A-7-3

Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp578-579

Study on nano-scale threshold switching behavior of NbO_x film for ReRAM selector application

YunMo Koo, Yonghoon Choi, Euijun Cha, Daeseok Lee, Jiyong Woo, Jeonghwan Song, Kibong Moon, Jaesung Park, Sangheon Lee, and Hyunsang Hwang

Dept. of Materials Science and Engineering, Pohang University of Science and Technology,
77 Cheongam-ro, Nam-gu, Pohang, Gyeongbuk, Republic of Korea
Phone: +82-54-279-5123, Fax: +82-54-279-5122, e-mail: hwanghs@postech.ac.kr

1. Introduction

To realize cross-point memory array, sneak path problem must be solved [1,2]. To achieve this, selector devices are being widely investigated [3-6]. One of the most attractive candidate for selector devices is NbO_x threshold switching (TS) selector because of its several outstanding features such as high current density (over 10^7A/cm^2), fast switching speed, good switching uniformity, and excellent scalability [7]. But previously shown device had critical weakness of high I_{OFF} (~20uA) at half of threshold voltage (V_T) and not enough selectivity (~50). In this work, Conductive Atomic Force Microscopy (C-AFM) analysis [8] was adopted to understand local TS behavior of the device in nano scale and to improve device characteristics (Fig. 1). As a result, extremely low I_{OFF} (<10pA) and high selectivity (>10^3) was observed from the crystalline phase of NbO_x. In addition, increasing crystallinity and carefully controlling relatively leaky spots are suggested as the solution to dramatically improve selectivity of NbO_x for ReRAM selector application.

2. Experiments

NbO_x TS thin film was deposited on Pt flat wafer (Pt/TiN/SiO_2/Si substrate) by RF reactive sputtering at 500℃ under Ar/O_2 mixed ambient. Device characteristics were measured both by probe station and by C-AFM.

3. Results & Discussion

The schematic diagram of C-AFM measurement is drawn in Fig. 2. In order to measure I-V characteristics, bias was applied to the flat Pt layer under NbO_x layer, which acts as bottom electrode (BE), and current flowing through the NbO_x film was measured by current reader attached to the Pt coated C-AFM tip. Reliability of this measurement was confirmed by comparing I-V curves of a typical resistor measured by C-AFM and by connected path (Fig. 3). The difference was under 0.5%.

I-V characteristics of the NbO_x device were measured in the first place by probe station as typical approach (Fig. 4(a)). It showed similar TS behavior to previously known NbO_x devices [7] with maximum selectivity (~50) observed at 1mA current compliance (I_{CC}). (Selectivity was defined as the ratio of I@V_{read} to I@1/2V_{read}.) Then TS characteristics were also measured by C-AFM in order to understand the local TS behavior (Fig. 4(b)). The biggest difference between these two measurements was the size of evaluated area. Measurement area of tips used in this work was 10um and 30nm respectively for probe station and C-AFM. To match the maximum current into same density, I_{CC} was set to 10nA in C-AFM analysis. In other words, device size and maximum current level of Fig. 4(b) are both 10^5 times smaller than those of Fig. 4(a). Interestingly, notably smaller I_{OFF} (I@1/2V_T), and thus significantly higher selectivity (higher than 10^3) was measured in the C-AFM analysis (Fig. 4(b)) from some of the local spots (~30nm size), which is preferable TS characteristics as a selector device. Besides the TS behavior of several spots, other spots showed much higher currents at bias lower than V_T without TS behavior, which seems to be leakage current (I_{leak}) by tunneling from relatively leaky spots. These two distinctive trends of I-V characteristics suggest that there are at least two different kinds of phases in NbO_x.

Fig. 6 shows surface morphology of NbO_x film. 5nm of height difference existed between local maximum and local minimum (Fig. 6 and 7(c)), and thicker spots showed higher current level (Fig. 7) at V_{read}. If difference between local spots was only thickness, then thicker spots would have higher resistance (since they are oxide), thus they would show lower current level. But it is not the case as Fig. 7(c) and (d). This fact suggests that crystalline is locally formed among amorphous phase in NbO_x film, thus composition difference exists between spots. (We also confirmed the co-existence of poly-crystalline and amorphous phases in NbO_x by TEM analysis.) Thicker spots (white colored spots in Fig. 6) are grains with crystalline phase which show TS, and deep valleys between them are amorphous phase which do not show TS but act as tunneling oxide with leakage current (I_{leak}) (Fig. 8). (By comparing with Fig. 4(b), the current at thicker spots can be interpreted as I_{ON} (the current at voltage higher than V_T).)

The differences in I-V shapes (Fig. 4(a) and (b)) can be explained as Fig. 10. Even though local spots with crystalline phase shows low I_{OFF} and high selectivity, I_{leak} from amorphous phase are dominant at voltage lower than V_T. Thus the high I_{leak} from amorphous phase hinders the I-V curve of the crystalline phase spots. The sum of all spots becomes "Sum of local spots" in Fig. 10 of which shape is similar to I-V curve from probe station analysis with V_T shift. V_T shift can be explained by Joule heating induced TS characteristic [9] and the transferred heat induced TS acceleration effect. Contacted under probe tip, local spots act as parallel-circuit connected to each other. Under bias, every local spots experience same voltage, and thus relatively leaky spots (amorphous phase in this case) produce more Joule heating. This heat is then transferred to other spots through the probe tip. Hence, local spots with crystalline phase could easily reach enough Joule heating required to induce TS at relatively lower voltage (so-called the transferred heat induced TS acceleration effect).

According to this understanding, increasing crystallinity and growing well-formed crystalline phase will dramatically lower I_{OFF} and increase selectivity of NbO_x device for selector application. Also, V_T can be controlled by utilizing the transferred heat induced TS acceleration effect by carefully controlling the proportion of relatively leaky spots.

4. Summary

Experimental evidence to realize ideal selector device characteristics are shown by analyzing local I-V properties of NbO_x selector device using C-AFM. It is shown that NbO_x selection devices can be greatly improved by lowering I_{OFF} and increasing selectivity over 10^3. Also, increasing crystallinity of NbO_x by adjusting fabrication process and delicately controlling relatively leaky spots will be the solution to realize the desirable TS property in real device.

Acknowledgments This work was supported by POSTECH-Samsung Electronics ReRAM Cluster Research, and the Pioneer Research Center Program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (2012-0009460).

References [1] C. J. Amsinck et al., *Nanotech.* **16,** 2251-2260 (2005) [2] S. H. Chang et al., *Adv. Mater.* **23,** 4063-4067 (2011) [3] Y. Sasago et al., *VLSI Symp.*, T2B-1 (2009) [4] K. Gopalakrishnan et al., *VLSI Symp.*, T19-4 (2010) [5] E. Linn et al., *Nature Mater.* **9**, 403 (2010) [6] J. H. Shin et al., *J. Appl. Phys.* **109**, 033712 (2012) [7] S. H. Kim et al., *VLSI Symp.*, 155-156 (2012) [8] M. Lanza et al., *Appl. Phys. Lett.* **101**, 193502 (2012) [9] Z. Yang et al., *Annu. Rev. Mater. Res.* **41**, 337-367 (2011)

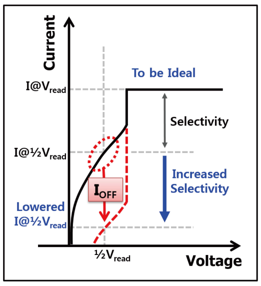

Fig. 1 Increasing selectivity by lowering I_{OFF} is necessary to realize cross-point memory array.

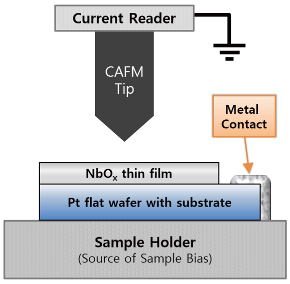

Fig. 2 Schematic diagram of C-AFM measurement.

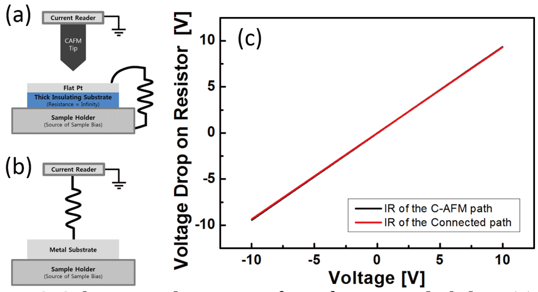

Fig. 3 Schematic diagrams of confirming reliability (a) by C-AFM path and (b) by connected path. (c) I-V curves of a typical resistor from (a) and (b).

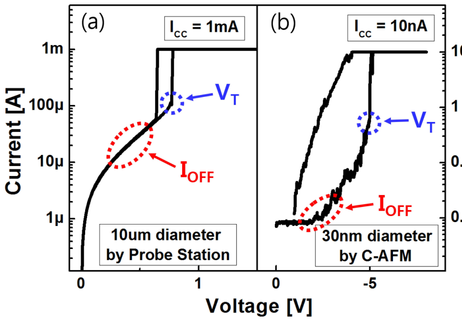

Fig. 4 TS characteristic of NbO_x selector device measured (a) by probe station and (b) by C-AFM.

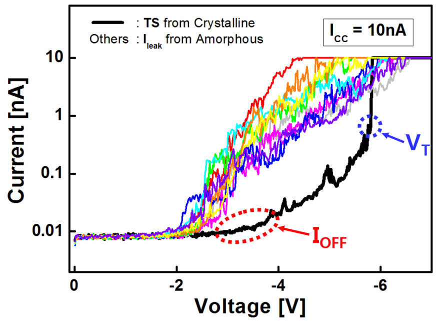

Fig. 5 Various I-V curves from local spots (~30nm size) with two trends. One is TS behavior with low I_{OFF} from crystalline phase and the other is tunneling current with high I_{leak} from amorphous phase.

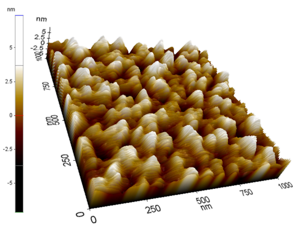

Fig. 6 Surface morphology of NbO_x selector device.

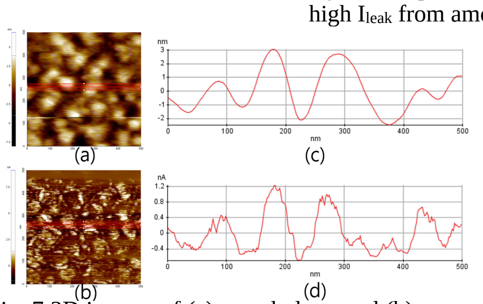

Fig. 7 2D images of (a) morphology and (b) current map at V_{read} and their line profiles (c) and (d) respectively, on the red lines. There exists strong correlation between morphology and current map.

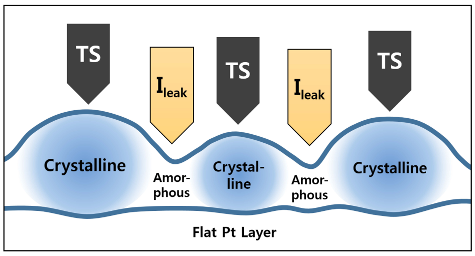

Fig. 8 Schematic diagram showing the crystalline and amorphous phases and their characteristics.

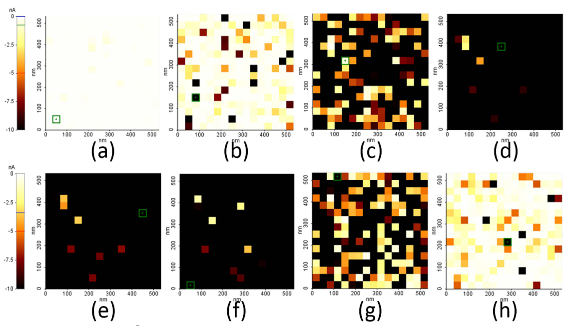

Fig. 9 Response of local spots under gradually changing bias. Each rectangular area represents a local spot. (a) 3V, (b) 5V, (c) 7V, (d) 8V while increasing bias, and (e) 8V, (f) 7V, (g) 5V, (h) 3V while decreasing bias. Several spots showed TS under 3V while some other spots showed leakage current at same bias.

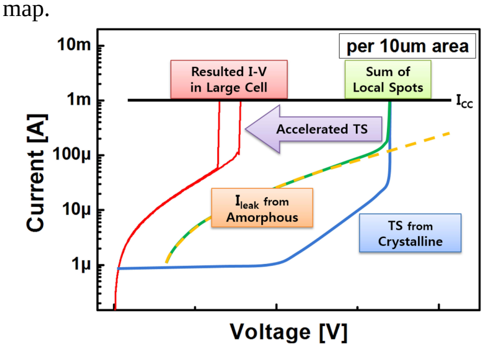

Fig. 10 Explanation for the difference in I-V curves 4(a) and (b). With the transferred heat induced TS acceleration effect, sum of all currents from local spots will be same as I-V from larger cell. Scales are normalized.