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Threshold switching-based bidirectional nonlinear characteristics of ZnTe selectors for 3D stackable crossbar-array applications

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Abstract

Three dimensional (3D) stackable memory devices including crossbar array frames have emerged as a promising candidate for the realization of high-density non-volatile memory electronics. However, the crossbar array using two terminal element is highly susceptible to sneak path issues that arise from unintended leakage current since each cell in a row and column is connected to each other. Thus, the integration of a suitable selector as a two way switches is crucially required. Here, we address electrical features of ZnTe-based selector, ensuring high bidirectional non-linearity of more than 10^4. Typical threshold switching (TS) after forming process was clearly observed, along with attaining the exponential increase in the Off-current with increasing voltages. We propose the possible conduction nature in the Off-current by utilizing a modified Poole-Frankel (PF) model. The observed threshold voltages of the selector exhibited a thickness dependency, thereby implying an adjustable nature in the device.

1. Introduction

One long-standing goal in the emerging fields of numerous electronic applications is to meet the demand of key memory market by developing 3D stackable crossbar array geometries, possibly ensuring high density non-volatile memory devices. But, their utilization has the disadvantages of introducing an essential sneak path issue in crossbar array frame that are typically composed of alternating bit-lines and word-lines perpendicular to each other. Therefore, the development of a suitable selector as a two-way switches is indispensable for enabling the production of 3D nano-scaled passive crossbar array frames based on two terminal devices, such as resistive random access memory (ReRAM)[1], and phase change memory (PCRAM)[2]. The selector, referring to volatile and non-linear I-V characteristics elements, is expected to suppress unwanted cells during writing/reading operations when the system accesses certain cell.

Numerous selectors ensuring bidirectional nonlinearity have strongly been employed including insulator-metal transition (IMT)[3], tunneling barrier[4], mixed-ionic-electronic conduction (MIEC)[5]. Among the recently developed selectors, the chalcogenides that are called ovonic threshold switching (OTS)[6] materials are rapidly becoming one of the most reliable candidates for bidirectional operation due to their outstanding electrical features. When the voltage more than threshold voltage (V_{th}) is applied to the OTS material, its high resistance (Off state) switches to the low resistance (On state). The On-state remains as long as the applied voltage is large than holding voltage (V_h). Unless, the OTS materials returns to the Off-state. Here, we introduce the electrical performance of ZnTe-based selector serving as an alternative material through the W plug bottom electrode. Systematic electric analyses were conducted by varying thickness and composition of ZnTe materials. In addition, the nature governing Off-current behavior is proposed by using a modified Poole-Frankel (PF) model to understand a significant effect on device performance when the ZnTe is chosen as an active material. The threshold voltages of the elector provided the thickness dependency of ZnTe material, which follows a trend expected by the PF model.

2. Experiment and data

Fig.1 (a) plots the schematics of ZnTe selector. At first, a 40 nm-thick ZnTe film was deposited on W plug wafer by rf sputtering using a ZnTe target, where the W plug serving as the bottom electrode was a 2 μm X 2 um in size. A 50 nm-thick W top electrode was defined using a conventional photolithography and lift-off process for 60 μm X 60 um cell sizes. DC characteristics of the selector were measured using a Keithley 4200 semiconductor characterization system. It should be noted that an additional resistor with variable resistances was serially-connected to the selector to prevent possible overshoot issue during the transition from Off-state to On-state and the compliance current was also limited to 1mA. Fig. 1(b) shows the representative I-V response of ZnTe-based selector. As seen in this figure, at first, the selector requires typical forming process (dash line) that is indicated by forming voltage (V_f), resulting in the increase in the conductance of the device. After the selector goes through the forming process, the representative OTS behavior was identified. The conductance of the selector was higher when the larger voltage than V_{th} was applied. The high conductance state remained unchanged as long as the applied voltage was higher than V_h (solid line). An initial current before forming process was lower that the Off-state current (I_{off}), in which the I_{off} exponentially increased as the voltages increased. The high nonlinearity of more than 10^4 was obtained at a half-biased read scheme (V_{read} = 1.6 V and $V_{read}/2$ = 0.8 V) in our experiment.

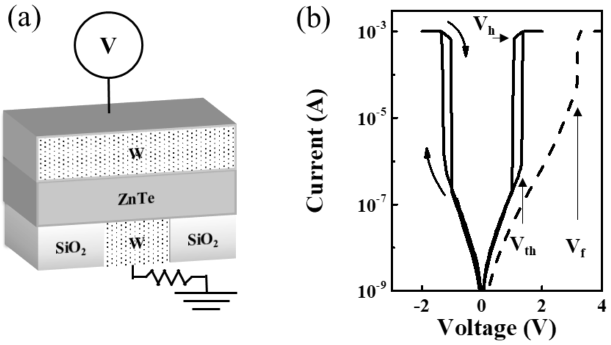

Fig. 1 (a) Schematics of ZnTe selector, where the W plug bottom electrode was serially connected to the external resistor. (b) Representative bidirectional I-V characteristics, where the $V_{f,}$, V_{th}, and $V_{h,,}$ were the forming, threshold, and holding voltages, respectively.

Fig. 2(a) and (b) show the XRD patterns and typical I-V response of the ZnTe selectors, respectively, where the ZnTe layers were prepared at two different rf powers of 10 W (upper line) and 40 W (lower line). As-grown ZnTe layers exhibited amorphous and cryalline phases depending on the rf powers used. However, the corresponding I-V responses remained mostly unaffected, regardless of crystal phases. It implies that the nature is also similar to each other. Thus, more detailed empirical results and comparisons are needed in order to establish a clearer explanation for the underlying mechanism observed in these devices.

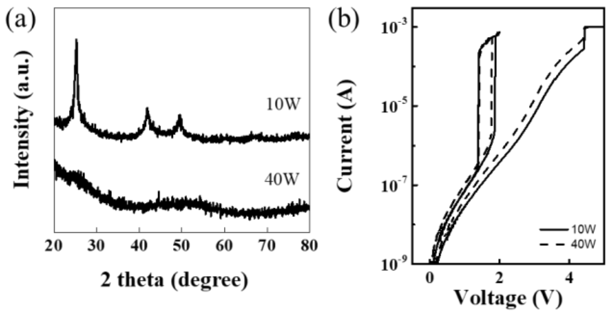

Fig. 2 (a) Power-dependent X-ray diffraction patterns of ZnTe layers prepared by different powers of 10 W and 40 W. (b) Typical I-V responses, ensuring the similar OTS behaviors, except intimal resistance, regardless of crystal phases.

To gain further insight into the above observations, the modified Poole-Frankel (PF) conduction mechanism proposed by Ielmini and Zhang[7] was adopted in Off-current region. Fig. 3(a) plots the experimental (circle) and simulated (line) I-V features of the selector in the Off-current region. Based on their models, the off current is given by

$$I_{off} = 2qAN_{T,tot}\frac{\Delta z}{\tau_0}e^{-\frac{E_C-E_F}{kT}}\sinh\left(\frac{qV_A}{kT}\frac{\Delta z}{2u_a}\right) \qquad (1)$$

where q is elementary charge, A is the area of the cell, $N_{T,tot}$ is the number of trap site, Δz is distance between traps, τ_0 is time to attempt to escape traps, E_c is conduction energy level, E_F is quasi fermi level, V_A is applying voltage on ZnTe layer, and u_a is thickness of ZnTe. As evident in Fig. 3(a), the experimental responses (white circle) were well-described by the contribution of field and thermal-assisted conduction (black circle) among initially present charge trap defects. In addition, the Ielmini's model supported the thickness dependency of V_{th}, as plotted in Fig. 3(b).

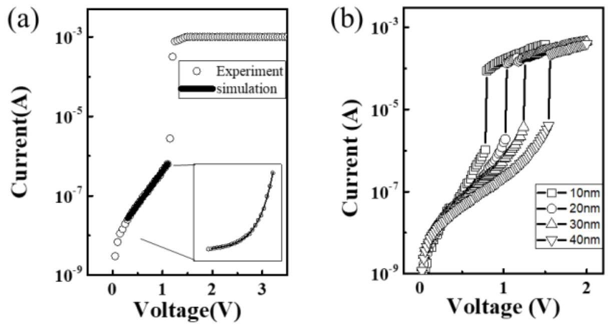

Fig. 3 (a) Experimental (circle) and Simulated (line) off current response. (b) Thickness-dependent TS voltages.

3. Conclusions

We addressed the electrical features of ZnTe selectors as a promising alternative bidirectional switches to solve sneak-path issue. Experimental findings provided evidence for typical threshold switching behaviors of ZnTe selectors with a high non-linearity, regardless crystal phase of ZnTe layer. The observed Off-current origin of the selector was explored by adopting the modified PF model, along with attaining the thickness dependency of V_{th} with ZnTe layer.

Acknowledgement

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