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Resistive switching in planar metal/NiO bilayer system with low voltage operation

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Abstract

We have developed a novel-type resistive switching memory based on an amorphous metal/metal oxide bilayer. The high resistive area, which is formed by passing the high-density current in a nano constriction of the amorphous metallic wire, enables to induce the resistive switching of NiO with low operation voltage. This novel-style operation combining the resistive and phase-change memories will provide the great endurance and reliability with variety of material combination.

1. Introduction

Development of nano-scale non-volatile memory device is an important milestone for next-generation nanoelectronics. Although many devices with different operation principles have been demonstrated, each memory device have both advantage and disadvantage. Resistive switching and phase-change memories based on the phase transition are the promising candidates because of their simple device structures with the high compatibility of the present CMOS technology. For further development of such devices, exploring the innovative material is believed to be indispensable. Especially, electrical control of phase change can be obtained only in the limited materials such as GeSbTe[1], Ga-Sb[2]. In addition, the heat control during the transition process is responsible for realizing the stable transition without breaking the device. However, the control of the device geometry, which is a key for controlling the heat flow, is very difficult in the vertical stack nanostructures. Very recently, we have developed a laterally configured resistive switching device based on a nanogap electrode[3]. This device configuration has greater advantage for the flexibility of the device geometry than the vertical device. However, the operation voltage is higher than the conventional vertical device. Here, we propose and demonstrate new memory device combining the PRAM and ReRAM technology.

2. Experimental Procedure

We have fabricated patterned structures for CoFeB monolayer and CoFeB/NiO bilayer on SiO2/Si substrates by magnetron sputtering with a standard lift-off technique, as shown in Fig. 1. The thicknesses for CoFeB and NiO layers are 30 nm and 20 nm, respectively. Here, the shape of the electrode has been optimized from the view point of the heat confinement by using COMSOL simulation. The resistance change was induced by flowing a high density current through the nano constriction.

3. Results and Discussion

First, we have measured the resistance as a function of the applied voltage characteristic for the CoFeB monolayer electrode from the initial state. As shown in Fig. 2, V=4.5 V, a clear resistance transition has been observed. The inset of Fig. 2 shows the SEM image after the resistance transition. It should be noted that there is no disconnection point, indicating that the resistance change is induced by not the disconnection but the formation of highly resistive area in the nano constriction of the CoFeB. We then further increased the bias voltage, then observed a next resistance transition at V= 6 V. From the SEM image after the measurement shown in the inset of Fig. 2(b), we have confirmed that a clear nano gap was formed by the electro migration. Thus, in the present device, an intermediate amorphous-like state was found to be formed before the nano-gap formation. It should be emphasize the importannce of the electrode design because there was no intermediate state in the device with other electrode shapes.

We then performed a similar experiment for the CoFeB/NiO bilayer sample. The first resistance transition into the intermediate state was observed at 1V, slightly smaller than that for the mono-layered sample. In the 2nd voltage sweep, we have clearly observed the set-reset resistive switching behavior with high reproducibility. As shown in Fig.3, this switching process does not depend on the voltage polarity, indicating the unipolar type. Since the SEM image did not show any structure change after the 10000–times switching measurement, the crystal structure change of the NiO is responsible for this switching process.

We also emphasize that the similar set-reset resistive switching process with the intermediate state has been obtained in Ta/NiO devices.

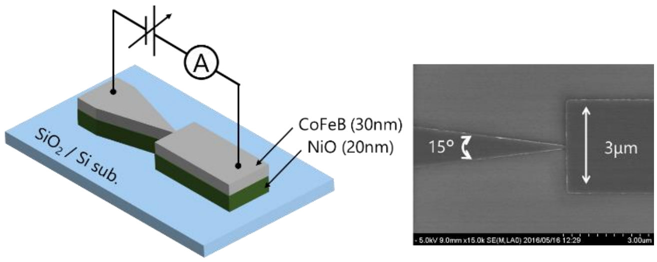

Fig. 1 Schematic illustration and SEM image of the fabricated resistive switching device consisting of the CoFeB/NiO bilayer.

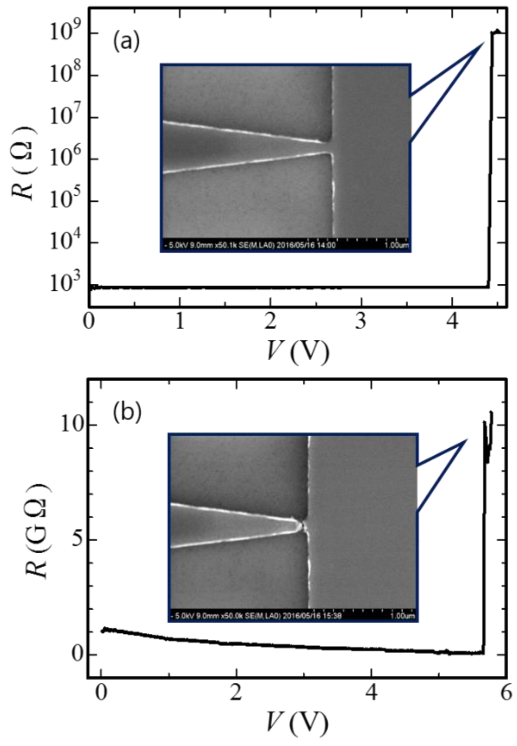

Fig. 2(a) Sample resistance as a function of the applied voltage (1st sweep) The inset is the SEM image after the resistance transition. (b) 2nd R-V characteristic together with the SEM image after the measurement.

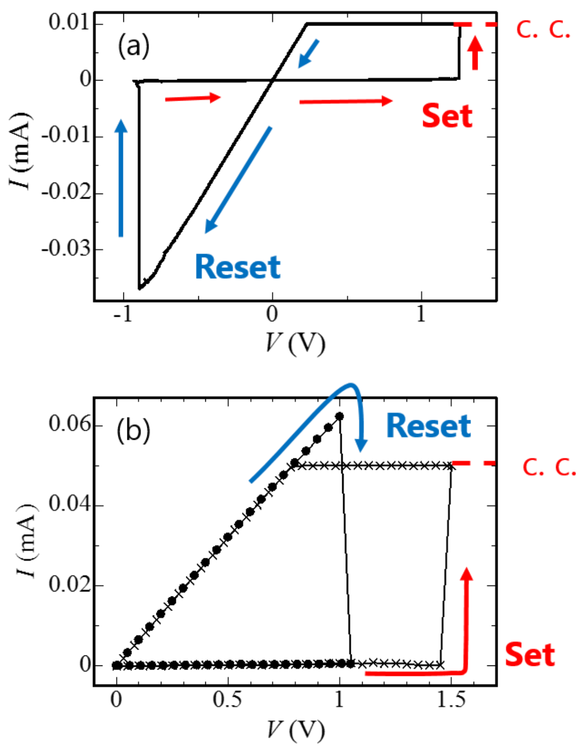

Fig. 3 Resistive switching property for the fabricated CoFeB/NiO bilayer wire after the 1st resistance transition. Bipolar-like (a) and unipolar-type IV characteristics (b) indicate the unipolar-type resistive switching with high stability.

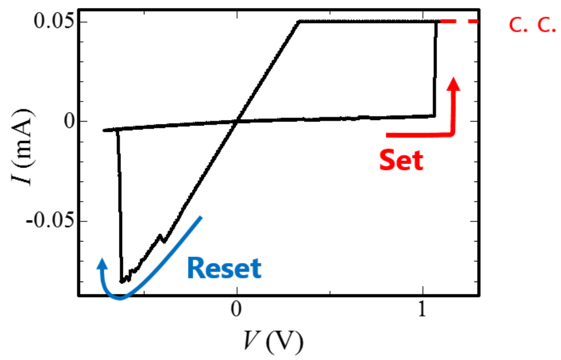

Fig. 4 Resistive switching property for the fabricated Ta/NiO bilayer system.

3. Conclusions

We have developed the method for inducing the phase transition of metallic nanowire by optimizing the electrode shape. By forming the high resistance area on a metal oxide NiO, we are able to induce the resistive switching of NiO with high reproducibility and high endurance. This innovative method based on the combination between the phase change of the amorphous metal and resistive switching of metal oxide will provide the stable operation of the resistive switching with low bias voltage.

References

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