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Fabrication and Resistance-Switching Behaviors of NiO Thin films by Thermal Oxidation of Evaporated Ni Films

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Abstract. Polycrystalline NiO thin films were fabricated on Pt (111)/Ti/SiO_2/Si substrates by thermal oxidation of the evaporated Ni films. Pt/NiO/Pt structures were prepared, and they showed reversible resistance switching behaviors. When the compliance set current was varied from 5 mA to 40 mA, the on-state currents increased, while the on-state resistances decreased. It is probably attributed to higher current compliance resulted in the formation of stronger and less resistive filaments, which in turn need more energy and power for their rupture. The resistive switching in NiO thin films is closely related to the formation and rupture of conducting filaments.

Introduction

Recently, binary transition metal oxide (TMO) such as NiO [1,2] or TiO_2 [3,4] based resistance random access memories (RRAM) have attracted great interest due to their simple strcutures, low operation voltage and process compatibility with complementary metal oxide semiconductor technology. The resistance switching between high resistance state (HRS) and low resistance state (LRS) has been attributed to the formation and rupture of the filamentary conductive path consisting of oxygen vacancies or mobile ions [5,6]. It is known that most of the polycrystalline NiO films are reported being deposited by reactive sputtering on conductive substrates to fabricated MIM structures [1,7-10].In this report, Polycrystalline NiO thin films were fabricated on Pt (111)/Ti/SiO_2/Si substrates by thermal oxidation of evaporated Ni films. Reproducible resistance switching behaviors were oberserved in Pt/NiO/Pt structures.

Experimental

Nanocrystalline Ni films were successfully grown on Pt (111)/Ti/SiO_2/Si substrates by electron beam evaporation deposition at room temperature. During the Ni metal evaporation, we maintained the pressure inside our chamber at 4×10^{-4} Pa, and the depositing velocity is 0.1nm/s. Then polycrystalline NiO thin films were fabricated on Pt (111)/Ti/SiO_2/Si substrates by thermal oxidation of the evaporated Ni films at 550 ^{o}C with a tube furnace. The oxygen flow rate was maintained at about 30 cc min^{-1}. For electrical measurements, Pt top electrodes with a diameter of 0.1mm were deposited using a mask by electron beam evaporation deposition.

A schematic diagram of the device structure and the measurement circuit is shown in the Fig.1(III). Current-voltage characteristics were examined by Kerthley 2410C source meter unit. X-ray diffraction (XRD) spectrum and scanning electron microscopy (SEM) were employed to characterize the crystalline and morphology of as-grown films respectively.

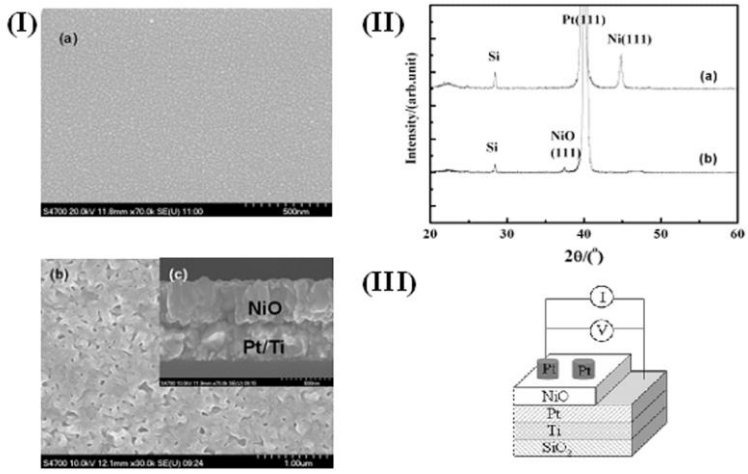


Fig 1(I). SEM images of Ni thin films and NiO thin films (a) top view of Ni films; (b) top view of NiO films; (c) cross section of NiO films. Fig.1(II) XRD patterns of Ni an NiO films fabricated on Pt (111)/Ti/SiO_2/Si substrates(a) Ni films; (b)NiO films. Fig.1(III). Schematic view of the sample and the overall circuit arrangement used in the measurement of the electrical characteristics.

Results and Discussions

Fig. 1(II) shows the typical XRD (θ-2θ) patterns for Ni and NiO films fabricated on Pt (111)/Ti/SiO_2/Si substrates. From these XRD spectra, it was found that no Ni phase was detected in the NiO films, indicating that the film was completely oxidized.

Fig.1(I) displays the SEM images of Ni and NiO thin films. The top view of Ni films indicates that metal Ni films exhibits nonocrystalline consisting of 20-30 nm grains. After oxiding, there is a large variety on surface seeing between Fig.1(I)(a) and (b). This may be attributed to the oxygen entering into the Ni films. The cross-sectional SEM image of NiO/Pt/Ti/SiO_2 structure is shown in Fig.1(I)(c). The SEM image reveals that the NiO films have a microstructure of columnar grains normal to the substrate. The thickness of the formed films is about 420 nm.

Fig.2 shows typical *I-V* curves obtained during the resistance switching of NiO films. The switching from the high-resistance state (HRS) to the low- resistance state (LRS) is called the set process, and that from LRS to HRS is called the reset process. During the set process, the compliance current was limited to 5 mA in order to avoid permanent damage to the samples. Fig. 3 shows the variations in V_{set} and V_{reset} of the sample with the number of switching cycles, respectively. The average V_{set} and V_{reset} are 2.62 V and 0.95 V, respectively. It can be seen that the dispesion of V_{reset} is more uniform than V_{set}. For 15 repeated switching cycles, the on-/off-state resistances are shown in Fig.4. The ratios between the high-resistance state (off state) and the low-resistance state (on state) are larger than 10^2.

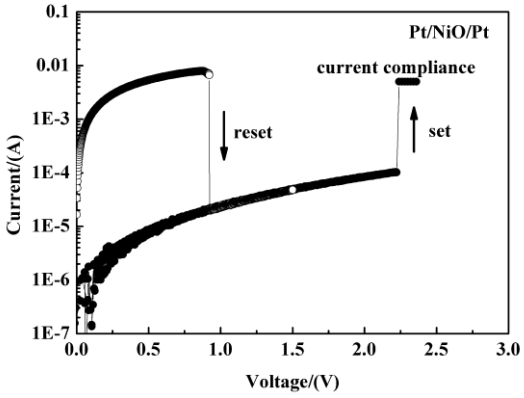


Fig.2. Typical unipolar switching characteristics of of Pt/NiO/Pt device, the current compliances are Pt/NiO/Pt structures with the number of 5 mA for set.

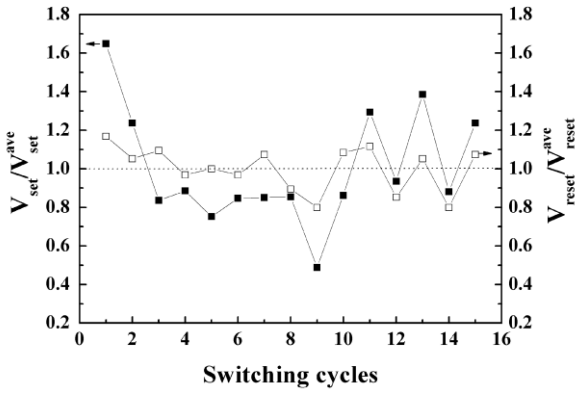


Fig.3. Variations in V_{set}/V_{set}^{ave}, $V_{reset}/V_{reset}^{ave}$ of Pt/NiO/Pt structures with the number of switching cycles.

The relationship between the compliance set current and the on-state current is shown in Fig.5. As shown in Fig.5(a), the reset voltage does't exhibit any dependence on the compliance set current, which confirms the filament mechenism that the reset process is correlated to current effects. As the compliance set current is increased from 5 mA to 40 mA, the on-state current(reset current) increases while the on-state resistances decreases, seen in Fig.5(b). This may be attributed to a higher current compliance resulted in the formation of stronger and less resistive filaments, which in turn need more energy and power for their rupture.

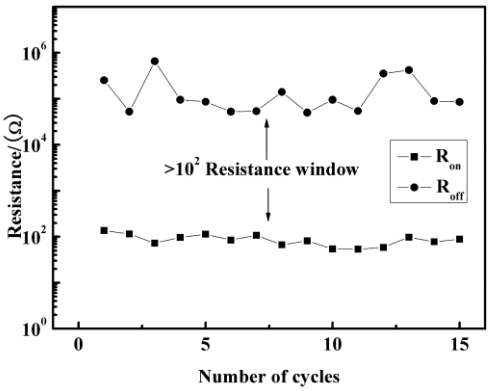
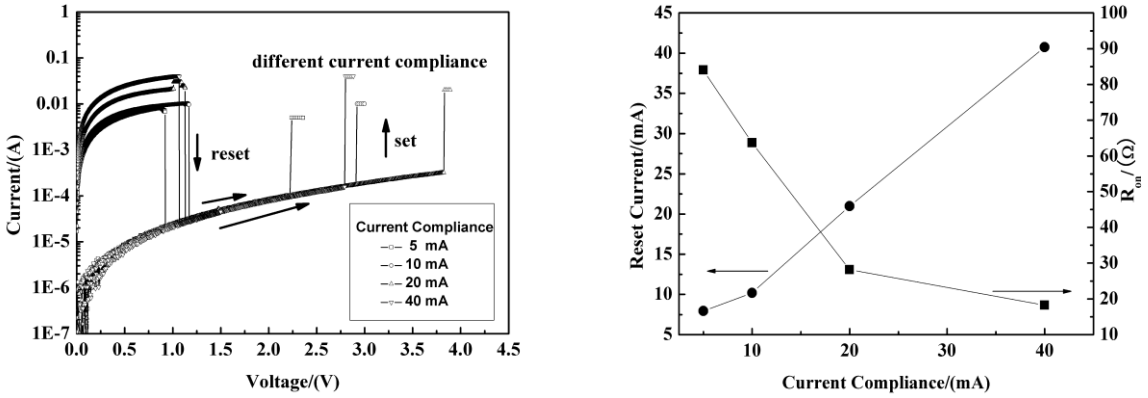


Fig.4. R_{on} and R_{off} dispersions for Pt/NiO/Pt according to switching cycles. R_{on} and R_{off} are measured at V=0.1 V.



(a) (b)

Fig.5(a). *I-V* curves obtained at compliance currents of 5, 10, 20 and 40 mA during electrical measurements.(b). dependence of maximum current and resistance in the on-state on the current compliance.

Conclusions

The polycrystalline NiO thin films were fabricated on Pt (111)/Ti/SiO2/Si substrates by thermal oxidation of evaporated Ni films, and its electrical properties were investigated for RRAM applications. The oxidation process is very cost-effective and is even compatible with mass-production-level processes. Thus, it is worth to pay more attention to the details of the thermal oxidation method. The nickel oxide films show typical reversible resistance switching properties. The ratios between the high-resistance state (off state) and the low-resistance state (on state) are larger than 102. As the compliance set current increases, the on-state current decreases due to the increase of the conducting path composed of defects.

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