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Superior Multilevel Resistive Switching Behaviors of N_2-Plasma-Treated Stacked SiN_x/GdO_x RRAMs

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Abstract

The multilevel resistive switching (RS) characteristics of N_2-plasma-treated SiN_x and stacked SiN_x/GdO_x resistance random access memories (RRAMs) have been investigated. The SiN_x RRAMs with N_2 plasma treatment present low operating voltages and high resistance ratio and the samples with stacked SiN_x/GdO_x RS layers show superior multilevel RS behaviors, promising for future high-density nonvolatile memory (NVM) applications.

1. Introduction

Due to severe scaling issues of conventional floating gate flash memories, RRAM with superiorities is considered as one of the promising candidates for next generation NVMs [1]. Among the RS layers, nitride-based materials have attracted lots of attention because of the wide applications, stable thermodynamics, long retention time, and nonlinearity in low resistance state (LRS) [2]. It is reported that the conduction mechanism of nitride-based RRAMs is the formation and rupture of conductive filaments (CFs) caused by the migration of nitrogen ions [3]. To enhance the RS of RRAMs, some plasma has been treated on the RS layer to increase the generation of CFs [4-5]. Further, multilevel cell (MLC) operation can be achieved by using the stacked RS layers [6]. In this work, the stacked SiN_x/GdO_x RRAMs with N_2 plasma treatment have been investigated to realize the superior multilevel RS behaviors. The low operating voltages, high resistance ratio and superior multilevel RS behaviors are accomplished by the N_2 plasma treatment and stacked SiN_x/GdO_x RS layers, respectively.

2. Experimental

Fig. 1 illustrates the process flows of stacked SiN_x/GdO_x RRAMs with N_2 plasma treatment. First, a 30-nm-thick Ti film was deposited as bottom electrode (BE) by a thermal evaporator. Then, a 12-nm thick SiN_x film was formed by sputtering. After that, some samples were treated by N_2 plasma for 10 minutes using an inductively coupled plasma (ICP) system and some were subjected to sputtering to deposit a 12-nm-thick GdO_x film to form the stacked RS layers. Finally, a 50-nm-thick Ir film was deposited by sputter as top electrode (TE). Meanwhile, an area of 200 μm in diameter was defined by the shadow mask technology. The electrical properties were measured by Keithley 4200 SCS and the voltage was applied on the Ir TE and the n^+-Si BE was connected to the ground.

3. Results and Discussion

Fig. 2 shows typical bipolar *I-V* curves of SiN_x RRAMs with and w/o N_2 plasma treatment. To operate these devices, a forming process is needed (not shown). Fig. 3 presents the statistical distributions of set and reset voltages, resistance at high resistance state (HRS) and LRS and resistance ratio of these samples. The PN_2 sample displays low operation voltages and high resistance ratio owing to the increase of the concentration of nitrogen vacancies (Fig. 4). Fig. 5 reveals the endurance testing of these samples, exhibiting a cycling operation of more than 100 times. On the other hand, the PN_2 sample demonstrates a retention time of more than 10^4 sec, which is larger than that of the SL sample (Fig. 6). Fig. 7 displays the *I-V* curves of the DL sample. In this figure, there are two additional middle resistance states which can be observed. The statistical distributions of the resistance at each resistance state are shown in Fig. 8. The resistance ratio between each resistance state is larger than 2, suitable for MLC operation. Fig. 9 presents the RS mechanism of the DL sample. Due to the difference of dielectric constant and Gibbs free energy between SiN_x and GdO_x layers, the drift velocity of the nitrogen vacancies is different from that of the oxygen ones, leading to the multilevel RS behaviors. The DL sample can be cyclingly operated with distinguishable four resistance state (Fig. 10) and the resistance at each resistance state can sustain for more than 10^4 sec (Fig. 11).

4. Conclusions

In this study, the effects of N_2 plasma treatment on SiN_x and stacked SiN_x/GdO_x RRAMs have been investigated. With the N_2 plasma treatment, the SiN_x RRAM showed low operation voltages and high resistance ratio. For the sample with stacked SiN_x/GdO_x RS layers, superior multilevel RS behaviors were achieved. The stacked SiN_x/GdO_x RRAMs treated by N_2 plasma can be applied in future high-density and low-voltage NVMs for artificial intelligence (AI).

Acknowledgements

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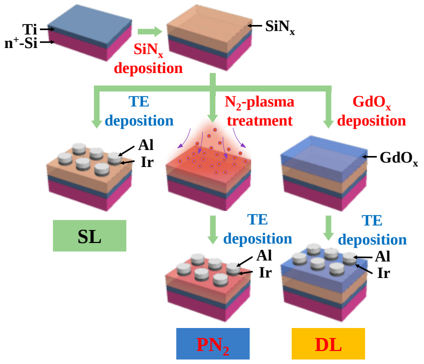

Fig. 1 Process flows of N_2-plasma-treated stacked SiN_x/GdO_x RRAMs.

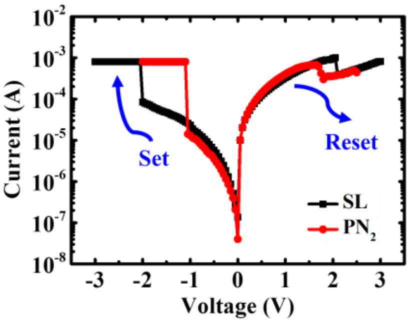

Fig. 2 Typical *I-V* characteristics of SiN_x RRAMs with and w/o N_2 plasma treatment. The samples show the bipolar RS behaviors.

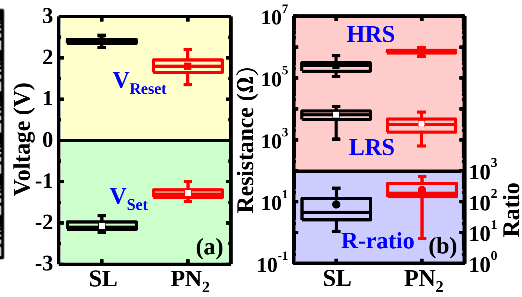

Fig. 3 Statistical distributions of SiN_x RRAMs with and w/o N_2 plasma treatment for (a) set and reset voltages and (b) resistance at HRS and LRS and resistance ratio.

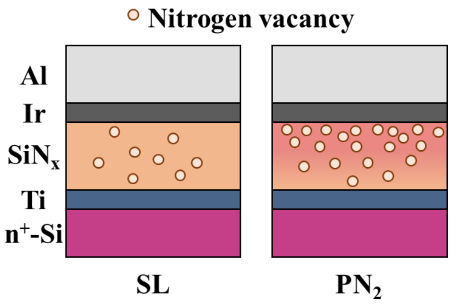

Fig. 4 Schematics of the formation of nitrogen vacancies for the SiN_x RRAMs with and w/o N_2 plasma treatment.

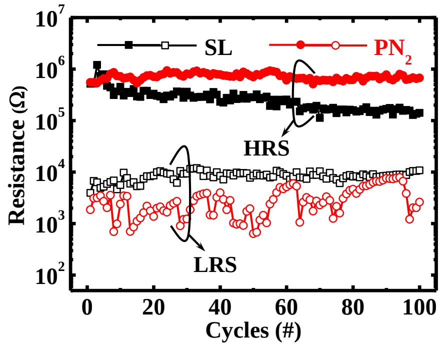

Fig. 5 Endurance testing of SiN_x RRAMs with and w/o N_2 plasma treatment.

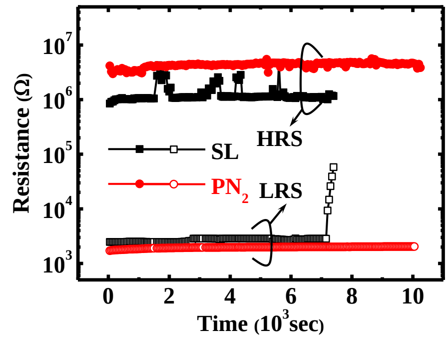

Fig. 6 Retention behaviors of SiN_x RRAMs with and w/o N_2 plasma treatment at HRS and LRS. All samples were measured in room temperature.

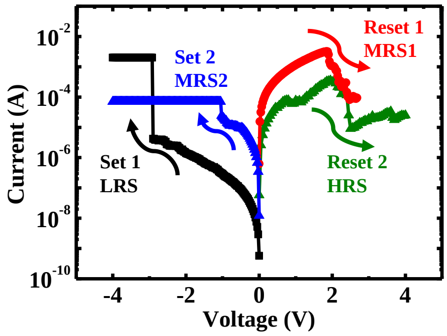

Fig. 7 Typical *I-V* characteristics of stacked SiN_x/GdO_x RRAMs with multi-level RS behavior. This sample shows the bipolar RS behavior.

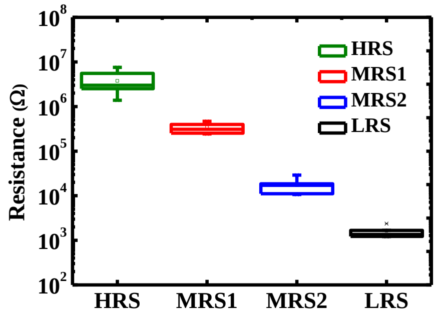

Fig. 8 Statistical distributions of stacked SiN_x/GdO_x RRAMs for the resistances in each resistance state.

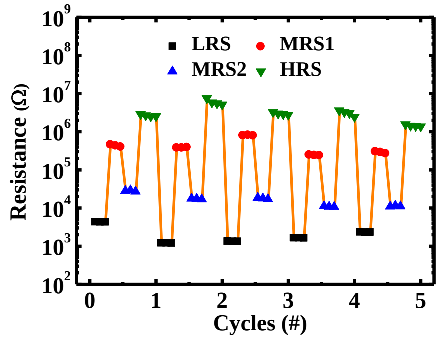

Fig. 10 Endurance testing of stacked SiN_x/GdO_x RRAMs with multilevel RS behavior for 5 cycles.

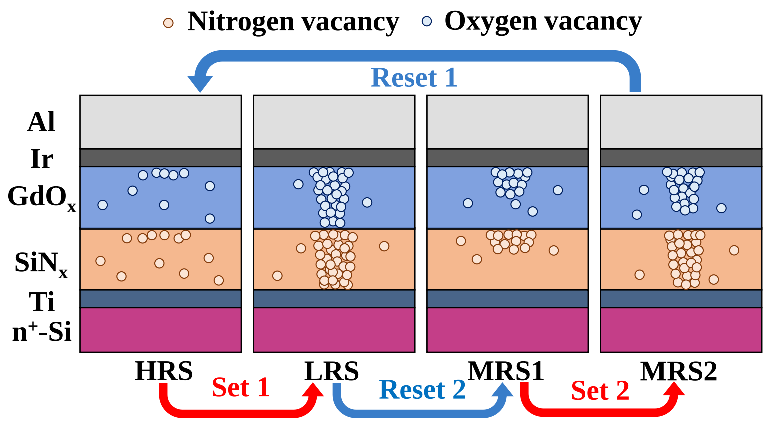

Fig. 9 Schematic diagrams of stacked SiN_x/GdO_x RRAMs (a) before forming and at (b) LRS, (c) MRS1, and (d) MRS2 respectively. Locally discontinuous filament within stacked SiN_x/GdO_x RS layers was suggested.

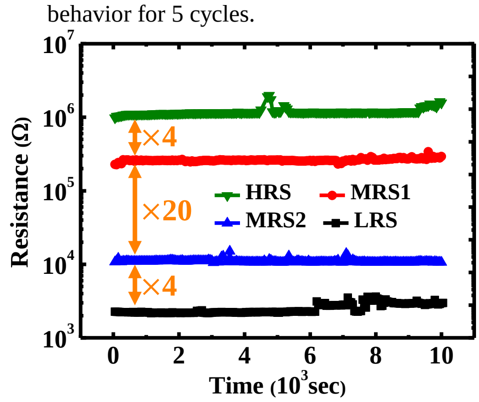

Fig. 11 Retention behaviors of stacked SiN_x/GdO_x RRAMs at HRS and LRS. All samples were measured in room temperature.