Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 244-245

D-3-2

Programming Characteristics of PRAM

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Abstract

In this paper, we analyze the Initialization of Chalcogenide Material (ICM) mechanism and propose the next generation PRAM scheme. It is proposed that the ICM operation power can be lowered by decreasing the chalcogenide film thickness. To overcome the inherent limitation of high operation power, the self-heat confined structure is proposed and the ICM power can be significantly reduced. The chalcogenide scaling scheme, based on new proposed structure can resolve the operation power limitation in PRAM development.

Introduction

The Phase-change Random Access Memory (PRAM) is a nonvolatile device based on the reversible phase change of chalcogenide material ($Ge_2Sb_2Te_5$). Since the resistance ratio between crystalline and amorphous states is about 10,000 as shown in Fig.1 [1], this device has the advantages of data sensing margin. However, the as-deposited chalcogenide material is not in the pure-crystalline state and overall characteristics are very sensitive to the as-deposited film quality. Thus, the heat treatment to the as-deposited film is indispensable to guarantee the reliable device operation, especially high sensing margin. The ICM that transforms as-deposited film from mixed to homogeneous states by applying the high current is one of heat treatments. Since the 2~3 times higher power than the RESET operation is required, however, the ICM is a major obstacle in PRAM development. In this paper, we extensively analyze the ICM mechanism by comparing experiments and simulation results to obtain the optimum ICM condition. In addition, we discuss the problem associated with cell size scaling and propose solution by using the simulation methodology incorporating the phase-change phenomena [2].

Structure and Characteristics of PRAM

The vertical TEM image in Fig. 2 shows the PRAM cell structure. There are two cells and one common drain on the one active. A MOS transistor is used as an access switching device. The chalcogenide material is placed between TEC (Top Electrode Contact) and BEC (Bottom Electrode Contact). M0 and M1 are formed as drain line and bit line, respectively. Fig. 3 shows the measured I-V characteristics of the chalcogenide material in crystalline and amorphous states. The RESET and SET resistances are clearly separated in the reading operation region [3]. As the threshold voltage appears at about 1.1 V, it is enough to avoid the reading disturbance.

Analysis of ICM Mechanism

Fig. 4(a) shows the TEM image of the chalcogenide film after the ICM operation. The region nearby the bottom contact (in dark color) is melted and then quenched into the amorphous phase. The surrounding region is crystallized. The remaining region is in the mixed phase and the phase is not changed in the following RESET/SET operations. We applied the simulation to analyze phase change phenomena and demonstrate the close agreement with TEM result as shown in Fig. 4(b). In the simulation, the crystal fraction of the as-deposited film is set to 40%. The same parameter sets including the electrical and thermal conductivities are verified with the measured R-I characteristics for various operating currents as shown in Fig.5. Using the simulation, which is verified by experimental results, we investigate the ICM mechanism analysis.

Fig.6 shows the measured resistance characteristics after ICM operation. From this result, the ICM operation effect is classified into three items; the difference of R_{SET}, RESET delay, and R_{RESET}. Firstly, Fig. 7(a) and (b) explain the difference of SET resistance after high and low power ICM operation. The SET resistance proportionate inversely to the volume which is affected by ICM operation, because the initial phase in the mixed state of amorphous and crystalline phases has a larger resistance than that of the crystalline phase. Therefore, the SET resistance after low power ICM is larger than that of high power ICM operation. Secondly, the characteristics of RESET delay can be explained by the difference of heat isolation as shown in Fig. 7(c) and (d). The heat isolation effect is larger in the low power ICM case because the thermal conduction of the mixed state is lower than that of the pure-crystalline state. Because of this reason, the I_{RESET} to reach a target RESET resistance in the low power case is lower than that of the high power ICM operation. Finally, after the high power ICM operation, the durability variation of nucleating sites or the migration of the Tellurium element causes the material characteristics to vary [4]. It causes the resistance variation under the RESET operation. As described in Fig.8, the variation of the electrical conductivity due to Te migration results in change of RESET resistance observed in experiments. As can be seen from the results of analysis, the ICM operation power can be lowered by decreasing the chacogenide film thickness.

Future Programming Scheme

The ICM operation of as-deposited chalcogenide is indispensable to PRAM development. However, the high power ICM operation is an obstacle of the development of high dense PRAM device because of the limitation of transistor drivability in terms of the cell size shrinkage. The ICM operation power is usually 2~3 times higher than the RESET power. Therefore, either the new ICM method or the method for decreasing ICM power in the present condition is absolutely required. In this paper, we propose the new cell structure of PRAM, called by self-heat confined structure. The magnitude of I_{RESET} or ICM power depends on how to increase the current density and decrease the heat loss. In the normal cell structure of PRAM, the heat is generated at the interface between the BEC and chalcogenide material. Although the current density is increased by the scaling of contact size, it is not easy to get low I_{RESET} because of the heat loss through the metal contact. This causes higher heat conduction than chalcogenide material. However, the heat generation of self-heat confined structure occurs in chalcogenide material as shown in Fig.9. The separation of the heat generation core from the metal contact interface should be accompanied with the chalcogenide scaling for increasing the current density, which is done by the contact scaling in the conventional structure. The scaling effect of the self-heat confined structure is shown in Fig.10. With the proposed structure, it is possible to reduce I_{RESET} by more than 50 percents compared to the normal type. In addition, it can avoid the side effects caused by multi cycle transition at the contact-chalcogenide interface and the cell scaling can be done more effectively with the chalcogenide scaling.

Conclusions

We have analyzed the ICM mechanism and proposed the next generation PRAM scheme using simulation. The ICM operation is the indispensable method in the PRAM process, but on the other hand it presents the limitation and challenges in future PRAM development. With the self-heat confined structure, the significant decrease of ICM power, the inhibition of side effect, and the densification of cell size are anticipated.

References

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[3] Y.-N. Hwang *et al.*, IEDM Technical Digest, 2003, pp. 893-896.
[4] R. Neale *et al.*, Electro. Engineering, 2001, pp. 67-78.

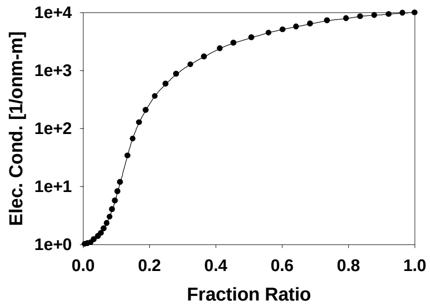

Fig. 1. Electrical conductivities of chalcogenide material, $Ge_2Se_2Te_5$, as a function of crystal fraction.

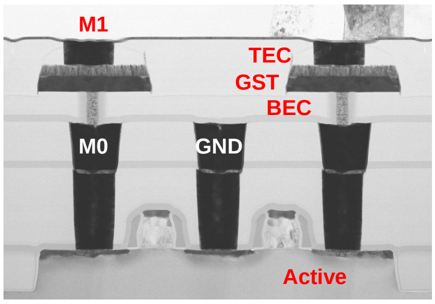

Fig. 2. Vertical TEM image shows full process integration.

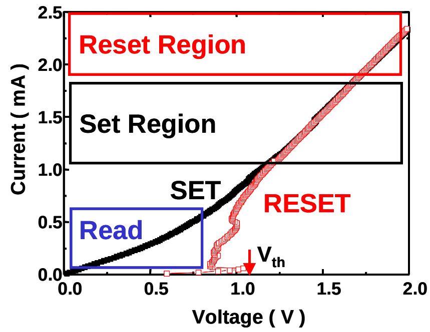

Fig. 3. Measured I-V characteristics of PRAM. The threshold voltage appears at about 1.1 V. It is enough to avoid the reading disturbance.

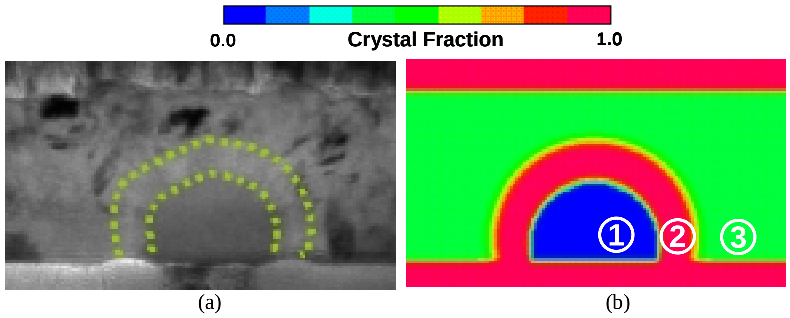

Fig. 4. Phase change phenomena after ICM operation. (a) TEM image. (b) simulation result. ①the amorphous state, ②the pure-crystalline state, ③the mixed state.

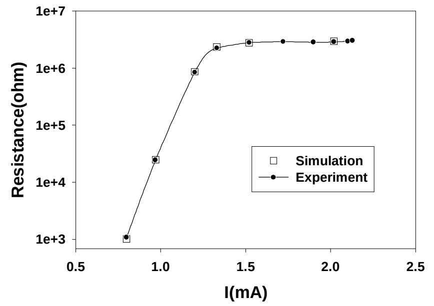

Fig. 5. Comparison of measured R-I characteristics with the simulation results using calibrated electrical conductivity.

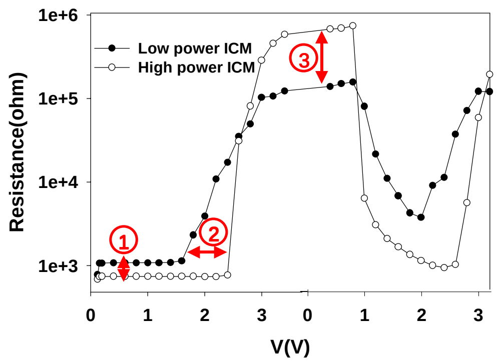

Fig. 6. Measured cell resistance after the high and low power ICM operation. Differences in ① R_{SET}, ② RESET delay, and ③ R_{RESET}.

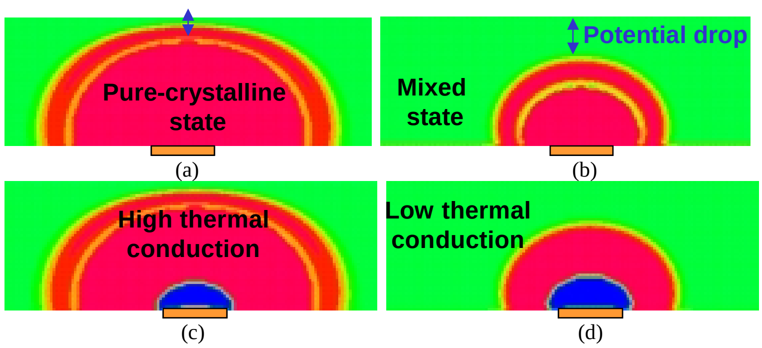

Fig. 7. Phase distribution. (a) SET after the high power ICM. (b) SET after the low power ICM. (c) RESET after the high power ICM. (d) RESET after the low power ICM.

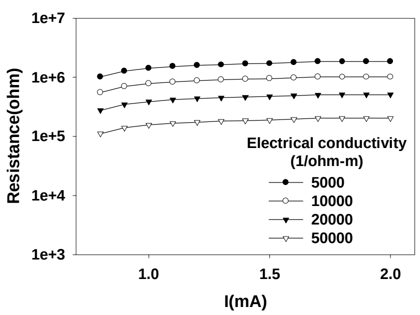

Fig. 8. Resistance variation for the variance of electrical conductivity in RESET operation after high power ICM operation.

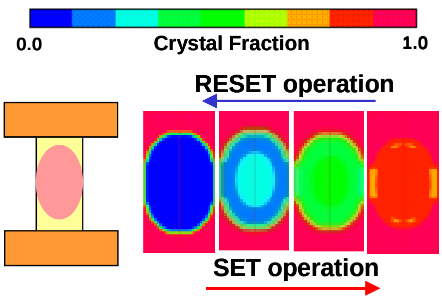

Fig. 9. Self-heat confined structure and phase change phenomena.

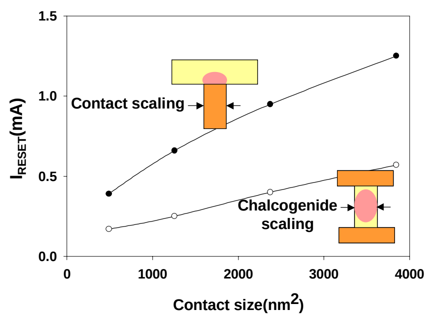

Fig. 10. I_{RESET} for scaling contact and cell size between normal bottom contact and self-heat confined structures.