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Crystallization behaviors of Si-doped GeTe phase change materials

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ABSTRACT

The effects of silicon addition on the temperature dependence of electrical resistance and the crystallization temperature were studied for GeTe film. The crystallization temperature T_x of $(GeTe)_{100-x}Si_x$ films increased with increasing Si content from 188ºC (GeTe) to 297ºC (Si : 13 at.%). It was found that the dependence of Si content on the T_x in a high Si content (Si ≥ 7 at.%) is larger than that in a low Si content. This may be due to that the strongest Si-Si bonds are formed in amorphous $(GeTe)_{100-x}Si_x$ with Si ≥ 7 at.%. The phase separation to α-GeTe and Si occurred in $(GeTe)_{87}Si_{13}$ film. It was concluded that the suitable Si content is 7 ~ 9 at.% because of the high crystallization temperature and no phase separation during the crystallization.

Key words: phase change memory, GeTe, Si addition, crystallization temperature

1. INTRODUCTION

Phase change random access memory (PCRAM) has been attracting considerable attention as a next-generation nonvolatile memory because of their low production cost and high scalability. $Ge_2Sb_2Te_5$ (GST) has been the most widely studied as a phase change material (PCM) for PCRAM application. The GST shows a fast crystallization speed and a good reversibility between amorphous and crystalline phases. However, since GST shows a low crystallization temperature of about 150ºC, GST is unsuitable for high temperature operation. Thus, new PCM with a high crystallization temperature is expected to be developed for improving the thermal stability of PCRAM. One of the promising PCMs is GeTe. The effects of third elements to GeTe have been studied by some researchers, such as C, N and In [1-3]. In this work, we report the effects of silicon addition on the temperature dependence of electrical resistance and the crystallization temperature of GeTe film.

2. EXPERIMENTS

Si-doped GeTe films with 200 nm in thickness were deposited on SiO_2/Si substrates by co-sputtering of GeTe, Te and Si targets. The different compositional samples were obtained by controlling the RF power of Si target and fixing the compositional ratio of Ge and Te (Ge : Te = 50 : 50). *In-situ* electrical resistance measurements were performed during heating and cooling process by a two-point probe method at 10 ºC/min under Ar atmosphere. An energy dispersive X-ray spectrometer (EDS) attached to a TEM was used to determine the sample composition. X-ray diffraction (XRD) analysis was employed for the structural identification of thin films at room temperature after annealing. X-ray photoelectron spectroscopy (XPS) analysis were performed on the undoped and doped $(GeTe)_{100-x}Si_x$ amorphous films to investigate the core-level spectra using an Al-Kα source.

3. RESULTS & DISCUSSION

Figure 1 shows the temperature dependence of the electrical resistance of the $(GeTe)_{100-x}Si_x$ (x = 0, 3, 4, 5, 7, 9 and 13 at.%) films during heating and cooling. All as-deposited films were confirmed to be amorphous by XRD measurements and showed a high electrical resistance. The electrical resistance of the amorphous films gradually

decreased with increasing temperature and drops with crystallization. It was confirmed by XRD that $(GeTe)_{100-x}Si_x$ films crystallized in a rhombohedral type α-GeTe structure and phase separation only occurred in $(GeTe)_{87}Si_{13}$ film to α-GeTe and Si. The crystallization temperature T_x are indicated by arrows in Fig.1, where T_x was determined from minimum value of the first derivative of the resistance. The T_x increases with increasing Si content from 188ºC (GeTe) to 297ºC (Si : 13 at.%). The XPS analysis implied the existence of Si-Te bonds in $(GeTe)_{100-x}Si_x$ amorphous films. The crystallization temperature change due to Si addition was calculated using Lankhorst's model [4] and the calculated crystallization temperatures were compared with the experimentally obtained results. Although the calculated crystallization temperature showed a good agreement with the obtained results in low Si content films (Si ≤ 4 at.%), the obtained value deviated from calculated line in a region of Si ≥ 7at.%. This may be due to the formation of the strongest Si-Si bonds in amorphous $(GeTe)_{100-x}Si_x$ films with a high Si content.

4. CONCLUSION

In this study, we studied about the effects of silicon addition on the temperature dependence of electrical resistance and the crystallization temperature of GeTe film. The crystallization temperature of $(GeTe)_{100-x}Si_x$ films increased with Si concentration. The calculated crystallization temperatures were compared with the experimentally obtained results and showed a good agreement in low Si content films. The phase separation occurred at $(GeTe)_{87}Si_{13}$ sample to α-GeTe and Si. Considering the increment of the crystallization temperature and the phase separation due to Si doping to GeTe, the suitable Si content is 7 ~ 9 at.% because of the high crystallization temperature and no phase separation during the crystallization.

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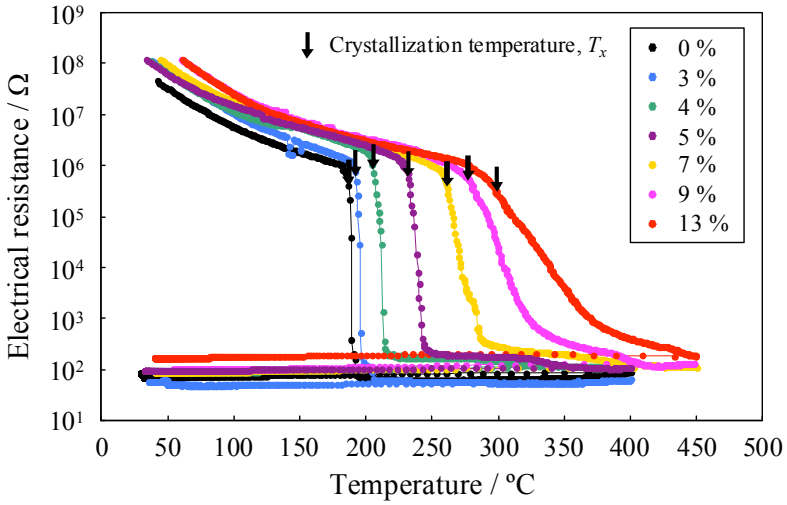

Figure 1. Temperature dependence of the electrical resistance of $(GeTe)_{100-x}Si_x$ (x : 0 ~ 13 at.%) thin films measured at heating rate of 10 ºC/min. The crystallization temperature, T_x, were indicated with arrows.

Biographies

Yuta Saito was born in 1985 in 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.