Available online at www.sciencedirect.com
SCIENCE DIRECT®
Physica B 358 (2005) 126–131
PHYSICA B
www.elsevier.com/locate/physb

Anomalous change of electrical resistivity with temperature in liquid Pb–Sn alloys

Xian-Fen Li*, Fang-Qiu Zu, Hou-Fu Ding, Jin Yu, Lan-Jun Liu, Qiang Li, Yun Xi

College of Materials Science and Engineering, Hefei University of Technology, Tunxi Road, Hefei Anhui province, 230009, People's Republic of China

Received 8 November 2004; received in revised form 8 November 2004; accepted 23 December 2004

Abstract

The patterns of electrical resistivity of lead–tin (Pb–Sn) alloys with different compositions, along with pure liquid lead and tin, have been investigated as a function of temperature, using the DC four-probe technique. Evident turning points are observed on resistivity–temperature curves of the four liquid Pb–Sn alloys, and the resistivities increase linearly with rising temperature before the turning points. Moreover, the turning points are all at the temperature scope far above the liquidus. In case of both liquids pure lead and tin, however, the resistivity–temperature curves are linear within the measured temperature. Since resistivity is one of the physical properties sensitive to structures, it is suggested that there are temperature-induced structure changes in the liquid Pb–Sn alloys.

PACS: 72.15.Cz; 61.20.−p; 61.25.Mv

Keywords: Liquid Pb–Sn alloy; Electrical resistivity; Structure change

1. Introduction

Crystalline solids can exist in different forms—polymorphs—with different structures and bonding patterns. Such polymorphs are usually stable under different conditions. The existence of liquid polymorphs is only just beginning to be recognized in recent years. For a long time, the idea of a transition between two liquids has not been considered seriously, because of the traditional viewpoint that liquid structures transit smoothly, i.e., continuously, with temperature and pressure. In recent years, the liquid–liquid phase change has been experimentally and theoretically proved to occur in some one-component and a few multiple-component systems [1–5]. Growing evidence for

*Corresponding author. Tel.: +86 551 2905057; fax: +86 551 290 1362.
E-mail address: lxfytt@163.com (X.-F. Li).

0921-4526/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.physb.2004.12.037

first-order transitions in liquids has come from the analysis of their physical properties and computer simulations [6,7]. Katayama et al. [8] describe a direct study of liquid phosphorus under high pressure, using synchrotron X-ray diffraction. Simply by increasing the pressure, the structure of liquid phosphorus jumps suddenly from a relatively open molecular structure to a new polymeric form with higher density, which provides direct evidence for pressure-driven structural transition in the liquid above the melting point. Moreover, with the internal friction method developed recently for liquids, temperature-induced discontinuous liquid structural changes at constant pressure have been newly put forward in some binary alloys, such as In–Sn, In–Bi, Pb–Sn and Pb–Bi far above the liquidus [9–12]. With the methods of electrical resistivity and EXAFS [13–15], covalent bonds derived from solid state were found remaining in Sb-rich In–Sb melts and liquid antimony near the liquidus, which broke at a high temperature. From the recent studies [13–18], chemical short-range orders (CSROs) corresponding to the crystal structures have proved to remain still in some single- and/or multi-component liquids at the temperature near liquidus besides the topological short-range orders.

The evidence available now indicates that phase or structure transitions do occur in the liquid state, but it should be further found out whether the phenomenon is widespread or only in some definite liquid systems. If it is the case of the latter, what about the conditions and inherent laws? In one word, there is a long way to go for us in understanding the liquid state, especially, to have a thorough grasp of the changes of the liquid structures and the physical properties.

In our earlier studies, the structure change of liquid Pb–Sn alloys has been suggested with the internal friction method [9], but the electrical properties of liquid Pb–Sn alloys have rarely been studied, especially within the higher temperature range. In this paper, the electrical resistivities (ρ) of liquid Pb–Sn alloys have been investigated as a function of temperature. The results show that obvious changes occur on the resistivity–temperature ($\rho-T$) curves of liquid Pb–Sn alloys at the temperature far above the liquidus. It is assumed that there are the Pb–Sn, Sn–Sn and Pb–Pb short-range orderings (SROs), which are derived from the solid states, retaining in the molten state within a certain temperature range and breaking at the turning temperature. It is also found that Pb–Pb and Sn–Sn SROs have some effects on the turning temperature on $\rho-T$ curves of the alloys.

2. Experiments

According to Pb–Sn phase diagram (Fig. 1), four compositions of Pb–Sn alloy were chosen for the $\rho-T$ experiments, that is, Pb–Sn20 wt%, Pb–Sn40 wt%, Pb–Sn61.9 wt%, and Pb–Sn80 wt%. In addition, the $\rho-T$ pattern of pure Pb, Sn were also studied for comparison with that of Pb–Sn alloys. All the Pb–Sn samples were prepared with pure lead (99.99%) and pure tin (99.99%). After being melted and held at 150 °C above the liquidus for 30 min, the melts were poured into quartz cells and cooled to room temperature for the following experiments. In order to minimize the deviation of the cell size, the cells were made of quartz whose thermal expansion is quite small.

The electrical resistivities were measured by the DC four-probe method, and the quartz cell was placed in the homogeneous heat area of the

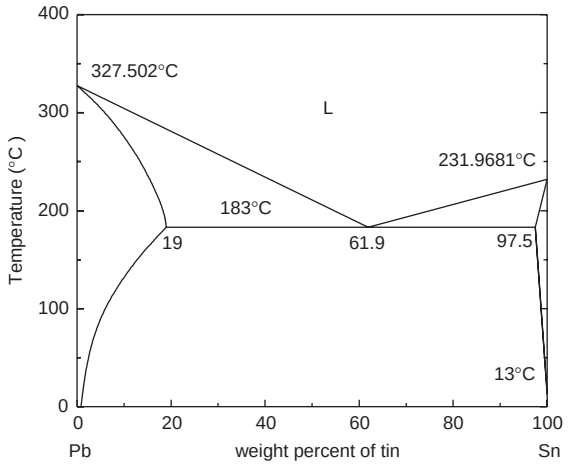

Fig. 1. The phase diagram of Pb–Sn alloy.