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Nanoscaling of Phase Change Memory Cells for High Speed Memory Applications

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1. Introduction

Phase change random access memory (PCRAM) is a promising universal memory that can be used in multiple applications, as it possesses near-ideal memory qualities of non-volatility, high density, low programming power, fast switching speed and high overwriting cycle [1].

GeSbTe (GST) phase change materials can be electrically switched between their amorphous and crystalline state, which was discovered by S. R. Ovshinsky in 1968 [2]. The GST materials with small dimensions have a very good scalability of the required switching power [2,3], and a rapid phase switching speed which is typically in tens nanoseconds [4]. The properties make the GST materials superior in memory device applications.

The current challenges are to reduce the programming power, and to achieve faster speed which is highly required for universal memory [5]. However, the switching speed is limited due to the material thermal activation. To resolve these issues, researchers have been mainly exploring various solutions through material modifications [5-6]. We have since studied the size effect of PCRAM nanocells which may provide a new approach to enhance the switching speed. While power has shown to improve with scaling, we are exploring to see how the PCRAM scaling can achieve higher speed to make one step forward towards the universal memory realization.

2. Experiment

The PCRAM nanocells were designed with a pore-like structure as shown in Fig. 1, consisting of five functional layers. The nanocells were using the near-filed scanning optical lithography, which can create nanocells with resolutions beyond the optical diffraction limit, while the conventional lithography was used to fabricate the other functional layers, to connect the nanoscale via regions to the external circuitry for electrical performance evaluation [7].

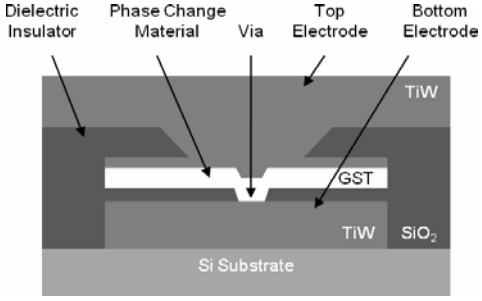

Fig. 1 Schematic diagram of the nanostructured GST

In order to investigate the feasibility of phase switching speed, we build an electrical testing platform which is capable of producing electrical pulses with pulse widths ranging from several tens picosecond to hundreds nanoseconds.

3. Results and discussions

The electrical switching performance in terms of power consumption was investigated for nanocells with via diameters of 30 nm, 162 nm and 457 nm as the SET and RESET processes shown in Fig. 2. It was found that the smaller nanocells require lower pulse amplitude to operate for both SET and RESET. Also, it was observed that the switching pulse amplitudes remained consistent when the pulse widths were relatively longer. However, as the pulse duration became shorter, the switching pulse amplitude required increase rather rapidly in a non-linear manner.

To study the correlation of the cell size effect on the switching speed, the dependence of the switching speed as a function of the cell size was evaluated for nanocells with diameters varying in a wide range from 19 nm to 467 nm as shown in Fig. 3. The shortest pulse widths required to switch the nanocells were investigated using fixed pulse amplitude of 0.8 V and 5 V for SET and RESET, respectively. The non-linear decreasing trend was observed as the cell sizes were reduced. It was noticed that the smaller nanocells required shorter pulse widths to SET/RESET. Moreover, the fastest switching speed among the nanocells was observed from the 19 nm cell, with SET and RESET speed of 2.5 ns and 400 ps, respectively.

It is believed that the GST materials present the intrinsic nature of semiconductors. It possesses a long range order in crystalline state and an intermediate range ordering in amorphous state. The GST band structures originate from the existence of vacancies in crystalline state, the electron lone-pairs bound to the local atoms, and the donor/acceptor defect pairs in amorphous state [1,5,8]. These localized free carriers and defects play important roles in the mechanisms responsible for the reversible and fast phase switching.

From another perspective, the nanostructured materials with sufficiently small dimensions can be seen as nanoclusters with higher surface/interface ratio. There have greater amount of dangling bonds near the surface or interface, which contributes to more unpaired atoms and free localized electrons as compared to the bulk materials.

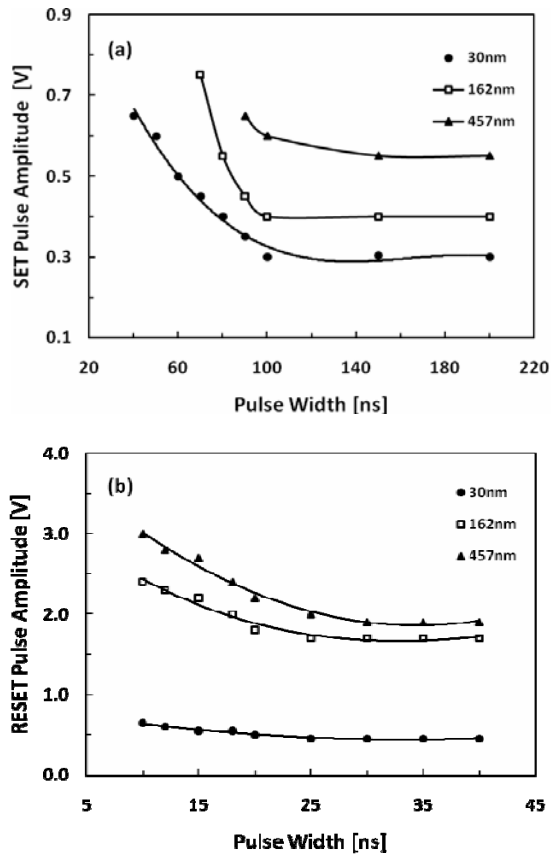

Fig. 2. Plots of pulse amplitude against pulse width for nanocells sizes of 30 nm, 162 nm and 457 nm in the (a) SET and (b) RESET process. Nanocells are switched between 100 kΩ and 10 kΩ. Smaller nanocells required lower pulse amplitudes. At shorter pulse widths, non-linearity in plot was observed while a relatively constant trend was noticed at longer pulse widths.

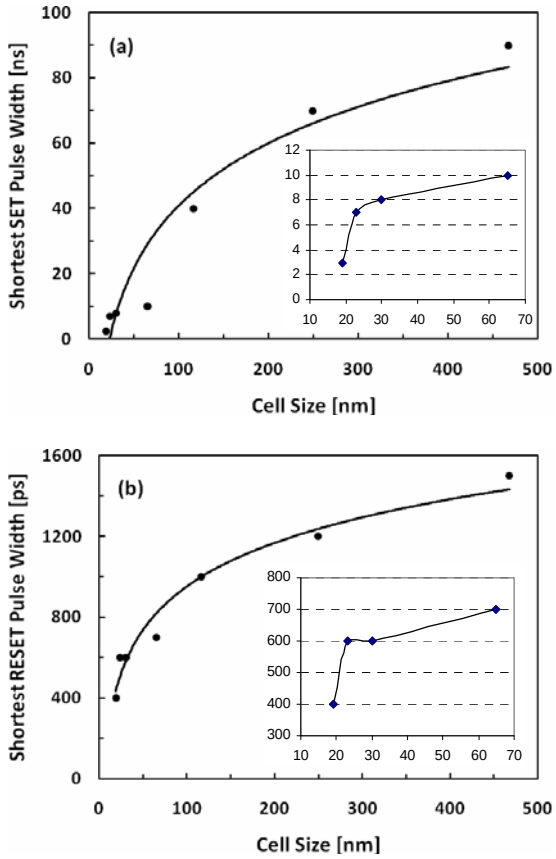

Fig. 3. Dependence of the shortest switching pulse width required for nanocells with dimensions in the range of 19 to 467 nm for: (a) SET, and (b) RESET. Nanocells are switched between 200~20 kΩ. Shorter pulse widths are observed for smaller cells as shown in the inserted curves. Fastest SET & RESET pulse widths are 2.5 ns and 400 ps respectively.

Theses atoms and electrons bring about an increase in the free carrier concentration that leads to faster threshold switching. Hence, when the nanocells become sufficiently smaller, the key interplay of more structural defects leads to the rise in the free carrier concentration, resulting in the faster phase switching into the picoseconds region.

4. Conclusions

We studied the correlation of nanocell size with its switching speed, and demonstrated a rapid and reversible PCRAM phase transformation. The fastest switching speeds achieved were observed in cells of 19 nm, with RESET pulse width of 400ps, and SET pulse width of 2.5ns. The ultrafast switching mechanisms was discussed which is due to the contribution of free carriers and defects at the material interface when cell size is sufficiently small. This nanoscaling of the phase change materials provides a new approach to enhance switching speed, which is highly essential for universal memory application.

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