Mahito Yamamoto¹
Ryo Nouchi,² ³ Teruo Kanki,¹ Shu Nakahara,⁴ Azusa N. Hattori,¹ Kenji Watanabe,⁴ Takashi Taniguchi,⁴ Yutaka Wakayama,⁴ Keiji Ueno,⁵ Hidekazu Tanaka¹
¹Osaka University, ²Osaka Prefecture University, ³JST PRESTO, ⁴National Insutitute for Materials Sciennce, ⁵Saitama University

mahito.yamamoto@sanken.osaka-u.ac.jp

Transfer characteristics of transition metal dichalcogenide transistors with VO₂ contacts

Vanadium dioxide (VO₂) is an archetypical correlated material that shows an abrupt metal-insulator transition (MIT) at ~ 340 K. Since the resistance of VO₂ changes by orders of magnitude across the MIT, VO₂ shows potential as a component of switching devices. In particular, recently, VO₂ has drawn as “active contacts” of semiconductor transistors, where the on/off switching is controlled predominantly by the MIT of the VO₂ electrodes [1]. Here we demonstrate such “phase transition transistors” based on van der Waals stacking of VO₂ microwires and transition metal dichalcogenides (TMDCs) films. Thin films of VO₂ were grown on Al₂O₃(0001) substrates by pulsed laser deposition and etched to form the microwires by photolithography and reactive ion etching. Then, thin films of molybdenum disulfide (MoS₂) or tungsten diselenide (WSe₂) were deposited onto the VO₂ 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 VO₂-contacted WSe₂ transistor, where VO₂ 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 VO₂ 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 VO₂ 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 VO₂-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 VO₂/TMDC junctions. Therefore, we next investigate the contact properties of the VO₂-contacted TMDC transistors. Figure 1C shows the temperature-dependent transfer characteristics of a MoS₂ transistor with both the source and drain electrodes being made of VO₂. 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 VO₂ 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 VO₂/MoS₂ contacts, independent of the phase state of VO₂. In a VO₂-contacted WSe₂ 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 WSe₂. Our results indicate that appropriate contact-engineering is needed for the realization of the high-performance VO₂-contacted TMDC transistors [3].

References

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.