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A new insight on I_{RESET} reduction of carbon-doped GST based PCM

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Abstract

In this paper, a detailed investigation of the electrical performances of phase-change memory devices integrating carbon-doped $Ge_2Sb_2Te_5$ is reported. Compared to reference GST devices, up to 50% of current reduction is observed, with a programming window superior to two orders of magnitude. The RESET current reduction is attributed to an increase of the dynamic resistance of the device and to a decrease of the phase-change material thermal conductivity.

1. Introduction

Thanks to its unique set of features such as short read and write times, multi-level capability and ease of integration, Phase-Change Memory (PCM) is receiving widespread interest as possible Flash memory technology replacement [1]. However, the high current required to switch from the low-resistive (SET) to the high-resistive (RESET) state, I_{RESET}, limits the minimum size of the selector element, and hence the maximum memory density [1]. Reduced I_{RESET} have been observed in large PCM devices integrating carbon-doped GST (GST-C) instead of pure GST [2]. Therefore, in this paper, the main electrical performances of lightly doped GST-C-based scaled devices are deeply investigated and the programming current reductions are explained using thermal conductivity measurement and TCAD simulations.

2. Device fabrication and electrical characterization

Devices here studied are wall-type PCM devices, having a doped-TiN heater with a nominal area ranging from 300 nm² to 900 nm² (Fig. 1) [3]. On top of the heater, a 70 nm-thick phase-change layer is deposited at room temperature by plasma-assisted co-sputtering from one target of pure GST and one target of pure carbon. Various carbon percentages were incorporated into GST (Table I).

Transition curves (R–I and I–V) of these PCM devices were obtained by measuring the resistance, sweeping the height of the voltage pulse through a load resistance, R_{LOAD}, of 1 KΩ (Fig. 1). Fig. 2 highlights the electrical performances of the 900 nm² devices as a function of the carbon content. It is worth noting that I_{RESET} is reduced up to about 50% when the carbon content increases up to 13.8%. Moreover, the overall power required to RESET (P_{RESET}) and SET (P_{SET}) the cell, and the energy needed to cycle the cell one time, E_{CYCLE}, are also reduced (Table I). However, adding carbon reduces the memory window, i.e. the ratio between the RESET and SET state resistances (Fig. 2d).

The impact of scaling on I_{RESET} was studied on GST, GST-C0.75% and GST-C3.7% based PCM devices. Fig. 3a and b show that I_{RESET} linearly scales down with the heater area while the I_{RESET} reduction increases when the heater area decreases. As a result, carbon reduces I_{RESET} even for scaled PCM devices with a 300 nm² heater area. Note that the memory window is not affected by scaling (Fig. 3c).

3. Interpretation and discussion about I_{RESET} reduction

It has been reported that the RESET behavior of GST-based PCM devices is controlled by few parameters: the resistance in the molten state called the device dynamic resistance, R_{DYN}, (Eq. 1) and the heat dissipation during melting (Eq. 2) [4]. Eq. 2 suggests that, in the steady-state, the decrease of P_{RESET} results from a modification of the thermal conductivity, κ (assuming a constant melting temperature). The κ of GST and GST-C3.7% have been measured using photothermal radiometry method [5] and a ratio of about 2.5 between the two values is obtained (Table II). Therefore, the decrease of κ contributes to the decrease of I_{RESET}. Furthermore, Fig. 4 shows that R_{DYN} increases with the carbon content meaning that in GST-C based devices, I_{RESET} decreases also thanks to the increase of R_{DYN}. Finally, using the PCM model of the Sentaurus Device tool from Synospys [6] and the GST parameters given in [7], TCAD simulations were performed. A good agreement between the simulated and the measured transition curves of GST based devices is obtained (Fig. 5). Taking only into account the decrease of κ by a factor 2.5, a decrease of I_{RESET} is observed. Then, to fit the measured transition curves of GST-C3.7% based devices and get an I_{RESET} reduction equal to the measured one, the increase of R_{DYN} was added.

4. Conclusions

In this study, we show that the I_{RESET} and P_{RESET} of carbon-doped GST scaled PCM devices are reduced up to 50% while maintaining a memory window higher than two orders of magnitude. TCAD simulations and thermal conductivity measurement strongly suggest that these reductions could be explained by two main factors: an increase of the dynamic resistance of the device and a decrease of the thermal conductivity of the phase-change material.

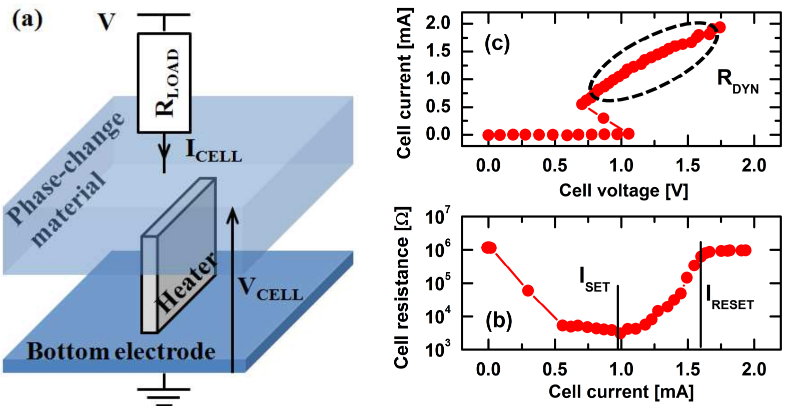

Fig. 1 Scheme of the wall-type device studied (a). Typical transition curves (R-I (b) and I-V (c) curves) of the GST-based PCM device with the 900 nm² heater.

Table I Electrical performances of the PCM devices with the 900 nm² heater.

Wafer number	Carbon content	I_{RESET} & I_{SET} reduction	P_{RESET} & P_{SET} reduction	E_{CYCLE} reduction	Memory window
01	0 at. %	---	---	---	630
02	0.75 at. %	20% - 21%	22% - 25%	25%	708
03	1.5 at. %	23% - 22%	24% - 22%	24%	500
04	2.4 at. %	23% - 25%	25% - 24%	27%	432
05	3.7 at. %	25% - 22%	18% - 24%	22%	333
06	6.9 at. %	29% - 23%	22% - 34%	28%	482
07	13.8 at. %	48% - 42%	45% - 57%	50%	203

The carbon contents were measured using PIXE, NRA and RBS methods with an overall precision of ±0.5%.

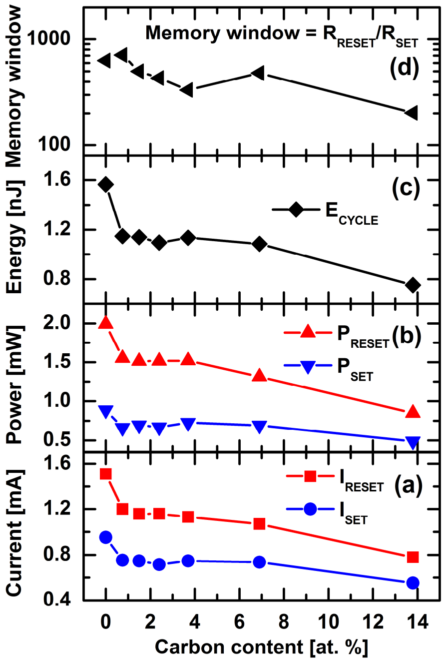

Fig. 2 Electrical performances of PCM devices with the 900 nm² heater as a function of the carbon content: programming currents (a) and powers (b), energy to RESET then SET the device (c), memory window (d).

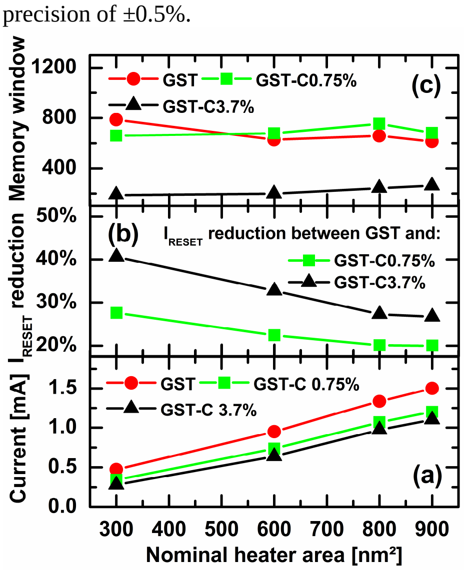

Fig. 3 I_{RESET} (a), I_{RESET} reductions (b) and memory window (c) of GST, GST-C0.75% and GST-C3.7% based PCM devices as a function of the nominal heater area.

$$P_{RESET} = R_{DYN} \cdot I_{RESET}^2 \quad (1)$$

$$C \cdot \frac{\partial T}{\partial t} + div(-\kappa \cdot grad(T)) = \rho \cdot J^2 \quad (2)$$

Table II Ratio between the thermal conductivity of GST and the one of GST-C3.7% at various temperature

Temperature	$\kappa_{GST} / \kappa_{GST\text{-}C3.7\%}$
85°C	2.4
135°C	2.3
185°C	2.0
265°C	3.0
285°C	3.0

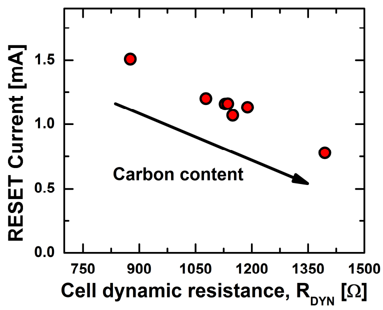

Fig. 4 I_{RESET} of the GST and GST-C based PCM devices as a function of the cell dynamic resistance.

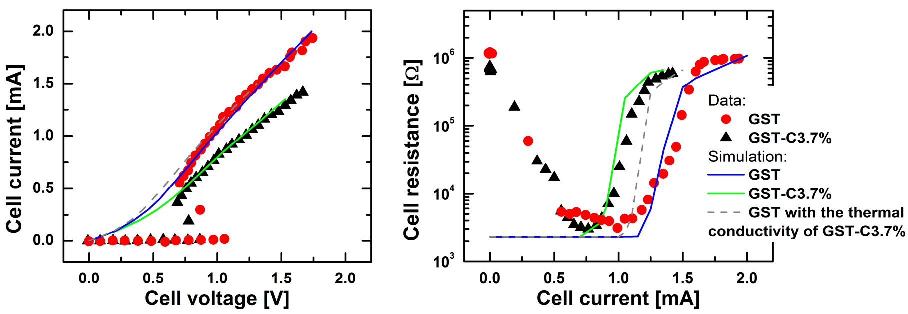

Fig. 5 Measured and simulated I-V (left) and R-I (right) curves of the GST and GST-C3.7% based PCM devices. The dash line represents the simulated transition curves of GST based devices with the phase-change material having the thermal conductivity of GST-C3.7%.

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