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Nanogap ReRAM based on natural aluminum oxide

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1. Introduction

Nanogap electrodes, a pair of electrodes with nanometer scale separation, have been used for contacting bottom-up nanostructures [1,2,3] and also for providing intrinsic physical effects such as nano-cavity effects [4], magnetic resistance [5], and reversible nanogap resistance switching effects [6]. In this work, we apply the nanogap electrodes for a filament–type ReRAM (Resistance Random Access Memory) material to study the switching mechanism, and to develop novel devices.

Recently, ReRAM has attracted attention as one of the most promising candidates for the next generation of nonvolatile memories. In some ReRAM materials, the underlying resistive switching mechanism of ReRAM is suggested to be a formation and disruption of conducting filaments composed of oxygen vacancies [7]. However, the full mechanism of the switching still unclear, which is one of the obstacles for ReRAM performance improvement. Here, we report a novel approach to resolve this challenge by adopting nanogap electrode to obtain new insights for the switching operation. We demonstrate unipolar and bipolar operations in the macro- and nano-gap device structures, and discuss the resistance switching behavior which depends on electrode gap distance.

2. Device structure

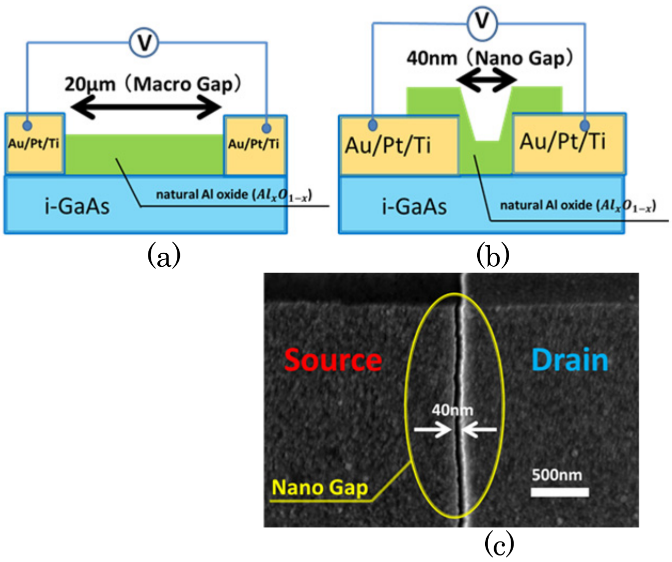

Fig. 1 Side views of ReRAMs with (a) macro-gap and (b) nano-gap electrodes. (c) SEM picture of the fabricated 40 nm nanogap taken before Al layer deposition .

We have used 10 nm thick aluminum oxide formed by natural oxidation of a thin Al layer as the ReRAM material. The use of naturally oxidized Al_xO_{1-x} may provide a way for large area, low-cost fabrication of ReRAM based on high Clarke number materials. We have fabricated two types of lateral ReRAM structures with 10/10/30 nm Ti/Pt/Au electrodes on the top. One device structure has macro-scale gap electrodes, as shown in Figure 1(a). The electrode area is about 100×100 μm², and the gap distance is about 40 μm. The other device structure has nano-scale gap electrodes, as shown in Figure 1 (b) and (c). The nanogap distance is about 40 nm, and the width is 2 μm.

3. Results

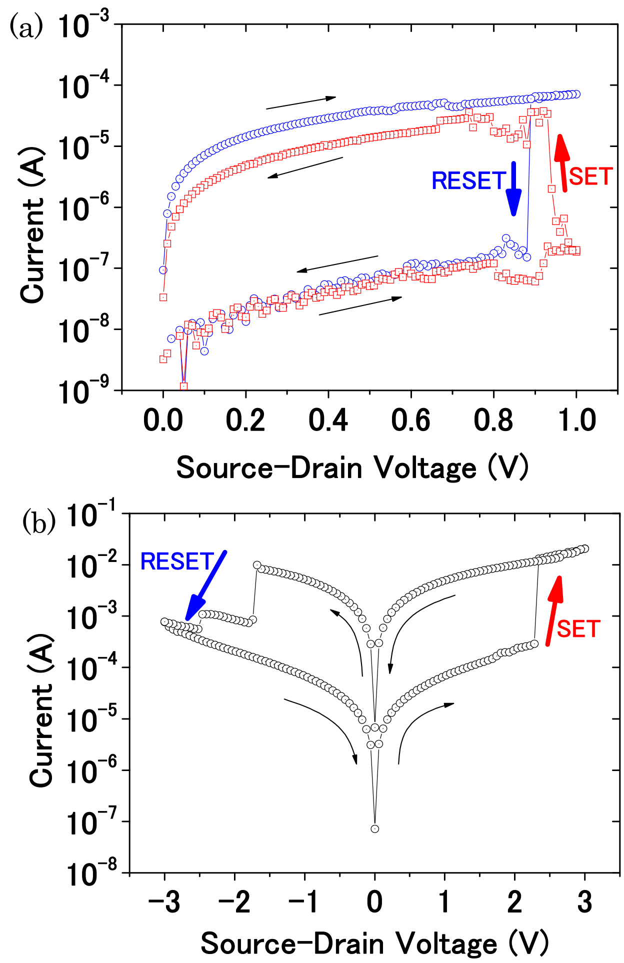

Fig. 2 I-V characteristics of (a) macro gap ReRAM and (b) nanogap ReRAM, plotted in a semi-logarithmic scale.

3. Macrogap ReRAM behavior

Figure 2 (a) shows the representative I-V characteristics of the macrogap ReRAM. We find the device exhibits unipolar switching behavior. No forming process is required. Both of the switchings from OFF to ON (SET) and from ON to OFF (RESET) are observed in the same voltage polarity. The SET and RESET voltages are less than 1 V. The resistance of a low resistance state (LRS) and a high resistance state (HRS) are 13 kΩ and 5.5 MΩ, respectively. To our knowledge, this is the first report of the ReRAM operation based on naturally oxidized thin film.

Our result observing unipolar switching is consistent with previous works using relative large area electrodes. In Al_xO_{1-x} system, unipolar operation has been reported in Al-rich Al_xO_{1-x} layer formed by anodizing Al thin film[8] and Al-Al_xO_{1-x} multilayered structures [9]. Our naturally oxidized film should be relatively Al-rich since natural oxidization is weak oxidation process.

4. Nanogap ReRAM behavior

Figure 2 (b) shows the I-V characteristics of the nanogap ReRAM. We find the device exhibits bipolar switching behavior. No forming process is required. The SET and RESET are observed in different voltage polarity. Both the SET and RESET voltages are about 2 V. The LRS and HRS resistances are 200 Ω and 14 kΩ, respectively.

The resistance switching in the nanogap structure appears under DC voltage sweep. Therefore, the resistance switching is attributed to the ReRAM material sandwiched between the nanogap electrodes rather than field-induced migration of the electrodes [10] which can be caused by pulse voltage application.

5. Discussion

We have observed both unipolar and bipolar type of switchings in the ReRAM film. The difference between macro- and nano-gap system is consistent with a recent atomistic model based on density functional theory calculations [7]. In their model, resistance switching is caused by cohesion and disruption of the filament due to carrier injection and removal. The switching becomes bipolar when both holes and electrons are injected from the electrode while the switching becomes unipolar when holes are injected from the electrode and then electrons are injected from the filament.

In our case, the observed unipolar switching behavior of macro-gap device suggests that electrons are injected from the filaments in our ReRAM material system. In other words, there is a separation between the filament and one of the electrode at the voltage. On the other hand, nanogap electrodes may serve to increase electron tunneling from the electrodes rather than from the filament because the nanogap electrode structure decreases the separation between the filament and one of the electrodes. The electron injection makes the switching bipolar.

6. Conclusions

We have fabricated lateral ReRAM based on naturally oxidized Al_xO_{1-x} with macro-and nano-gap electrodes. We have successfully achieved unipolar and bipolar operations in the macro- and nano-gap device structures. The result suggests the controlling the resistance switching behavior by electrode gap distance or the filament length. Our method can be used to develop a hybrid system of nonvolatile resistance memories and nanogap electrode structures.

Acknowledgements

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