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Temperature-Dependence of Electrical Resistivity of Cd-Sn, Bi-Sn, and Al-Si Eutectic and Al-3wt.%Si Hypoeutectic Alloys

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Cd-Sn, Bi-Cd, and Al-Si eutectic and Al-3wt.%Si hypoeutectic alloys of high-purity (99.99%) metals were produced in a vacuum atmosphere. Current-voltage (*I-V*) characteristics of these specimens were measured at various temperatures between 100 and 475 K. The electrical resistivity (ρ) and temperature coefficient (α) for each specimen, depending on the temperature, were calculated using results obtained from the *I-V* measurements. The electrical resistivities and the residual resistivity of the specimens increase with increasing temperature for each alloy system. These results are compared with literature results.

Keywords: crystal growth, electrical properties, metals and alloys

1. Introduction

Eutectic alloys are the basis of most engineering materials (Ref 1-3). Eutectic alloys have relatively low melting points, excellent fluidity, and good mechanical and electrical properties. Consequently, a broad spectrum of eutectic alloys that are available for different applications have been developed. Electrical resistivity data can be useful to understand various phenomena in metals and alloys. For example, electrical resistivity and its temperature coefficient measurements provide an easy and inexpensive tool for studying phase transitions with changes of temperature in metals and alloys (Ref 4-15).

The purpose of this work is to experimentally investigate the variation of electrical resistivity depending on temperature in different alloys (Cd-Sn, Bi-Cd, and Al-Si eutectic and Al-3wt.%Si hypoeutectic) and to determine the temperature coef-

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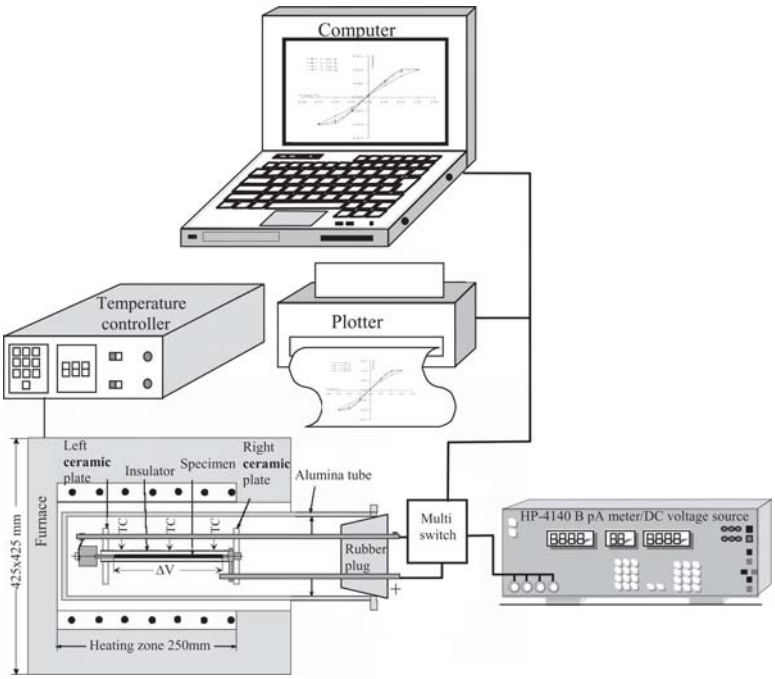

Fig. 1 Experimental measurement system

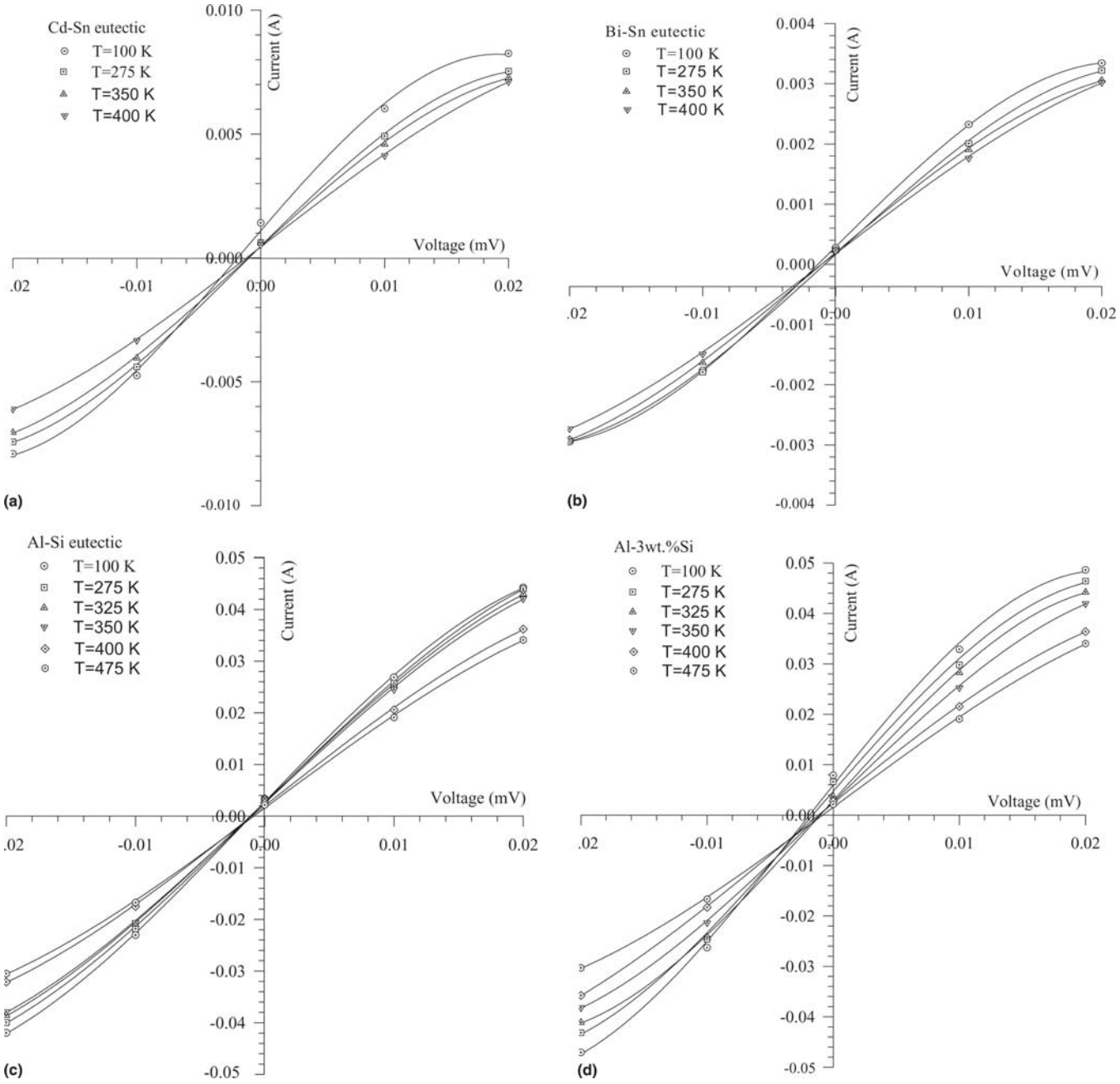

Fig. 2 Current-voltage characteristics measured at various temperatures for different alloy systems: (a) Cd-Sn eutectic, (b) Bi-Sn eutectic, (c) Al-Si eutectic, and (d) Al-3wt.%Si hypoeutectic

ficient of resistivity (α) for each of these alloy systems. We chose alloy systems whose resistivities at 273 K are known. The electrical resistivities of the specimens were calculated from the following equation:

$$\rho = \frac{\Delta V \pi D^2}{4IL}$$

where ρ is the electrical resistivity, D is diameter of the specimen, L is length of the specimen, I is the current, and ΔV is the voltage difference between two probes positioned at a distance of L. The $\Delta V/I$ values obtained from I-V plots.

2. Experimental Procedures

Eutectic (Cd-Sn, Bi-Sn, Al-Si) and hypoeutectic (Al-3wt.%Si) alloys were prepared by melting weighted quantities of >99.9% high-purity Cd, Sn, Bi, Al, and Si in a graphite crucible placed into a vacuum melting furnace (Ref 16). After allowing time for melt homogenization, and then each of the molten alloys was poured into a prepared graphite crucible (200 mm in length, 4 mm ID, and 6.35 mm OD), placed in a hot filling furnace, and then left to cool (Ref 17). After this process, each specimen was removed from its graphite mould.

Thin silver wires (0.05 mm diameter) were then contacted to the ends of the specimens (Fig. 1), and they were fixed using

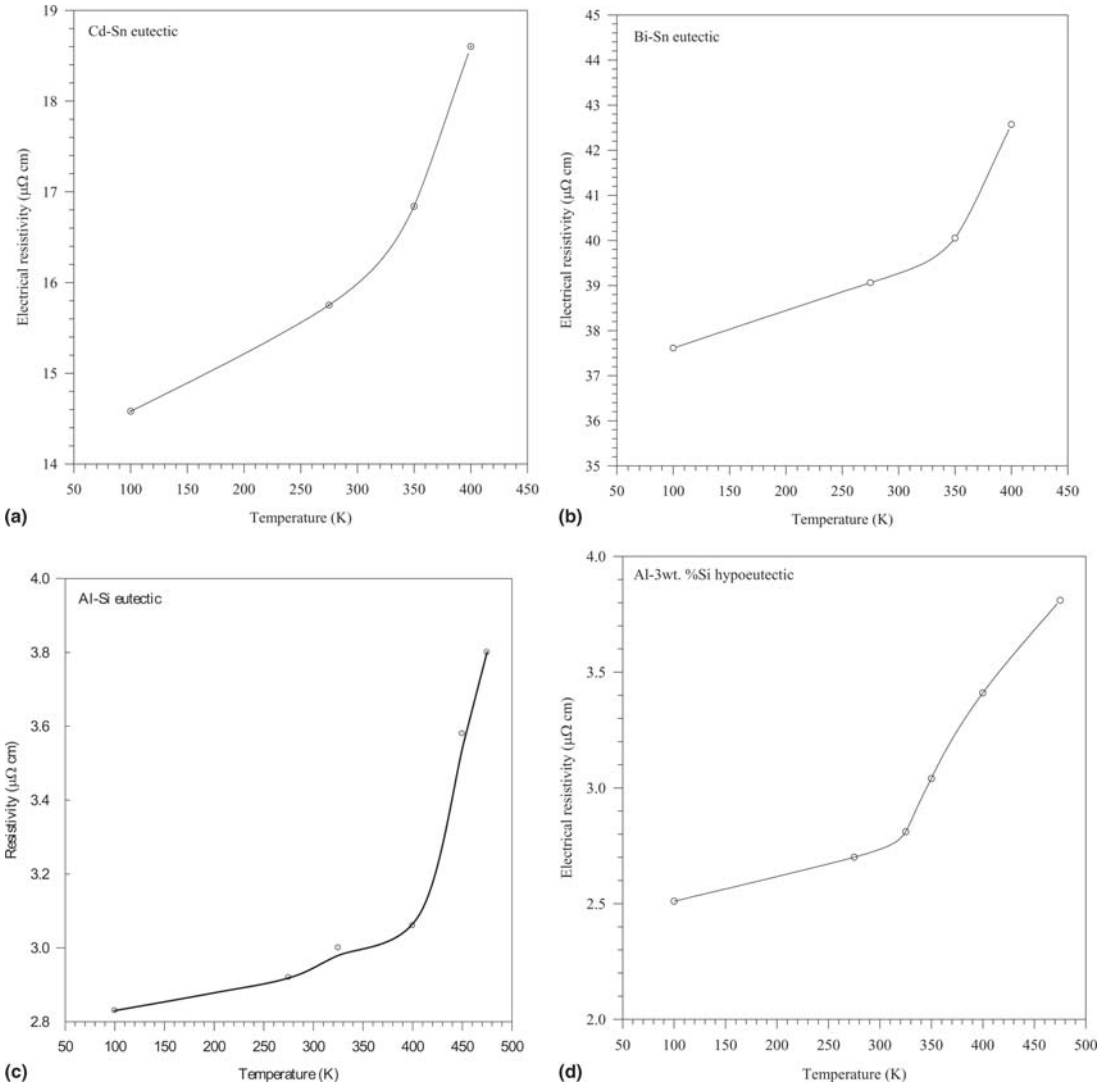

Fig. 3 Electrical resistivity as a function of temperature for different alloy systems: (a) Cd-Sn eutectic, (b) Bi-Sn eutectic, (c) Al-Si eutectic, and (d) Al-3wt.%Si hypoeutectic

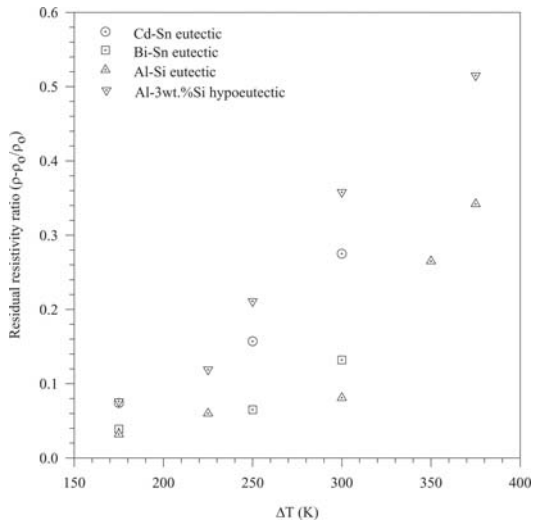

Fig. 4 Variation of the residual resistivity ratio ($\rho - \rho_o/\rho_o$) as a function of ΔT for different alloy systems

silver paint. Specimens prepared in this way were placed in a horizontal heating furnace on ceramic plates that were aligned horizontally with the specimens. A four-probe direct current (dc) method was used to measure the resistivity.

As can be seen in Fig. 1, the experimental system consists of a horizontal heating furnace, a temperature controller, a Hewlett-Packard (Santa Clara, CA) HP4140B picoammeter (dc voltage source), a plotter, and a computer. *I-V* characteristics were measured at temperatures between 300 and 475 K in the horizontal heating furnace for each specimen (length 200 mm, diameter 4 mm). After the thermal conditions in the furnace were stabilized, a low voltage (−0.02 to +0.02 mV) was applied to the ends of the specimen.

Current-voltage (*I-V*) characteristics were obtained by using the Hewlett-Packard HP4140B picoammeter for different temperatures.

During the experiments and at constant temperature, a low voltage (mV) was applied to the ends of the specimen because the cylindrical metallic specimens have very low resistance. Liquid nitrogen and ice-water were used for electrical resistivity measurements of the specimens at temperatures between

100 and 275 K, respectively. Hence, the *I-V* characteristics of all the specimens have been measured over the temperature range 100-475 K.

The temperature distribution along the specimens was measured by means of three thermocouples (K-type) positioned (not welded) approximately 6 cm apart from each other and perpendicular to the specimen; the furnace temperature was controlled by the temperature controller. Average specimen temperatures were calculated with the temperature values measured by means of these thermocouples.

3. Results and Discussion

Graphs of the *I-V* characteristics of the specimens obtained by using measurement data are shown in Fig. 2(a)-(d). As can be seen in these figures, the current values are linearly proportional with the voltage values in both directions (forward and reverse), but this ratio decreases as the temperature increases. As can be seen in Fig. 3(a)-(d), the electrical resistivities of the specimens increased with increasing temperature for each alloy system. Electrical resistivity (ρ) gradually increases with increasing temperature up to 350 K but increases rapidly above 350 K. The electrical resistivity versus temperature plots of the specimen Cd-Sn are given in Fig. 3(a), and the resistivity versus temperature plots of Bi-Sn are shown in Fig. 3(b). As can be seen in these figures, the electrical resistivity of Cd-Sn increases from 14.5 to 18.6 $\mu\Omega \cdot$ cm and that of BiSn increases from 37.6 to 42.6 $\mu\Omega \cdot$ cm with an increase in temperature. The obtained resistivity ranges are in good agreement with previous work (Ref 18). As can be seen in Fig. 3(c) and (d), the electrical resistivities of the Al-Si eutectic and Al-3wt.%Si hypoeutectic alloys increase from 2.8 to 3.8 $\mu\Omega \cdot$ cm and from 2.5 to 3.8 $\mu\Omega \cdot$ cm with an increase in temperature, respectively. The resistivity ranges obtained for these samples are in good agreement with previous work (Ref 18, 19).

The residual resistivity ratio $(\rho - \rho_o)/\rho_o$ as a function of ΔT is shown in Fig. 4, where ρ_o is the resistivity at 273 K. The figure shows that the residual resistivity ratios increase with increasing ΔT for each alloy system. The behavior of the residual resistivity ratio $(\rho - \rho_o)/\rho_o$ depending on ΔT was also observed in different alloy systems by various researchers (Ref 20-22). The calculated average temperature coefficients of electrical resistivities (α) of the Cd-Sn and Bi-Sn eutectic alloys in the temperature range of 100-450 K were found to be 1.56×10^{-3} and 0.71×10^{-3} K^{-1}, respectively. Similarly, the average α values of the Al-Si eutectic and Al-3wt.%Si hypoeutectic alloys were found to be 1.5×10^{-3} and 2.34×10^{-3} K^{-1} in the temperature range of 100-475 K, respectively.

4. Conclusions

As a result, the temperature dependence of electrical resistivity and the residual resistivity ratio of Cd-Sn, Bi-Sn, and Al-Si eutectic and Al-3wt.%Si hypoeutectic alloys were investigated. The experimental results obtained for Cd-Sn and Bi-Sn eutectic alloys are in good agreement with previous work (Ref 18). Similarly, the results obtained for Al-Si eutectic and Al-3wt.%Si hypoeutectic alloys are in good agreement with the results in Ref 19.

Acknowledgments

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