the continuation of Moore's law [1,2]. In this work, complementary MoS_2 and WSe_2 FETs were fabricated by selective patterning with alignment technique. WSe_2 and MoS_2 channels were placed on highly doped-Si/SiO_2 substrate using mechanical exfoliation and dry transfer method to utilize p- and n-type channel, respectively. Then, we successfully obtained ambipolar transfer curves from the complementary MoS_2 and WSe_2 FETs. In addition, I_d-V_d and I_d-V_g characteristics of each polarity transistor were analyzed to verify the ambipolar operation and several advantages of the complementary FETs. This work can provide useful information of structure design to investigate proper electrical operation of 2D material-based ambipolar transistors.

Introduction

The complementary metal oxide semiconductor (CMOS) industry is facing the SCEs issue caused by the down-scaling of logic devices. Therefore, CMOS using 2D TMD materials is studied. The polarity controlling of conventional silicon-based CMOS transistors is achieved by a heavy dose of impurity ion doping. However, 2D TMD-based complementary FET (CFET) can be fabricated by the difference between the work function of the contact electrode and the band gap of the semiconducting material [3].

Results and Discussion

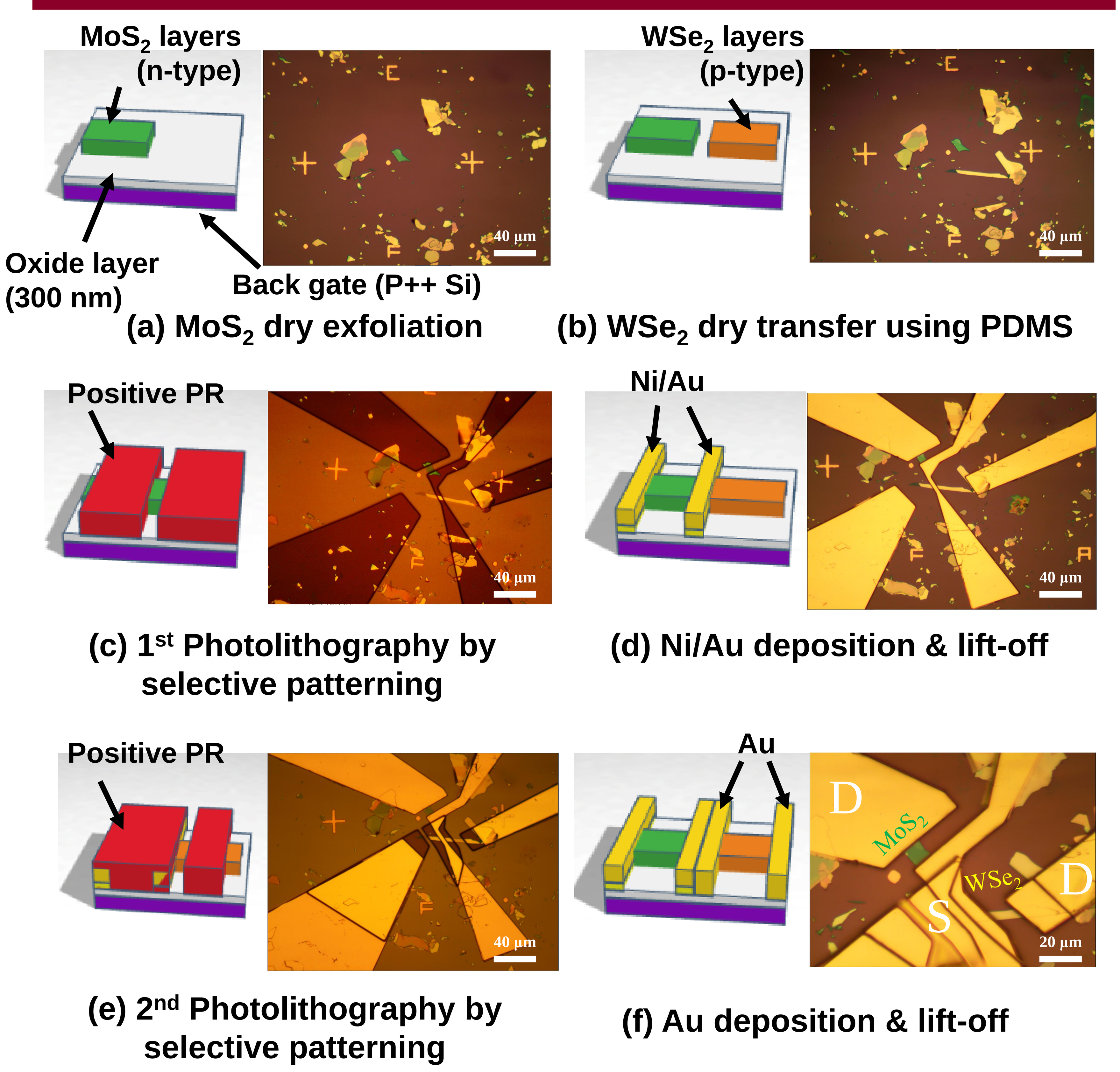

Figure 1. Illustrations and corresponding optical microscope images showing the fabrication procedure of CFET in this work, (a) MoS_2 dry exfoliation and (b) WSe_2 dry transfer using the PDMS on the P++ Si/SiO_2 substrate. (c) First photolithography, (d) thermal evaporation and lift-off for 10/70 nm Ni/Au electrode patterning. (e) secondary photolithography, (f) thermal evaporation and lift off for 70 nm Au electrode patterning.

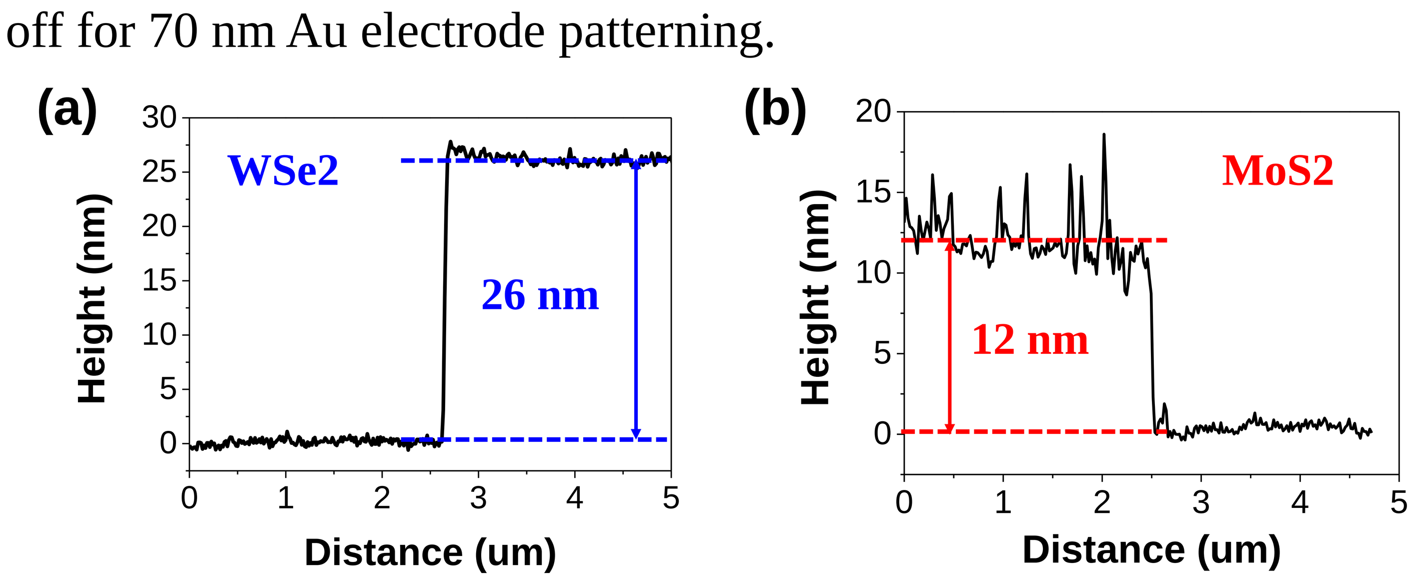

Figure 2. Atomic force microscope (AFM) step heights of each channel layers. thickness of (a) WSe_2 and (b) MoS_2 layers were 26 nm and 12 nm, respectively.

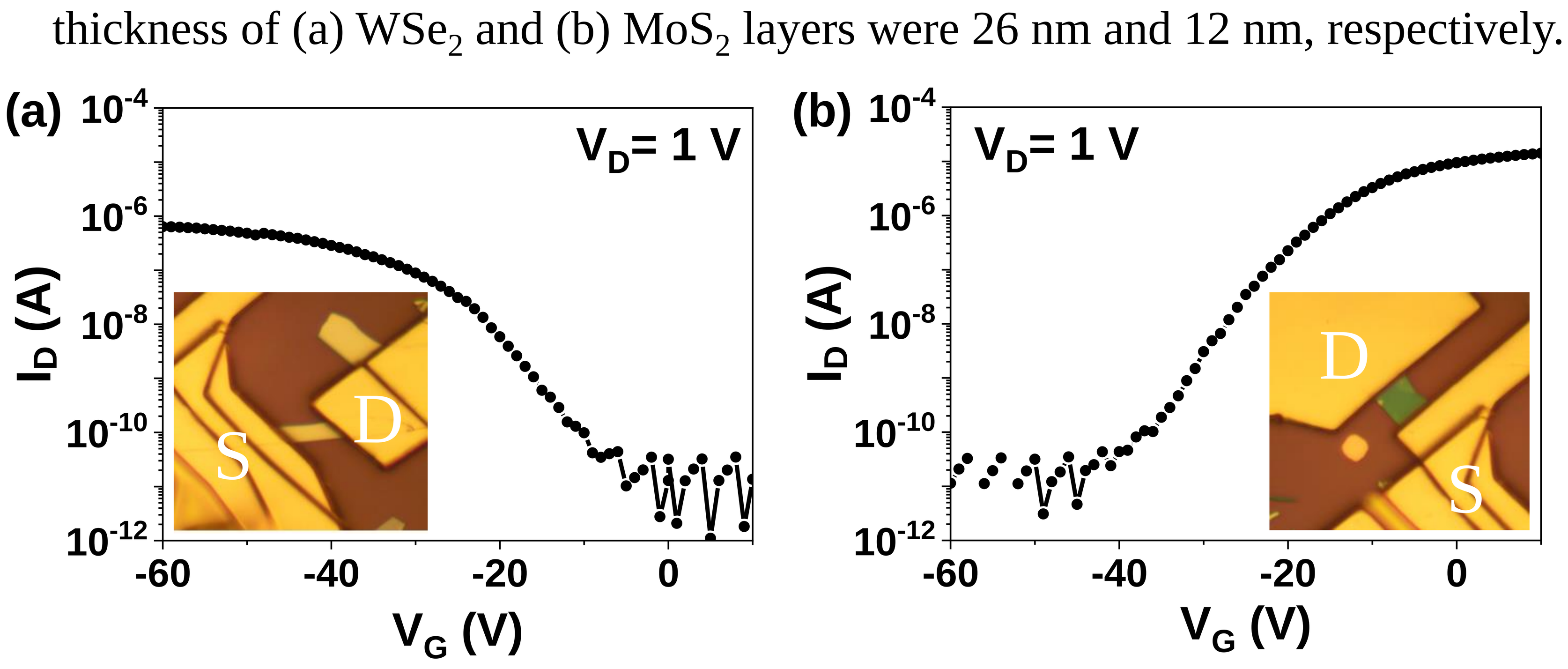

Figure 3. Transfer characteristics (I_d vs V_g) of (a) p- and (b) n-type FETs. Gate bias range was -60 to 10 V, and V_d was 1 V. Inset show the optical microscope image of each transistors.

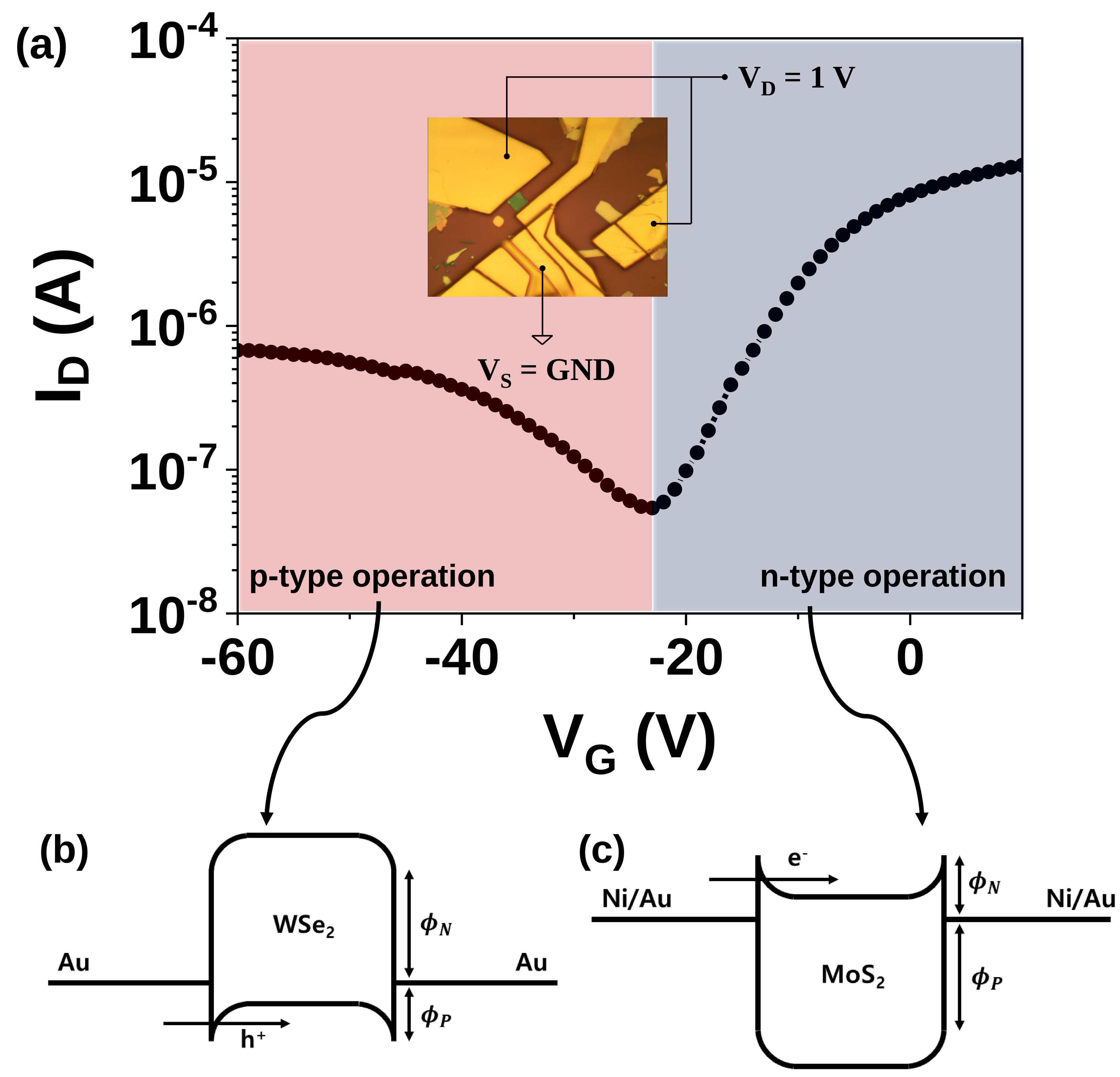

Figure 4. (a) Ambipolar characteristics of CFET. Under the -23 V gate bias (V_g), it depends on (b) p-type operation, over the -23 V gate bias (V_g), it depends on (c) n-type operation. Inset show the schematics of connected circuit.

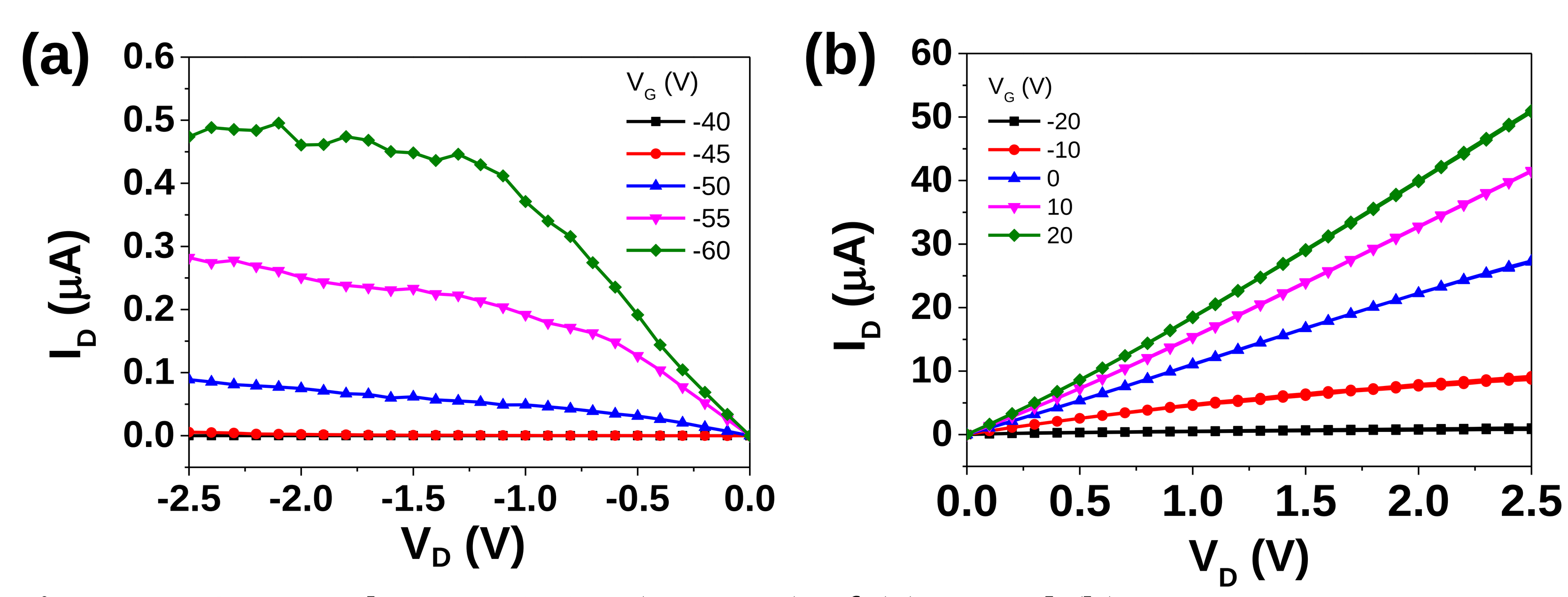

Figure 5. Output characteristics (I_d vs V_d) of (a) p- and (b) n-type FETs as gate bias (V_g) ranges from -60 to -40 V and from -20 to -20 V, respectively.

Conclusions

In conclusion, both MoS_2 and WSe_2-based ambipolar transistor was fabricated by mechanical exfoliation, dry transfer method, selective patterning process on single substrate. Ni and Au electrodes were contacted to multi-layers MoS_2 and WSe_2 for n- and p-type FETs, respectively. The fabricated device has shown reasonable ambipolar characteristics with ohmic-like contacts. Transfer curves and output characteristics were also analyzed in detail.

Acknowledgements

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