Vertical 2D Crystal Hetero-structures: The Preparation, Device Application and Selective Growth

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The major advantage of two-dimensional (2D) crystals for practical applications is that their unique material characteristics can be observed within one to few atomic layers [1]. However, with the intense investigation of single 2D materials for device applications, their performances have gradually come to an upper limit. Therefore, in recent years, many groups have turned their attention to 2D crystal hetero-structures trying to further enhance the device performances [2]. In this report, a 9-layer WS_2/MoS_2 hetero-structure is established on a sapphire substrate after sequential growth of large-area and uniform 5- and 4- layer MoS_2 and WS_2 films by using sulfurization of pre-deposited 1.0 nm Molybdenum (Mo) and Tungsten (W), respectively. As shown in Fig. 1(a), the Raman spectrum has revealed the co-existence of the two 2D crystals WS_2 and MoS_2. The cross-sectional HRTEM image of the sample shown in Fig. 1 (b) has revealed that a 9-layer 2D material is obtained. The layer number is the same as the summation of the standalone 5- and 4- layer MoS_2 and WS_2 samples. The HAADF image of the sample shown in Fig. 1 (c) has confirmed that a abrupt vertical WS_2/MoS_2 2D crystal hetero-structure is obtained. By using the results obtained from the UPS and the absorption spectrum measurements of the standalone MoS_2 and WS_2 samples, a type-II band alignment is predicated for the WS_2/MoS_2 hetero-structure as shown in Fig. 1(d). After fabricating the hetero-structure into transistors, increasing drain currents and enhanced field-effect mobility value are observed for the device as shown in Fig. 2 (a). The results suggest that a channel with higher electron concentration compared with the standalone MoS_2 transistor channel is obtained with electron injection from WS_2 to MoS_2 under thermal equilibrium due to the type-II band alignment of the hetero-structure. From figure 2(b), selective 2D crystal growth with four different regions is demonstrated on a single sapphire substrate. The results have demonstrated the potential of this growth technique for the hetero-structure establishment and the selective growth of 2D crystals.

References

[1] C.-R. Wu *et al*, J. Phys. D Appl. Phys., 48 (2015) 435101.
[2] C.-R. Wu *et al*, Nano Lett., 16 (2016) 7093.

Figures

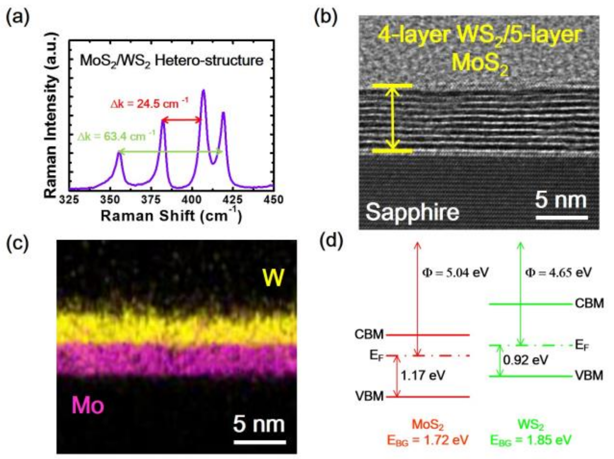

Figure 1: (a) The Raman spectrum, (b) the cross-sectional HRTEM image, (c) the HAADF image and (d) the schematic band alignment of the sample with the WS_2/MoS_2 hetero-structure.

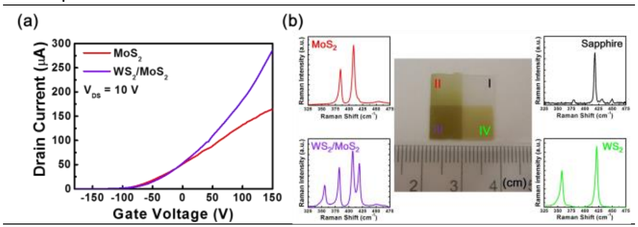

Figure 2: (a) the I_D-V_{GS} curves of the two devices with MoS_2 and WS_2/MoS_2 channels at V_{DS} = 10 V. (b) The picture and the Raman spectra in the four different regions of the sample with standalone MoS_2, WS_2 and their hetero-structure on a single wafer.