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High Performance Resistive Switching Characteristics of SiN Films with a Cu/Ta/SiN/Cu/SiN/TiN Multilayer Structure

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Abstract. The bipolar resistive switching properties of SiN based conductive bridge random access memory (CBRAM) device are investigated for non-volatile memory applications in a Cu/Ta/SiN/Cu/SiN/TiN multilayer structure. The device shows good switching characteristics with set voltages between 0.8 V and 1.3 V and reset voltages between -0.3 V and - 0.7 V with a variation of less than 0.1 V. The Cu/Ta/SiN/Cu/SiN/TiN multilayer CBRAM device exhibits excellent memory performance, such as long stable endurance cycles (> 4.5×10^3) during the test without any degradation, good retention ability (>10^4 s) at a temperature of 120 ^{0}C with more than 10^2 on/off resistance ratio.

1. Introduction

Resistive random access memory (RRAM) has been considered to be a promising candidate to replace NAND FLASH memory because of its high scalability, high retention, large memory window, fast speed and low power consumption [1-3]. Among the several kinds of RRAMs, the CBRAM has profound interest due to its excellent scaling, large non-volatile memory window, low voltage, low current applications, reconfigurable logic circuits, and CMOS compatibility [4,5]. Several kinds of switching materials have been used to investigate the CBRAM characteristics such as oxide materials like Al_2O_3, ZrO_2, HfO_2, SiO_2, TiO_2 and non-oxide materials, SiCN, Si_3N_4, a-Si_3N_4 [6-14]. The resistive switching (RS) phenomenon in Ox-RAM device is based on the formation and rupture of the conductive filament due to the oxygen vacancies. Furthermore, the reduction of metal (Cu^+, Ag^+) ions are responsible for the RS in the CBRAM devices instead of oxygen vacancies by the application of the external bias [2,5,14]. The transition metal oxides (TMO) have shown advantages than other materials in their excellent process compatibility [15,16]. However, several problems such as large reset currents, small on/off ratio, long reset time and large variations in both resistances states [17]. Nitride-based CBRAM shows relatively excellent RS characteristics such as high on/off ratio, low voltage, superior endurance, retention, and high switching speed [14,18]. Silicon Nitride and Cu metal are widely used in current CMOS technology as insulating layer and interconnect materials, respectively. Sun et al. have reported that an Ag/Si_3N_4/Pt bipolar resistive switching (BRS) device working based on the Ag filament model has shown good retention characteristics [16]. Kim et al. have also reported bipolar resistive switching in Ag/Si_3N_4/Al with the on/off resistance ratio more than 10^7 but the device has shown poor endurance and high forming voltage [18]. Still, these devices using Ag metal electrodes may possibly limit the applicability to CMOS manufacturing technology. However, the natural random formation and rupture of conductive filament (CF) is serious problem in the CBRAM devices, which shows a huge variation of switching voltages and resistance states [13,16,19].

To reduce these problems, we have investigated a Cu/Ta/SiN/Cu/SiN/TiN multilayer structure with the insertion of thin Cu metal layer between the SiN layers. This multilayer device has shown good and highly stable switching characteristics with minimum dispersion in the memory switching parameters like very low set/reset voltages, high endurance and long retention time, showing its applications in real time devices. In this study, we have investigated a SiN-based CBRAM device with the Cu/Ta/SiN/Cu/SiN/TiN multilayer structure, and systematically investigate resistive switching characteristics of this device. The device shows that the low forming voltage, narrow fluctuations in the operating voltages and good stable endurance.

2. Experimental Details

In the experiment, the Cu/Ta/SiN/Cu/SiN/TiN device was fabricated as follows. Firstly, a 200 nm thick SiO_2 layer was deposited on Si substrate by using Plasma Enhanced Chemical Vapor Deposition (PECVD). Secondly,30 nm thick TiN was deposited on the SiO_2/Si substrate by Atomic Layer Deposition (ALD). After that, a 5 nm thick SiN layer was deposited on the TiN bottom electrode (BE) by electron beam evaporation system. Then, a 2 nm thick Cu film was deposited on the SiN layer by RF sputtering. After that, again a 5 nm thick SiN layer was deposited on Cu layer. Finally, a 4 nm Ta adhesion barrier layer and 250 nm Cu top electrode (TE) were deposited by RF magnetron sputtering to form Cu/Ta/SiN/Cu/SiN/TiN multilayer CBRAM device. The Agilent B1500A semiconductor parameter analyzer was used to measure the resistance switching characteristics of the present device, in which the bias voltage was applied to the Cu top electrode with the TiN bottom electrode grounded.

3. Results and Discussion

The schematic diagram of the Cu/Ta/SiN/Cu/SiN/TiN multilayer structure is illustrated in Figure 1. The schematic diagram shows the clear and distinguished presence of various layers within the device. The multilayer device consists of Cu top electrode, 4 nm Ta adhesion barrier layer, 6 nm SiN films are on both sides of 2 nm Cu layer, and 30 nm TiN bottom electrode.

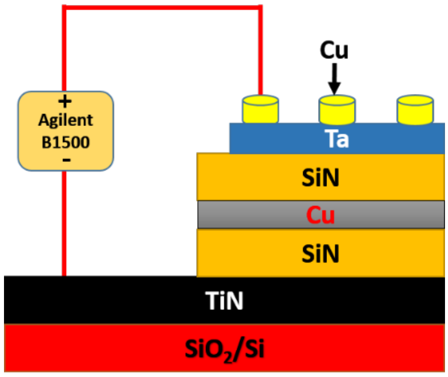

Figure l. A schematic configuration of the Cu/Ta/SiN/Cu/SiN/TiN multilayer device

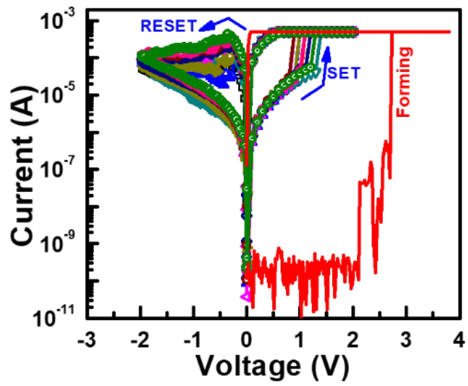

Figure 2. Forming process and I-V resistive switching curves of the multilayer device

Figure 2 shows the typical forming behavior of the Cu/Ta/SiN/Cu/SiN/TiN multilayer device, where compliance current (CC) of 500 μA is used to protect the device. The bipolar resistive switching current – voltage (I–V) of the multilayer device is revealed in Figure 2. During the forming process, the device is switched from the initial state to the low resistance state (LRS), with the application of positive voltage on the Cu top electrode. By sweeping the negative voltage from 0 V to – 2 V on Cu top electrode, the device is switched from the LRS to the high resistance state (HRS), which is called as the reset process. Then, the device is swept by positive voltage from 0 V to +2 V on the Cu top electrode to switch the device back to the LRS, which is called the set process. The device has shown LRS/HRS ratio of about 10^2 for multilayer device at the read voltage of 0.2 V, which is useful for non-volatile memory applications.

The resistive switching characteristics of the Cu/Ta/SiN/Cu/SiN/TiN multilayer device are very similar to that of transition oxide based CBRAM devices [14, 19-20]. The resistive switching phenomenon of the multilayer device is based on formation and rupture of Cu conductive filament. When the positive bias is applied on the Cu top electrode, the Cu atoms get oxidized and become Cu ions. The electric field generated by the applied positive voltage between top and bottom electrodes drifts the ionized Cu atoms from the top electrode towards the TiN bottom electrode, resulting in the formation of Cu filaments, called set process.

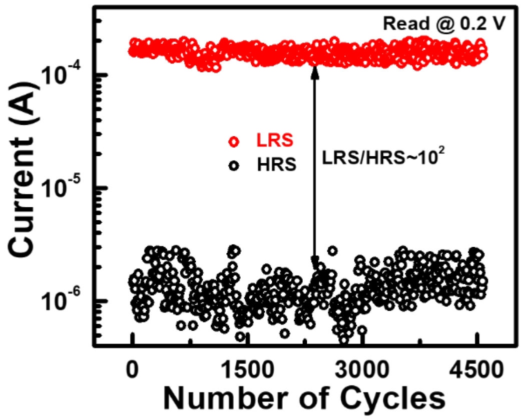

Figure 3. Endurance test for multilayer device measured at 120 ^{0}C temperature

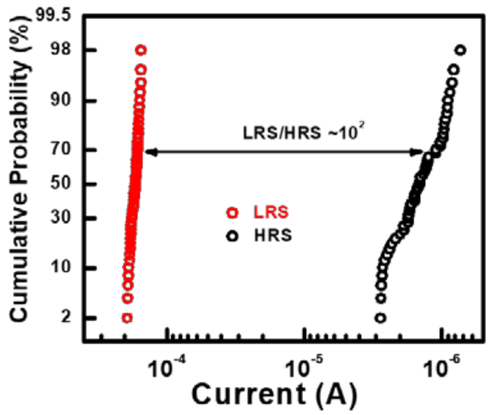

Figure 4. Resistance distribution of the device at both HRS and LRS conditions

Conversely, the negative bias applied on the Cu top electrode causes the electrochemical reaction, and the Cu atoms becomes Cu ions and drift back to the TE due to the applied electric field, resulting rupture of the Cu filaments, called reset process. Figure 3 shows the endurance characteristics the Cu/Ta/SiN/Cu/SiN/TiN multilayer structure at the read voltage of 0.2 V.

The device is maintained its both resistance (LRS/HRS) states up to 4500 cycles without showing any degradation. During the resistive switching cycles, the resistance ratio of HRS to LRS is maintained in the range of 10^2. The cycle to cycle variation of the device in both LRS/HRS resistance states are detected at the read voltage of 0.2 V during the 100 continuous switching cycles as shown in Figure 4. As shown in the resistance evolution during these given cycles, there is a minimum fluctuation in HRS and LRS. The device shows sharp distribution in LRS and narrow distribution in HRS with maintained the resistance ratio around 10^2.

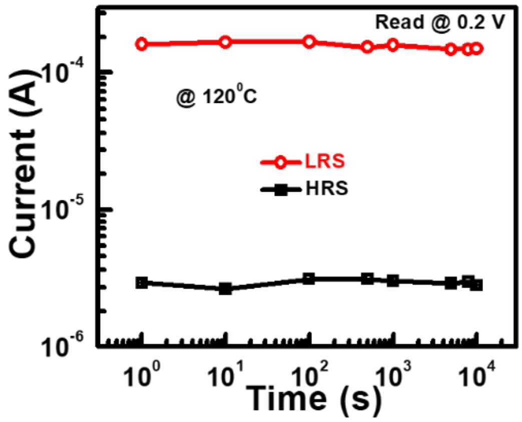

Figure 5. Retention behavior is measured at 120 ^{0}C for multilayer device

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The high temperature retention characteristic is also measured for the approval of memory performance of the device with the read voltage of 0.2 V, at temperature of 120 ^{0}C as shown in Figure 5. It is observed that the device can well maintain its both LRS/HRS states for more than 10^4 s without any degradation.

4. Conclusions

The switching characteristics and uniformity of the Cu/Ta/SiN/Cu/SiN/TiN multilayer device has been investigated. The device shows that the LRS/HRS resistance ratio around 10^2 and endurance more than 4500 cycles are achieved without any degradation during the continuous resistive switching cycles. The device also possesses good retention property up to 10^4 s at 120 ^{0}C. These results indicate that the multilayer structure has high potential for non-volatile memory applications

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