Ge-rich PCM cell endurance study versus programming pulse shape

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ABSTRACT

Ge-rich chalcogenide alloys are recently being investigated due to their retention improvement performances with respect to conventional $Ge_2Sb_2Te_5$. In this scenario it is important to explore also the other characteristics of this alloys as endurance behavior.. We present a study of Ge-rich PCM cell endurance with respect to programming pulse shape.. In order to understand physical mechanisms critical for cycling, two different approaches for SET programming have been considered, where crystalline phase is obtained starting or not from the melted material. A 90nm Wall-like cell is considered. Endurance performances are studied as function of energy and power of applied pulses. We will show that endurance is correlated either with pulses energy or power depending on the SET programming approach. Improved endurance of integrated devices is obtained if SET pulse is engineered according to the "crystallize once" approach, where the maximum temperature is well below the melting point. These results are in agreement with those already found for conventional $Ge_2Sb_2Te_5$, thus confirming basically the same physical mechanisms driving endurance fails in case of Ge-rich alloys.

Key words: phase change memory, Ge-rich alloy, endurance

1. INTRODUCTION

Phase Change Memory is the most mature among novel memory concepts. Embedded PCM technology can be a real breakthrough for process cost saving and performances. Nevertheless some doubts still persist with respect to this solution, due to limitations in High Temperature Data Retention (HTDR). As shown in recent works [1-3], this limitation can be overcome by engineering the chalcogenide material inside the ternary diagram. Despite in principle unlimited endurance of chalcogenide materials, PCM cell cycling performance depends on the integrated device and on programming conditions. This study explores cycling performance of Wall-like PCM cells integrated with optimized GST (T_x ~350˚C) with the aim of understanding the role of programming pulse parameters, with particular emphasis on energy and power. Moreover, we will show that the learning curve established for $Ge_2Sb_2Te_5$ is still valid.

2. EXPERIMENTS

Electrical characterization has been performed at the level of analytical cell (~ 40 cells on a same wafer for each experiment). Reference process is a 90nm 6 Metal Level logic platform, with a Wall-like PCM cell integrated after plug definition [4]. Phase Change material is a Ge-rich GeSbTe alloy with crystallization temperature around 350˚C. Cell endurance has been evaluated monitoring SET and RESET resistances evolution during constant current cycling (3 read-outs per decade) till end-of–life. Cell failure is defined when SET resistance level increases by a factor 3 with respect to minimum SET level or when RESET resistance decreases by a factor 3. This is a quite severe criterion as, in many failure cases, cell should be still working with a reduced SET-RESET window.

In Fig.1 a typical example of window evolution is shown. In most of cases failures are due to reduced reset-ability with respect to t_0 (RESET failures).

3. RESULTS AND DISCUSSION

Cell endurance behavior has been evaluated in case of two different approaches for SET pulse (Fig.1). The first one is the so called "Melt and crystallize" [5] where crystallization process starts from a completely molten material (Iset=Ireset>Imelt) and crystallization is achieved with a proper quenching time depending on the chalcogenide alloy. The second one is the so called “Crystallize once” [5] where crystallization is achieved without melting the amorphous material (Iset<Imelt) by a box pulse long enough (or trapezoidal pulse to avoid spurious RESET in case of Imelt variation).The choice between the two approaches depends on programming speed and energy constraints.

A first group of experiments was performed in order to study endurance behavior in case of “Melt and crystallize” SET. For the sake of simplicity a “RESET only” approach has been followed by the use of two RESET box pulses. One cycle was defined as the sum of the two RESET pulses. Several experiments have been carried out by changing current pulses height and width (Fig.3). It is important to clarify that, in all considered cases, the current pulse was able to melt a portion of GeSbTe material (Iset=Ireset >Imelt). In this case the number of cycles cumulated distributions is clearly modulated by pulses energy/cycle as shown by plot in Fig.5 (each “RESET only” experiment is identified by a circle with the same color used in Fig.3). A second group of experiments was performed in order to study endurance behavior in case of “Crystallize once” SET. One cycle was defined as the sum of a RESET box pulse and a lower current trapezoidal SET pulse (Iset<Imelt).We will refer to these experiments with “SET&RESET” label. In Fig.4 “SET&RESET” cycling results with different SET width are compared with “RESET only” cycling results with the same RESET pulse current and width. It is evident that endurance is better if SET pulse is lower enough with respect to RESET pulse. This result cannot be simply explained by a lower energy/cycle as it is true not considering SET pulse width.In case of “SET&RESET” cycling there is no more correlation between number of cycles and energy/cycle as it is clear in Fig.5 where results are identified by triangular points. At a fixed energy/cycle value “SET&RESET” cycling allows to achieve a higher number of cycles with respect to “RESET only” cycling. Reporting the number of cycles as a function of the average current between SET and RESET pulse I_{mean} /cycle, one can notice that “SET&RESET” cycling points are aligned to “RESET only” points with the same I_{mean} /cycle value and the same RESET pulse width (100ns).Therefore the major player for endurance performance seems to be the I_{mean} /cycle or, in other words, the $Power_{mean}$/cycle, while SET pulse energy plays a marginal role. This result is aligned to what already found for conventional $Ge_2Sb_2Te_5$ [6].

In order to understand the different behaviour between “RESET only” and “SET&RESET” cycling, some consideration about the involved “driving forces”, power and energy, can be done. In case of Iset=Ireset>Imelt, temperature inside GST is pinned at melting point so programming current (power) modulates temperature inside heater element [7] and electromigration phenomena inside GST, while programming time (energy) modulates only electromigration. In case of Iset<Imelt<Ireset, we can assume that electromigration phenomena are negligible. This could explain the unsensitivity of endurance with respect to SET pulse energy (width). On the other hand, programming current still has a role in modulating temperature inside heater (and GST). As a consequence “SET&RESET” cycling endurance performances will be aligned to “RESET only” cycling with the same Imean/cycle and the same Ireset pulse width.

4. CONCLUSIONS

A study of Ge-rich PCM cell endurance versus programming pulse shape has been presented. It has been shown that endurance is correlated either with pulses energy or power depending on the SET programming approach. In case of “crystallize once” approach, in particular, endurance is only correlated with SET and RESET programming currents, regardless the width of SET pulse. This means that “Crystallize once” SET approach can be used as alternative of “Melt and crystallize” for improving endurance with no draw-back on SET-ability. These results are in agreement with those already found for conventional $Ge_2Sb_2Te_5$ [6], thus confirming basically the same physical mechanisms driving endurance fails in case of Ge-rich alloys.

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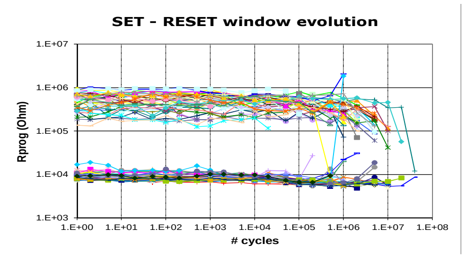

Fig.1 Typical SET-RESET window evolution during cycling. Main failure mode is RESET one.

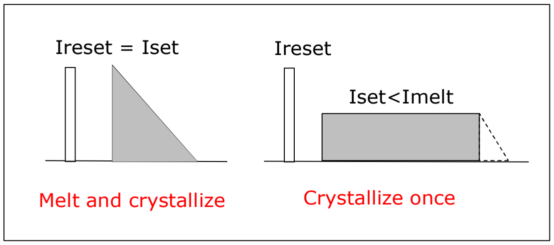

Fig.2 Comparison between "Melt and crystallize" and "Crystallize once " approaches for SET operation.

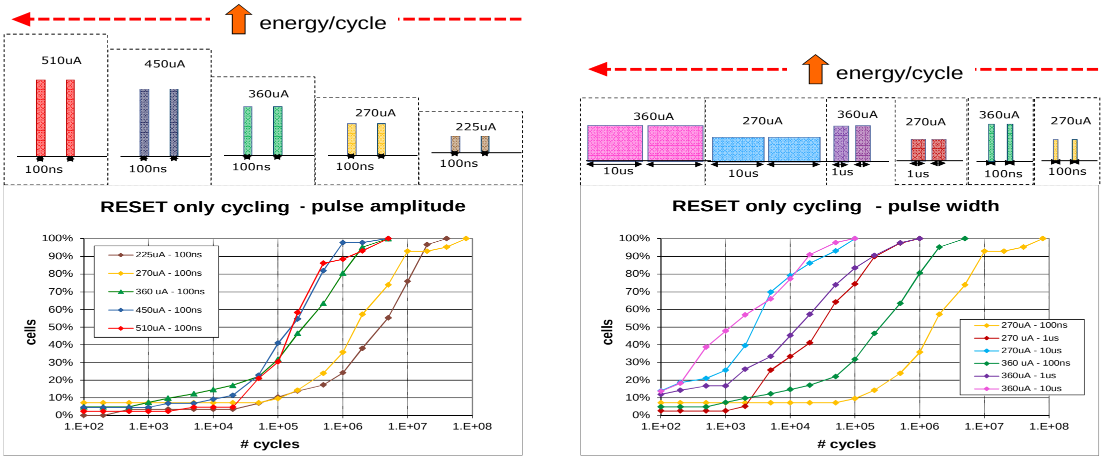

Fig.3 "RESET only" experiments results. In both cases of pulse amplitude variation (left) and width variation (right), the number of cycles decreases with energy pulse increasing.

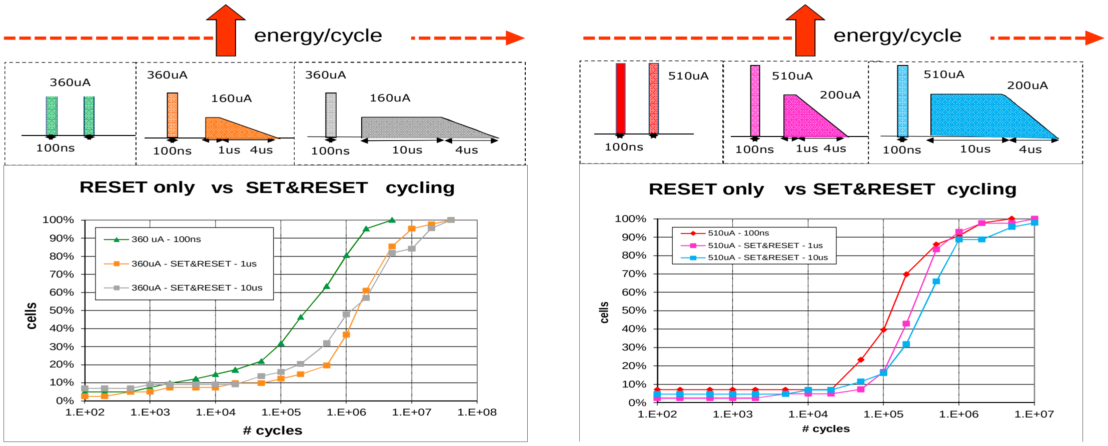

Fig.4 "SET&RESET" experiments results compared to "RESET only" with same Ireset (Ireset=360uA,Ireset=510uA). In both cases "SET&RESET" cycling is better than "RESET only" despite the higher energy per cycle value due to long SET pulse. It is worth noticing the unsensitivity of endurance with respect to SET pulse plateau.

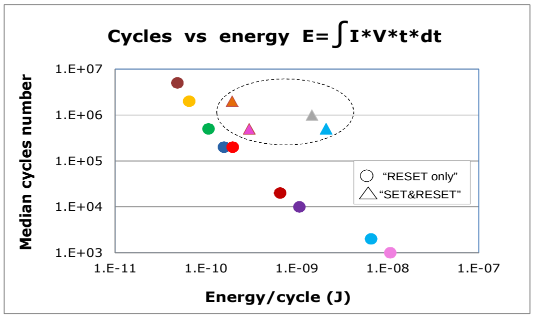

Fig.5 Number of cycles (median of distribution) as a function of energy per cycle. In case of "RESET only" cycling there is a clear correlation while it is not in case of "SET&RESET" cycling.

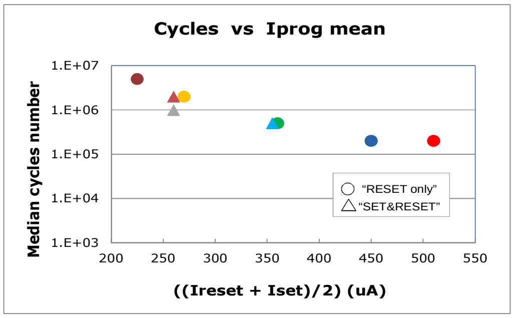

Fig.6 Number of cycles (median of distribution) as a function of Iprog mean per cycle. "SET&RESET" cycling results are aligned to "RESET only" ones with same Iprog mean per cycle and same RESET pulse width