Voltage Dependent Electroforming of TiO_2-based Memristive Devices

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Metal oxides based memristive devices are promising candidates for the next generation memory and beyond. Before the normal SET/RESET operations of these devices, an electroforming step is usually needed to greatly change conductivity of the switching materials [1]. Here we systematically studied the voltage dependence of the electroforming process of TiO_2 based memristive devices. We discovered that devices could be formed to either ON or OFF state using voltages of the same polarity but with different amplitudes. The initial forming step also affects the subsequent switching behavior.

We used 5 μm × 10 μm cross point devices that consisted of 5 nm Ti/10 nm Pt/17 nm TiO_2/10 nm Pt layers (Fig. 1). Both the bottom electrodes (10 nm Pt/5 nm Ti) and the top electrodes (10 nm Pt) were deposited through metal shadow masks in an electron beam evaporator. The TiO_2 film of the devices was sputtered from a titanium dioxide target at room temperature. The finished samples were annealed at 275 ^oC in N_2 protective atmosphere for 1 hour.

As shown in Fig. 2a, the TiO_2 device could be electrically formed to ON state with a negative voltage (-8 V). Fig. 2b exhibits the representative switching curves afterwards. Devices of the same structure could be formed to OFF state using a negative voltage of higher amplitude (-10 V) (Fig. 2c). The device was also readily switched ON and OFF afterwards (Fig. 2d). Fig. 3 schematically illustrated our proposed model on the electroforming mechanisms. During the forming process, a certain negative voltage will bridge the top and bottom electrodes with oxygen vacancies (Fig. 3a), resulting in low resistance state after forming. While with a negative voltage of higher amplitude, all oxygen vacancies near the BE/oxide interface are attracted away, forming a non-conductive gap that leads to high resistance state (Fig. 3b). The subsequent switching events take place at different interfaces for these two cases.

Similarly, the TiO_2 devices can be formed to ON or OFF states using positive voltages of different amplitudes. The device behavior afterwards was also affected by the forming history. The forming and switching are attributed to the creation and motion of oxygen vacancies under electric fields.

[1]. Yang, J. J et al. Nanotechnology **20**, 215201 (2009).

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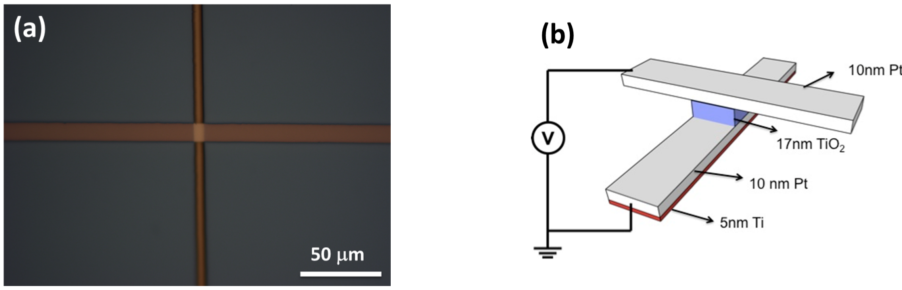

Figure 1. (a) Optical micrograph of a typical device used for this study. (b) Schematic illustration of the device geometry and the measurement set up.

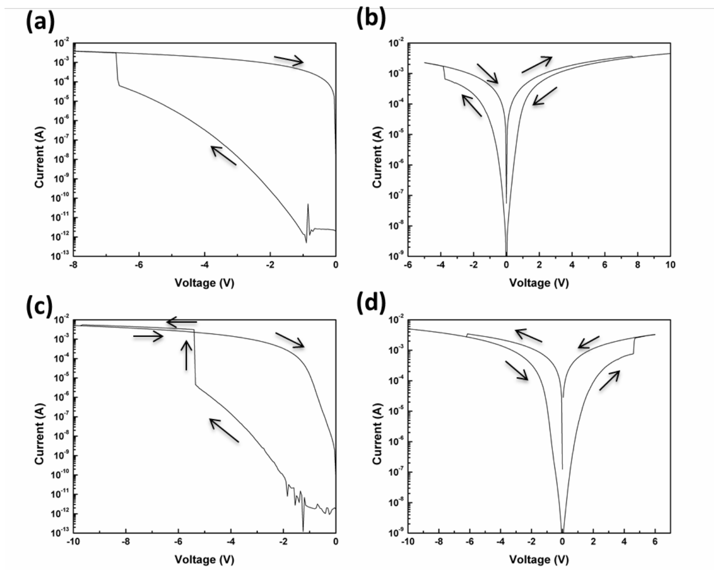

Figure 2. Typical IV curves for electroforming at negative voltages and the subsequent switching. (a) Forming ON, and (b) the subsequent switching. (c) Forming OFF, and (d) switching afterwards. The arrows indicate the switching directions.

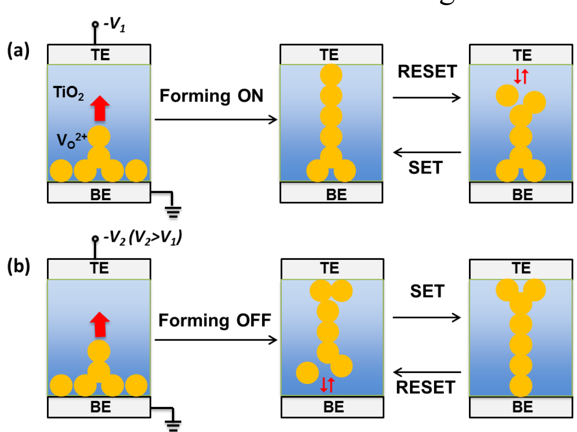

Figure 3. Schematic illustration for negative forming and the subsequent switching mechanisms. (a) Oxygen vacancies (V_o^{2+}) inside of TiO_2 are attracted to the top electrode (TE), forming the device ON. (b) A larger negative voltage ($-V_2$) leads to a gap at the BE/oxide interface. The double red arrows indicate the subsequent switching interfaces.