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Amorphous SiC based non-volatile resistive memories with ultrahigh ON/OFF ratios

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ABSTRACT

Amorphous SiC based resistive memory Cu/a-SiC/Au devices were fabricated and their resistive switching characteristics investigated. Co-existence of bipolar and unipolar behavior has been observed with ON/OFF current ratio in the range of 10^8–10^9. These high ratios are due to the conduction in the OFF state being dominated by the Schottky barrier between the Au and SiC. ON/OFF ratios exceeding 10^7 over 10 years were predicted from retention characterization. The unique performance combination of the extremely high ON/OFF ratio, coexistence of bipolar and unipolar switching modes as well as excellent stability and retention suggest significant application potentials of Cu/a-SiC/Au RM devices.

1. Introduction

Non-volatile resistive memories (RMs) have attracted great attention in recent years as they show considerable potentials to replace conventional Flash memories which face stringent scaling and performance difficulties in the near future [1,2]. As the resistive switching is governed by formation/dissolution of nano-scale metallic filaments, RMs also exhibit considerably greater down-scaling potential than Flash memories, leading to a promising solution for future high density data storage [2]. RMs usually consist of simple metal-solid electrolyte-metal stack structure configuration. The ON and OFF states are distinguished by low (R_{ON}) and high (R_{OFF}) resistance of the devices which can be electrically achieved by applying voltages across the metal electrodes. Based on the polarity of applied voltage, resistive switching can be broadly classified into two modes: bipolar and unipolar switching [3,4]. For bipolar switching, the switching direction is dependent on the polarity of applied voltage, i.e., SET (OFF to ON) and RESET (ON to OFF) process require opposite voltage polarities. On the contrary, in unipolar mode SET and RESET process can occur under the same voltage polarity. RMs operating in unipolar mode are particularly advantageous for high density integration, as the peripheral circuits can be simplified [4]. On the other hand, bipolar switching RMs feature faster switching speed, better uniformity and lower operation power [5]. While most RMs reported to-date exhibit either bipolar or unipolar behavior, it is envisioned RMs with both switching modes may fit a broader range of operation requirements [5,6]. High ON/OFF current ratios are also one of the key RM performances for their future applications as they not only enable fast and reliable detection of the states of memory cells, but also simplify the periphery circuit to distinguish the storage information [7].

Although RMs with a range of solid electrolyte materials have been reported [2,8], suitable electrolyte materials that lead to these desirable performances (e.g. high ON/OFF switching current ratio, reliability, retention and coexistence of bipolar and unipolar behaviors etc.) are yet to be found. Recent studies show that amorphous SiC (a-SiC) based RMs exhibit bipolar switching characteristics with excellent retention properties [9]. Nevertheless, only bipolar switching characteristics were observed with relatively low ON/OFF ratio in the order of 10^2–10^3 [9].

This work focuses on the study of Cu/a-SiC/Au RMs. Coexistence of typical non-volatile bipolar and unipolar resistive switching characteristics have been observed with ultrahigh ON/OFF switching ratios ($\sim 10^9$). *I–V* transport properties for both ON-state and OFF-state have been systematically studied with a view to investigating their respective switching mechanisms. Device stability and retention properties have also been studied.

2. Experimental

The schematic fabrication route of the Cu/a-SiC/Au RM devices is shown in Fig. 1. Si wafers with 1 μm thermally grown SiO_2 layer

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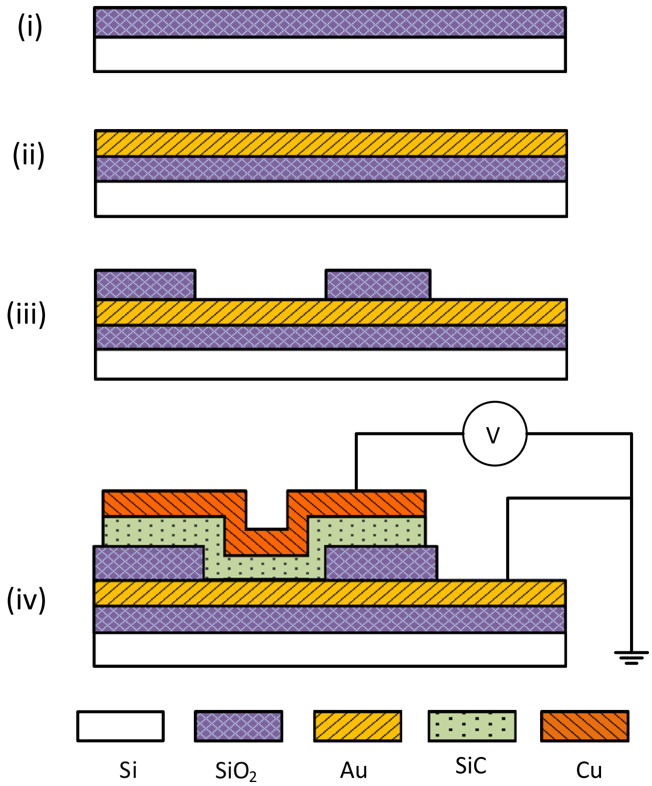

Fig. 1. (i–iv) Schematic drawings of fabrication process flow for the Cu/a-SiC/Au resistive memory devices, with (iv) also showing the electric connection configuration during the switching tests.

on top were used as starting substrates. Firstly a 300 nm thick Au layer was deposited by magnetron sputtering followed by a reactively sputtered SiO_2 layer of 250 nm in thickness. Photolithography and Reactive Ion Etch (RIE) were then applied to define the device active areas. Subsequently, a 40 nm a-SiC layer and a 300 nm Cu layer were deposited using sputtering without breaking the chamber vacuum. This is to minimize any possible contamination at a-SiC/Cu interface. Finally a lift-off process was performed to form the devices. All processes were carried out at room temperature.

Cross-sectional view of a typical Cu/a-SiC/Au device was obtained by Focused Ion Beam (FIB) milling and Scanning Electron Microscope and is shown in Fig. 2. The dark a-SiC layer is clearly visible between two bright metal layers. Switching performance of these Cu/a-SiC/Au RMs has been characterized by sweeping voltage across the top Cu active electrode and bottom Au counter electrode as depicted in Fig. 1(iv), using an Agilent B1500A semiconductor device parameter analyzer. The Au electrode was constantly grounded during testing, while sweeping voltage was applied on the Cu electrode. To test bipolar mode switching, the voltage sweeping sequence was 0 V → +V → 0 V → −V → 0 V, while for unipolar mode, the sweeping voltage was 0 V → +V → 0 V → +V → 0 V. Current compliance was applied during SET cycles to prevent permanent breakdown.

3. Results and discussion

Coexistence of bipolar and unipolar resistive switching with ultrahigh ON/OFF ratios in the range of 10^8–10^9 has been observed, as is shown in Fig. 3. The results were acquired from a Cu/a-SiC/Au device with device active area of 1 μm diameter and 40 nm thick a-SiC layer. The SET voltages in both switching modes were approximately +2.4 V, while the RESET voltages were approximately −1 and +0.9 V for bipolar and unipolar modes, respectively. In bipolar mode, R_{ON} and R_{OFF} measured at 0.1 V were typically 7×10^2 and 6×10^{11} Ω, respectively, leading to extremely high ON/OFF ratio of approximately 8×10^8. Similarly, the ON/OFF ratio for unipolar switching was approximately 5×10^8. R_{OFF} for unipolar devices is slightly lower than that for bipolar devices which we believe is likely caused by the different RESET mechanisms in the two modes, as will be discussed later. Furthermore, it is important to note that, once the device has undergone the first SET process with positive voltage sweep, for the subsequent cycles, the bipolar switching modes could also be observed using negative voltage SET processes, i.e. 0 V → −V → 0 V → +V → 0 V; similarly, unipolar switching mode could also be obtained through negative voltage SET, i.e. 0 V → −V → 0 V → −V → 0 V. Again, we believe this likely indicates localised rupture of the filament during RESET process which leaves residue Cu at the Au electrode. Such residue Cu can then act as an effective electrode in the subsequent cycles. More details will be included later. Nevertheless, since all switching cycles present similar behavior for bipolar and unipolar switching, respectively, typical bipolar and unipolar cycles are presented in Fig. 3 for clear comparison. To the best of our knowledge, our Cu/a-SiC/Au devices present the highest ON/OFF ratio reported to date among devices exhibiting coexistence of bipolar and unipolar

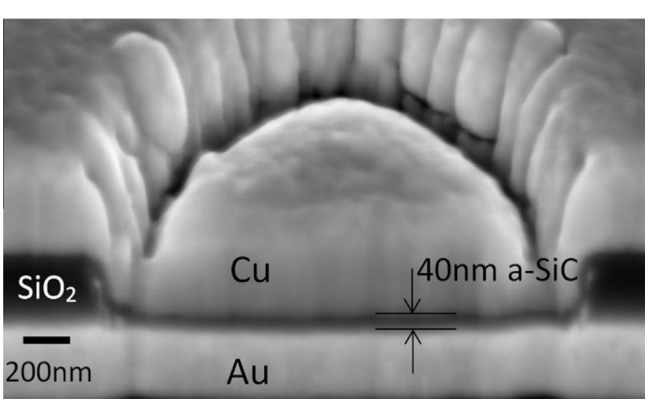

Fig. 2. Cross-sectional view of a typical Cu/a-SiC/Au device.

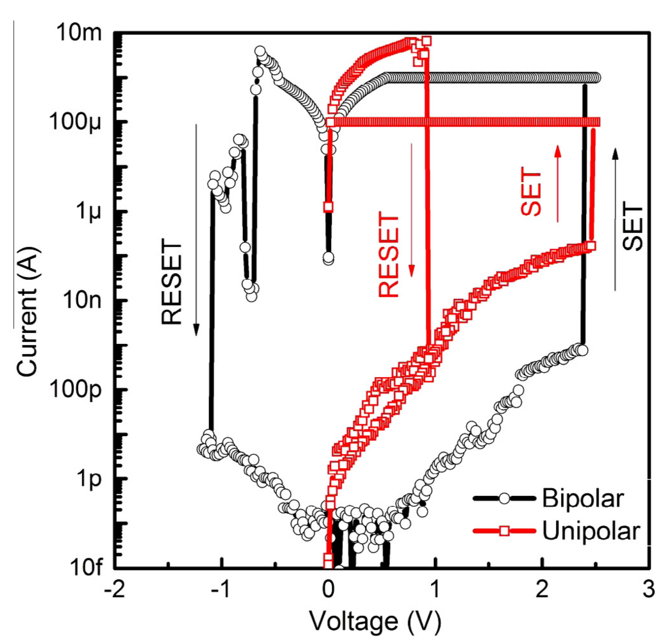

Fig. 3. Typical bipolar and unipolar switching behavior observed in a typical Cu/a-SiC/Au RM. The set and reset processes in both modes are also indicated.