Improved Switching Uniformity for TiO_2/HfO_2 Bi-layer Memristive Devices

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Memristive device has attracted considerable attention as one potential choice for the next generation non-volatile random access memory (NV-RAM) [1]. One of the obstacles for wide application of these devices is the performance variation. Here we report that by introducing a thin HfO_2 layer into the $Pt/TiO_2/Pt$ device geometry, the device performance uniformity can be greatly improved.

In this study, both single oxide layer (TiO_2) and bilayer (TiO_2/HfO_2) devices of 5 μm by 10 μm were fabricated and tested. The device geometries were 10 nm Pt/17 nm TiO_2/10 nm Pt/5 nm Ti and 10 nm Pt/17 nm TiO_2/2 nm HfO_2/10 nm Pt/5 nm Ti, respectively. TiO_2 was deposited by sputtering at room temperature while the HfO_2 was fabricated using atomic layer deposition (ALD). Both the bottom electrodes (10 nm Pt/5 nm Ti) and top electrodes (10 nm Pt) were fabricated by electron beam evaporation through a shadow mask. Fig. 1 shows the optical image of our typical cross point device used here and also the measurement set-up.

Typical switches in single layer and bilayer devices are shown in Fig. 2. Bilayer devices usually need a larger forming voltage because of the HfO_2 insulator layer. However both of their SET and RESET voltages are comparable with those in single layer devices. The distribution of high and low resistance states for the bilayer devices, however, was much more uniform than that of the single layer devices. Fig. 3 plots the cumulative distribution function for the resistance states. Both LRS and HRS resistances in bi-layer devices exhibit evidently lower dispersion. The variations of LRS resistances (standard deviation/mean value) were 0.8% for bi-layer devices and 20% for single layer devices, while those for HRS were 2.5% and 49% separately.

The bilayer structure leads to improved uniformity. Resistive switching in transition metal oxides has been widely attributed to the formation and rupture of conductive filaments that based on oxygen vacancies. The distribution of the resistance both at ON and OFF states becomes wider when the number of conductive filaments increases [2]. It is believed that the formation of filament can be described by Poisson distribution [3]. The probabilities of filament formation P_1 (in TiO_2) and P_2 (in HfO_2) are independent. When total possible number of active spots at the bottom electrode (BE)/oxide interface is n, the average number of possible filaments will be nP_1 in single TiO_2 while nP_1P_2 in TiO_2/HfO_2 bi-layer. Since P_1, $P_2 < 1$, fewer filaments should be obtained in bi-layer devices (Fig. 4). We believe n is the same for both devices since the bottom electrodes were fabricated in the same batch. Fewer filaments mean that the switching is more confined so that the variation is greatly reduced.

[1]. Yang, J. J et al. Nature Nanotech. **8**, 13 (2013).
[2]. Yu, S et al. IEEE Trans. Electron Devices **59**, 1183 (2012).
[3]. Yoo, I. K et al. Appl. Phys. Lett. **92**, 202112 (2008).

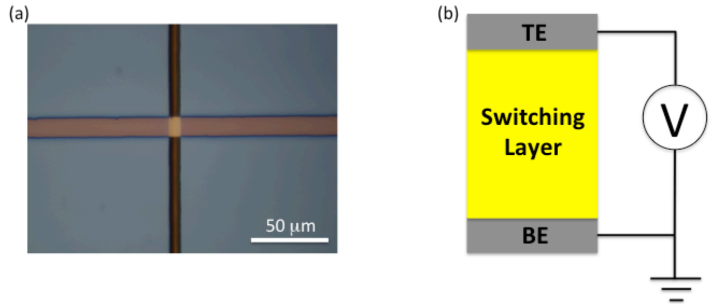

Figure 1. (a) Optical micrograph of a typical device. (b) Schematic illustration of the device geometry and the measurement set up.

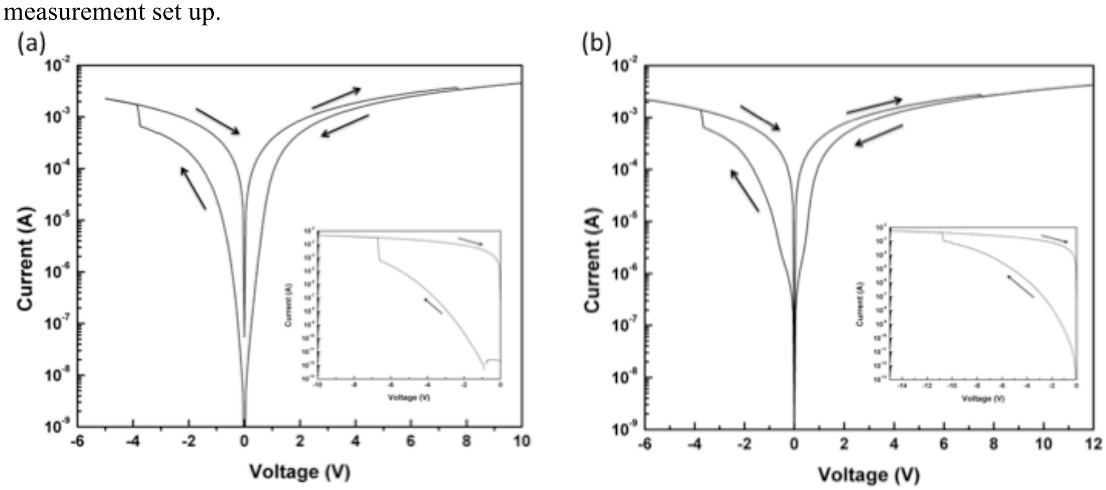

Figure 2. Typical IV curves for devices based on (a) TiO_2 and (b) TiO_2/HfO_2. Insets show the first forming steps separately.

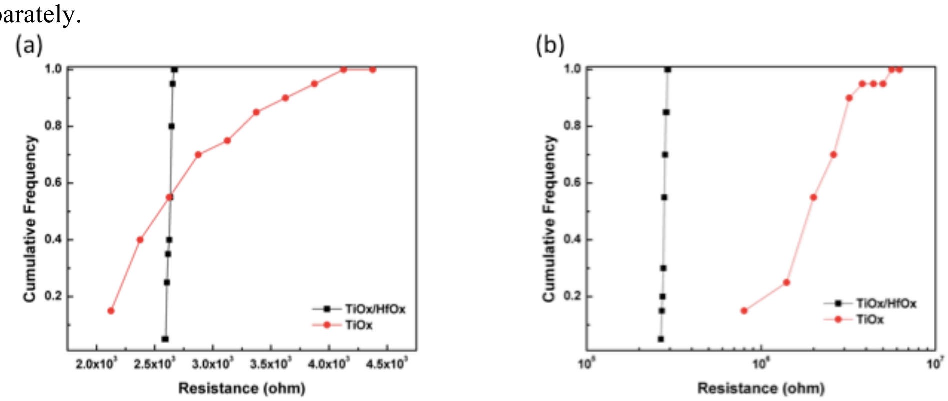

Figure 3. Distribution of (a) Low resistance state (LRS) and (b) High resistance state (HRS) resistances.

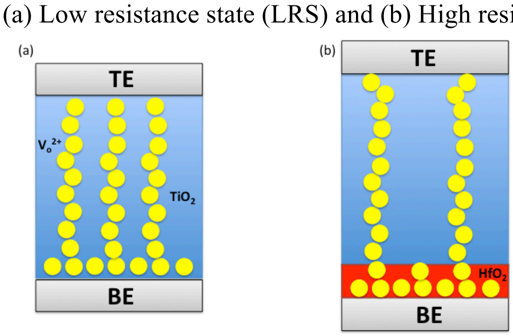

Figure 4. Filament formation in (a) TiO_2 and (b) TiO_2/HfO_2. Fewer conductive filaments are formed in bilayer structure, leading to more uniform switching behavior.