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Au doped Sb_3Te phase-change material for C-RAM device

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Abstract

Au doped Sb_3Te phase-change films have been investigated by means of *in situ* temperature-dependent resistance measurement. Crystallization temperature of 2 at.% Au doped Sb_3Te has been enhanced to 161 °C, which leads to a better data retention. The physical stability of the film has been improved evidently after adding Au as well. Resistance contrast has been improved to 1.1×10^4, one order of magnitude higher than that of pure Sb_3Te. X-ray diffraction patterns indicate the polycrystalline Au–SbTe series have hexagonal structure, similar with pure Sb_3Te alloy, when Au doping dose is less than 9 at.%.

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Keywords: Phase-change; Crystallization temperature; Data retention; Au doped Sb_3Te

1. Introduction

In recent years, chalcogenide random access memory (C-RAM) has been developed to be one of the most promising candidates for the next generation nonvolatile memories due to its many advantages. The advantages of C-RAM include nonvolatility, high density, ability for scaling down and compatibility with complementary metal-oxide semiconductor (CMOS) process compared with other new memory technologies [1–4].

At present, high speed and good stability are desired qualities in C-RAM development. For stability, many researches focused on improving phase-change material [5–7]. The essential is to optimize the material's crystallization properties. There are two important aspects of the optimization, one is thermal stability and the other is physical stability. Preferable thermal stability and physical stability would make archival life longer and the phase-change film more reliable. However, improving stability may deteriorate other material properties such as resistance contrast or crystallization speed [5]. Suitable phase-change material should have good stability and other advantages at the same time.

Eutectic Sb–Te material is widely used for C-RAM device and optical storage disk, and it has been proved to be suitable in high-speed applications. The most superior property of Sb–Te alloys compared with other materials is the fast crystallization speed due to its growth dominated crystallization mechanism which would lead to crystallization speed scales inversely with the size of contact area [8–10]. It has been found that the speed of crystallization increases with the Sb/Te ratio, but the thermal stability scales inversely with it [8,11]. In our former study, Sb_3Te has preferable performance compared with other Sb–Te alloys. Hence, Sb_3Te is discussed in this work.

Although eutectic Sb–Te alloys have the above-mentioned superior properties, it has some obvious deficiencies, such as a relatively poor thermal stability. Thus, our investigation is mainly focused on the improvement of Sb–Te material performance combining high thermal stability with good physical stability and large resistance contrast by adding foreign element Au. Furthermore, the influence of Au content will be discussed to give the best composition.

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2. Experiments

The Au doped Sb_3Te films have been deposited by co-sputtering single element Sb, Te and Au targets on SiO_2/Si (1 0 0) substrates. The size of sample is about 3 cm × 3 cm. Different power was applied on Au target in order to achieve different composition. In this experiment, the fixed Sb/Te ratio was obtained by applying the specific DC power applied on Sb and Te targets. The measured ratio is changeless with the value of 3:1 according to energy dispersive spectroscopy (EDS) measurement. The background pressure in the sputtering process was below 2×10^{-4} Pa, and the sputtering Ar pressure was 0.27 Pa. The thickness of the film is about 220 nm according to scanning electron microscope (SEM) cross-section observation. The films were annealed in N_2 atmosphere at 250 °C for 1 min and 300 °C for 2 min in order to carry out X-ray diffraction (XRD) measurement and SEM surface observation, respectively. XRD was employed to characterize the structure of the film. The XRD patterns were taken in the 2θ range of 20–70° using a Cu target with a scanning step of 0.02°, and the data acquisition time in each step is 0.3 s. *In situ* temperature-dependent resistance measurement has been carried out in a vacuum chamber, inside which the temperature is regulated by a refrigerator [6]. In the refrigerator, high purity nitrogen is employed for refrigeration by Joule-Thomson effect, and a resistance wire is for Joule heating. The dependence of electrical resistance on temperature has been measured in discrete model with step of 2 K.

3. Results and discussion

Fig. 1 shows the XRD patterns of pure and various Au doped Sb_3Te after annealed at 250 °C for 1 min. When Au content is less than 4 at.%, it could be found that the crystalline structure of Au–SbTe series material is similar to pure Sb_3Te. It indicates that Au doping does not change the type of lattice structure. All the materials are with hexagonal structure, and it accords with the reported research [12]. The peaks of Au–Sb compound would appear in the material with high Au content.

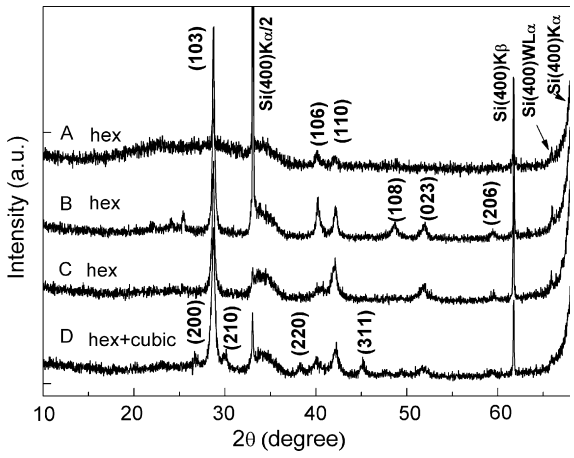

Fig. 1. X-ray diffraction patterns of Au–SbTe films on Si (1 0 0) substrate, annealed at 250 °C for 1 min, where (A) represents pure Sb_3Te, (B) 2 at.% Au doped Sb_3Te, (C) 4 at.% Au doped Sb_3Te and (D) 9 at.% Au doped Sb_3Te.

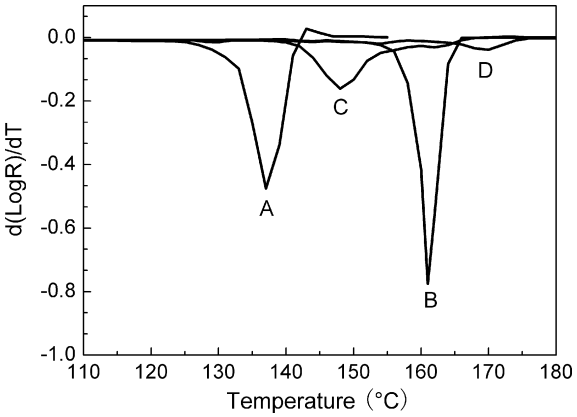

Fig. 2. Measured d(Log R)/dT as a function of temperature at a heating rate of 15 °C/min, where (A) represents pure Sb_3Te, (B) 2 at.% Au doped Sb_3Te, (C) 4 at.% Au doped Sb_3Te and (D) 9 at.% Au doped Sb_3Te.

An important effect of Au content is to increase thermal stability. Thermal stability is a basic property of phase-change material, and it will result in better data retention (long-term archival stability) and less thermal crosstalk in the C-RAM devices. In order to increase data retention of the phase-change material, a relatively high crystallization temperature (T_c) is desired [13]. In our research, T_c is obtained from *in situ* resistance measurement. The crystallization temperature is determined by the minimum in the derivative (d(Log R)/dT) [14]. Fig. 2 shows analyzed curves of d(Log R)/dT as a function of T, where R represents measured resistance and T temperature. Table 1 shows the crystallization temperature of Sb_3Te and Au–SbTe series materials. For 2 and 4 at.% Au doped Sb_3Te films, the crystallization temperature is 161 and 148 °C, respectively, when heating rate is fixed at 15 °C/min. Nevertheless T_c of pure Sb_3Te is only 137 °C which is too low for practical applications. No obvious crystallization has been observed when Au concentration exceeds 9 at.%.

The data retention of C-RAM is generally determined from the thermal stability of phase-change material. Therefore, Au–SbTe materials promise better data retention due to the higher T_c which offers better stability against spontaneous recrystallization at room temperature. Obtaining characteristic of data retention in this work is to evaluate the failure time (t_f) at a certain annealing temperature [6,15,16]. Here t_f is defined as the duration when the resistance of the material drops to 10% the value of amorphous state in annealing process. Resistance of films as a function of time at various temperatures is shown in Fig. 3. It is obvious that the Au–SbTe films have better data retention compared with Sb_3Te since longer time needed to complete phase transition at the same temperature. Fig. 4 shows failure time of amorphous 2 at.% Au doped Sb_3Te and pure

Table 1
Crystallization temperature of various Au–SbTe films with different Au content

Composition	Crystallization temperature (°C)
Sb_3Te	137
2 at.% Au doped Sb_3Te	161
4 at.% Au doped Sb_3Te	148