Solid-State Electronics 120 (2016) 52–55

Contents lists available at ScienceDirect

Solid-State Electronics

journal homepage: www.elsevier.com/locate/sse

Superlattice-like film for high data retention and high speed phase change random access memory

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ARTICLE INFO

Article history:
Received 19 August 2015
Received in revised form 4 March 2016
Accepted 14 March 2016
Available online 25 March 2016

The review of this paper was arranged by Prof. S. Cristoloveanu

Keywords:
Superlattice-like
PARAM
$Ti_{0.43}Sb_2Te_3$

ABSTRACT

Superlattice-like film (SLF) was formed alternately by $Ti_{0.43}Sb_2Te_3$ (TST) and TiN, and TST is employed as phase change layers and TiN is employed as isolation layers of TST film. Comparing with single TST film with the same thickness, SLF owns higher data retention, higher phase change speed (5 ns) and endurance up to 1×10^5 cycles, and its power consumption of reset operation is significantly decreased by 65.2%. Two-dimensional thermal transient simulation of reset operation indicates that SLF-based device owns higher heating efficiency than 30-nm-thick TST-based device.

1. Introduction

Phase change random access memory (PCRAM), as one of the most promising next generation non-volatile memory, is attracting more and more attention for its high speed, low power consumption, good scalability and fabrication compatibility with complementary metal–oxide–semiconductor (CMOS) process [1–3]. In PCRAM, data is recorded by exploiting a reversible phase change between high resistive amorphous (reset state, "0") and low resistive crystalline (set state, "1") phases of a material. The outstanding attributes make PCRAM as a contender for a universal nonvolatile memory. However, the traditional phase change materials, such as $Ge_2Sb_2Te_5$ (GST), Sb–Te materials, can't exhibit comprehensive qualities of PCRAM due to some defects, especially in thermal stability [4,5]. Researchers usually improve the thermal stability through doping modification in phase change materials, such as N, C doped GST [4,6], Zn, Ga doped Sb–Te [7–9]. But at the same time doping modification wakens other qualities, for example, N doped GST improves the thermal stability but lowers the crystallization speed. Thus, it is well worth researchers to search for other ways to improve the thermal stability of PCRAM.

As a new potential candidate storage medium for PCRAM, $Ti_{0.43}Sb_2Te_3$ (TST) exhibits higher speed and lower power consumption in comparison with GST, but its thermal stability is still relatively poor [10–12]. In our studies, it is found that 10 nm-TST film (10F) owns higher crystallization temperature (T_c) and better thermal stability than 30 nm-TST film (30F) due to the increasing surface-to-volume ratio. In this paper, 30F was divided into three 10 nm layers by adding two isolation layers (in Fig. 1), to form superlattice-like film (SLF) and increase surface-to-volume ratio. Because of good adhesion and low resistivity, TiN is chosen for isolation layer with a thickness of 5 nm. It is expected that the superlattice-like structure can solve the contradiction between thermal stability and fast crystallization speed.

2. Experimental

The TST/TiN films with different thicknesses were deposited on SiO_2 substrates by magnetron co-sputtering using Ti and Sb_2Te_3 targets at room temperature. The thicknesses were varied by changing the sputtering time. In situ sheet resistance versus heating temperature (R–T) measurements were implemented using the four-point probe technique in a vacuum chamber with a heating rate of 20 °C/min. The sample temperature was measured by a TP

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http://dx.doi.org/10.1016/j.sse.2016.03.005
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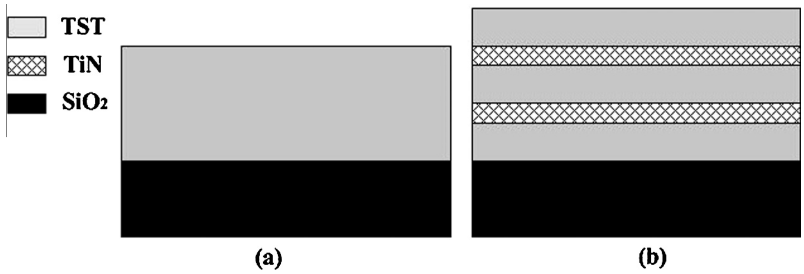

Fig. 1. Schematic cross-section structure of (a) 30F, (b) SLF.

94 temperature controller (Linkam Scientific Instruments Ltd., Surrey, UK). The entire set-up was connected to a computer on which the resistance and temperature of the wire were recorded by a real-time measurement program. The data retention relying on the evaluation of the time-dependent resistance change of the amorphous films at isothermal annealing temperatures was performed. Finally, T-type PCM devices were fabricated using 0.13 μm CMOS technology, in which 30F and SLF were deposited respectively on the W bottom electrode with 190 nm in diameter, followed by the deposition of 10 nm thick TiN and then 300 nm thick Al top electrodes. Resistance–voltage (R–V) and endurance measurements were implemented by a Keithley-2004m digital sourcemeter and an arbitrary waveform pulse generator (Tektronics AWG 5002B).

3. Results and discussions

To analyze crystallization temperature of SLF, 10F and 30F, we carried out R–T measurements at a heating rate of 20 °C/min. The crystallization temperature (T_c) is determined by the temperature corresponding to minimum of the first derivative of R–T curve, where resistance drops fastest. From Fig. 2 (a), we can see that SLF and 10F own the same crystalline regions in the blue box and their T_c are 253 °C and 257 °C, much larger than 197 °C of 30F. Because in R–T measurements both of probes located in the top surface of SLF, TST and TiN films are in parallel, leading to small amorphous and crystalline resistance of SLF, as shown in Fig. 2(a). But in device TST and TiN films are in series, so SLF still owns high amorphous and crystalline resistance and large high/low resistance ratio. In our previous researches [13], we measured the change of the resistance with time at different temperature and calculated the 10-year data retention temperature ($T_{10\text{-yr}}$) from the extrapolation of the isothermal Arrhenius plots. Fig. 2(b) shows the fitting for $\ln t$ versus $1/k_BT$ on the basis of Arrhenius equation:

$$t = \tau \exp(E_a/k_BT) \tag{1}$$

where t, τ, k_B is the failure time, proportional time coefficient and Boltzmann's constant. The t is defined as the time where the film resistance drops to half of its initial value at the holding temperature and the insert in Fig. 2(b) shows its value in different temperature. It is found that $T_{10\text{-yr}}$ of 10F is better than that of 30F and $T_{10\text{-yr}}$ of 10F reaches to 147 °C. Normalized resistances of SLF and 10F as a function of time under the isothermal condition are measured. At 200 °C (Fig. 2(c)), when resistance decreases to 70% of its initial value, SLF

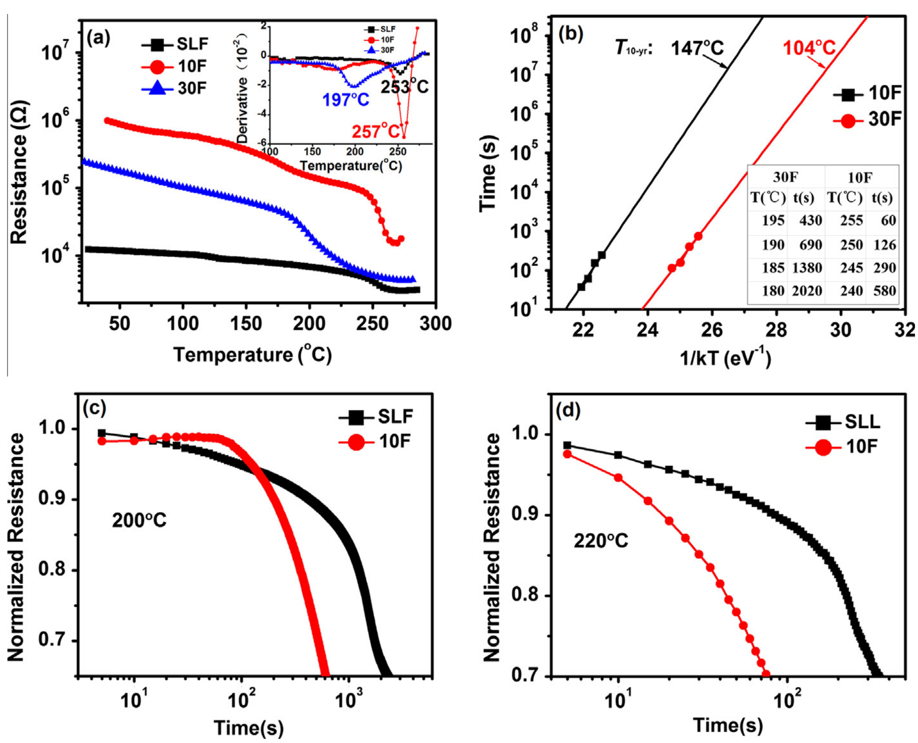

Fig. 2. (a) Sheet resistance of SLF, 10F and 30F as a function of the temperature with a heating rate of 20 °C/min. the insert is the figure of the first derivative of R–T curve and the minimum is T_c. (b) Arrhenius fitting plots of 10F and 30F for evaluating data retention. Normalized resistance of SLF and 10F as a function of time under the isothermal condition: (c) 200 °C and (d) 220 °C.