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RRAM Technology for Fast and Low-Power Forming/Switching

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1. Introduction

Since resistance random access memory (RRAM) was first demonstrated [1], RRAM has been intensively investigated as one of the candidates for future nonvolatile memories. There was remarkable advancement in the RRAM technology by a lot of researches. Accordingly, feasibility of RRAM, in terms of the high switching speed and the low electric power manufactured from the material with the good compatibility with CMOS, has been proven [2-6]. However, crucial problems to be overcome still remain: That is, it is necessary to achieve a stable switching performance by the well-controlled forming processes. Speeding up and lowering power of the forming process as well as fast and low-power resistance switching are essential to realize practical RRAM. Moreover, it is necessary to clarify the relation between the structure and the electrical property on metal oxide/electrode interface, and to optimize the electrode material.

In this study, we investigated the influence of the oxygen potential of the electrode material, the change of the Gibbs free energy in the oxidation process, on the forming and switching performance, because it is believed that oxygen plays a considerable role in the switch of resistance. As a result, it was clarified that electrodes with low oxygen potential, which are also CMOS-friendly, are very effective to achieve fast and low-power forming/switching.

2. Experimental

Top electrode (TE) /CoO/Pt bottom electrode (BE) stacks were fabricated on thermally oxidized Si substrates by RF magnetron sputtering and photolithography. Pt, W, Ta, Ti and Al were used as the TE material. TE size, which corresponds to device size, is 10 - 100 um^2. External series resistors were used for current regulation during forming and set operation, because current compliance function of *I-V* measurement instrument which is often used is not enough to control the current in nanoseconds range. 1T-1R configuration, which has better current regulation capability, was also made fabricating RRAM on a submicron n-MOS FET.

3. Fast Forming

Figure 1 shows forming speed of Ta/CoO/Pt RRAM with two different CoO thickness (50 nm and 10 nm) as a function of $V_{forming}$ divided by CoO thickness d, which is a measure of electric field. It was confirmed that thinner oxide is advantageous to faster forming as well as low-voltage forming [2]. TE material dependence on forming speed of 10 nm-CoO RRAM is shown in Fig. 2. TE with low oxygen potential such as Ta enables fast forming less than 1 μs at relatively low forming voltage, while the forming speed of Pt-TE RRAM is very slow.

4. Fast and Low-Writing-Current Switching

Figure 3 shows reset current of CoO RRAM with various TEs as a function of forming current. It is clearly seen that lower forming current, which is controlled by the external series resistor with larger resistance, results in lower reset current. Furthermore, RRAM with Pt and W TE exhibits lower limit of reset current around 1mA, while Ta electrode can reduce the reset current down to 100 μA. We speculate that low forming current would form fine filament resulting in the increase in resistance of low resistance state and oxide formed from TE material at the interface plays a role in confining the current path depending on the resistivity of the interface oxide.

Figures 4 show applied pulse voltage and writing current waveforms of Ta/CoO/Pt for (a) Set and (b) Reset. Fast switching (50 ns) with low writing current around 100 μA was achieved. Set current increase and reset current decrease with time are observed. *I-V* hysteresis curve measured with 100ns triangular voltage sweep is shown in Fig. 5. Figure 6 shows resistance switching behavior of RRAM with various TEs. All the samples shown here, which have low oxygen potential, exhibit fast switching (50ns). Only the sample with W TE showed large reset current exceeding 1 mA. Pt-TE RRAM could not be switched by short voltage pulse application.

5. Stable Switching in 1T-1R Configuration

Current waveform during +5 V 500ns pulse forming in 1T-1R configuration [Fig. 7 (a)] is shown in Fig. 8. The steep current increase indicates the start of the forming. The RRAM resistances before and after forming were 10^{10} Ω and 10^4 Ω, respectively. After the forming, stable fast switching (50ns) with low writing current around 100μA and high resistance switching ratio over 10 was obtained as shown in Fig. 9. This would be due to good current regulation during set operation by 1T-1R configuration. The resistance repeatability of set operation and its set condition dependence are shown in Fig. 10. It seems that higher writing current results in better resistance repeatability.

50ns-fast monopolar switching in the configuration shown in Fig. 7 (b) was also successfully demonstrated as shown in Fig. 11.

6. Conclusions

It has been demonstrated that fast forming as well as fast switching with low writing current, which is essential for real nonvolatile memory application, can be achieved with thin metal oxide and CMOS-friendly electrode having low oxygen potential.

Acknowledgments

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Reference

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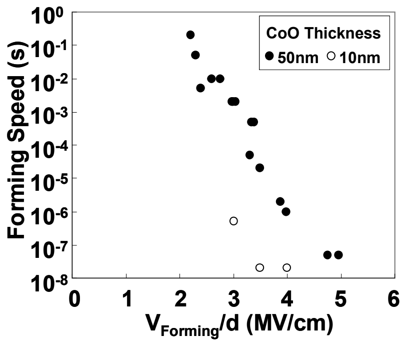

Fig. 1 Forming speed of Ta/CoO/Pt RRAM with two different CoO thickness as a function of $V_{forming}$ divided by CoO thickness d.

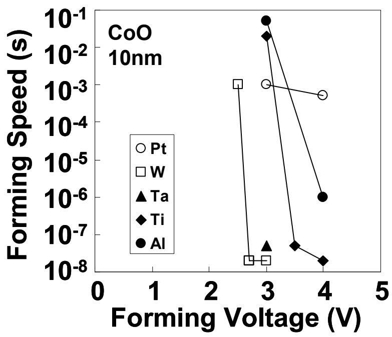

Fig. 2 Forming speed as a function of forming voltage for TE/CoO/Pt RRAM. The oxide thickness is 10nm.

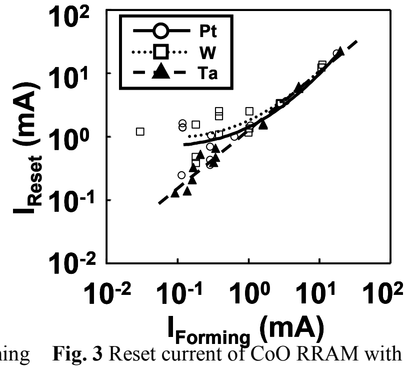

Fig. 3 Reset current of CoO RRAM with various top electrodes as a function of forming current.

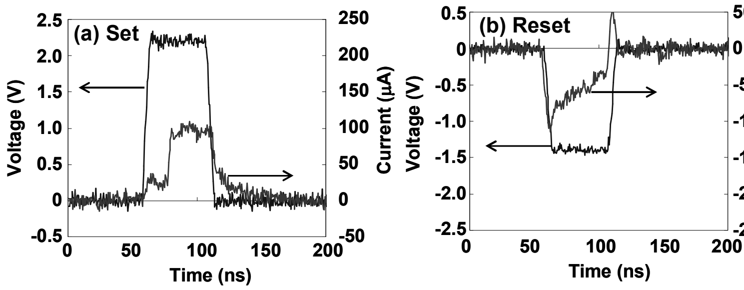

Fig. 4 Applied pulse voltage and writing current waveforms of Ta/CoO/Pt for (a) Set and (b) Reset. Set and reset conditions are 2.2 V 50 ns and -1.4 V 50 ns, respectively.

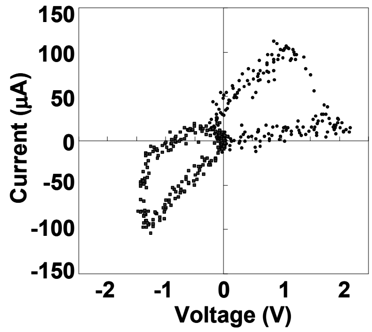

Fig. 5 Set and reset behavior of Ta/CoO/Pt RRAM measured with 100ns triangular voltage application.

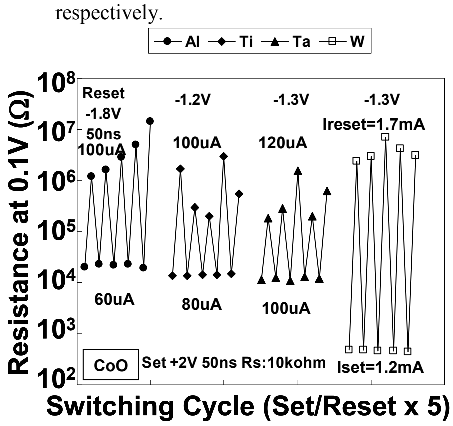

Fig.6 Resistance switching characteristics of CoO RRAM with various top electrodes (Al, Ti, Ta, W). Set and reset voltage pulse width is 50 ns.

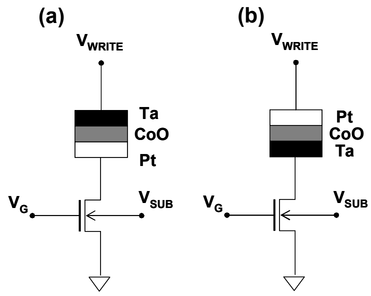

Fig. 7 1T-1R configurations for (a) bipolar switching and (b) monopolar switching.

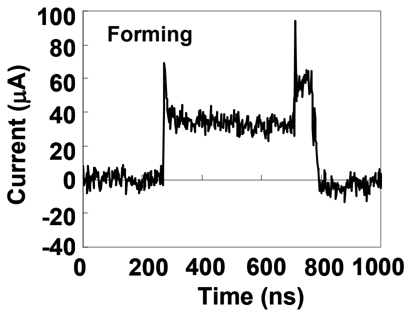

Fig. 8 Current waveform during forming in 1T-1R configuration.

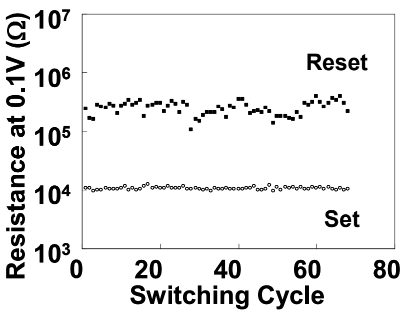

Fig. 9 Resistance switching characteristic of Ta/CoO/Pt in 1T-1R configuration.
Set: 3V 50ns V_G=1.8V
Reset: -1.7V 50ns V_G=3V

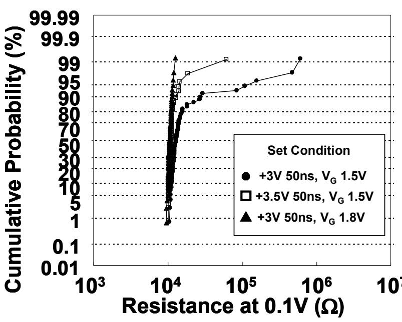

Fig. 10 Resistance repeatability for three different set conditions in 1T-1R configuration.

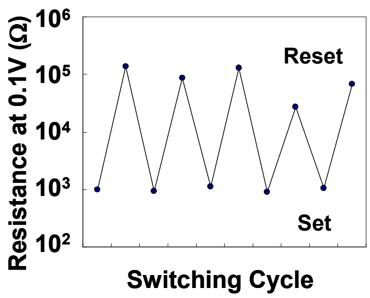

Fig. 11 Monopolar Switching of Ta/CoO/Pt in 1T-1R configuration.
Set: 3V 50ns V_G=1.8V
Reset: 1.2V 50ns V_G=3V