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Mechanical deformation behavior and mechanism of Sn-58Bi solder alloys under different temperatures and strain rates

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ABSTRACT

The mechanical deformation characteristics of the eutectic Sn-Bi alloys were investigated by tensile tests combined with in-situ observation and nanoindentation. The effects of temperature and strain rate on mechanical deformation behavior were investigated. Tensile tests reveal that the increasing of temperature improves the ductility of the alloys. However, the ductility significantly deteriorated at high strain rate. The nanoindentation results show that there exist different deformation mechanisms applying different strain rates. The deformability of the alloy decreased at high stain rate because of the mechanism transformation form phase boundary related mechanism to dislocation glide mechanism. This impact of strain rate on the deformability appears weaker due to the enhancement of the interface sliding at high temperature.

1. Introduction

Because of the environmental and health issues of Sn-Pb solders, many different solder alloys have been proposed as potential lead-free solder [1–3], e.g., Sn-Ag-Cu, Sn-Ag, Sn-Cu, Sn-Zn, and Sn-Bi [4–6]. Among them, Sn-Bi based solder has received much attention as an important alternative especially for its lower melting temperature [7], good wettability [8], well tensile strength and excellent creep resistance [9]. The Sn-Bi solder alloys have been applied in the outer layers of classification packaging. To implement the low temperature lead-free solder to more electronic products, studies are required to be further investigated in terms of solderability, mechanical strength, ductility, creep resistance, thermal fatigue resistance, corrosion resistance, etc. [10,11] Of these, the frangibility and poor ductility are still the major problems restraining the essential processing and application of Sn-Bi solder alloys in industry. As the Sn-Bi alloys contain a large quantity of brittle Bi phases and Sn-rich phases, it should display quite a different deformation characteristics compared with most of the Sn-based solders which have only small quantities of intermetallic compounds or precipitated phases distributed in the Sn matrix. In order to find the primary cause of the brittleness and solve the problem of Sn-Bi alloys, the characteristics and mechanisms concerning the mechanical deformation are necessary to be further researched.

Most of the studies so far only focus on adding minute amount of rare earth (RE), Ag, Cu, Zn, and nanoparticles into the alloys to improve their microstructure and mechanical performances [9,12–17]. Few reports have investigated the relationships between the macro-scale mechanical behavior and micro-scale mechanism under different conditions. Zhang et al. [18] used in-situ observation method to research the creep-fatigue fracture behaviors of the SnBi/Cu solder joints and obtain the corresponding fracture mechanism. It is available to explore the deformation behavior and mechanism related to the mechanical properties by using in-situ observation. Because the creep behavior of eutectic Sn-Bi alloy is stress sensitive involving different controlling mechanisms in different stress region [19], it is significant to investigate the effects of strain rate on the deformation behavior combining with in-situ observation. In the present paper, the mechanical properties of the eutectic Sn-58Bi alloy under different strain rates and also different temperatures were first investigated. Then the in-situ tensile tests were employed to observe the mechanical deformation process and assess the mechanism. The nanoindentation tests were also carried out to research the related mechanism.

2. Experimental

The eutectic Sn-Bi solder alloys were prepared from pure Sn

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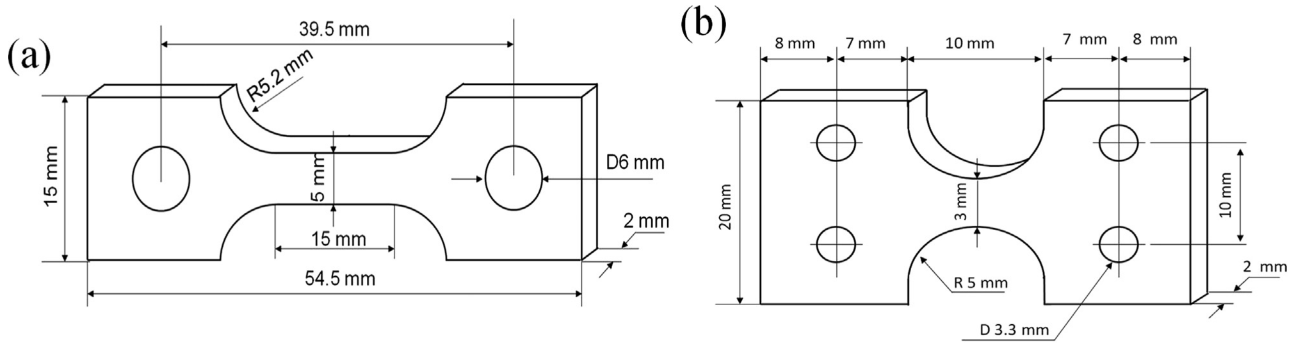

Fig. 1. Schematic illustrations of the specimens for (a) tensile tests and (b) in-situ tensile tests.

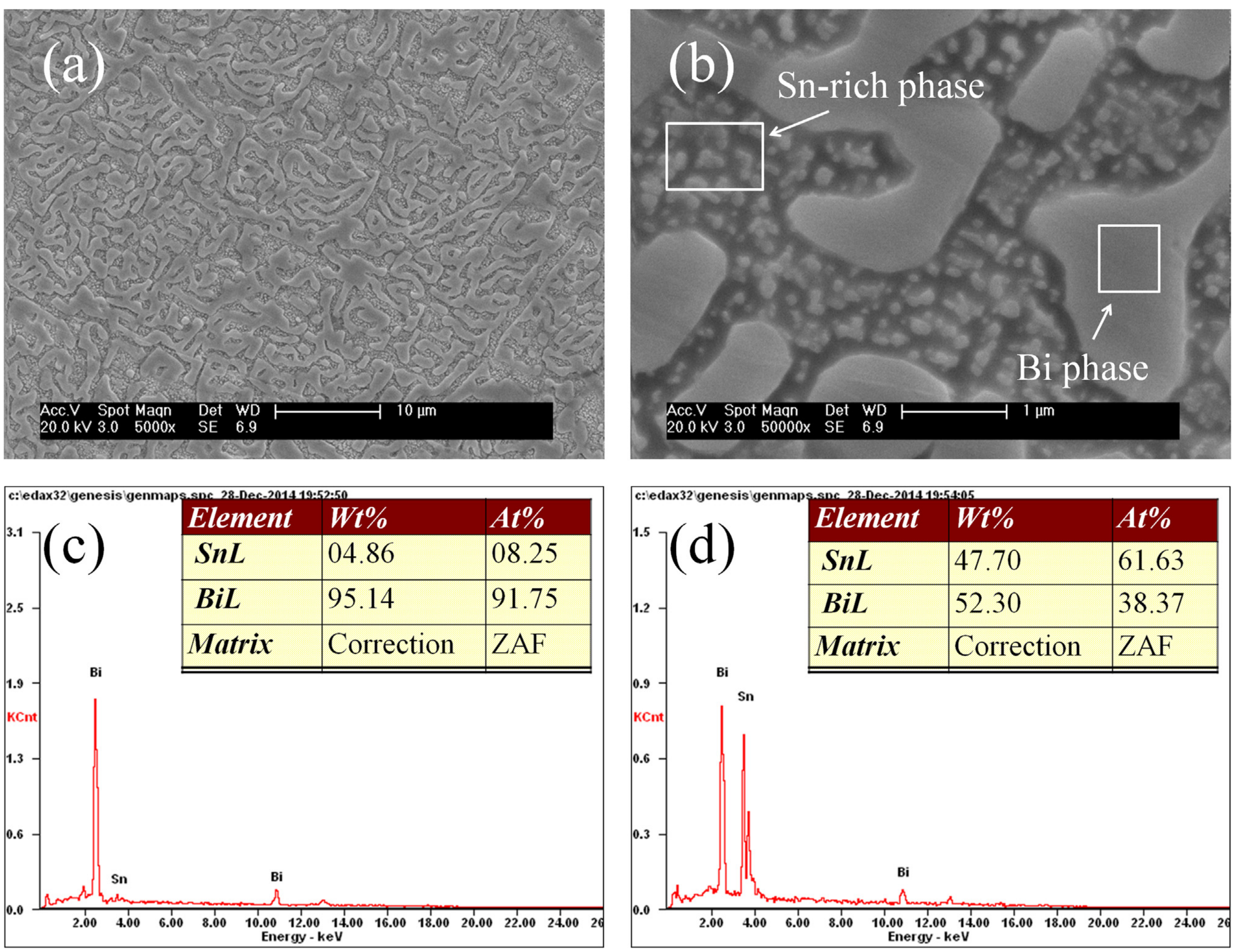

Fig. 2. The microstructure of Sn-58Bi alloy and EDS analysis results: (a) low magnification of Sn-58Bi, (b) high magnification of Sn-58Bi, (c) EDS results of Bi phase and (d) EDS results of Sn-rich phase.

(99.90%) and Bi (99.90%) metals. After melted and homogenized in an alumina crucible at 300 °C for 30 min, the alloys were poured into a steel rectangle-shaped mold. Microstructure and composition of the alloys were examined using a scanning electron microscope (SEM, Sirion) equipped with an energy dispersive spectrometer (EDS, GENESIS 60 S). The specimens of tensile tests were cut from the center of the ingot. Tensile tests were conducted at different temperature (i.e. 25, 75, and 125 °C) and at different strain rate (i.e. 0.0004, 0.002, 0.01and 0.05). Three samples were tested for each composition to obtain reliable data. The in-situ tensile tests were performed using a screw-drive tensile stage placed inside the chamber of the SEM. The dimensions of the specimens for tensile tests and in-situ tensile tests are presented in Fig. 1(a) and (b), respectively. The strain velocities applied in the tests were 1 mm/min and 0.1 mm/min. The nanoindentation tests were performed at 25 °C, 75 °C and 100 °C using a Micro Materials Nano Test system. The indenter was pressed into the sample until 2 μm and then the load was held constant for 10 s followed by unloading. Seven strain rates ranging from 0.001 to 0.1 were applied at each temperature. A transmission electron microscopy (TEM, Tecnai G^2) was used to carry out TEM observations before and after tensile test. The TEM samples were thinned by conventional mechanical polishing and ion milling method.