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Oxide Memristors Based on SiO_2 with Cu/Ag Alloy Metallization for Neuromorphic Computing

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Abstract Text:

By mimicking biomimetic synaptic processes, the success of artificial intelligence (AI) has been astounding with various applications such as driving automation, big data analysis, and natural-language processing.[1-4] Due to a large quantity of data transmission between the separated memory unit and the logic unit, the classical computing system with von Neumann architecture consumes excessive energy and has a significant processing delay.[5] Furthermore, the speed difference between the two units also causes extra delay, which is referred to as the "memory wall".[6, 7] To keep pace with the rapid growth of AI applications, enhanced hardware systems that particularly feature an energy-efficient and high-speed hardware system need to be secured. The novel neuromorphic computing system, an in-memory architecture with low power consumption, has been suggested as an alternative to the conventional system. Memristors with analog-type resistive switching behavior are a promising candidate for implementing the neuromorphic computing system since the devices can modulate the conductance with cycles that act as synaptic weights to process input signals and store information.[8, 9]

The memristor has sparked tremendous interest due to its simple two-terminal structure, including top electrode (TE), bottom electrode (BE), and an intermediate resistive switching (RS) layer. Many oxide materials, including HfO_2, Ta_2O_5, and IGZO, have extensively been studied as an RS layer of memristors. Silicon dioxide (SiO_2) features 3D structural conformity with the conventional CMOS technology and high wafer-scale homogeneity, which has benefited modern microelectronic devices as dielectric and/or passivation layers. Therefore, the use of SiO_2 as a memristor RS layer for neuromorphic computing is expected to be compatible with current Si technology with minimal processing and material-related complexities.

In this work, we proposed SiO_2-based memristor and investigated switching behaviors metallized with different reduction potentials by applying pure Cu and Ag, and their alloys with varied ratios. Heavily doped p-type silicon was chosen as BE in order to exclude any effects of the BE ions on the memristor performance. We previously reported that the selection of TE is crucial for achieving a high memory window and stable switching performance. According to the study which compares the roles of Cu (switching stabilizer) and Ag (large switching window performer) TEs for oxide memristors, we have selected the TE materials and their alloys to engineer the SiO_2-based memristor characteristics. The Ag TE leads to a larger memory window of the SiO_2 memristor, but the device shows relatively large variation and less reliability. On the other hand, the Cu TE device presents uniform gradual switching behavior which is in line with our previous report that Cu can be served as a stabilizer, but with small on/off ratio.[9] These distinct performances with Cu and Ag metallization leads us to utilize a Cu/Ag alloy as the TE. Various compositions of Cu/Ag were examined for the optimization of the memristor TEs. With a Cu/Ag alloying TE with optimized ratio, our SiO_2 based memristor demonstrates uniform switching behavior and memory window for analog switching applications. Also, it shows ideal potentiation and depression synaptic behavior under the positive/negative spikes (pulse train).

In conclusion, the SiO_2 memristors with different metallization were established. To tune the property of RS layer, the sputtering conditions of RS were varied. To investigate the influence of TE selections on switching performance of memristor, we integrated Cu, Ag and Cu/Ag alloy as TEs and compared the switch characteristics. Our encouraging results clearly demonstrate that SiO_2 with Cu/Ag is a promising memristor device with synaptic switching behavior in neuromorphic computing applications.

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