Effects of Programming Current and Environment on the Resistive Switching of a Nanoscale Memristive Device

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Recently we implemented a novel radiofrequency (RF) switch with excellent RF performance based on a memristive device[1]. The device relies on the bridging and separation of two metal electrodes using a silver filament. It exhibited sub-1 V programming voltages and $>10^{12}$ ON/OFF conductance ratio. Here, we report the dependency of the switching behavior on the programming current and environment. We demonstrate that the ON state conductance (G_{ON}) can be increased and the programming voltage can be lowered under proper conditions.

The SEM image of the device used in this study is shown in Fig.1A. Specifically, a ~45 nm wide planar air-gap between a pair of Ag-Ti/Au electrodes were fabricated on an intrinsic Si wafer with 380 nm thick thermally grown SiO_2. The switching of the device is implemented by growing/fracturing a single Ag filament inside the gap under DC voltage sweeps with a current compliance (Fig. 1B). The device is switched ON (SET) with a positive voltage and turned OFF (RESET) with a negative voltage.

The G_{ON} of the Ag filament increases with the programming current (Fig. 2). This is due to wider Ag filaments formed at higher currents (Fig. 2A-C). The SET process involves cation reduction, and a wider Ag filament is formed when more Ag^+ are reduced (with larger current). However, the filament would stop growing or even break with a too large current, and 55 mA was found to be optimal to achieve the largest G_{ON} in this study.

The programming voltages are dependent on the environment such as humidity (*Hr*) and temperature (*T*). The SET voltage drops with higher *T* or *Hr*, but the RESET voltage stays almost unchanged (Fig. 3). The humidity dependence could be explained by the critical role of moisture in the Ag oxidation and Ag^+ migration.[2, 3] At high humidity, the absorbed moisture on the SiO_2 surface forms a hydrogen-bond network that provides necessary counter charges for Ag oxidation and lowers the activation energy for Ag+ migration, leading to a smaller SET voltage. On the other hand, SET is also a thermally activated process and a higher temperature favors the formation of the Ag filament even at a lower programming voltage. The RESET process originates from filament melting because of strong Joule heating and thus is less influenced by ambient environment.

Our finding indicates that both the programming condition and the ambient environment affect the switching behavior of the Ag-filament based memristive device. This work opens new venues for device engineering to achieve high performance RF switches.

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[2]. Tsuruoka, T. *et al. Adv. Func. Mat.* **22**, 70-77 (2012).
[3]. Tappertzhofen, S. *et al. ACS Nano.* **7**, 6396-6402 (2013).

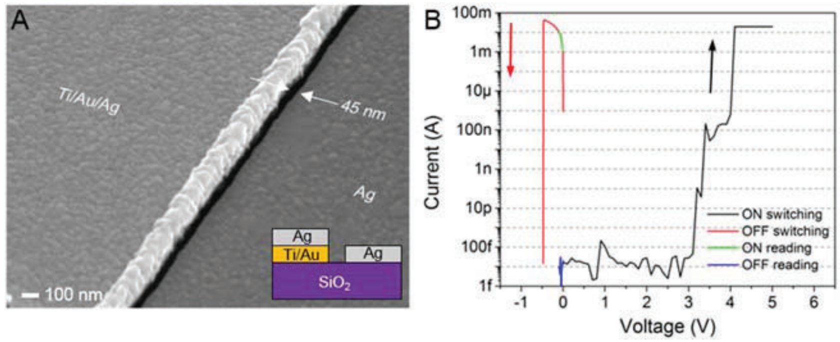

Figure 1: A. SEM image of a device junction. Inset shows a schematic of device cross section. B. Typical I-V curve of the memristive switch. The device can be SET with 4 V (compliance current of 20 mA) and RESET with -0.5 V (compliance current of 100 mA).

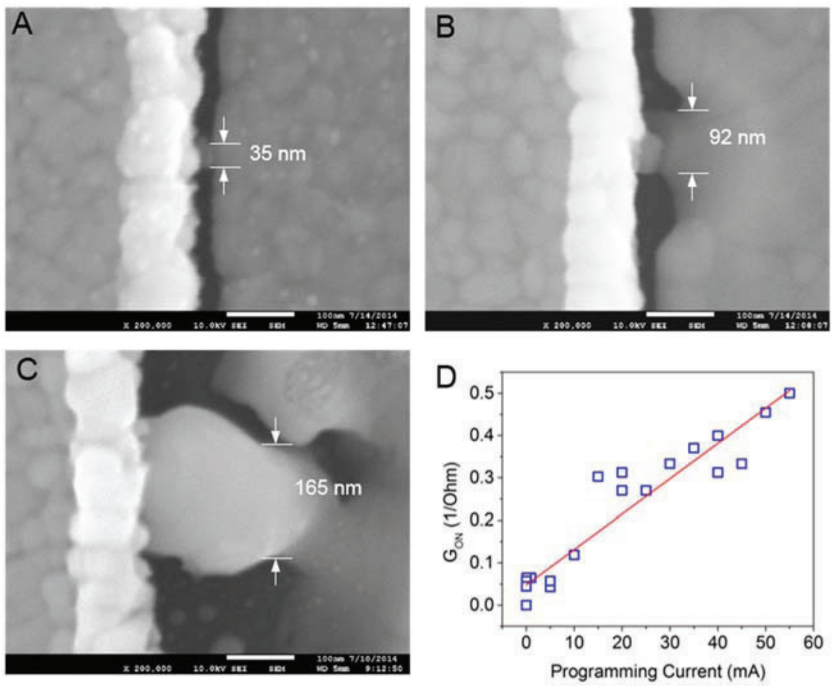

Figure 2: Dependence of ON state conductance on programming current. A-C. SEM images of the conductive filaments of varied widths formed with programming currents of 10 nA (A), 25 mA (B) and 55 mA (C). D. Plot of G_{ON} vs. programming current. A higher programming current leads to higher conductance.

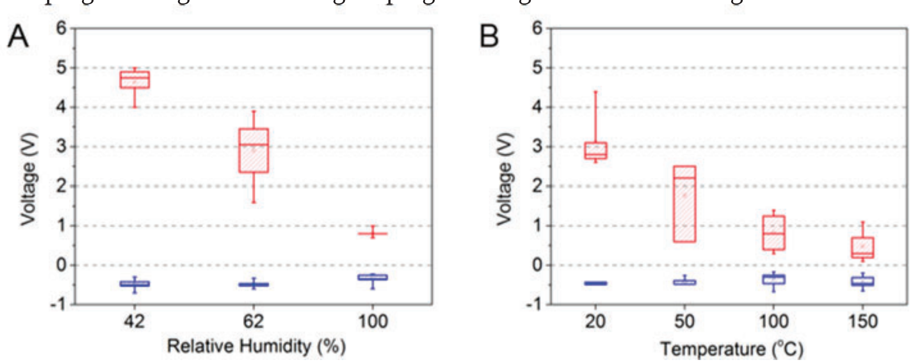

Figure 3: Dependence of SET (red) and RESET (blue) voltages on humidity (A) and temperature (B). The SET voltages decreased with higher temperature and humidity, while the RESET voltages remained nearly unchanged.