In-situ TEM Characterization of Ultra-robust memristors Based on Two-dimensional Materials

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Memristor has been considered as a promising candidate for future storage electronics [1] due to the advantages of device scalability, multi-state storage, high switching speed and endurance, as well as CMOS compatibility [2]. However, for those used in extreme environments such as high temperature and bending substrates, their reliability and robustness has not been much studied yet. In this work, we designed and fabricated an ultra-robust memristor based on a Van der Waals (vdW) heterostructure laminated with graphene/$MoS_{2-x}O_x$/graphene (FMG) as shown in Fig.1 a) and b). Our experiments suggest that the total life up to 10^7 cycles has been achieved with an ultra-high thermal stability, which allow it to work at temperature up to 340°C [3]. These results show that vdW heterostructures made up through stacked 2D layered materials can integrate each component's unique properties then fit actual requirements in detection and production.

In order to understand the fundamental relationship between the ultra-robustness and crystal structure of the GMG memristor device during the switching, we carried out *in situ* scanning transmission electron microscopy (STEM) experiments. *In-situ* device sample was fabricated using FEI helios 600i dual-beam FIB system and mounted onto our home made in-situ electrical testing chip as shown in Fig. 1 c) and d). HAADF and STEM-EDS analyses were carried out to reveal the structural change and mass migration during the switching process. The analyses were performed on a FEI Titan Cubed G2 60-300 aberration corrected S/TEM. The operation voltage of 60 kV was used to reduce electron beam damage to graphene and $MoS_{2-x}O_x$. By switching the device between ON/OFF states inside the S/TEM, we were able to observe the microstructural changes in the conduction channel area in $MoS_{2-x}O_x$ layer in real-time and shed a light on the switching mechanism, which attributes to the migration of oxygen ions. We found out that at ON state the content of O atoms was deficient in conduction channel region, whereas at OFF state, the content of O atoms was rich in conduction channel region. Therefore, we concluded that the changing of oxygen vacancy intensity caused two different resistance states.

References:

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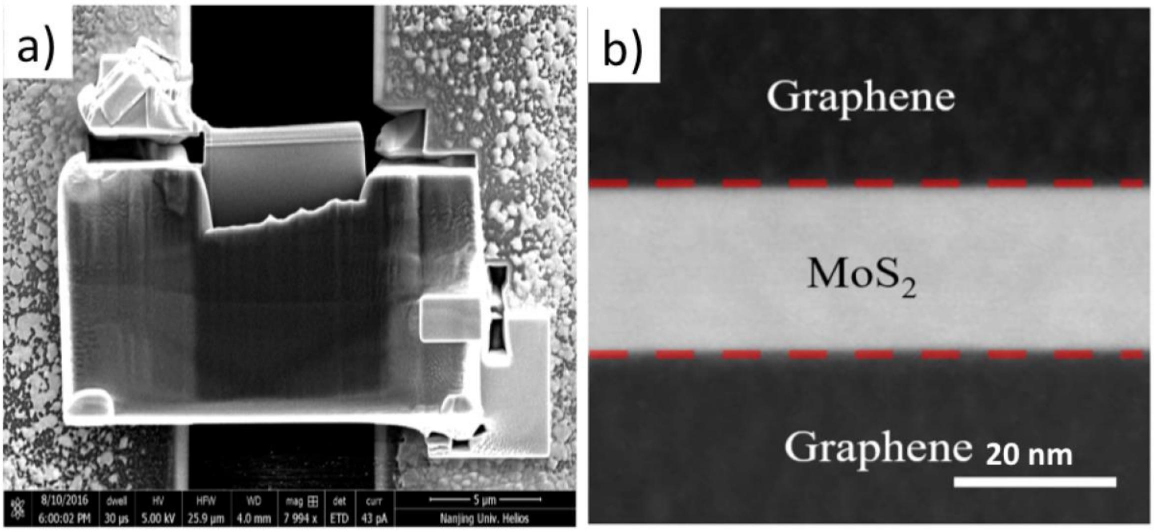

Figure 1. (a) (c) In-situ GMG device sample welded on a home-made in-situ electrical biasing chip. (b) Cross-section HAADF image of a pristine GMG device.