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Endurance study of switching characteristics in NiO films

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Abstract

Bi-stable switching effect has been studied in nickel oxide films with three different thicknesses. The best sample of our experiments was 150-nm NiO film. Its resistance ratio between high and low states was 3.6 in endurance measurement. The maximum resistance ratio in *I–V* curve could reach two orders of magnitude, and it could endure over 200 times of reverse processes with the ratio remaining about 1.46. This indicates that the nickel oxide has potential to be a promising material on resistance random access memory.
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Keywords: Nickel oxide; RRAM; Bi-stable memory switching effect

Non-volatile memory (NVM) plays an important role in semiconductor industry. Besides the flash memory, others such as magnetic random access memory (MRAM), phase change random access memory (PCRAM) and resistance random access memory (RRAM) are very interesting research topic. The bi-stable memory switching effect of RRAM has been reported in metal–oxide–metal (MOM) structure with Nb_2O_5 [1], TiO_2 [2], ZrO_2 [3], Ta_2O_5 [4], Al_2O_3 [5], NiO [6], Cr-doped $SrZrO_3$ [7], (Pr,Ca)MnO_3 [8] and Fe oxides [9]. Much works have been done in this field, starting already in the late 1960s. Recently, NiO has been reported to be a promising material due for RRAM to its high resistivity ratio and simple constituents [10]. In this study, we reported the electrical and endurance properties with different thickness of NiO films.

The ion beam sputtering system with 99.95% nickel target was used to prepare our films at room temperature. In the deposit processes, we controlled the oxygen partial pressure to the working pressure about 56%. NiO films with different thickness from 30 to 150 nm were deposited in a 300×300 nm pattern area using Ti and W for top and bottom electrodes. Electrical properties were measured by Agilent 4156C semiconductor parameter analyzer, pulse voltage was supplied by Agilent 81110A and switching bridge was controlled by Keithley 707A.

Bi-stable memory switching effect of poly-crystal nickel oxide (not show here) has been studied in this report. Fig. 1 shows the typical current–voltage measurement (*I–V* curve) of bi-stable memory switching effect NiO film with different thickness. In order to facilitate the use of a semi-log scale, we plot the absolute value of current ($|I|$). It is obvious to observe that the hysteresis phenomenon with two states in the electrical property measure process. In this measurement, we defined these bi-stable states as set (low resistance:high induction current) and reset (high resistance:low induction current) states that were controlled by voltage. In this process, we could see the resistance change from reset state to set state when we poured a positive voltage. Similarly, we poured a negative voltage, resistance changes from reset state to set state. An asymmetric shape of the *I–V* curve might be attributed to the different work functions of Ti/NiO and NiO/W interfaces [11]. In addition, we found that the thicker films need more voltage to change the state, and the ratio of two states was bigger on thicker films. For 30-nm NiO film, the resistance ratio was very small and the two states were not obvious. When we increased the thickness, it is obvious that the ratio increased. And the maximum ratio of our samples is about one to one hundred of 150 nm.

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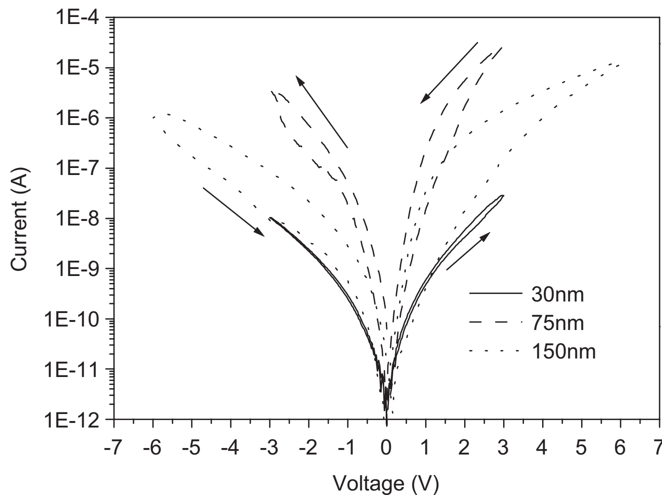

Fig. 1. The current–voltage measurement of different thickness NiO films.

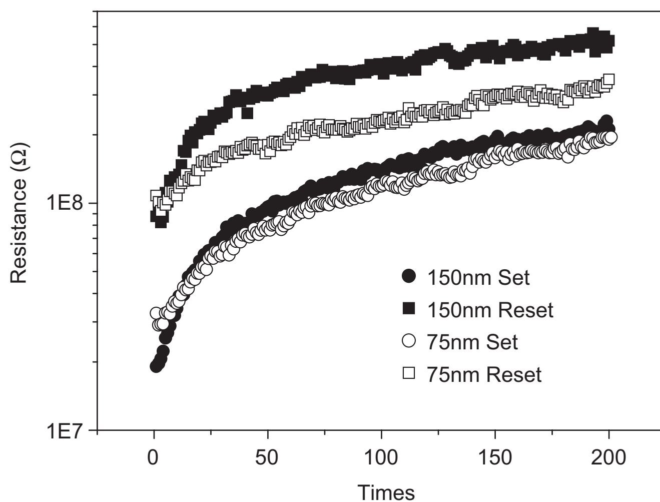

Fig. 2. The endurance of NiO films using pulse voltage to reverse the states with different thickness.

About the endurance of NiO films, we poured a pulse voltage to reverse the states. Fig. 2 shows the endurance of NiO films with different thickness. Because the two states almost overlap in 30-nm NiO film, we just showed the endurance about 75 and 150 nm. In this figure, we found that the films could endure the set and reset processes about 200 times without overlap. Then we defined the value of $(R_{reset}-R_{set})/R_{set}$ as resistance ratio in order to observe the influence with switching processes. The resistance ratio of these two samples did not reach the same level as Fig. 1 because the pulse voltage and the real voltage in films that we used did not reach the best reverse voltage. Moreover, we found that the resistance and resistance ratio were larger on thicker films. These results conform to the basic physics and electrical properties. In the initial of fresh sample, the resistance ratio was 3.6(2.3) of 150(75)-nm NiO film. After 200 times reverse processes, the ratio reduced to about 1.46(0.8) of 150(75)-nm NiO film. Meanwhile, it is

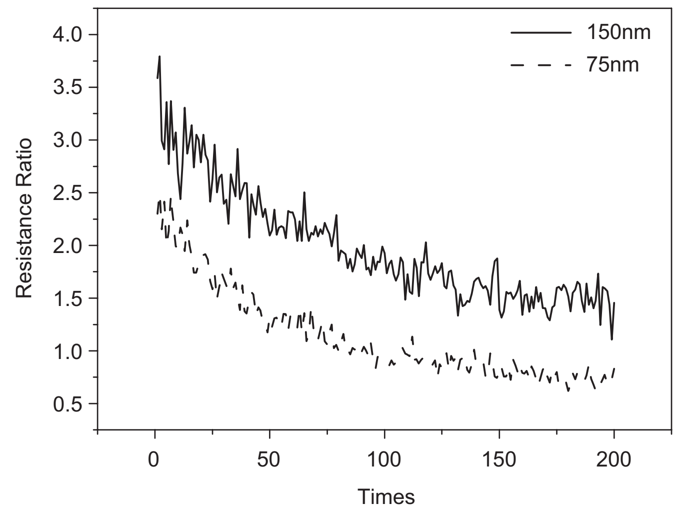

Fig. 3. The resistance ratio of different thickness NiO films in the endurance measurement.

obvious that the resistance increased. It might be attributed to the localized ‘‘burned’’ pits with create-like geometry generated and the structure shorted [12].

In Fig. 3, it is obvious to observe that the ratio decreased in the endurance measurement. This time dependence can be well fitted by a double exponential decay function of the form $R(t) = R_0 + A_1 \exp(-t/t1) + A_2 \exp(-t/t2)$. In fitted program, we found the ultimate ratio was 1.29 (0.437) of 150 (75)-nm NiO film when we fixed the constants of A_1, A_2, t_1, t_2, and defined t to infinite.

In summary, bi-stable switching effect in nickel oxide films has been studied with three different thicknesses. Its maximum resistance ratio can reach one hundred in *I–V* curve and it can endure over 200 times of reverse processes with the ratio remaining about 1.46. So, the nickel oxide has potential to be a promising material on resistance random access memory.

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