

Ge-Cu-Te films for phase change random access memory

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ABSTRACT

Simple memory devices with a $\text{Ge}_1\text{Cu}_2\text{Te}_3$ (GCT) were fabricated to evaluate the set-reset switching behaviors of the GCT film. Moreover, the crystallization processes of the amorphous GCT film were investigated by differential scanning calorimetric measurements under non-isothermal conditions. It was confirmed that the GCT device showed typical memory switching behaviors as well as GST device. Moreover, it was found that the local activation energy of the crystallization of the GCT amorphous film decreases with increasing crystallization fraction, which indicates that the crystallization process of the amorphous GCT film has a multi-step mechanism.

Keywords: $\text{Ge}_1\text{Cu}_2\text{Te}_3$, switching behavior, local activation energy, crystallization mechanism

INTRODUCTION

Phase change random access memory (PCRAM) has attracted much attention as a new class of non-volatile memories because of its low production cost and high scalability. $\text{Ge}_2\text{Sb}_2\text{Te}_5$ (GST) film has been widely studied as a phase change material for PCRAM because GST shows a fast crystallization speed and a good reversibility between the amorphous and crystalline states [1,2]. However, GST has a low crystallization temperature T_x of about 150°C and a high melting point T_m of over 600°C [1,3], which limits data retention capability and causes high power consumption for *reset* operation, respectively.

Very recently, the present authors have found that a $\text{Ge}_1\text{Cu}_2\text{Te}_3$ (GCT) amorphous film has a high crystallization temperature of about 250°C [4]. Since GCT compound has a low melting point of about 500°C [5], the GCT is expected to be suitable for PCRAM applications. In the present study, we investigated the electrical properties of the GCT films and the crystallization behaviors of the sputter-deposited GCT amorphous films.

EXPERIMENTS

Simple phase change memory devices of the GCT films as shown in Fig. 1 were fabricated using a conventional photolithography technique to measure the I - V characteristics and switching behaviors, where those of the GST films were also fabricated for comparison. The GCT films were prepared by sputtering of a Ge-Cu-Te alloy target. Differential scanning calorimetric (DSC) measurements were employed to investigate the crystallization kinetics of the GCT films on the SiO_2/Si substrate at various heating rates of 12 - 50°C/min in Ar atmosphere. Film thickness for the DSC measurements was set to be 1500 nm in order to clearly detect an exothermic peak for the crystallization.

RESULTS AND DISCUSSION

Figures 2(a) and (b) show the plots of device resistance vs. voltage applied to the device for the GCT and GST devices, respectively. It is seen that the GCT device shows set-reset switching behaviors as well as the GST device. Figure 2(b) indicates that the V_{reset} for the GCT device are 5.7 V which is lower than that for the GST device of 8.1 V. The power consumption W_{reset} for the reset operation can be estimated by the relation of

$(V_{\text{reset}})^2/R_{\text{PCM}}$, and the W_{reset} for the GCT and GST devices are estimated to be 0.55 W and 0.61 W, where the electrical resistance R_{PCM} was obtained by averaging the electrical resistance of the set state of the devices. The power consumption ratio $W_{\text{reset}}^{\text{GCT/GST}}$ of the GCT to GST devices is calculated to be 0.9, which means that the GCT device achieves a 10% reduction in power consumption for the reset operation compared with the GST device, which is mainly due to a lower melting point of GCT compound.

Figure 3 shows the fraction of crystallization x as a function of temperature at different heating rates, where the crystallization fraction x was determined from the DSC curves [6]. Based on the results of Fig. 3, the local activation energy $E_a(x)$ of the crystallization for different crystallization fractions x is estimated from the following equation, suggested by Ozawa for non-isothermal crystallization [7,8]:

$$\log \beta = \text{const.} - 0.4567 \frac{E_a(x)}{RT} \quad (1).$$

Here, β is heating rate, R is gas constant and T is temperature for a given value of x . Figure 4 shows the $E_a(x)$ plots as a function of the crystallization fraction x . The results indicate that the $E_a(x)$ decreases with increasing crystallization fraction x . This variation of the $E_a(x)$ may be due to the variation of the nucleation and growth processes during crystallization. The overall average activation energy E_a of the crystallization is 2.78 eV, which is very close to the activation energy of 2.81 eV obtained from Kissinger plots using the results of two-point probe resistance measurements [4]. The GST film also shows a similar variation of the local activation energy and the E_a was 2.08 eV. Consequently, the activation energy of the GCT film for crystallization is seen to be higher than that of the GST film.

CONCLUSION

We investigated the electrical switching and the crystallization behaviors of the GCT film. The GCT film showed a typical switching behavior and the GCT device has a 10% lower power consumption for the reset operation than the GST device. The local activation energy $E_a(x)$ of the GCT film decreased with increasing crystallization fraction x , indicating a multi-step crystallization mechanism and the overall activation energy of the crystallization of the GCT amorphous film was higher than that of the GST film. Therefore, the GCT film with a low melting point, high thermal stability of the amorphous phase is a promising PCM for PCRAM application.

ACKNOWLEDGMENT

This work was supported by “Japan Science and Technology Agency” and KAKENHI(23360297).

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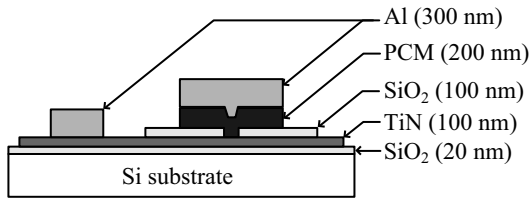


Figure 1
Schematic cross-sectional view of fabricated device. PCM indicates phase change material.

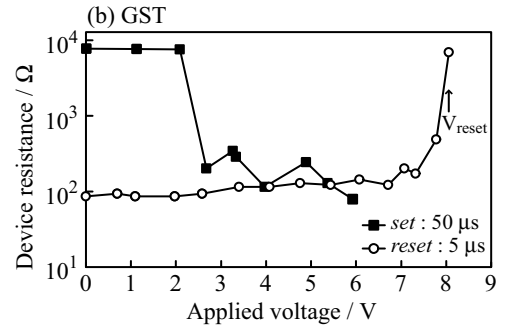
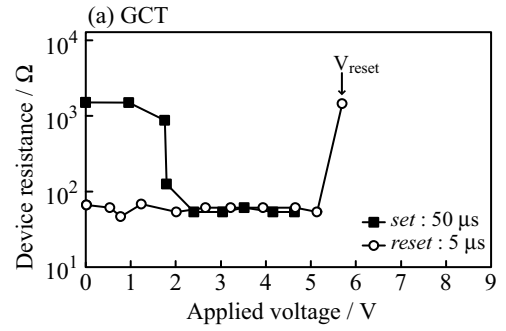


Figure 2
Set-reset switching behaviors of (a) GCT and (b) GST devices as a function of pulse voltage, the voltage pulse width for the set and reset operations being set to 50 μ s and 5 μ s, respectively.

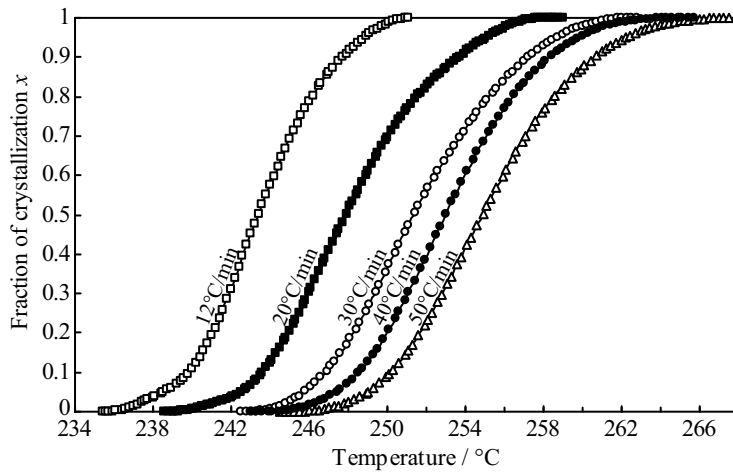


Figure 3
Plots of crystallization fraction x as a function of temperature obtained from DSC curves at different heating rates.

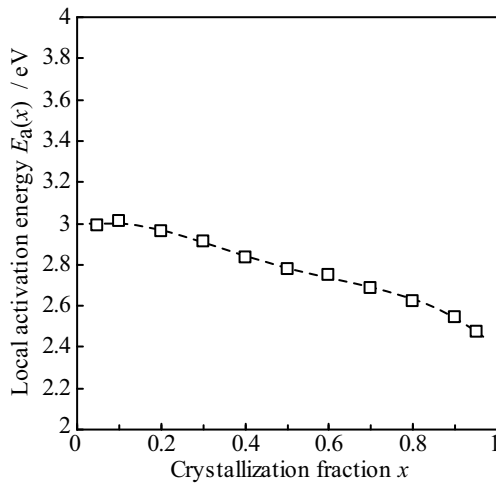


Figure 4
Dependence of the local activation energy $E_a(x)$ on the crystallization fraction x .