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Endurance enhancement of elevated-confined phase change random access memory

H. X. Yang [1,2*], L. P. Shi[1], H. K. Lee[1], R. Zhao[1] and T. C. Chong[3]
[1] Data Storage Institute, A*STAR (Agency for Science, Technology and Research)
DSI Building, 5 Engineering Drive 1, Singapore 117608
Phone: +65-68745093 Fax: +65-67778517 E-mail: Yang_Hongxin@dsi.a-star.edu.sg
[2] Department of Electronic and Computer Engineering, National University of Singapore, Singapore 117608
3 Singapore University of Technology and Design, 287 Ghim Moh Road, Singapore 279623

1. Introduction

Phase change random access memory (PCRAM) is the most promising candidate for the next-generation nonvolatile memory. [1][2] Recently, elevated-confined PCRAM using an elevated metal column was proposed as a promising approach to achieve lower RESET current [3]. Besides the RESET current, endurance is another critical parameter for PCRAM. In this paper, we investigated the failure mode for endurance test and proposed a writing optimization method to enhance the overwriting cycles for elevated-confined PCRAM.

2. Elevated-confined PCRAM

Figure 1 shows the cross-section view of an elevated-confined PCRAM. A metal column (TiW of 30nm in height and 200 nm in diameter) was formed on a planar bottom electrode (TiW of 200nm in thickness) and a via (200nm in diameter) was formed on top of this metal column by having a dielectric (50nm in thickness) around it. The phase change material, $Ge_2Sb_2Te_5$ (40nm in thickness) was then deposited into the via, followed by the top electrode (TiW of 200nm in thickness) formation.

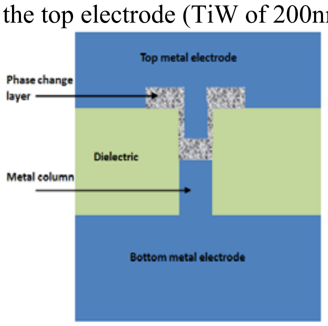

Fig.1 Cross-section of elevated-confined PCRAM

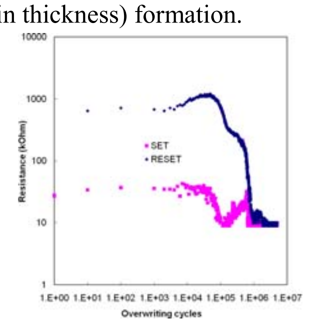

Fig. 2 Endurance cycle for cell from first group with SET 400ns 0.67mA and RESET 20ns 1.66mA

3. Failure mode of Elevated-confined PCRAM

For a mushroom structure, the failure mode is categorized into two types: "stuck SET" and "Stuck RESET". [4-6] Stuck SET was mainly caused by GeSbTe element segregation and diffusion. Stuck RESET is resulted by void formation. To investigate the failure mode of elevated-confined PCRAM, more than hundred elevated-confined PCRAM cells have been tested with different pulses. Even with different writing pulses, it was found that all elevated-confined PCRAM cells failed in the same mode: "Stuck SET". Fig.2 shows one of the tested endurance cycle results. As diffusion is the main killer for Stuck SET, it is better to control the diffusion speed to enhance the endurance of elevated-confined PCRAM. And diffusion is highly dependent on working temperature. Hence, the temperature distribution of elevated-confined PCRAM was simulated.

4. Simulation and discussions

Finite element method (FEM) simulation has been done to investigate the thermal distribution of elevated-confined PCRAM. In this simulation, it is assumed that the melting temperature T_m of $Ge_2Sb_2Te_5$ is 600 °C and initial state is fully crystalline state. By applying 6 ns and 50 ns pulses of 1.5V on separate occasions, the temperature distributions of elevated-confined PCRAM were achieved as shown in Fig. 3(a) and (b)). Comparing Fig. 3(a) with Fig. 3(b), it can be seen that the melting region when using 50ns pulse is much larger than that of 6ns pulse. That means the RESET amorphous region is much larger for 50ns pulse than that for 6ns pulse with same amplitude. In addition, the top electrode temperature and peak temperature in $Ge_2Sb_2Te_5$ are much higher for 50ns than those of 6ns. That indicates much faster diffusion with longer pulse width at same pulse amplitude.

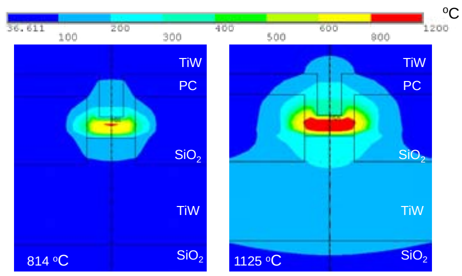

Fig.3 Temperature distribution of elevated-confined PCRAM under pulse (a) 6ns 1.5V and (b) 50ns 1.5V

With second simulation, 6ns pulse of 1.54V and 50ns pulse of 1.3V was applied, on separate occasions, to the cell to reach same peak temperature of around 850 °C. Fig.4 (a) and (b) shows the simulation results. It can be observed that the regions above 600 °C and 800 °C when using 50ns pulse of 1.3V are still much larger than those of 6ns. Hence, it can be concluded that writing pulse width is more effective in controlling the surrounding temperature and diffusion as compared to the pulse amplitude.

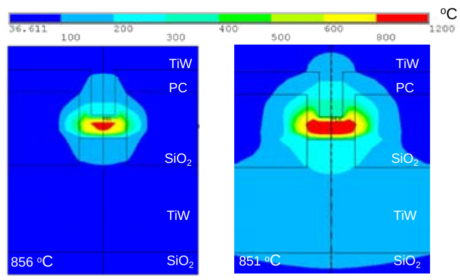

Fig.4 Temperature distribution of elevated-confined PCRAM under pulse (a) 6ns 1.54V and (b) 50ns 1.3V

As a result, the phase change region of elevated-confined PCRAM cells can be controlled with proper initialization pulse with the pulse width being more effective than the pulse amplitude. As diffusion of $Ge_2Sb_2Te_5$ is the key failure mode for confined \PCRAM structure, it will be more serious at higher temperature, which will cause fast failure of elevated-confined PCRAM. The other advantage of small phase change region is that the surrounding as-deposited $Ge_2Sb_2Te_5$ will be a good barrier for phase chagne region diffusion. Hence, the endurance cycles of elevated-confined PCRAM can be enhanced with smaller active region (together with shorter RESET pulse with and lower pulse amplitude).

5. RESET R-I curve of Elevated-confined PCRAM

The R-I curve of elevated-confined PCRAM has been measured in two different sequences. At first, the R-I curve was measured with short electrical pulses of 6 ns increasing to longer pulses of 50 ns and with current ranging from 0 mA to 1 mA. The measured result was shown in Fig.5 (a). It can be observed that RESET current is higher with longer pulse width. The RESET current is 0.5mA for 6ns pulse and 0.7mA for 50ns. The R-I curve was then measured with long pulse decreasing to short pulse. Fig.5 (b) showed the RESET R-I curve measured with 50ns to 6ns pulses. It can be seen that RESET current becomes larger with shorter applied pulse width.

RESET current of the two testing methods has been summarized in Fig.6. It's very clear that RESET current becomes higher with shorter pulse when the initially applied pulse is longer. This is consistent with reported results. [7] However, the RESET current becomes higher with longer pulse when from the initially applied pulse is shorter. This is because the phase change region gets larger and larger when the applied pulses increased from 6ns to 50ns in pulse widths. R-I curve testing from long pulse to short pulse doesn't have this issue as the initial long pulse has already created the largest possible phase change region. To RESET the same amount of phase change region, short pulse will need higher current amplitude than that of the longer pulse.

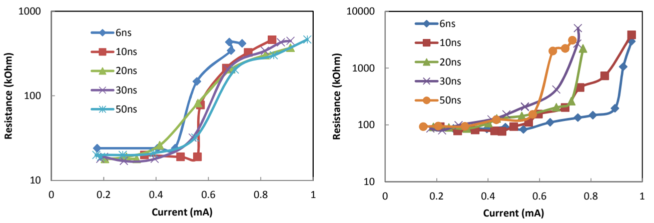

Fig. 5 RESET Resistance-current curves (a) measured from short pulse to long pulse and (b) from long pulse to short Pulse

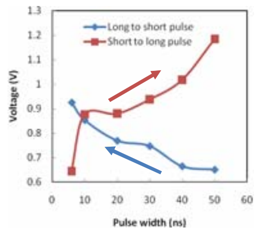

Fig.6 RESET current dependent on pulse width

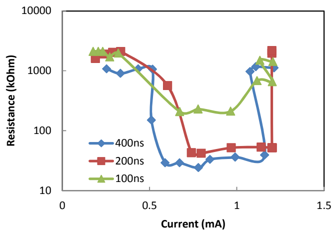

Fig.7 SET Resistance-current curves with different pulse width

Figure 7 shows the SET Resistance-current curve for elevated-confined PCRAM. The elevated-confined PCRAM cells can be SET with pulse width ≥200ns. Lower SET current is needed for longer pulse width.

6. Endurance of elevated-confined PCRAM

Overwrite cycling experiments of elevated-confined PCRAM cells were performed. The elevated-confined PCRAM cells were separated into two groups. The first group was initialized with a strong pulse and the second group was initialized with a weak pulse. The phase change region of the elevated-confined PCRAM cells from the first group will be larger than that of the second group [8]. It is measured that the RESET and SET conditions of cells from the first group are higher than those of cells from the second group. For example, one cell from the first group has RESET pulse of 20ns at 1.66mA and SET pulse of 400ns at 0.67mA. The other cell from the second group has RESET pulse of 15ns at 0.96mA and SET pulse of 400ns at 0.47mA. With these SET and RESET conditions, endurance cycle test have been done for the two cells. The endurance cycle testing results are shown in Fig. 2 and Fig.8 separately. It can be observed that the cell from the second group has a better overwriting cycle of $>10^8$ when compared to that of the cell from the first group one ($<10^6$). The failure mode of both elevated-confined PCRAM cells are "stuck SET", which is caused by diffusion. From these results, it can be concluded that the endurance of elevated-confined PCRAM can be enhanced with lower initialization pulse, shorter RESET pulse width and smaller active region. This is consistent with simulation results.

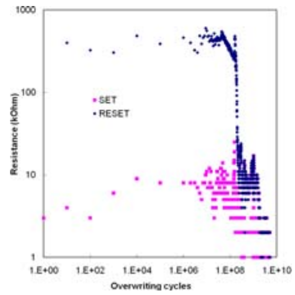

Fig. 8 Endurance cycle for cell from second group with SET 400ns 0.47mA and RESET 15ns 0.96mA

7. Conclusions:

200nm elevated-confined PCRAM cells were fabricated and tested. It is found that value of RESET current is related to the initial RESET pulse width and amplitude. Both experiment and simulation results show that RESET current is lower with lower initial RESET pulse and smaller phase change region. With lower initial RESET pulse, the overwriting cycles of elevated-confined PCRAM cells can reach to above 10^8 instead of 10^6. Controlling the initial phase change region can effectively reduce power consumption and enhance the endurance. More results will be reported in the conference.

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