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Miniaturization Limit of Memory Cell in Polycrystalline-NiO-ReRAM

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1. Introduction

Recently, the research to establish the high density memory cell array is advancing. In particular, resistive random access memory (ReRAM) using a reversible resistance change characteristic of transition metal oxides (TMOs) is expected as the memory for the next generation because of the nonvolatility, high-speed operation, and simple device structure [1-3].

ReRAM takes the sandwich structure where TMO such as NiO and TiO_2 was placed between a top and a bottom electrode. TMO films prepared by using the sputtering technique often consist of the polycrystalline structure [4,5]. However, where the resistance change takes place has not yet been specified and thus the minimum area which is necessary to generate the resistance change effect has not yet been clear either. From the viewpoint of downsizing of a memory cell, these issues should be elucidated as soon as possible.

In this paper, current distribution for the localized area of a NiO polycrystalline film was investigated by using conducting atomic force microscope (C-AFM). It was suggested that the minimum unit to generate the resistance change effect of polycrystalline NiO films was one crystal grain.

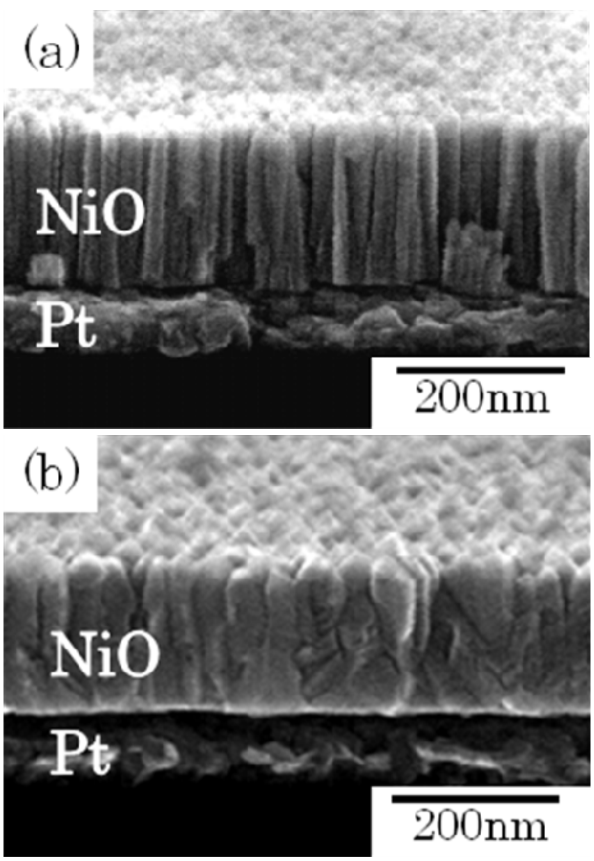

Fig.1 Cross-sectional SEM images of NiO films deposited at (a) 200 °C and (b) 380 °C.

2. Experimental

The NiO films were deposited on the Pt-bottom electrode (BE)/Ti/SiO_2 substrates in the atmosphere of the mixture gas of Ar and O_2 for substrate temperatures, T_{sub}'s, of room temperature, 200℃, 250℃, 300℃, and 380℃ by using the DC magnetron sputtering technique. The NiO films with thicknesses of 60 nm and 200 nm were prepared for the C-AFM and scanning electron microscope (SEM) measurements, respectively. During the deposition, sputtering power was kept at 1kW. Crystallinity of the NiO film was estimated by the X-ray diffraction (XRD) measurement, and the cross-sectional image was measured by using SEM. The surface morphology and the current distribution were estimated by using C-AFM. The Rh-coated Si tip of the C-AFM, which acts as a mobile top electrode (TE), was grounded, and a dc bias voltage, V_{bias}, was applied to the bottom electrode.

3. Results and Discussion

Fig.1(a) and 1(b) show cross-sectional SEM images of the NiO films deposited at T_{sub} of 200 ℃ (NiO(200 ℃)) and 380 ℃ (NiO(380 ℃)), respectively. Columnar grain growth was confirmed in both Fig. 1(a) and 1(b). The similar results were observed in the NiO film deposited with other T_{sub}'s. The radius of the columnar grains increased with increasing T_{sub}.

Fig.2(a) shows the current image for the area of 1.5 x 1.5 μm^2 of the NiO(380 ℃) film measured by C-AFM. Here, a sensing voltage was +1V. The brighter region corresponds to the region with lower resistivity. It was shown that the current flows predominantly in the grain boundary in the initial state. Moreover, this result was also confirmed in the other NiO films deposited with different T_{sub}. Subsequently, the low resistance state (LRS) was written in the center 1.0 x 1.0 μm^2 area (inside of the dotted line of Fig.2(a)) by scanning the tip under the V_{bias} of +5 V to the BE, as shown in the current image of Fig. 2(b). Finally, the high resistance state (HRS) was written in the center 0.5 x 0.5 μm^2 area (inside of the inner dotted line of Fig.2(b)) by scanning the tip under the V_{bias} of -5 V as shown in the current image of Fig.2(c). The inset of Fig.2(c) shows the enlarged view around the neighborhood of the boundary of the 0.5 x 0.5 μm^2 writing area. As for the crystal grains which step over the boundary of the voltage application area, the whole of the crystal grain causes the resistance change. This suggests that the minimum unit to cause the resistance change effect is one grain. In addition, it was also suggested that the location where resistance switching takes place is the grain boundary. Since the resistivity of the grain boundary is much lower than that of grains, the current flows from the contact between the AFM-tip and the crystal grain to the grain boundary through the surface of the grain when AFM-tip contact a grain. Therefore, it was suggested that the resistance change of the crystal grain was

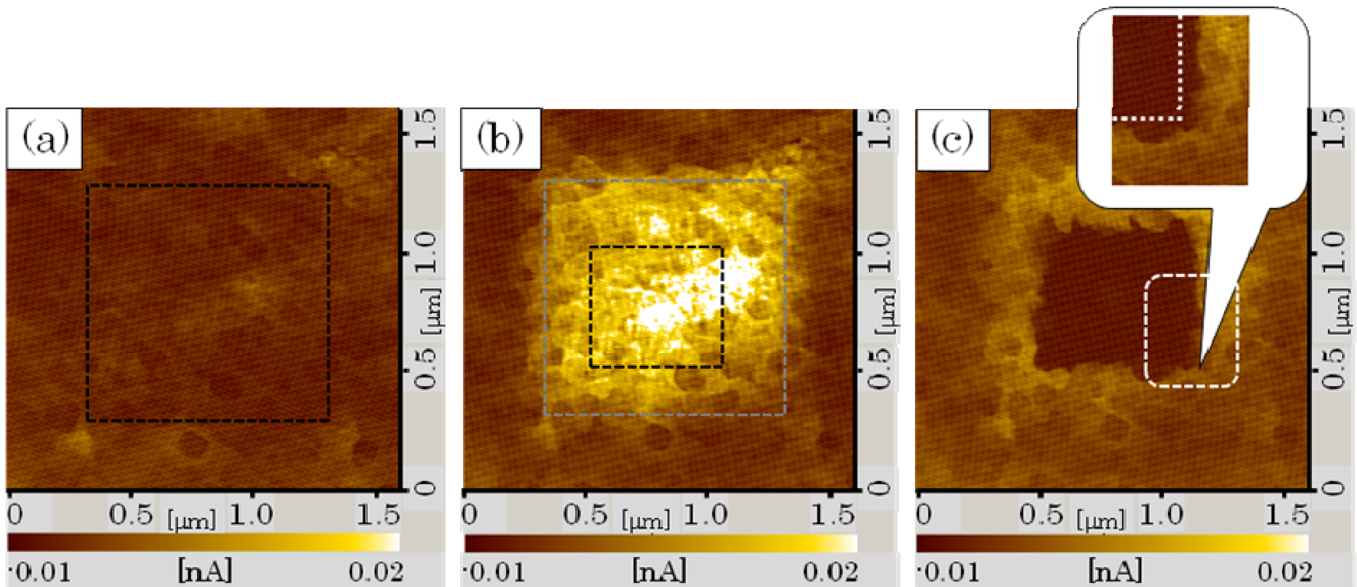

Fig. 2 (a) Current image of the NiO film deposited at 380℃(NiO(380℃)) before voltage application. (b) Current image of NiO(380℃) after scanning the center 1.0 x 1.0 μm^2 area (surrounded by dotted line in (a)) with the AFM tip under the V_{bias} of +5V. (c) Current image of NiO(380℃) after scanning the center 0.5 x 0.5 μm^2 area (surrounded by dotted line in (b)) with the AFM-tip under the V_{bias} of -5V. Current images (a)-(c) were obtained successively. Sensing voltage was 0.1 V. The inset of (c) shows the enlarged image of the area surrounded by the dotted line in (c).

caused not by the change in the resistivity of the grain itself but by the change in the resistivity of the grain boundary.

Fig.3(a) shows the current image for the area of 0.5 x 0.5 μm^2 of the NiO(380°C). Fig. 3(b) shows a current image after application of the V_{bias} of +10V to the crystal grain of NiO, which is surrounded by the dotted line of Fig.3(a), by using the AFM-tip. The resistance of the crystal grain was changed to the LRS. Fig.3(c) shows the current image after application of the V_{bias} of -10V to the same crystal grain of NiO(380°C). The crystal grain has changed to the HRS. Then, the same crystal grain changed back to the LRS by subsequently applying the V_{bias} of +10V, as shown in Fig.3(d). These results confirmed that the resistance change occurred in one crystal grain.

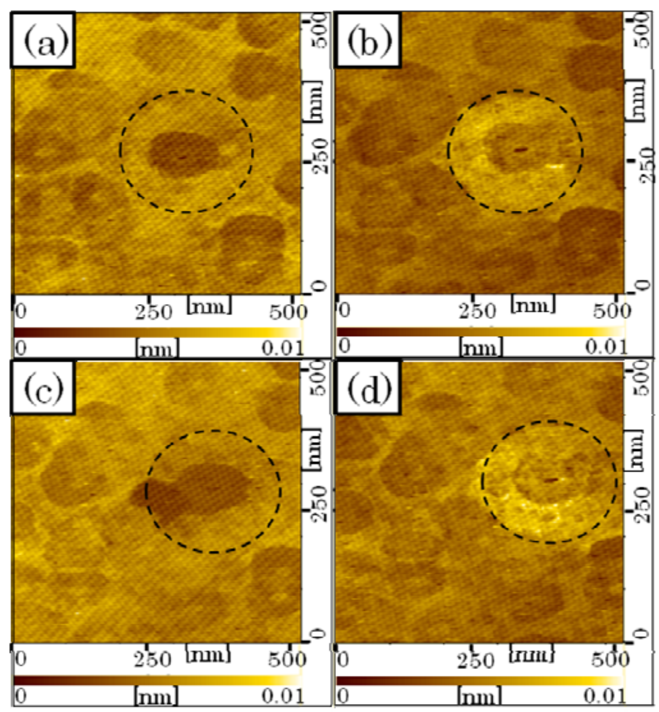

Fig. 3 (a) Current image of the NiO(380℃) before voltage application. (b) Current image of the NiO(380℃) after the application of V_{bias} of +10V to the grain surrounded by dotted line. (c) Current image of NiO(380℃) grain after the application of V_{bias} of -10V to the grain surrounded by dotted line. (d) Current image of the NiO(380℃) after the application of V_{bias} of +10V to the grain surrounded by dotted line. Current images (a)-(d) were obtained successively.

4. Conclusion

The present study showed that the minimum area which was necessary to generate the resistance change effect in polycrystalline NiO films was one crystal grain. This suggested that the resistance change effect of polycrystalline NiO films occurred in the grain boundary. Therefore, it was suggested that the minimum limit of the downsizing of memory cells was decided by the size of one crystal grain.

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