TiO_{2-x}/TaO_y Bilayer Memrsitive Devices with High Endurance and High ON/OFF Ratios

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Due to advantages such as fast switching speed, low power consumption, long endurance, and excellent scalability, memristive devices are promising for next generation nonvolatile memory and unconventional computing [1]. Transition metal oxides are widely used as the switching layer. TiO_2 based devices usually exhibit high ON/OFF ratios but low endurance, Ta_2O_5 based devices, on the other hand, have high endurance but poor ON/OFF ratios. In this work, we demonstrate that by using a TiO_{2-x}/TaO_y bilayer structure, both high ON/OFF ratios and high endurance can be achieved.

For a bilayer device, an insulating top layer and a conductive bottom layer are sandwiched between a Pt bottom electrode (BE) and a top electrode (TE). The conductive base layer was prepared by DC reactive sputtering of metal targets with a mixture of Ar and O_2 gases, while the top-insulating layer was deposited by RF sputtering from ceramic targets. The BEs were shared for all devices on the same wafer while the TEs were isolated metal disks of 50 μm diameter. A metal shadow mask was employed during the deposition of the TEs by electron beam evaporation. During IV measurements, the bottom electrodes were grounded while the top electrodes were biased. For endurance measurement, 1 μs pulses were used to switch the device ON or OFF and device resistance was measured at 100 mV between switching events.

Typical I-V curves and endurance tests from Ta_2O_{5-x}/TaO_y and TiO_{2-x}/TiO_y devices are shown in Fig. 1. High endurance ($>10^8$) was obtained in tantalum oxide systems while the ON/OFF was very limited (~10) (Fig. 1(a) and (c)). On the contrary, titanium oxide based devices exhibited high ON/OFF ratio (several hundreds) but poor endurance (10^3) (Fig. 1(b) and (d). In order to get both high endurance and on/off ratio, we combined the two families of oxide materials and adopted a TiO_{2-x}/TaO_y structure. Depending on the thickness of the top TiO_{2-x} layer and the deposition condition of the TaO_y base layer (particularly the oxygen ratio during reactive sputtering), the device behavior was significantly different. With 5 nm TiO_{2-x} and TaO_y prepared with 15% O_2 flow ratio (15%-TaO_y), devices exhibited endurance over 10^7 cycles while a relatively low ON/OFF ratio (about 20) (Fig. 2(a) and (d)). Increasing the thickness of the TiO_{2-x} layer to 10 nm resulted in an improved ON/OFF ratio (~100) but lower endurance (~ 10^6 cycles) (Fig. 2(b) and (e)). Finally, in devices with 10 nm TiO_{2-x} and 25%-TaO_y, both the ON/OFF ratio and the endurance were enhanced (~100 and $>10^8$ respectively) (Fig. 2(c) and (f)). TaOy in all three cases were 30 nm thick.

We believe the performance could be further improved for smaller devices and measurement protocol using shorter pulses. Stable switching with high endurance was also achieved by changing the top TiO_{2-x} layer to very thin Al_2O_3 or SiO_2 layer. Physical characterizations including detailed TEM studies will be conducted to uncover the mechanism behind the current observation.

[1]. J. J. Yang et al. Nature Nanotech. **8**, 13 (2013).
[2]. G. Park, et al. Nature Comm. **4**, 2382 (2013).

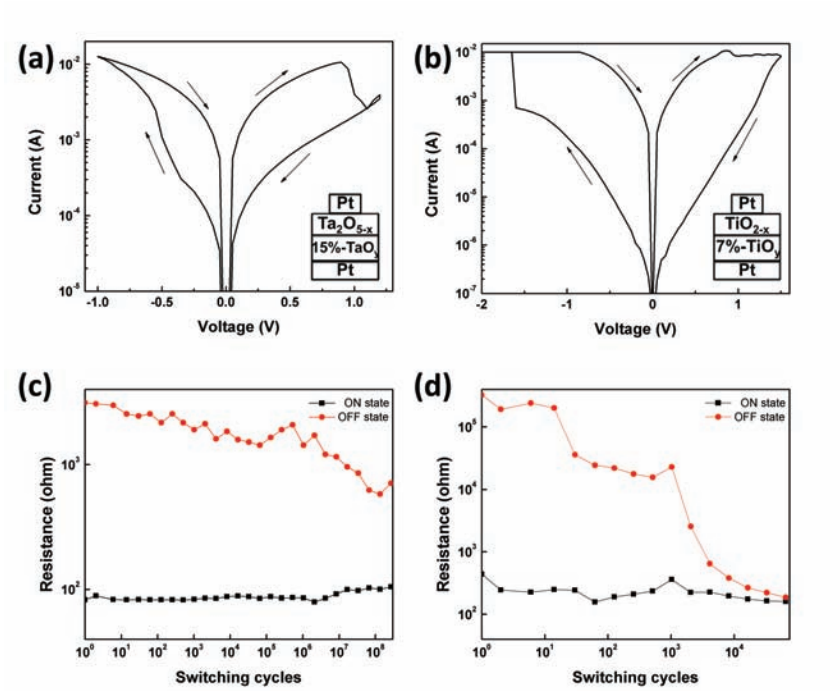

Figure 1. (a) I-V curve and (c) endurance test from the device with a Ta_2O_{5-x}/TaO_y structure. The tantalum oxide based device switched more than 10^8 cycles with an ON/OFF ratio of 10. (b) I-V curve and (d) endurance test from the device with a TiO_{2-x}/TiO_y structure. The titanium oxide based device exhibited high ON/OFF ratio but failed after 10^3 cycles.

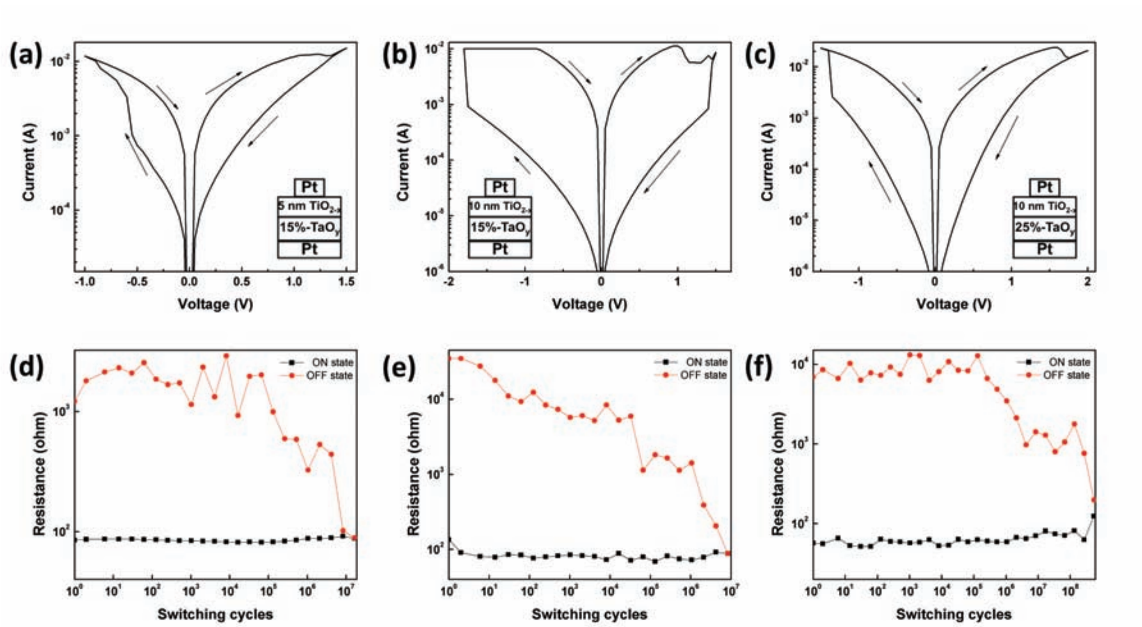

Figure 2. High endurance and high ON/OFF ratio for devices with TiO_{2-x}/TaO_y structures. (a) and (d) With 5 nm TiO_{2-x} and TaO_y prepared with 15% O_2 flow ratio (15%-TaO_y), devices exhibited endurance over 10^7 cycles while a relatively low ON/OFF ratio (about 20). (b) and (e) When the thickness of the TiO_{2-x} layer was increased to 10 nm, the device showed improved ON/OFF ratio (~100) but lower endurance (~ 10^6 cycles). (c) and (f) In devices with 10 nm TiO_{2-x} and 25%-TaO_y, both high ON/OFF ratio and high endurance were obtained (~100 and >10^8 respectively).