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Transfer characteristics of transition metal dichalcogenide transistors with VO_2 contacts

Vanadium dioxide (VO_2) is an archetypical correlated material that shows an abrupt metal-insulator transition (MIT) at ~ 340 K. Since the resistance of VO_2 changes by orders of magnitude across the MIT, VO_2 shows potential as a component of switching devices. In particular, recently, VO_2 has drawn as "active contacts" of semiconductor transistors, where the on/off switching is controlled predominantly by the MIT of the VO_2 electrodes [1]. Here we demonstrate such "phase transition transistors" based on van der Waals stacking of VO_2 microwires and transition metal dichalcogenides (TMDCs) films. Thin films of VO_2 were grown on Al_2O_3(0001) substrates by pulsed laser deposition and etched to form the microwires by photolithography and reactive ion etching. Then, thin films of molybdenum disulfide (MoS_2) or tungsten diselenide (WSe_2) were deposited onto the VO_2 microwires by the dry transfer method. After depositing the Ti/Au electrodes on the TMDC channels, hexagonal boron nitride (hBN) films were transferred onto the van der Waals stacks and used as gate dielectrics. Figure 1 shows the optical image and the transfer characteristic of a VO_2-contacted WSe_2 transistor, where VO_2 served as a drain electrode and Ti/Au was used as the source electrode. As shown in Figure 1B, the transistor showed an abrupt current increase at a gate voltage of around 17 V. This is because the VO_2 electrode was in the insulating state below 17 V, but above 17 V, underwent a thermal insulator-to-metal transition due to Joule heating. The observation suggests that VO_2 can be used as an effective active contact for semiconducting TMDC transistors [2].

Although the observations have important implications for the realization of steep-slope devices using VO_2-contacted TMDC transistors, the subthreshold swing (SS) for the gate-mediated switching was observed to be ~140 mV/decade, which is still above the theoretical limit in conventional semiconductor transistors (see the inset of Figure 1B). This is partly because of the high contact resistance at the VO_2/TMDC junctions. Therefore, we next investigate the contact properties of the VO_2-contacted TMDC transistors. Figure 1C shows the temperature-dependent transfer characteristics of a MoS_2 transistor with both the source and drain electrodes being made of VO_2. The transistor showed a n-type transport both before and after the MIT. Across the MIT, the drain current was increased only by a factor of 4, even though the resistance of the VO_2 electrode changed by several orders of magnitude, indicating the existence of the high contact resistances. From Arrhenius analyses for the gate-dependent drain current, we determined the formation of the interfacial barriers with heights of ~ 200 meV at the VO_2/MoS_2 contacts, independent of the phase state of VO_2. In a VO_2-contacted WSe_2 transistor, alternatively, we observed an ambipolar transport, suggesting the formation of the interfacial barriers with heights comparable to the half of the band gap of WSe_2. Our results indicate that appropriate contact-engineering is needed for the realization of the high-performance VO_2-contacted TMDC transistors [3].

References

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[3] M. Yamamoto, et al., In preparation.

Figures

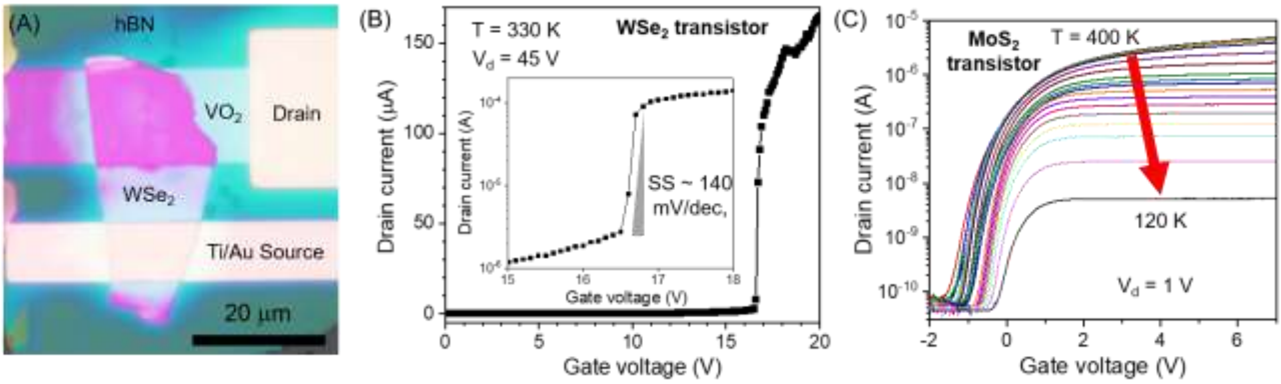

Figure 1: (A) Optical image of the VO_2-contacted WSe_2 transistor before depositing the gate electrode. (B) Transfer characteristic of the transistor measured at T = 330 K and V_d = 45 V. The inset shows the transfer curve in the semi-log scale. (C) Transfer characteristics of the VO_2-contacted MoS_2 transistor measured at various temperatures. The drain bias voltage is 1 V.