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Si-Nanowire-Based Memristors Constructed Using Top-Down Methods for Flexible Electronic Systems

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1. Introduction

Resistance-switching memories, which are generally referred to as memristors (memories + resistors) or resistance-switching random access memories (RRAMs), have widely been researched as a strong candidate for next-generation nonvolatile memories, due to their structural simplicity and excellent memory characteristics [1,2]. Plastic-substrate-based electronic devices are attractive due to their merits of flexibility, light weight, and low cost, which can lead to new opportunities in broad areas of commercial electronics.

Recently, a few studies on Si-based memristors, with the structure of Ag / amorphous Si (a-Si) / heavily doped *p*-type Si, have been reported by other groups, and these memristors showed peculiar properties compared with general metal-oxide-based systems, such as intrinsic hysteresis and rectifying behavior [3,4]. In this research, a new top-down route, consisting of the crystallographic wet etching of Si wafers, transfer onto plastic substrates, and thin film patterning, is suggested to construct Si-based memristors on plastic, and the memory characteristics and flexibilities of our memristors prepared by this new route are analyzed.

2. General Instructions

A schematic illustration of a representative memristive device constructed on a plastic substrate is shown in Fig. 1. Ag and a heavily doped *p*-type Si NW are used as the electrodes and *a*-Si is used as a switching medium. Then, a single switch is formed at the junction of Ag / *a*-Si / Si NW. The Si NWs were formed by the crystallographic wet etching of Si wafers, and the formed Si NWs, exhibiting the triangular crosssection with the base length of ~340 nm, were transferred onto plastic substrates by a direct transfer method [5].

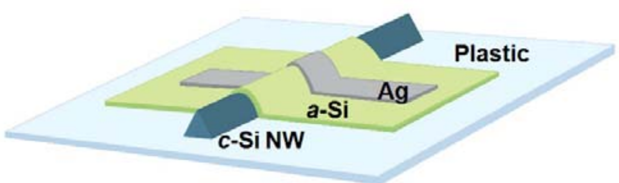

Fig. 1 Schematic illustration of the memristive device fabricated on a plastic substrate.

Figure 2 shows the *I-V* curve of the typical device, exhibiting the well-defined hysteresis induced by the transitions between the high resistance state and low resistance state. The set voltage and reset voltage, averaged from several *I-V* curves, were 2.9 V and -0.2 V, respectively. Rectification behavior is also observed, which means a low current level at negative voltages, even in the on-state. The on/off resistance ratio is well maintained at $>10^5$ for up to 100 cycles. In retention tests, little changes in current levels are observed up to 10^3 sec, which confirms the nonvolatile nature of the fabricated device. To evaluate the flexibility of the device, bending tests were performed. The shapes of the *I-V* curves in the flat and bent states are similar. The bending durability was also tested by observing the changes of the on/off junction resistances during bending cycling. The durability test confirmed that the performance is well maintained for up to 1000-bending cycles, as shown in Fig. 3. The Ag-filament-related nanostructures were examined with TEM, SIMS, and the tunneling-current model to explore the switching mechanism of our memristors. Intrinsically, a nonuniform Ag diffusion profile into the a-Si matrix is observed after the fabrication process. Most of the 30-nm-thick a-Si is metallic, due to Ag inclusion, and the filament with a length of several nanometers controls the device performance.

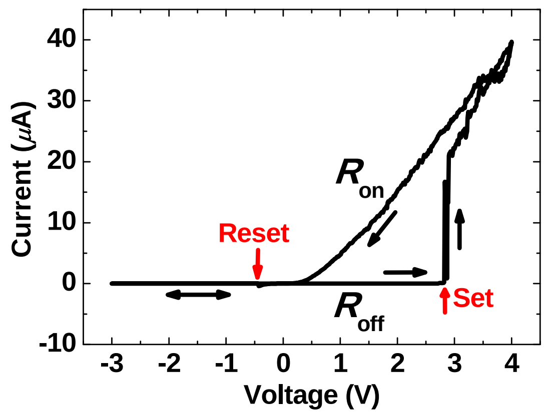

Fig. 2 A *I-V* loop obtained from the typical device in the range between -3 V and 4 V.

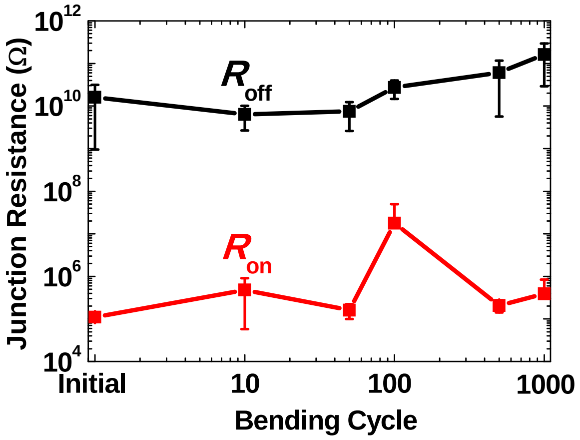

Fig. 3 The change in the junction resistance as a function of bending cycles. 1-bending cycle means that the device is returned to the flat state after bending with a fixed curvature.

3. Conclusions

In summary, Si-based memristive devices were successfully constructed on plastic through our new top-down route. The devices showed excellent memory characteristics and flexibility, such as intrinsic hysteric and rectifying behaviors, on/off resistance ratio of $>10^5$, retention time of $>10^3$ sec, and durability for up to 1000-bending cycles. The Ag-filament-related nanostructures were carefully analyzed to explore the switching mechanism by TEM, SIMS, and the tunneling-current model. These results can help us to gain an understanding about the correlation among the nanostructure, memory/switching mechanism, and device performance for various memristive systems. Furthermore, our study suggests the promising potential of Si-based memristors as future flexible nonvolatile memory devices.

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