Crystallization processes of eutectic Si-Te and Ge-Te phase change materials

Yuta Saito*, Yuji Sutou and Junichi Koike
Department of Materials Science, Tohoku University, Sendai 980-8579, Japan
*E-mail: b0td5307@s.tohoku.ac.jp

ABSTRACT

The temperature dependence of the electrical resistance and corresponding phase change processes were investigated in eutectic $Si_{15}Te_{85}$ and $Ge_{15}Te_{85}$ amorphous thin films. The $Si_{15}Te_{85}$ amorphous film showed two-stage electrical resistance change upon heating. The $Si_{15}Te_{85}$ first crystallized into Te crystals at 170 ºC and the residual amorphous phase crystallized into Si_2Te_3 crystals at 310 ºC accompanying the resistance drops. On the other hand, the $Ge_{15}Te_{85}$ amorphous film showed only one drastic resistance drop at 250 ºC corresponding to the crystallization of GeTe. It was found by TEM analysis that the $Si_{15}Te_{85}$ and $Ge_{15}Te_{85}$ amorphous films exhibited different types of the crystallization mechanisms.

1. INTRODUCTION

Phase change random access memory (PCRAM) is attracting considerable attention as a new class of nonvolatile memories due to low production cost and high scalability. In the PCRAM, the data recording is accompanied by the reversible phase transition between high-resistance amorphous and low-resistance crystalline phases caused by Joule heating. $Ge_2Sb_2Te_5$ (GST) is drawing strong attention as a phase change material for the PCRAM. The GST shows a fast crystallization speed and a good reversibility between amorphous and crystalline phases. However, a high reset current is necessary because of its relatively high melting point (~630 ºC). Therefore, eutectic alloys with low melting point have been studied as new phase change materials[1, 2]. In this work, we focused on Si-Te and Ge-Te binary eutectic alloys which have melting points of 407 ºC and 375 ºC, respectively.

2. EXPERIMENTS

$Si_{15}Te_{85}$ and $Ge_{15}Te_{85}$ films were deposited on SiO_2/Si substrates by co-sputtering of Si and Te targets for $Si_{15}Te_{85}$ alloy and GeTe and Te targets for $Ge_{15}Te_{85}$, respectively. In-situ electrical resistance measurements were performed during annealing process of these films by a two-point probe method at 10 ºC/min under Ar atmosphere. X-ray diffraction (XRD) analysis was employed for the structural identification of thin films at room temperature after annealing. Transmission electron microscope (TEM) analysis was carried out to investigate the microstructure. The compositions of thin films were confirmed by energy dispersive X-ray spectroscopy (EDS) attached to TEM.

3. RESULTS & DISCUSSION

Figure 1 shows the temperature dependence of the electrical resistance of $Si_{15}Te_{85}$ and $Ge_{15}Te_{85}$ films. The $Si_{15}Te_{85}$ film shows two steps of resistance decrease during annealing. XRD results indicate that the first resistance decrease at 180 ºC corresponds to the crystallization of Te and the second resistance drop corresponds to the crystallization of Si_2Te_3. Before the second resistance drop at about 310 ºC, the resistance once gradually increases with annealing temperature from 250 ºC. TEM observation indicates that the temporal increase in electrical resistance is caused by the formation of the high-resistivity Si-rich amorphous phase around the Te crystals. Further heating leads to the decrease in the electrical resistance because of the crystallization of the Si_2Te_3 phase[3].

The $Ge_{15}Te_{85}$ film shows electrical resistance drop at 250 ºC corresponding to GeTe crystallization. Although Te crystallizes at about 170 ºC, the electrical resistance doesn't decrease notably and only the temperature dependency changed slightly. This is because the Te crystal has higher electrical resistivity (2.6×10^5 $\mu\Omega\cdot$cm) than GeTe crystal (2.0×10^2 $\mu\Omega\cdot$cm). The electrical resistance difference between $Si_{15}Te_{85}$ and $Ge_{15}Te_{85}$ crystalline phases after annealing can be explained by the difference of the constituent phases which are Te and Si_2Te_3 for $Si_{15}Te_{85}$, and Te and GeTe for $Ge_{15}Te_{85}$, respectively. TEM observation revealed that the crystallization mechanism of Te in $Ge_{15}Te_{85}$ is growth-dominated, while that in $Si_{15}Te_{85}$ is nucleation dominated.

4. CONCLUSION

We demonstrated that the temperature dependence of the electrical resistance and corresponding phase change processes in eutectic $Si_{15}Te_{85}$ and $Ge_{15}Te_{85}$ amorphous thin films. The $Si_{15}Te_{85}$ amorphous film showed two-stage electrical resistance change upon heating. The $Si_{15}Te_{85}$ first crystallized into Te crystals at 170 ºC and the residual amorphous phase crystallized into Si_2Te_3 crystals at 310 ºC accompanying the resistance drops. On the other hand, the $Ge_{15}Te_{85}$ amorphous film showed only one drastic resistance drop at 250 ºC corresponding to the crystallization of GeTe. It was found by TEM analysis that the $Si_{15}Te_{85}$ and $Ge_{15}Te_{85}$ amorphous films exhibited different types of the crystallization mechanisms. The $Ge_{15}Te_{85}$ film showed better characteristics than $Si_{15}Te_{85}$ for PCRAM, such as the low melting point and the large difference of the electrical resistance between the amorphous and the crystal phases.

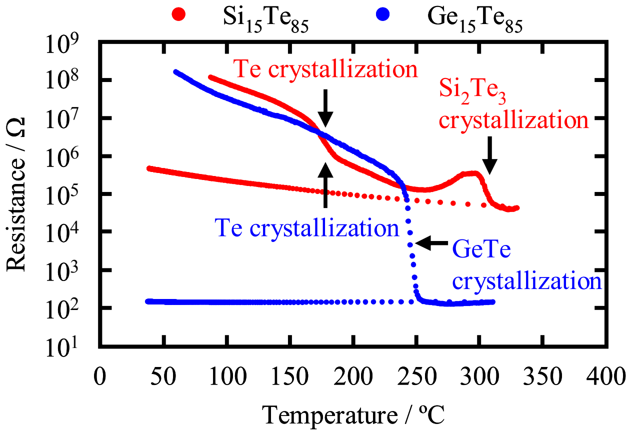

Fig. 1 Temperature dependence of electrical resistance of $Si_{15}Te_{85}$ and $Ge_{15}Te_{85}$ films.

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Biographies

Yuta Saito was born in 1985 in Yamagata, Japan. He received his B.S. and M.S. degrees from Tohoku University, Japan in 2008 and 2010, respectively. He has been a doctoral student in Tohoku University since 2010. He is a Research Fellow of the Japan Society for the Promotion of Science (JSPS) during 2010-2013. His research topic includes the development of phase change materials and the investigation of phase change processes for next generation non-volatile memory.