The Precipitation Strengthening Behavior of Cu-Ni-Si Alloy used as Micro-Components Evaluated by Micro-Tensile Tests

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Abstract

Cu materials are often used as micro-components in MEMS devices [1]. For applications of materials in MEMS, investigating mechanical properties of micro-sized specimens is very important. Mechanical behaviors of samples with small dimensions are different from that of bulk materials, which is known that strength of the specimen is stronger when the specimen size is decreased. So, micro-mechanical test has been extensively studied since when a technique was proposed and developed by Uchic et al [2]. Based on this technical background, we have reported several studies on micro-bending [3], micro-compression [4] and micro-tensile [5] tests with a specially designed micro-testing machine.

Cu-Ni-Si alloy is a precipitation strengthening-type alloy and receives a lot of attention for its high strength, high electrical conductivity and excellent bending workability [5]. However, there is still no report on micro-mechanical properties of the alloy. In this study, we report deformation behaviors of the Cu-Ni-Si alloy using micro-tensile test and the precipitation strengthening as compared with pure Cu. In this study, Cu-2.4Ni-0.51Si-9.3Zn-0.15Sn-0.13Mg alloy [5] and pure copper of 99.99% were used. Micro-tensile specimen with dimensions of 10 × 10 × 40 μm³ was fabricated by focus ion beam (FIB) and tested by a testing machine designed for micro-sized specimens capable of providing a constant displacement rate at 0.1 μm/s under a uniaxial loading [3-5].

Fig. 1 shows scanning ion microscopic (SIM) images of the tensile specimens before and after the tensile tests. Both specimens after the test showed necking and concentration of large slip lines. Fig. 2 shows the engineering stress-strain curves of the specimens and the typical serrations and load drops during the plastic deformation, while the serrations were not observed in the bulk material [6]. These serrated drops were caused by a large slip of dislocation in the micro-specimen, and the movement of dislocation became more obvious in the micro-tensile test. Fig. 3 and 4 show work hardening behavior of the samples. The micro-specimens of Cu-Ni-Si alloy showed a work hardening behavior different from that of the pure Cu. This means that the precipitations in Cu-Ni-Si alloy could obstruct movement of the dislocation. Also, a deformation twinning was reported in this alloy [6], and the twin boundaries could act as barriers for the dislocation motion and promote the strain hardening.

This paper is a first report of the precipitation strengthening in metallic micro-components. These results demonstrated that micro-tensile test using micro-tensile specimens is a powerful tools to evaluate the deformation directly caused by the movement of dislocation.

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References:

Figure 1. SIM image of micro tensile specimen. (a)Cu before tensile (b)Cu after tensile (c) Cu-Ni-Si before tensile (d) Cu-Ni-Si after tensile

Figure 2. Stress-Strain curve of Cu and Cu-Ni-Si micro tensile test

Figure 3. Work hardening rate of the pure Cu micro-tensile specimen

Figure 4. Work hardening rate of the Cu-Ni-Si micro-tensile specimen