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High-performance Ni/Yb_2O_3/TaN Programmable Memory Cell for Nonvolatile Memory Applications

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***Abstract*—Resistive switching in Ni/Yb_2O_3/TaN programmable memory cells was investigated. We proposed a rearrangement of oxygen vacancies under electric field plays role in resistive switching. Under negative bias, oxygen vacancies or other metallic defects migrate through Yb_2O_3 oxide and SET occurs. A reproducible resistance switching behavior was observed with high resistance ratio of about 10^5 with excellent data retention, and good immunity to read disturbance, are also revealed. In particular, the simple sandwich structure and excellent electrical performance of the memory cell making them ideal for the basis for high-speed, high-density, nonvolatile memory applications.**

Keywords- ***Memory, Resistive switching, SCLC, Yb_2O_3***

I. INTRODUCTION

Nonvolatile memory plays a key role in the semiconductor industry due to their well-liked applications in portable equipment. Recently, next-generation NVMs, such as phase change, magnetic, and ferroelectric random access memory, have attracted extensive research interest as a result of the conventional NVMs approaching their scaling limit. Resistive-switching memory (ReRAM) is an promising alternate, based on the electrical field induced change in conductivity in some metal oxides, for future nonvolatile memory applications considering its high scalability, integration density, switching speed, simple design, and compatibility with complementary metal–oxide– semiconductor process [1]-[6]. Resistance switching behavior has been demonstrated for several binary oxides, e.g. CuO_x [2], ZrO_2 [1], [3], Cu/WO_x [7], and Nb_2O_5 [4]. ReRAM active oxide usually sandwiched between two metal electrodes, where the application of electrical voltage/currents results in a change of conductance between two different states, namely a high-conductance ON state (LRS) and a high-resistance OFF state (HRS). Although resistance-switching effects in several metal oxides or other materials have been known from decades, the lack of information of detail switching mechanisms and two resistive states hinders the device for implication. Different switching model such as domain and tunneling model [8], filament model [9]-[10], field induced crystallinity and charge trapping model [11]-[13] have been studied extensively. However, exact switching phenomena are not clearly understood yet.

Therefore, this study investigated the switching behavior in sputtered deposited Yb_2O_3–based ReRAM cell and attributed the switching mechanism to the rearrangement of oxygen ions/vacancies by external electric field to the oxide layer. Furthermore, the bipolar switching characteristics in Ni/Yb_2O_3/TaN ReRAM cells are analyzed based on the proposed switching mechanism. The Yb_2O_3-based ReRAM device exhibited stable resistive switching up to 100 cycles and excellent data retention for 10-year life span.

II. EXPERIMENTS

A thin film of 25-nm thick oxide of Yb_2O_3 was deposited on TaN/SiO_2/Si substrate at room temperature by rf-magnetron sputtering. The as deposited film was in amorphous phase with a dielectric constant of approximately 13 and good insulating properties. After Yb_2O_3 film deposition, 100 nm Ni top electrodes with a diameter of approximately 200 μm were fabricated by thermal evaporation through a metal shadow mask. During the electrical measurements of resistive switching, the TaN bottom electrode was grounded and the bias voltage was applied to the top electrode. Resistive switching was tested using Agilent E5260A high speed measurement mainframe with a cascade semiautomatic probe station.

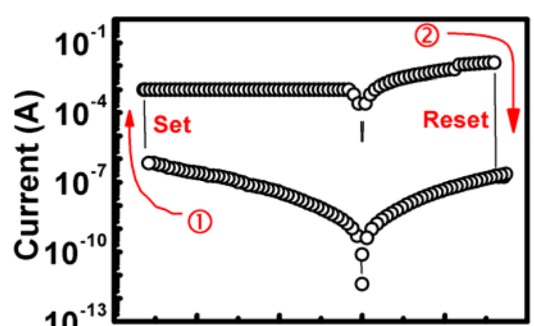

Fig. 1. Typical Bipolar resistive switching characteristics of Ni/Yb_2O_3/TaN ReRAM device cell. The arrow indicates the bias sweeping direction.

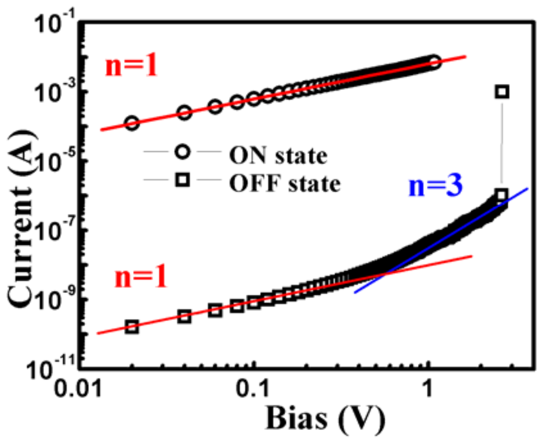

Fig. 2. Double logarithmic plots of |I|-|V| curves of Ni/Yb_2O_3/TaN ReRAM device. The LRS indicates Ohmic conduction making the slope (n) value close to one and the varying slope of HRS confirms SCLC conduction above 0.2V.

III. Results and Discussion

A typical bipolar resistive switching characteristic of the fabricated Ni/Yb_2O_3/TaN ReRAM cell is shown in Fig. 1. After the standard forming process, stable switching characteristics were observed for all the samples. By sweeping the voltage at top electrode to negative values with respect to the bottom electrode, the leakage current suddenly increases by four order of magnitude at 2.5V and switches the oxide to a low resistance state (LRS). Subsequently sweeping the voltage back to positive values leads to a abrupt decrease of the leakage current and thereby restores the resistance of the oxide to its initial high resistance state (HRS). A repetitive switching behavior was observed in Ni/Yb_2O_3/TaN ReRAM cell. A little dispersion in set and reset voltage was observed during the cycling test of the devices.

To clarify this intrinsic memory effect in the Yb_2O_3 oxide, the current conduction mechanism in both HRS and LRS were investigated. In order to understand the conduction mechanism, the I-V curves are plotted on logarithmic scale, as shown in Fig. 2. Interestingly, the I –V characteristic in both LRS and HRS follows a linear ohmic behavior at low voltage with the addition of nonlinearity at higher voltage, $I(V) = aV + bV^n$. This nonlinearity is typical for an insulator with shallow trap and space charge limited current conduction (SCLC). It can be clearly observed that the I-V characteristics in HRS show linear behavior up to approximately 0.2V, suggesting that thermionic emission limited conduction (TELC) is the dominant mechanism where carrier injection from electrodes plays a minor role. Beyond that, the increase in slope ($I \propto V^n$, where n = 2 □ 3), can be understood as a transition from Ohmic TELC to space charge limited current (SCLC). In the LRS, I-V curve ($I \propto V$) represents that the Ohmic conduction is dominant in all bias range.

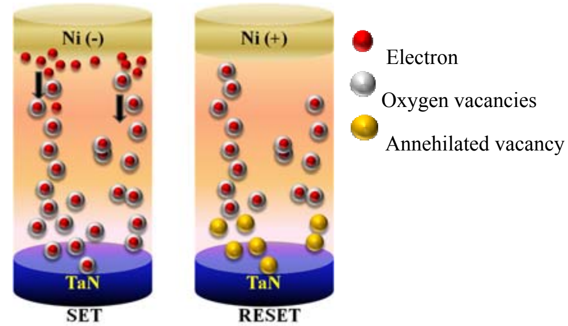

Fig. 3. Schematic diagram of the driving mechanism of bipolar resistive switching operation.

Based on the above experimental result, we propose the switching mechanism in Ni/Yb_2O_3/TaN devices as the redistribution of charge carriers, most possibly ions/vacancies. When the dc sweeping voltage was applied to the top electrodes, the oxygen ions/vacancies in the Yb_2O_3 thin film were influenced by the high electric field (a few hundreds kV/cm) and began to move towards the electrodes with the opposite polarities. There is few evidence for the oxygen ion movement under a high electric field even at room temperature. It is believed that the low work function metals have more stable oxide [14] and act as a sink of oxygen. Hence, with Kröger-Vink notation it can be well represented by

$$O_O^{\times}(TaN) + V_O^{\bullet\bullet}(Ox) \leftrightarrow V_O^{\bullet\bullet}(TaN) + O_O^{\times}(Ox) \quad (1)$$

where oxygen ions are assumed to have a charge of -2. The TaN bottom electrode oxidizes easily and a space charge region of oxygen vacancies accumulates near the Yb_2O_3/TaN interface. Now, it has to be remembered that resistance switching was only possible under positive bias. Under this condition, O_2 vacancies in the Yb_2O_3 thin film were pulled into the Ni electrode during negative sweeping bias. This migration of oxygen vacancies under electric field results the formation/annihilation of a conducting path by Eq. (1), which is attributed as set/rest process, as shown in Fig. 3.

Shown in Fig. 4 is the dependence of the resistance on the repetitive switching cycles of a Ni/Yb_2O_3/TaN ReRAM cell. The device was set and reset by negative and positive voltage respectively. The resistance values were measured at 0.2 V. It can be seen from that experimental data that the low resistance state (LRS) is distributed in a narrow range, while the high resistance state values were distributed in a wide range of about 2-100 MΩ. However, the resistance ratios of HRS to LRS were in the range of 4-5 orders of magnitude within the 100 dc cycles of test guarantees the possible application in the device. The uniformity of resistance values is a very important parameter for practical application. The statistics of two resistance state are

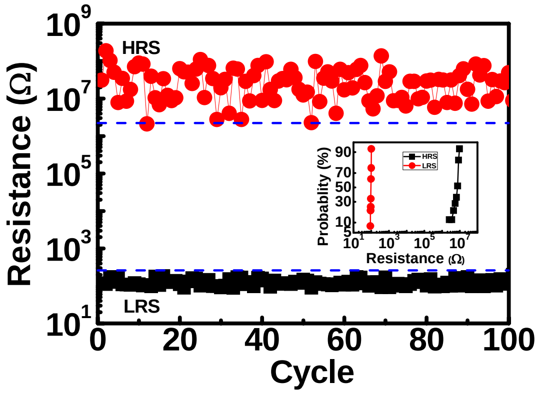

Fig. 4. Evolution of resistance of the two well-resolved states in 100 cycles for a Ni/Yb_2O_3/TaN ReRAM device. Inset shows the probability distribution of the resistance for different devices.

depicted in inset of Fig. 4.

A relevant property of the memory cell is its ability to

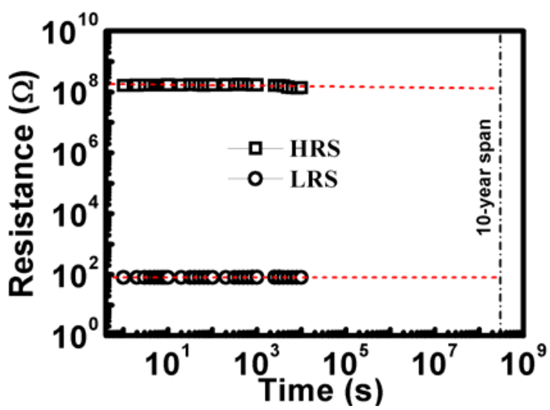

Fig. 5. Data retention behavior of the fabricated Ni/Yb_2O_3/TaN ReRAM devices in HRS and LRS under room temperature.

retain its information for longer times. To confirm the potentiality for its application, long time data retention properties were also examined, as shown in Fig. 5. It can be seen from Fig. 5, that high resistance state of the memory devices exhibit a little degradation of resistance value within 10^4 s while LRS exhibits a constant value of the resistance. It is also demonstrated the extrapolated 10-year retention with nondestructive read-out under room temperatures. The superior data retention characteristics of the Ni/Yb_2O_3/TaN ReRAM cell reveal the potentiality for nonvolatile memory applications.

IV. CONCLUSION

In summary, the high performance resistive switching characteristics of Ni/Yb_2O_3/TaN were investigated for nonvolatile memory applications. The conductivity modulation by oxygen ions/vacancies plays role in stable bipolar resistive switching behavior. Furthermore, the ReRAM devices exhibited good endurance and retention performance for future practical memory application.

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REFERENCES

[1] C. Y. Lin, C. Y. Wu, C. Y. Wu, T. C. Lee, F. L. Yang, C. Hu, and T. Y. Tseng, "Effect of top electrode material on resistive switching properties of ZrO_2 film memory devices," IEEE Electron Device Lett., vol. 28, no. 5, pp. 366–368, May 2007.

[2] H. B. Lv, M. Yin, X. F. Fu, Y. L. Song, L. Tang, P. Zhou, C. H. Zhao, T. A. Tang, B. A. Chen, and Y. Y. Lin, "Resistive memory switching of Cu_xO films for a nonvolatile memory application," IEEE Electron Device Lett., vol. 29, no. 4, pp. 309–311, Apr. 2008.

[3] Y. Li, S. Long, M. Zhang, Q. Liu, L. Shao, S. Zhang, Y. Wang, Q. Zuo, S. Liu, and M. Liu, "Resistive switching properties of Au/ZrO_2/Ag structure for low-voltage nonvolatile memory applications," IEEE Electron Device Lett., vol. 30, no. 2, pp. 117–119, Feb. 2010.

[4] H. Sim, D. Choi, D. Lee, S. Seo, M. J. Lee, I. K. Yoo, and H. Hwang, "Resistance-switching characteristics of polycrystalline Nb_2O_5 for nonvolatile memory application," IEEE Electron Device Lett., vol. 26, no. 5, pp. 292–294, May. 2005.

[5] S. Yu, and H.-S. P. Wong, "A phenomenological model for the reset mechanism of metal oxide RRAM," IEEE Electron Device Lett., vol. 31, no. 12, pp. 1455–1457, Dec. 2010.

[6] W. W. Zhuang, W. Pan, B. D. Ulrich, J. J. Lee, L. Stecker, A. Burmaster, D. R. Evans, S. T. Hsu, M. Tajiri, A. Shimaoka, K. Inoue, T. Naka, N. Awaya, K. Sakiyama, Y. Wang, S. Q. Liu, N. J. Wu, and A. Ignatiev, "Novell colossal magnetroresistive thin film nonvolatile resistance random access memory (RRAM)," in IEDM Tech. Dig., 2002, pp. 193–196.

[7] M. N. Kozicki, C. Gopalan, M. Balakrishnan, and M. Mitkova, "A lowpower nonvolatile switching element based on copper–tungsten oxide solid electrolyte," IEEE Trans. Nanotechnol., vol. 5, no. 5, pp. 535–544, Sep. 2006.

[8] M. J. Rozenberg, I. H. Inoue, and M. J. Sánchez, Phys. Rev. Lett. 92, 178302 (2004).

[9] J. F. Gibbons, and W. E. Beadle, Solid-State Electron. 7, 785 (1964).

[10] K. Tsunoda, Y. Fukuzumi, J. R. Jameson, Z. Wang, P. B. Griffin, and Y. Nishi, Appl. Phys. Lett. 90, 113501 (2007).

[11] N. A. Tulina, S.A. Zver'kov, Y.M. Mukovskii and D.A. Shulyatev, Europhys. Lett. 56, 836 (2001).

[12] J. G. Simmons, R. R. Verderber, Proc. R. Soc. London, Ser. A 301, 77 (1967).

[13] S. Q. Liu, N. J. Wu, and A. Ignatiev, Appl. Phys. Lett. 76, 2749 (2000).

[14] J. Robertson, O. Sharia, and A. A. Demkov, Appl. Phys. Lett. 91, 132912 (2007).