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Reproducible resistance switching of defect-engineered NiO_x with metallic Nb impurity

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ABSTRACT

The effect of Nb doping on the resistance switching characteristics of NiO_x films was investigated. Pt/Nb-doped NiO_x/Pt metal–insulator–metal stacks were fabricated using NiO_x films with various Nb contents sputtered by reactive dc magnetron sputtering. The resistance switching behaviors of the metal–insulator–metal stacks were then examined in conjunction with a study on the physical properties such as the chemical bonding of NiO_x films.

Nb doping of NiO_x at a T_{dep} of 400 °C and an O_2 partial pressure of 5% resulted in an improved endurance of SET/RESET processes with a narrower distribution of V_{SET}, and a larger memory window compared to undoped NiO_x films. NiO_x with 5.47% Nb deposited at an O_2 partial pressure of 15% showed bistable resistance switching behavior while undoped NiO_x material, deposited under the same condition did not. A study of the chemical bonding states by X-ray photoelectron spectroscopy showed that the Nb-doping of NiO_x films produced an increase in the density of Ni^0 and a reduction in the density of Ni^{3+}, compared to corresponding values for undoped NiO_x films deposited under the same condition. The resistive switching behavior of NiO_x was enhanced by defect engineering with metal impurity with different oxidation valence.

1. Introduction

Resistive switching in NiO_x thin films has been investigated intensively for applications to resistive random access memory (ReRAM) devices [1,2]. ReRAM devices are promising candidates for next-generation nonvolatile memory due to their low operating voltage, fast switching speed (<10 *ns*), excellent scalability, and good reproducibility. Transition metal oxides, including NiO_x and TiO_x [3,4], show resistive switching behavior in which the resistance of the film is switched reversibly between a high resistance state (HRS) and a low resistance state (LRS) under an applied external voltage.

Resistive switching is classified into a unipolar resistive switching (URS) and a bipolar resistive switching (BRS). URS is independent of the polarity of the applied voltage, so that both the set process (HRS → LRS) and the reset process (LRS → HRS) occur regardless of the polarity of the applied voltage. The URS shows a high LRS/HRS ratio and good scalability down to 20 nm and below [5,6]. It has been reported that URS is caused by the formation of a conducting path during the SET process and the subsequent rupture of the path during the RESET process in oxide films under a bias [5].

On the other hand, BRS behavior depends on the polarity of the applied voltage, and has a faster reset switching time of several *ns* compared to URS [6].

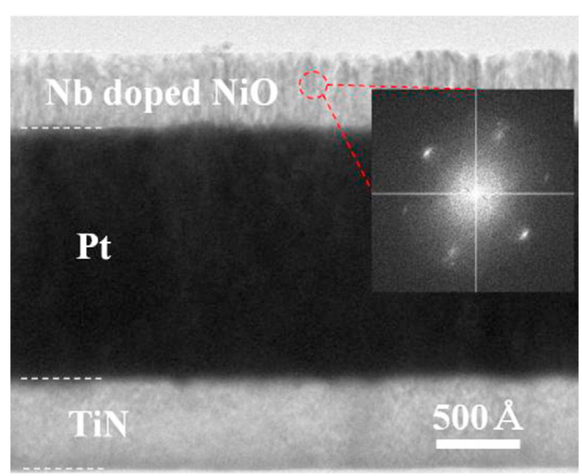

Fig. 1. Cross-sectional TEM image and Fourier transformed diffraction of a Nb-doped NiO_x film deposited on a $Pt/Ti/SiO_2/Si$ substrate.

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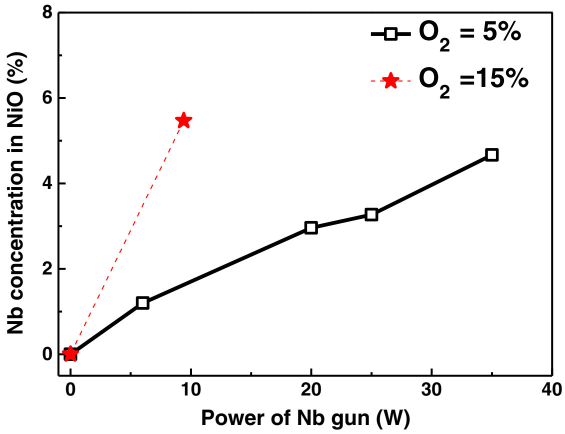

Fig. 2. Nb concentration in Nb-doped NiO_x films as a function of Nb gun power. Nb concentration was measured by AES.

Point defects in oxide films are known to play important roles in resistance switching [1,2]. Such defects may be formed in metal oxides by changing the compositional stoichiometry. Also, it is expected that metal impurities with a bonding valence different from that of the constituting elements of the metal oxide with high oxide formation energy would be more effective in generating compositional stoichiometry. Indeed, it was recently reported that the doping of Ti, Li, or Nb in NiO_x films resulted in improved resistive switching properties in NiO_x films [7–9]. However, the effect of metallic impurities on resistive switching behavior has not been investigated in detail in terms of practical applications of doped metal oxides for use in memory devices.

In this study, we report on a detailed investigation of the Nb doping effect on resistive switching properties of NiO_x films as a function of Nb concentration. The physical properties of NiO_x films, including their microstructures, composition and bonding states, were investigated in relation to changes in resistive switching behavior.

2. Experimental details

n-type silicon (100) wafers were used as starting substrates for fabrication of ReRAM devices. After removing native oxides with buffered oxide etchants, the 100 nm-thick SiO_2 films were grown on Si substrates by wet oxidation. Pt (150 nm)/Ti (15 nm) stacks were then deposited as bottom electrodes on the SiO_2 by dc magnetron sputtering at room temperature. Then, 50 nm thick NiO_x films with various levels of Nb doping were deposited on Pt with oxygen partial

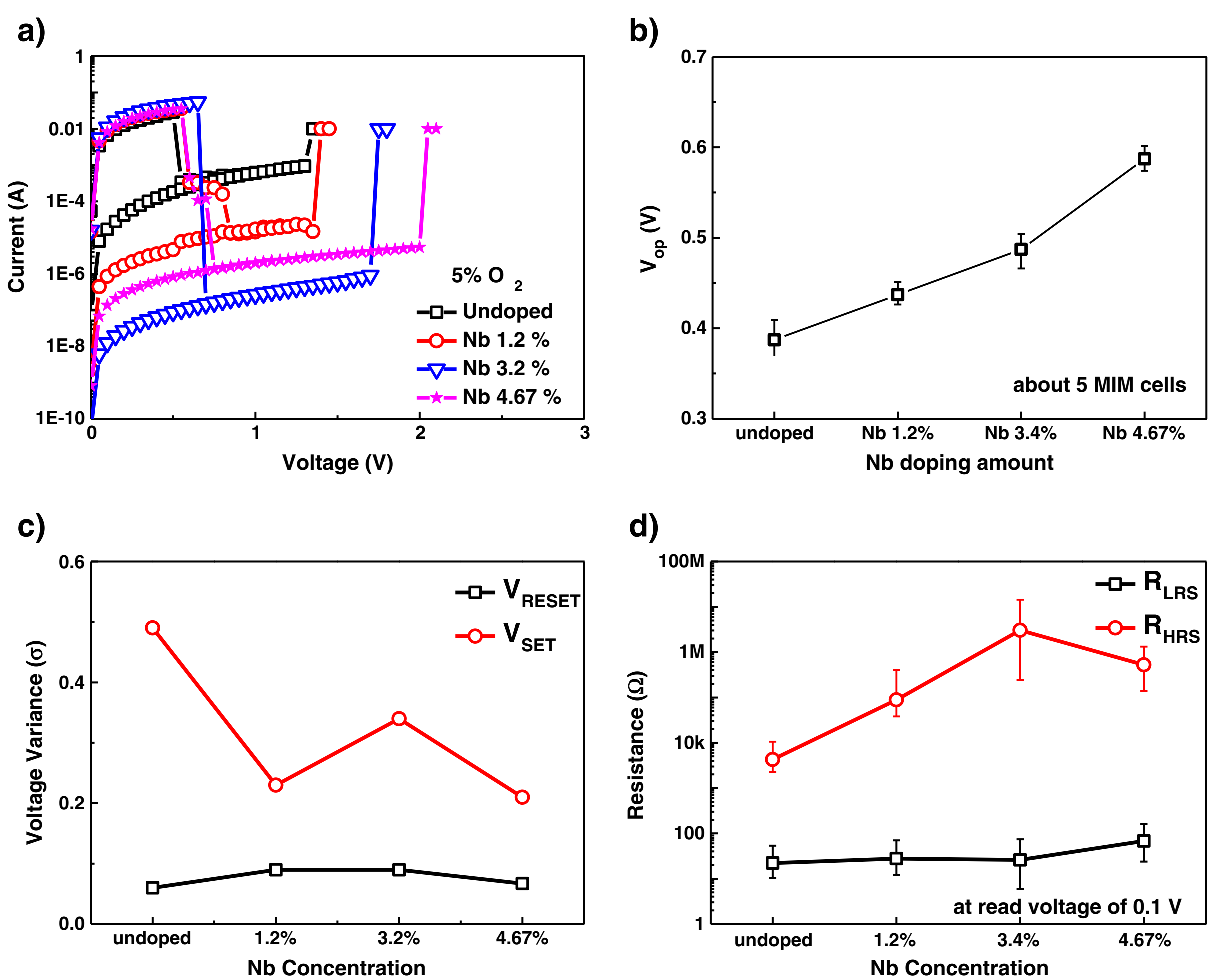

Fig. 3. (a) Resistance switching behavior of Pt/NiO_x (50 nm) with 0–4.67% Nb/Pt MIM stacks and (b) memory window, ΔV_{op} which is defined as ($V^{min}_{SET} - V^{max.}_{RESET}$) (c) variance of set and reset voltages (d) resistance distribution of HRS and LRS states during a dc sweep. NiO_x films were deposited with 5% O_2 partial pressure at 400 °C.