Thermal Conductivities of Phase Change Material Sb-Te Alloys in solid states

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ABSTRACT

Sb-Te alloys have drawn much attention due to the application in phase change random access memory. The design and optimization of phase change random access memory device structures require thermophysical properties such as thermal conductivities of Sb-Te alloys. In this work, the thermal conductivities of Sb-*x* mol%Te alloys (*x* = 14, 25, 44, 60, 70 and 90) have been measured by the hot strip method from room temperature up to temperature just below the respective melting points. The thermal conduction mechanism was discussed based on the temperature dependence. It is proposed that free electron dominates the heat transport below 600 K and Wiedemann-Franz law can be applied to predict the thermal conductivities of alloys using the electrical conductivities. Ambipolar diffusion is thought to contribute to the increase in the thermal conductivity at higher temperatures.

Keywords Sb-*x* at%Te alloys, Thermal conductivity, phase change materials

1. INTRODUCTION

Phase change random access memory (PCRAM) is a promising nonvolatile data storage technology for next generation memory owing to higher performance characteristics such as faster operation and higher scalability[1]. Sb-Te binary alloys are the important candidates for phase change materials (PCMs) in PCRAM devices[2-4]. In PCRAM devices, the Joule heating induces a transformation of PCMs between amorphous and crystalline states reversibly, which provides a dramatic change in electrical resistivity, and this resistivity change is the basis for data storage[5]. The design and optimization of PCRAM device structures require thermophysical properties such as thermal conductivities of Sb-Te alloys. There have been some investigations about thermal conductivities of Sb-Te alloys; however, most of them focused on the properties of thin films[6, 7]. It has been proved that the thermal conductivity of thin film is sensitive to the microstructure, and the heat conduction mechanisms should be discussed based upon the thermal conductivity of bulk materials[8]. However, there are no enough thermal conductivity data for bulk materials of Sb-Te alloys available, especially for high temperature. Consequently, the aims of the present work are to measure the thermal conductivities of Sb-Te alloys as functions of temperature and chemical composition and to discuss the heat conduction mechanisms of Sb-Te alloys based on the temperature and compositional dependences.

2. EXPERIMENTAL

Samples used were Sb-*x* at% Te (*x* = 14, 25, 44, 60, 70, and 80). Thermal conductivity was measured by the hot strip method as shown in Figure 1[9]. Cylindrical samples of Sb-Te (20mm diameter and 40-50mm length) were prepared from Sb and Te powders with 99.9 mass% purity. A powder mixture (100 g) was melted in a quartz crucible (20mm inner diameter) at 973K for 4 h in vacuum, followed by furnace cooling. Subsequently, the sample was taken from the tube and cut into two along the vertical axis, and the cross sections were mechanically polished using emery papers up to #2000. Thermal conductivity measurements were conducted in argon atmosphere from 298 K up to temperatures just below the respective melting points. Prior to measurements of Sb-Te alloys, the thermal conductivity of fused silica was measured to confirm the reliability of the hot strip method because the thermal conductivity of fused silica is close to that of Sb-Te binary alloys. Two pieces of fused SiO_2 block ($40\times20\times10$ mm) were used as the samples.

3. RESULTS AND DISCUSSION

Fig. 2 shows typical temperature rises of the heater as a function of logarithm of time obtained during measurements at 293K and 773 K for $Sb_{75}Te_{25}$ by the hot strip method. It can be seen that there is good linearity between ΔT and ln$t$ at each temperature, which supports the reliability of the present measurements.

The thermal conductivities of Sb-*x* mol% Te alloys at room temperature are shown as a function of the Te concentration in Fig. 3, together with the data for thin films reported by Kuwahara et al[10] and the data for Sb and Te recommended by Touloukian et al[11]. The thermal conductivities of the Te-rich alloys at room temperature are close to those of Sb_2Te_3 and Te. The thermal conductivities of the Sb-rich alloys at room temperature increase remarkably with decreasing Te concentration. The present data seem close to those obtained by Kuwahara et al. for thin films[10] except the composition of Sb-33 mol% Te.

Fig. 4 shows the temperature dependence of Sb-rich alloys together with the data for Sb obtained by Konno et al[12]. It can be seen that the thermal conductivities of all Sb-rich alloys keep roughly constant below approximately 600 K and, above 600 K, increase with increasing temperature. The thermal conductivities of the Sb-rich alloys decrease with increasing Te concentration. Fig. 5 shows the temperature dependence of thermal conductivities for the Te-rich alloys together with the data for Sb_2Te_3. It can be seen that the thermal conductivity of Sb_2Te_3 decreases with increasing temperature up to approximately 600 K and then increases. The thermal conductivities of the Te-rich alloys decrease with temperature increase until their melting points, and this behavior is similar to that of Sb_2Te_3 below 600 K. The same dependence of the thermal and electrical conductivities[13] of the Sb-Te single phase alloys at room temperature on the Te concentration suggests that free electrons are predominant carriers for both the heat and electrical transport in the Sb-Te single phase alloys. At higher temperature, the ambipolar diffusion is thought to be more effective and contribute to the increase of thermal conductivity.

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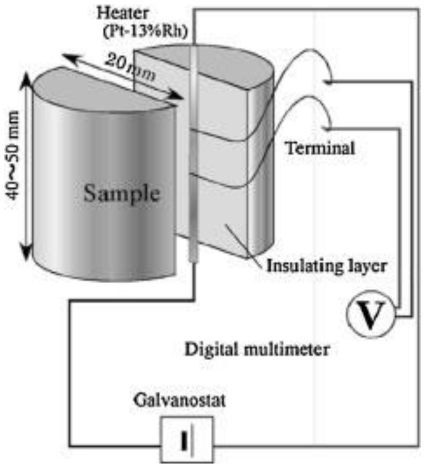

Fig. 1 Schematic diagram for hot strip method

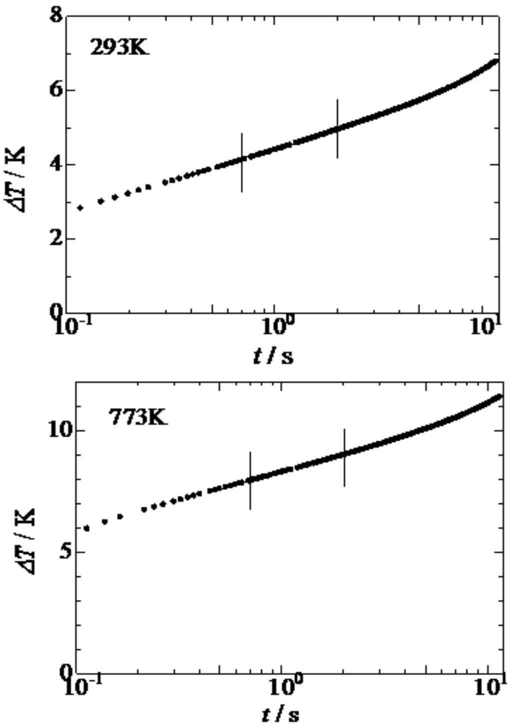

Fig. 2 Temperature rises of heater with time at 293 K and 773 K for $Sb_{75}Te_{25}$

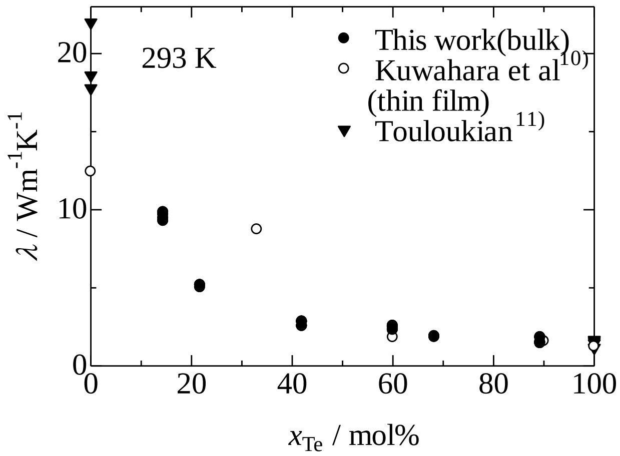

Fig.3 Thermal conductivities of Sb-Te alloys at room temperature as function of Te concentration

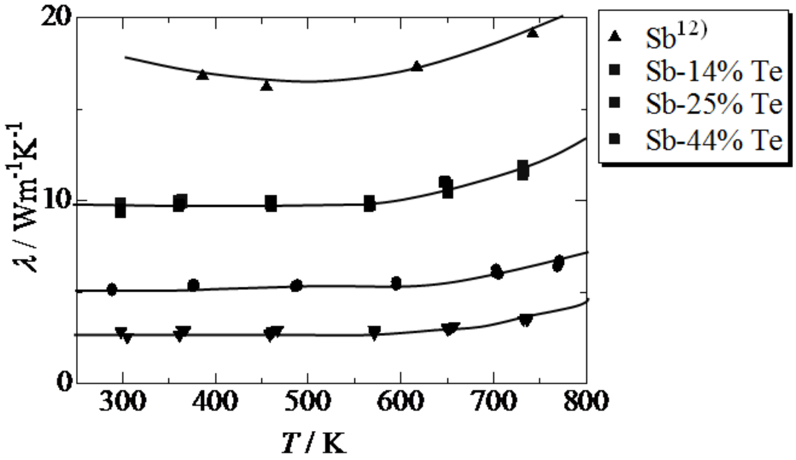

Fig.4 Thermal conductivities of Sb-rich samples as function of temperature

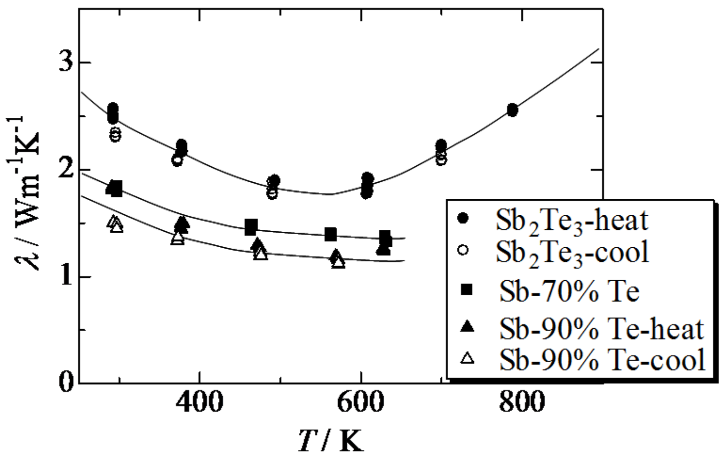

Fig.5 Thermal conductivities of Te-rich samples as function of temperature