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Low-Power High-Performance Flexible Sm_2O_3 ReRAM for SoC applications

Somnath Mondal, Ching-Hao Chueh, and Tung-Ming Pan*

Department of Electronic Engineering, Chang Gung University, 259 Wen-Hwa 1st rd. Gueishan, Taoyuan, Taiwan 33302
Tel: 886-3-211-8800 ext. 3349, Fax:886-3-211-8507, Email:tmpan@mail.cgu.edu.tw

Abstract

Low-power, very high-performance and flexible resistive memory device are demonstrated. The device exhibits good operational memory window of more than 10^3 on/off ratio with very low switching power of < 25 μW. Excellent memory reliability of switching endurance, mechanical endurance and data retention are achieved in highly flexible $Ni/Sm_2O_3/ITO$ device.

1. Introduction

Flexible electronic devices are attractive because of their inherit merits of low cost, light weight, and excellent portability. The realizations of such flexible electronics are challenging as a result of the lack of good performance non-volatile memory (NVM) devices due to its low temperature fabrication process [1]. Alternatively, the resistive random access memory (ReRAM) shows favorable NVM performance on flexible medium when processed at low temperature [2]. However, the increased programming power, large dispersion in switching parameters and poor reliability are the basic issues which hinder its application for high-density and low-power operation in flexible electronics. In this paper, a low-power, very high-performance, and physically flexible ReRAM device are demonstrated for flexible system-on-chip (SoC) NVM applications.

2. Device Fabrication

The photograph of the fabricated flexible memory device and the schematic structure of the $Ni/Sm_2O_3/ITO$ ReRAM are shown in Fig. 1. A 20-nm-thick rf-sputtered amorphous Sm_2O_3 thin film was deposited on ITO/PET substrate at room temperature followed by 50 nm of Ni as the top electrode and patterned by shadow mask.

3. Results and Discussion

The typical resistive switching characteristics of flexible $Ni/Sm_2O_3/ITO$ device are shown in Fig. 2. A low set current compliance of 100 μA was applied during programming at negative bias. Very low $V_{set/reset}$ of -0.25/0.2 V and even lower reset current than the set compliance are observed with large memory window of 10^3 on/off ratio. The lower set/reset powers of 25μW/19μW were achieved. Very sharp dispersion in $V_{set/reset}$ (Fig. 3) and resistance state (Fig. 4) are observed for more than 1000 switching cycles. Fig. 5 shows scalability efficiency of the Sm_2O_3 ReRAM device to be used in 10X technology node. To understand such low power switching, the current conduction behavior in ReRAM is analyzed. Fig. 6 shows the fitted I-V data at both switching states. The OFF state current conduction is dominated by Schottky emission via high work function of Ni electrode and ON state current is best fitted with defect-conductive Ohmic conduction model. The Ohmic-like conduction in ON state is attributed to traps in the Sm_2O_3 thin films. From the XPS study in Fig. 7, the oxygen vacancies/ions (defects) are observed in the Sm_2O_3 film. Therefore, very low power switching operation is believed due to electron hopping via these defects [3]. Moreover, the sharp distribution of $V_{set/reset}$ and ON/OFF resistance can be well explained by higher surface roughness (Fig. 8a) of the oxide film and field localization effect. Fig. 8b shows schematic of switching mechanism in Sm_2O_3 ReRAM cell.

The reliability in switching endurance and data retention were tested at both room temperature (RT) and at 85 °C. Fig. 9 shows excellent endurance characteristics under impulse switching voltage. At 85 °C, small fluctuation in resistance state is observed but, the device still maintains a functional large memory window. Fig. 10 shows good retention characteristics at RT, but a monotonous decrease in OFF state resistance is observed at 85 °C for short period of time and a stable memory state is achieved after. This may be attributed to stress induced leakage conduction via generated defects in the oxide thin films. However, the low power flexible device operates at much lower temperature than the typical 85 °C retention temperature. The mechanical endurance is also an indispensable factor for flexible applications and was investigated up to several hundred cycles of bending test for various bending curvature (Fig. 11). The memory switching state is scarcely affected by severe bending radius down to 5 mm and even a slight increase in sensing window is observed. The excellent mechanical endurance may be due to high ductility of the amorphous oxide films. Table I shows a better comparable switching characteristics compared with other works [4-6].

3. Conclusions

In summary, a novel high-performance $Ni/Sm_2O_3/ITO$ ReRAM device has the potential to be used in low power flexible electronics due to its low switching energy of 0.5 pJ, large memory window of 10^3 order, excellent endurance of 10^4 cycle, good retention of 10^5 s and high ductility.

References

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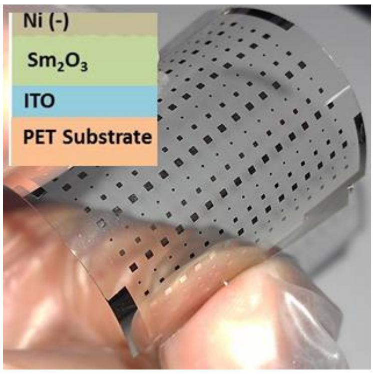

Fig. 1 Photograph of flexible Ni/Sm_2O_3 /ITO ReRAM device. Inset shows the schematic structure of the device.

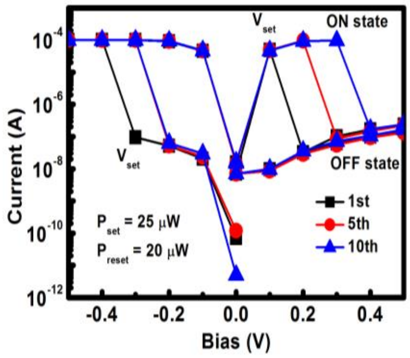

Fig. 2 The resistive memory switching behavior of the Ni/Sm_2O_3/ITO ReRAM device for 10 dc sweeping cycle.

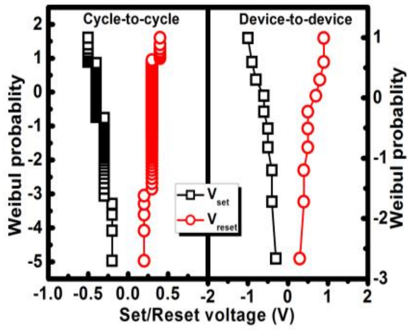

Fig. 3 Set/reset voltage distribution of flexible ReRAM cell. 100 switching cycle is measured for each 10 different devices.

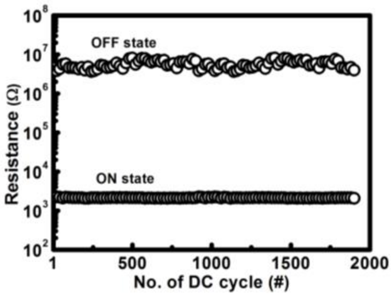

Fig. 4 Variation of resistance switching values with continuous bias sweeping cycle of flexible Ni/Sm_2O_3 /ITO ReRAM device.

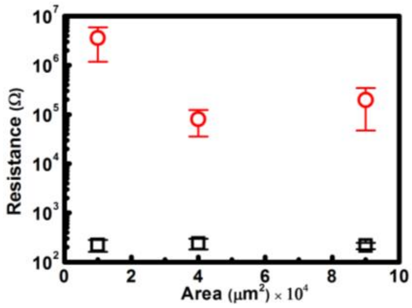

Fig. 5 Memory switching characteristics of ReRAM cell for different cell sizes. Randomly selected 10 different devices were measured for each cell size.

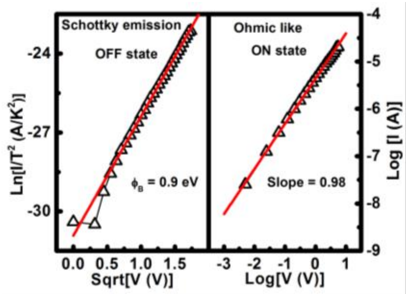

Fig. 6 Fitted I-V characteristics with Schottky emission model and Ohmic conduction model at room temperature.

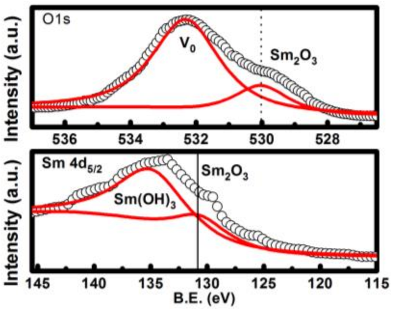

Fig. 7 De-convoluted XPS Sm $4d_{5/2}$ and O 1s spectra sputter deposited Sm_2O_3 thin film on ITO/PET substrate.

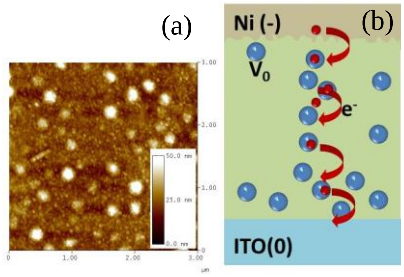

Fig. 8 (a) AFM image of the Sm_2O_3 surface deposited on ITO/PET substrate. (b) Schematic resistive switching model of the Ni/Sm_2O_3/ITO ReRAM device.

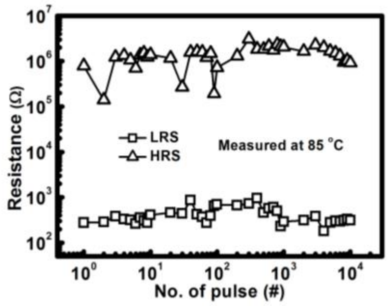

Fig. 9 ReRAM endurance characteristics under impulse switching voltage of ±1V, 500 μs. 20 ns switching speed can be achieved at ±5V.

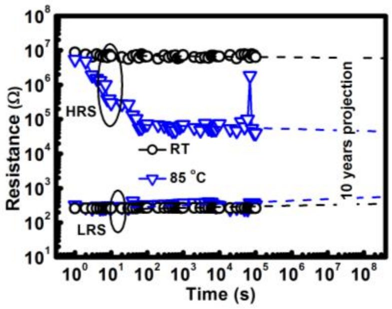

Fig. 10 Device reliability of retention characteristic of Ni/Sm_2O_3 /ITO ReRAM device at RT and 85 °C.

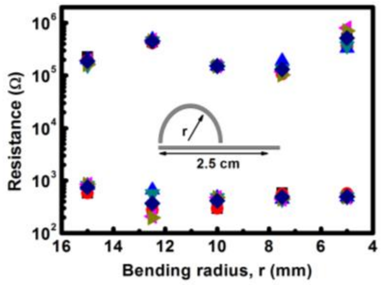

Fig. 11 Mechanical endurance characteristics of the Ni/Sm_2O_3/ITO ReRAM cell for different bending curvature for flexible NVM application.

Table I Comparison of resistive switching parameters of Ni/Sm_2O_3/ITO ReRAM device compared with other flexible memory devices.

ReRAM matrix	ON/OFF window	End.(#)	Power (W)	
			Set	Reset
GO[4]	10^3	100	20m	15m
α-IGZO[5]	10^2	150	1.5m	5m
TiO_2[6]	10^4	--	15m	10m
GeO_x/TiO_y[3]	30	10^5	27μ	3μ
Sm_2O_3[*]	10^3	10^4	25μ	20μ

GO: Graphene oxide, IGZO: InGaZnO, *: This work.