

Temperature Dependence of Phase Change Random Access Memory Cell

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1. Introduction

Phase change random access memory (PCRAM) technology is based on the reversible electrical switching phenomena in the disordered semiconducting materials originally reported by S. R. Ovshinsky in the late-1960s[1]. Electrical pulses are applied to switch the chalcogenide film between amorphous state and crystalline state induced by Joule heating. The amorphous state with a high resistance and the crystalline state with a low resistance are programmed by the current pulses with different current magnitude and pulse duration, and are denoted as "0" and "1". Since the binary information is represented by two different stable structure states of material, it is inherently nonvolatile. PCRAM is regarded as one of most promising next-generation non-volatile memory technology because it has near ideal advantages such as high scalability, low process complexity, low cost and fast writing time.

Ge-Sb-Te Chalcogenide material, which has commercially used in rewritable optical disk, is the most popular material used in PCRAM as a recording material because it has a wide composition tolerance for high speed crystallization. In the Ge-Sb-Te system, two binary compounds GeTe and Sb₂Te₃ and three ternary compounds Ge₂Sb₂Te₅, Ge₁Sb₂Te₄ and Ge₁Sb₄Te₇ are in a row on the a pseudobinary line connecting GeTe and Sb₂Te₃[2].

Compared with other next-generation non-volatile memories such as MRAM and FRAM, the thermal engineering in PCRAM is a key challenge for PCRAM technology because a thermal energy induces the data writing and erasing based on a phase transition between the amorphous and crystalline states, meanwhile it brings the thermal deterioration on device. The thermal properties of PCRAM cell are dominated by the phase change recording material. To evaluate the thermal properties and thermal deterioration of PCRAM cells with different materials at different temperature, the temperature dependence of PCRAM cell on phase change recording materials were studied and compared, the possible mechanism was discussed.

2. Experimental Procedure

The circular patterning of PCRAM cells employed a Canon FPA 2000i1, which is an i-line stepper capable of printing 0.5 micron lines with a wavelength of 365 nm and a NA of 0.52. The different Ge-Sb-Te compound films (GeTe, Sb₂Te₃, Ge₂Sb₂Te₅, Ge₁Sb₂Te₄ and Ge₁Sb₄Te₇) were sandwiched by two TiW electrodes in lateral and covered with a ZnS-SiO₂ isolator film deposited by a Balzers CUBE sputtering system. From the substrate up, the layer specifications were as follows: a 200 nm TiW layer, a 100 nm ZnS-SiO₂, a 50 nm GeSbTe phase change layer followed by a 50 nm TiW layer, a 100nm ZnS-SiO₂ and finally a 150 nm TiW layer. All the

characterization experiments for PCRAM cells including set, reset and read were conducted in an in-house multi-functional PCRAM tester. PCRAM cell were fixed tightly on the thermo chuck with 8 sharp probes in a Cascade probe station. The set /reset signals were provided by a current pulse generator with an arbitrary waveform generator (AWG) controlled by a computer. A Tektronix TDS784A oscilloscope monitored the actual current flowing across the CRAM cell. The resistance was measured with a multimeter (PCI-DMM). The I-V measurement was conducted through Keithley 4200 Semiconductor Characterization System. The cells were annealed for 3 minutes at each setting temperature from room temperature to 200 °C.

The phase transition temperature, melting temperature and the activation energy for crystallization of Ge-Sb-Te films were measured by a Shimadzu DSC-50 differential scanning calorimeter. The optical constants and optical energy gap were characterized using a Uvisel spectroscopic phase-modulated ellipsometer. The micro-Raman spectra of samples were measured using an ISA T64000 Raman spectrometer.

3. Results Discussion

Figure 1 shows the phase diagram of Ge-Sb-Te system with material characteristic. Our DSC and ellipsometer measurement results of GeTe, Sb₂Te₃, Ge₂Sb₂Te₅, Ge₁Sb₂Te₄ and Ge₁Sb₄Te₇ films show that GeTe has a high crystallization temperature & a high melting point which make it very stable, and it has a bigger band gap at room temperature which lead to a slow crystallization speed. Sb₂Te₃ has a lower crystallization temperature & the melting point which results in a poor stability, and it has a smaller band gap at room temperature causing a fast crystallization speed. The ternary compounds can be regarded as the different combinations with GeTe and Sb₂Te₃ binary compounds, such as Ge₂Sb₂Te₅ ↔ (GeTe)₂(Sb₂Te₃), Ge₁Sb₂Te₄ ↔ (GeTe)(Sb₂Te₃), and Ge₁Sb₄Te₇ ↔ (GeTe)(Sb₂Te₃)₂. GeSbTe compound materials possess both the stability at amorphous states and the high crystallization speed. Along this pseudo line from GeTe to Sb₂Te₃, the crystallization speed becomes faster and the thermal stability becomes poor. Figure 2 shows the temperature dependence of ln(α/T²) of Ge-Sb-Te films. The activation energies for crystallization of Ge-Sb-Te films were calculated. For example, the activation energy for crystallization of Ge₂Sb₂Te₅ film is 2.28eV. Sb₂Te₃ film does not have data because it has already been crystallized during sputtering. Also, the temperature dependence of the micro-Raman spectra of Ge-Sb-Te films was measured and identified the phase transition.

Figure 3 shows the relative resistance of Ge-Sb-Te films on the annealed temperature. The GeTe has a big resistance variation while Sb₂Te₃ has a small resistance variation between amorphous state and crystalline state.

Figure 4 shows the temperature dependence of Set/Reset resistance of $\text{Ge}_2\text{Sb}_2\text{Te}_5$ cell at the reset state. The electrical conduction activation energy was calculated. The results will be presented in the meeting. The I-V curve of $\text{Ge}_2\text{Sb}_2\text{Te}_5$ cell at different temperature is shown in Fig.5. Fig.6(a) shows the temperature dependence of the threshold voltage of $\text{Ge}_2\text{Sb}_2\text{Te}_5$ cell. Fig.6(b) shows the temperature dependence of $\ln V_{th}$ of $\text{Ge}_2\text{Sb}_2\text{Te}_5$ cell. The calculated mean value of threshold voltage activation energy of $\text{Ge}_2\text{Sb}_2\text{Te}_5$ cell is about 0.65eV. The I-V curves at different temperature and the temperature dependence of the threshold voltage of other cells (GeTe , Sb_2Te_3 , $\text{Ge}_1\text{Sb}_2\text{Te}_4$ and $\text{Ge}_1\text{Sb}_4\text{Te}_7$) had also been studied, the results will be presented and compared in the meeting.

4. Computer Simulation and Mechanism Discussion

The temperature dependence of current density, 3D electric field and temperature field of PCRAM cell with different materials was simulated by our in-house PCRAM cell design software[3]. The simulation results will be reported in the meeting.

The activation energy for crystallization, electrical conduction activation energy and threshold voltage energy were compared, the relation was analyzed and derived from electrothermal breakdown process. The temperature dependence mechanism of Ge-Sb-Te PCRAM cell based on the electrical conduction model and electro-thermal model such as the contribution from phonon, electron, electron-hole pair was discussed. More detailed discussion will be reported in the meeting.

5. Conclusions

The temperature dependences of the resistance, I-V curve, threshold voltage of PCRAM cells on the phase change recording materials GeTe , Sb_2Te_3 , $\text{Ge}_2\text{Sb}_2\text{Te}_5$, $\text{Ge}_1\text{Sb}_2\text{Te}_4$ and $\text{Ge}_1\text{Sb}_4\text{Te}_7$ were studied and compared, the mechanism was discussed.

References

- [1] S. R. Ovshinsky, Reversible electrical switching phenomena in disordered structures, Phys. Rev. Lett., 21(20), 1450(1968).
- [2] N. Yamada, Erasable phase-change optical materials, MRS Bulletin, 21(9), 48(1996).
- [3] J. M. Li, et al., SSDM'05, Japan, (2005)

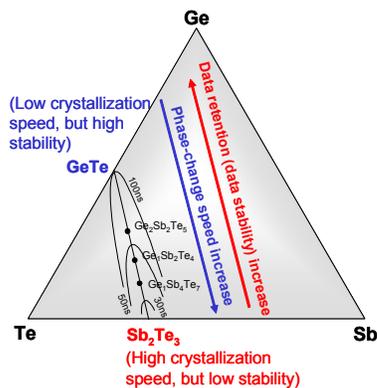


Fig.1 Phase diagram of Ge-Sb-Te ternary system.

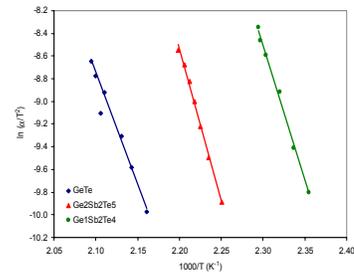


Fig.2 Activation energy for crystallization of Ge-Sb-Te

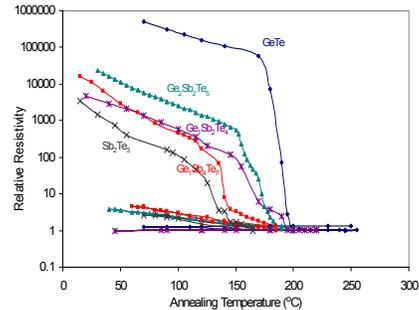


Fig.3 Relative resistance of Ge-Sb-Te films

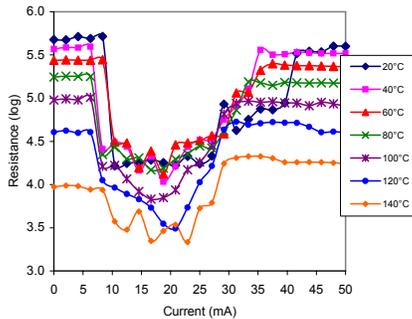


Fig.4 Set/Reset resistance of $\text{Ge}_2\text{Sb}_2\text{Te}_5$ cell

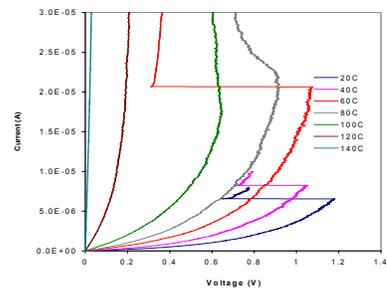


Fig.5 I-V cures of $\text{Ge}_2\text{Sb}_2\text{Te}_5$ cell

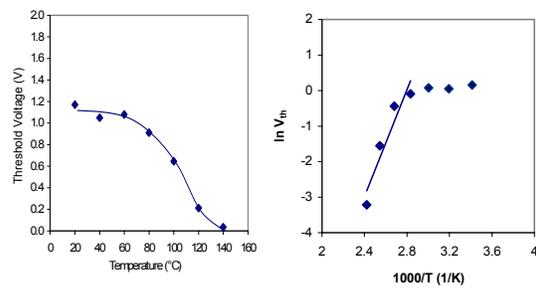


Fig.6 (a) Threshold voltage temperature dependence (b) Threshold voltage activation energy