Hybrid Tuning of Sub-filaments to Improve Analog Switching Performance in Memristive Devices

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Memristors are electrical resistance switchable devices in which various resistance states can be activated by applying different voltages or currents. The internal resistance states of memristors are usually non-volatile; therefore the memristors can store and process information[1]. Interestingly, not only two resistance states (conductive ON state and less conductive OFF state) exist in memristor devices, but continuous tunable states also have been observed. Considering other merits such as small device size and easy integration with other electronic devices, the memristors become a promising candidate for analog computing[2]. Larger dynamic ranges and more sufficient multilevel states can enable the significant development of memristor-based utilizations. With the development of analog computing especially the neuromorphic computing, there is an increasing demand on memristors with large resistance tuning range and high energy efficiency.

In this work, we report a new method to improve the analog switching performance of memristors through a hybrid tuning of two sub-filaments. One sub-filament takes charge of a coarse resistance adjustment, and the other is responsible for a fine adjustment. The two sub-filaments are created by deploying Pt metal islands inside the oxide switching layer. Because of a stronger electric field strength near Pt islands under applied bias, the dopant ions tend to move toward the metal islands. A complete filament is then cut into two sub-filamentary sections by the islands. By selecting appropriate material stacks and thicknesses, two sub-filaments exhibit different switching behavior to play diverse roles (coarse and fine tuning). To experimentally demonstrate the above mechanism, Pt/Ta/Al2O3/Pt/Al2O3-x/TiOy/Al2O3-x/Pt memristors with Pt islands and ultra-thin Ti layer were fabricated and characterized. This thin Ti layer is used to provide extra dopants to lower the required voltage and current for the switching process. The hybrid tuning of two sub-filaments results in a dynamic range from 600 Ω to 50 kΩ, such range is significantly broader than the dynamic range (600 Ω - 8 kΩ) of a reference Pt/Ta/Al2O3/Pt memristor without sub-filaments. It is noteworthy that large numbers of multilevel conduction states are uniformly distributed within this broad dynamic range. More importantly, the mechanism of creating sub-filaments is compatible with existing memristors, it can provide guidance for the future research on large dynamic range and energy-efficient memristors.

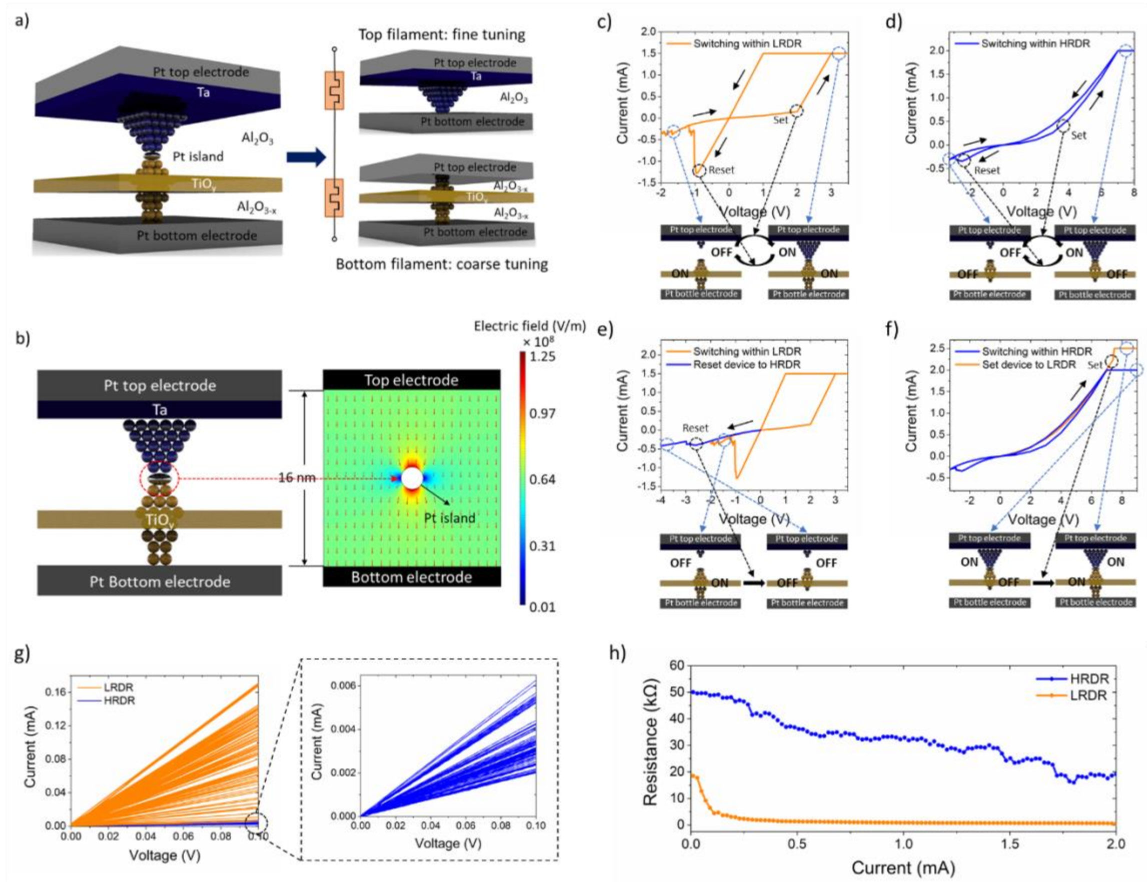

Figure 1. (a) Schematic of sub-filaments in Pt/Ta/Al2O3/Pt/Al2O3-x/TiOy/Al2O3-x/Pt memristor. Two sub-filaments are divided by Pt islands, and the whole memristor can be considered as a series connection of two sub-memristors. (b) Simulation of Electric field distribution in Al2O3 switching layer when there is a Pt island inside. The electric field is stronger near the Pt island, and the dopants inside the switching layer tend to move toward the island. (c) I-V characteristics of Pt/Ta/Al2O3/Pt/Al2O3-x/TiOy/Al2O3-x/Pt memristor within LRDR. The corresponding dynamic range is 600 Ω - 19 kΩ. (d) I-V characteristics of Pt/Ta/Al2O3/Pt/Al2O3-x/TiOy/Al2O3-x/Pt memristor within HRDR. The corresponding dynamic range is 19 kΩ - 50 kΩ. (e) Switching from LRDR to HRDR by applying a higher negative voltage (blue curve). (f) Switching from LRDR to HRDR by applying higher positive current and voltage (orange curve). (g) Multilevel states within LRDR (orange lines) and HRDR (blue lines). (h) Relation between resistance and programming current of Pt/Ta/Al2O3/Pt/Al2O3-x/TiOy/Al2O3-x/Pt memristor within LRDR (orange curve) and HRDR (blue curve).

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2. Zidan, M.A., J.P. Strachan, and W.D. Lu, *The future of electronics based on memristive systems.* Nature electronics, 2018. **1**(1): p. 22-29.