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Simulation of Retention Behavior for the Phase Change Memory

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1. Introduction

Phase change memory (PCM) has been identified as a promising candidate for the next generation nonvolatile application because of its large endurance, fast speed and long retention [1-2]. The SET state (crystallization) and the RESET state (amorphous) are two basic stable state in PCM, and it can be transformed to each other under certain conditions [3]. The data retention properties are the fundamental of the capacity of PCM cells. Usually room temperature data retention is at least 10 years, accurate accelerate methods should be adopted to obtain the reliability characterization and estimation [4]. Based on a comprehensive simulation program of PCM including the electrical, thermal, phase change and percolation model developed by us [5], the simulation of PCM retention behavior is developed and investigated. Both the macro resistance and micro phase change process are simulated. And, three factors including temperature, pre-existing grains' amount and its distribution on the PCM retention behavior are evaluated.

2. Device Structure and Simulation Method

Fig.1 shows the simulated phase change memory cell where a thin film phase change material (GST) is contacted by a top electrode (TE) and a cylindrical bottom electrode (Heater). Corresponding parameters are listed in Table 1. In the simulation program, we consider the four coupled models including electrical model, thermal model, phase change model and percolation model. SET state can be obtained by holding the GST material to a certain temperature (below the melting temperature) and then annealled slowly. RESET state can be obtained by rapidly melting and annealing GST [3]. The data retention model describes the formation of crystalline grains in the amorphous phase (HRS) according to the standard nucleation theory [6]. A temperature accelerate method is used to estimate this process [5].

3. Results and Discussion

Fig.2 shows the resistance dependency on SET time. With the application of the SET pulse amplitude of 2.5V, resistance of PCM begins to drops at 60ns due to the formation of a high conduction crystalline path between TE and heater as shown in the inserts of Fig.2. Fig.3 shows programmed resistances as a function of variable pulse amplitudes. Resistance for the initial crystalline state remains low until RESET pulse amplitude close to 2.5V (melting point) and then gradually increases toward the highest resistance state above 3.5V (RESET point). Fig.4-8 shows the simulated macro and micro retention process. The resistance of PCM R evolution with time is shown in the Fig.4, the high resistance tends to be lower by crystallization gradually due to the metastable nature of the amorphous phase. Four special points A, B, C and D are marked in the macro R-t curve and the corresponding micro phase distributions are shown in Fig.5. As we can see, the transition from amorphous region to the crystalline region is caused by crystalline grains' growth (inner growth and outer growth) and nucleation which are quantitatively analyzed through probability contours in Fig.6-8. Inner growth probability decreases (0.654 to 0.131) at gradient direction of the contour circles which is centered closed to the amorphous region edge. Outer growth probability decreases (0.833 to 0.167) at gradient direction of the region-edge-like contour, while inner nucleation increases (0.0118 to 0.0589) similarly. Fig.9 shows the simulated retention behavior of R-t curves at the T=210℃, 200℃, 190℃ and 180℃ and the retention time increases with the temperature decreases. The retention time t_h which corresponds the time when R drop to the half of the initial resistance with different temperature are simulated and shown in Fig.10. The experimental data [7] are also plotted for comparison. The results verified our simulation. Pre-existing grains' amount and its distribution on the PCM retention behavior is evaluated. The retention behavior with various proportion (0%, 20% and 40%) pre-existing grains in the amorphous region with random distribution are simulated and shown in Fig.11. Besides, the distribution of the same 10% quantitative pre-existing grains has a great effect on the retention process (see Fig.12). The curve shifts to the right with the angles θ increases (0º, 30 º, 60 º and 90 º).

4. Summary

In this research, we exhibit a new self-consistent PCM simulator. Programming operations (SET, RESET and RENTENTION) are investigated by simulator. Compared the macro and micro process, we can understand of the phase change physical mechanism in the retention process. Our results show that different temperatures impact the retention time greatly. The amount of pre-existing grains has a slight influence on the retention time while the influence of the distribution of pre-existing grains is obvious.

Acknowledgements

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References

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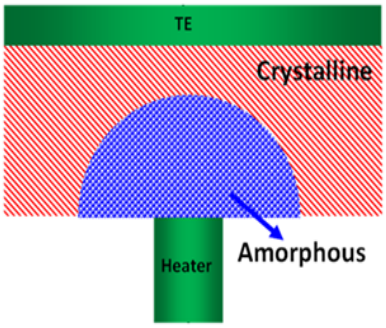

Fig.1 Schematic of a PCM cell simulated in this research.

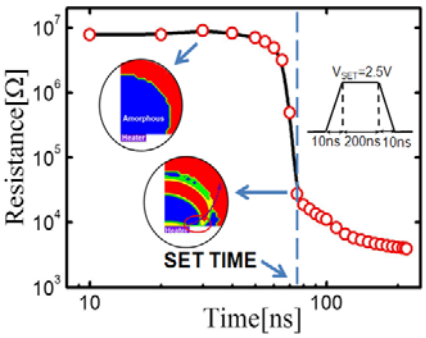

Fig.2 Resistance evolution with variable SET time for the cell in the initial amorphous state.

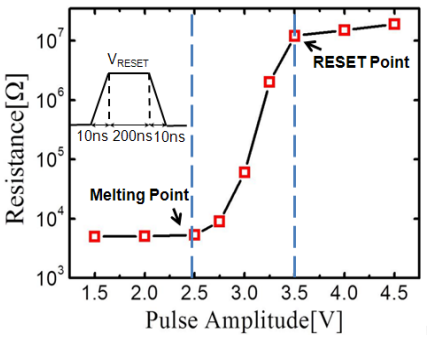

Fig.3 Resistance evolution with the increasing RESET Pulse voltage for the cell in the initial crystalline state.

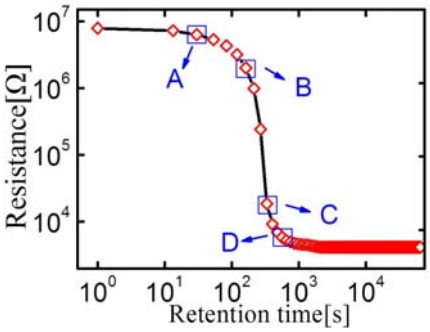

Fig.4 Resistance evolution with the Retention time for the cell in the initial amorphous state. (T=200℃)

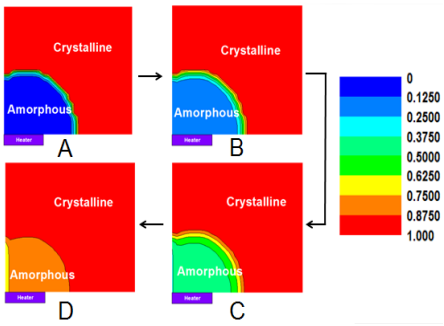

Fig.5 Micro phase distribution in the retention process. (point A, B, C and D)

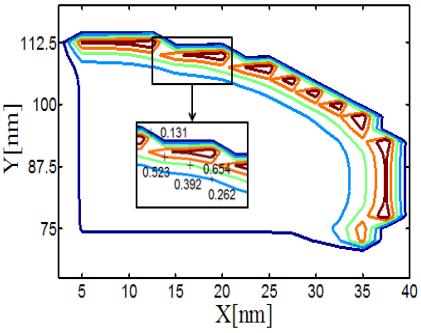

Fig.6 Inner growth probability in the phase change area. (point B in Fig.5)

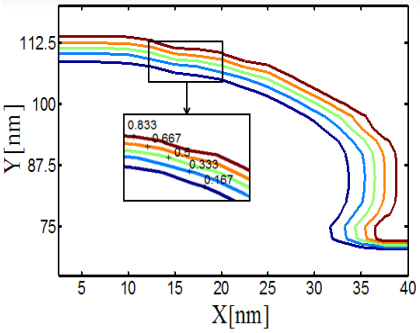

Fig.7 Outer growth probability in the phase change area. (point B in Fig.5)

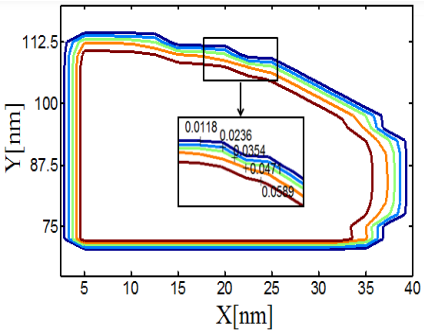

Fig.8 Inner nucleation probability in the phase change area. (point B in Fig.5)

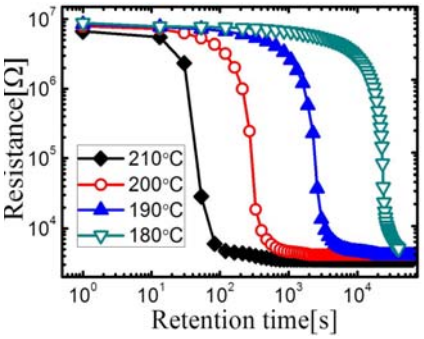

Fig.9 Simulated R−t curves at the temperature of 210℃, 200℃, 190℃ and 180℃ in the retention process.

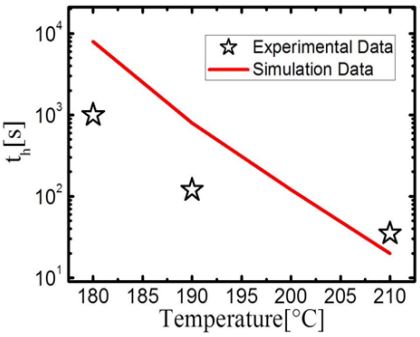

Fig.10 Simulated t_h−T curves for the different retention temperatures. The experimental data [7] is also shown.

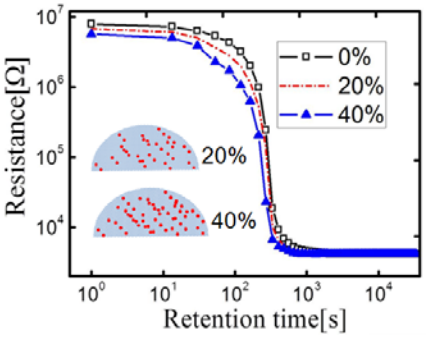

Fig.11 Simulated R−t curves with different initial crystallization grain proportion (0%, 20% and 40% with random distribution.

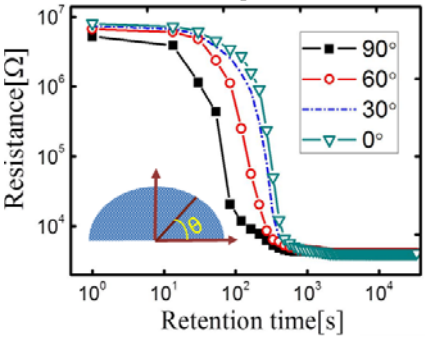

Fig.12 Simulated R−t curves with the initial same amount grains at different θ angles to the horizontal axis.

Table.1 Parameters used in the simulation.

PARAMETERS	VALUES	PARAMETERS	VALUES	PARAMETERS	VALUES
Device Width (W)	300nm	SiO_2 electrical resistivity	$1\times10^{14}\Omega$m	TiN thermal capacity	0.7×10^{6}J/m^{3}K
Heater Width(W)	70nm	SiO_2 thermal conductivity	1.4W/mK	Crystalline GST thermal capacity	1.2×10^{6}J/m^{3}K
Heater Width(W)	50nm	SiO_2 thermal capacity	3.1×10^{6}J/m^{3}K	Amorphous GST thermal capacity	1.2×10^{6}J/m^{3}K
Top Electrode Length (Ht)	30nm	TiN electrical resistivity	$2\times10^{-5}\Omega$m		
GST Material Thickness (Hm)	100nm	TiN thermal conductivity	30 W/mK		