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Microstructural Characterization in Reliability Measurement of PRAM

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1. Introduction

Flash memories have been scaled down continuously since its introduction and become the mainstream of non-volatile memory (NVM) technology. In recent, phase-change random access memory (PRAM) has been attracting a considerable interest in view of the increasing scaling difficulties of NAND and NOR Flash memories. Since the early discovery of Stanford Ovshinsky in 1968 [1], improvements in phase-change material technology paved the way for development of commercially available compact disk rewriteable (CD-RW) and digital versatile disk (DVD). These advances have motivated development of the PRAM technology at the present technology node [2]. The new confined type cell structures are being attempted in order to be more scaled [3,4], and the reliability of the scaled down cell should be investigated. We have classified the failure mechanism of the confined type cell after a large number of programming cycle, and investigated the physical structure by Transmission Electron Microscope (TEM) and the electrical properties.

2. Experimental Results

Failed cells after 10M cycles are classified into 3 groups which are stuck set of reset state, stuck reset of set state, and tails from the distribution of reset state whose resistance is lower than normal cells. Tails from the set distribution whose resistance is high was not occurred in this cycle test because both set and reset resistances tend to decrease with cycles. Resistance distributions of set and reset states after 1k, 10k, 100k, 1M, and 10M cycles are shown in Fig. 1. Set and reset resistances decrease gradually with cycles, but the gradual decrease of reset resistance is not obvious because the conversion scale of resistance is not sensible at high resistance. In a measurement for a single cell in real resistance scale, the gradual decrease of reset resistance was confirmed.

Stuck reset of set state after 10M cycles is OPEN due to a void created at the interface between GeSbTe (GST) film and bottom electrode contact (BEC) which is shown in Fig. 2 (a). The stuck reset has been investigated by several research groups [5,6], and their results were also a void at the GST and BEC interface. They reported that the tiny cavities inside GST film due to volume shrinkage after BEOL processes coalesce each other with cycles in order to lower their surface energy, and becomes a large void that leads to failure by covering the whole BEC. In addition to the image analysis, we have analyzed the compositional change of GST by energy dispersive X-ray spectrometer (EDS) in Fig. 2 (b), which shows the excessive increase of Sb from that of virgin cell. The fact that Sb increase with cycles from the virgin GST cell is already known, but the degree of Sb increase in the stuck reset is more excessive than the normal cells.

Reset failures with cycles are grouped into the stuck set that cannot be operated anymore under normal writing conditions and tails from the distribution of reset state that is insufficiently written after a large number of cycles. Fig. 3 (a) shows the TEM bright field image of the stuck set after 10M cycles, where we see the density of the active region has been lowered rather than surroundings, but there is no distinct void like the stuck reset in Fig. 2 (a). The dark field image in Fig. 3 (b) is more definite about the lowered film density. That the film density at the active region is lowered without a distinct large void means that smaller voids are spread throughout the active region. Therefore, the small voids or lowered film density make the melting and subsequent transition into reset state impossible by blocking heat

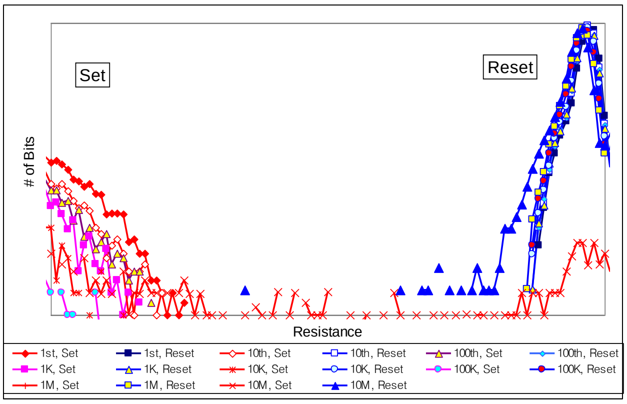

Fig. 1 Distribution of set and reset resistance.

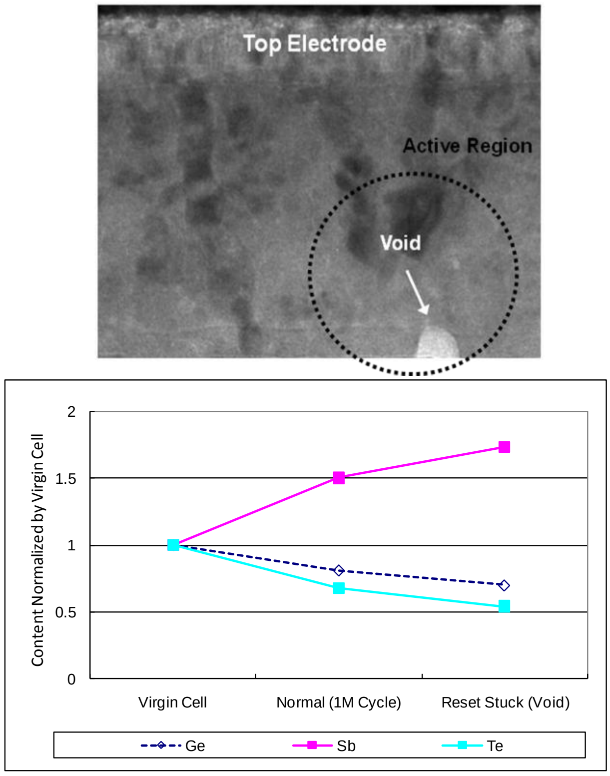

Fig. 2 (a) TEM image of the stuck reset due to a large void that covers the whole BEC, (b) More excessive Sb increase in the reset stuck cell than normal cell after cycles analyzed by EDS.

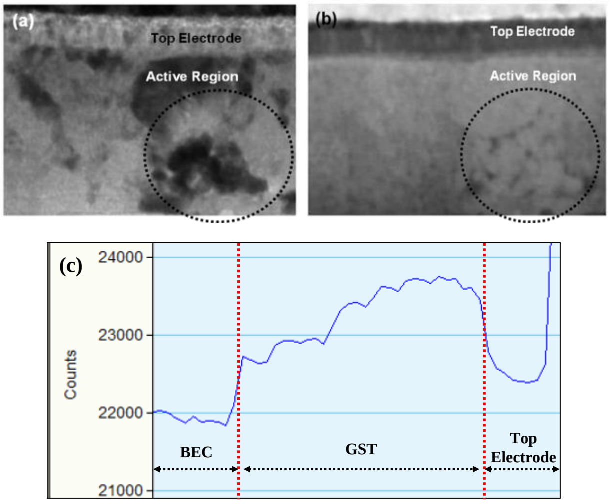

Fig. 3 (a) TEM bright field image of set stuck cell, (b) TEM dark field image of set stuck cell shows the lowered density of GST film at the active region, (c) Gradual decrease of EDS peak intensity from top to bottom of the GST film at the active region.

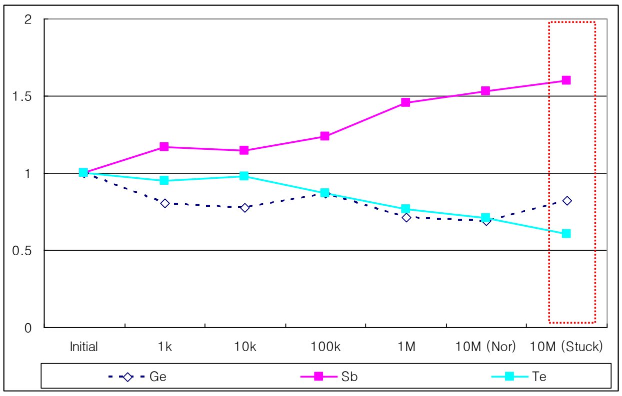

Fig. 4 Gradual increase of Sb with cycles. The stuck set at 10M cycles shows the more excessive compositional change than normal cells.

from BEC. Fig. 3 (c) shows the EDS peak intensity gradually decreases from top to bottom of the GST film, which means that the density of the active region at the bottom is lower than the top region that does not suffer from melt and stress. The compositional change of the stuck set is different from the normal cells, but not remarkable.

As already mentioned, set and reset resistances gradually decrease with cycles, which is shown in Fig. 1. Gradual decrease of both resistances are related to the fact that at least one of the resistance components in the serial path of BEC, interface, and GST decrease with cycles. Although BEC contamination by Ge with cycles [6] can cause the resistance decrease, Sb increase inside the active region which is already reported [5] is also revealed in this analysis. Fig. 4 shows the gradual increase of Sb with cycles from the initial stage. Although the compositional change of the stuck cell at 10M cycles is different from the normal cell, they are not remarkable because the stuck cell basically results from the lowered film density.

Fig. 5 shows the behavior of tail cells from the reset distribution that are insufficiently written. When applied by 10% higher writing current, the reset distribution recovers its initial distribution. This means that the current needed to make high reset resistance shown at initial stage increases gradually because the resistivity of active region goes down due to the increase of Sb with cycles. Although a higher current should be delivered into the tail cells in order to make high reset resistance, the way to prevent the resistance decrease with cycles should be ultimately researched.

3. Conclusions

As the GST cell in PRAM is scaled down, the unusual reliability failure can be encountered. We have classified the cycling endurance failure into 3 groups, and analyzed the each failure electrically and structurally. Both the stuck set and the stuck reset are due to a void. A large void that covers the whole BEC causes the stuck reset, and the lowered density of GST film at the active region by small voids leads to the stuck set. Gradual Sb increase with cycles caused the tails from the reset distribution, which recovers its initial high resistance by higher writing current. Research should be done in order to prevent the gradual change inside the active region with cycles and abrupt void formation at high cycle.

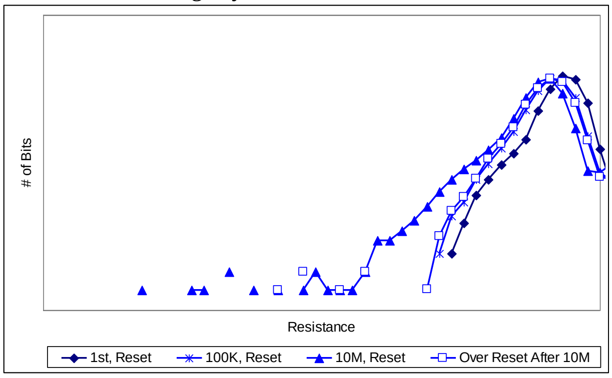

Fig. 5 Recovery of tails from the reset distribution after 10M cycles to their initial distribution by delivering higher writing current.

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