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Mechanical Properties of Cu-Ni-Si alloy Evaluated by Micro-Tensile Test for Application in MEMS

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Abstract

Micro-mechanical test of a precipitation strengthening-type Cu alloy, Cu-Ni-Si alloy, was performed using a micro-sized tensile specimen with 10 x 10 μm^2 in cross-section and 40 μm in length, and the results were compared with the bulk sample. The micro-specimen was fabricated by a focused ion beam system and tested by a micro-mechanical testing machine. The micro-tensile test showed the characteristic deformations of the work-hardening and typical serrated behavior.

1. Introduction

Cu materials are often used as micro-components in MEMS devices [1]. When size of the material is miniaturized to micro or nano order, mechanical properties of the material would be different from those of the bulk counterparts, and this is called sample size effect. There are several studies reported on sample size effect [2,3], and it is known that strength of the specimen is stronger when the specimen size is decreased, so called “Smaller is Stronger”. Also, volume fraction of a single grain in a electronic component would be higher when size of the electronic component is decreased. In this case, the effect of crystal anisotropy would become more significant with a decrease in size of the electronic component or device [2]. The study of crystal anisotropy can be conducted using specimens fabricated from a single crystal bulk material with controlled orientation. However, it is difficult to evaluate the effect of crystal anisotropy on fracture strength, elongation and fracture behavior of materials in micro-scale since it is difficult to conduct the micro-tensile test. Based on this technical background, we have reported several studies on micro-bending, micro-compression and micro-tensile test with a specially designed micro-testing machine [4-6].

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 [8]. However, there is still no report on micro-mechanical properties of the alloy. In this study, we will report deformation behaviors of the Cu-Ni-Si alloy using micro-tensile test.

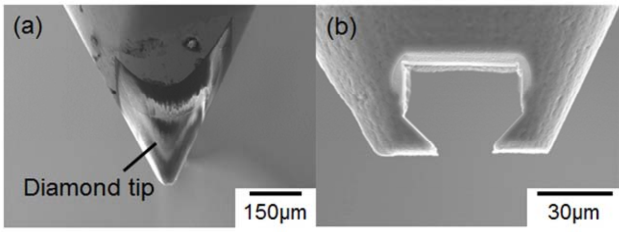

Fig.1. SEM images of the (a) commercially available diamond-tip micro-indenter and (b) as-fabricated micro-gripper.

2. Experiment methods

In this study, Cu-2.4Ni-0.51Si-9.3Zn-0.15Sn-0.13Mg alloy [8] was used. The sample was first thin-down to about 50 μm in thickness by mechanical polishing. The micro-gripper and micro-specimen for the micro-tensile test were both fabricated by focus ion beam (FIB, FB2100, Hitachi) operated at 40 kV. Micro-gripper for the micro-tensile test was fabricated from a diamond-tip micro-indenter (Synton-MDP: Spherical tip) as shown in Fig. 1. The specimen for the micro-tensile test was fabricated by FIB milling as shown in Fig. 2 [5,6]. The micro-tensile test was conducted by controlling a constant displacement rate at 0.1 μm/s under a uniaxial loading using a testing machine designed for micro-sized specimens until 20% of strain was reached. The specimens were observed by a scanning electron microscope (SEM. Hitachi S-4500SE) equipped with electron back scatter diffraction (EBSD).

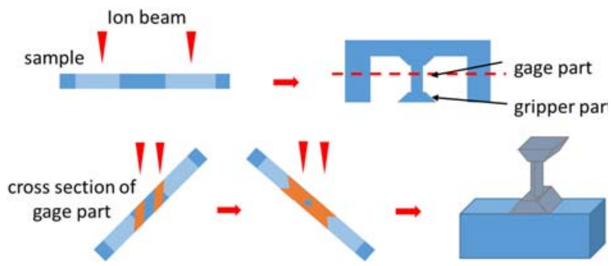

Fig.2 Fabrication process of micro-specimen by FIB

3. Results and discussion

In present work, the micro-tensile specimen was composed of only two grains as shown in Fig. 3(a). Scanning ion microscopy (SIM) image of the specimen after the micro-tensile test taken by the FIB machine is shown in Fig. 3(b). The deformation occurred only at the upper grain, which had [313] orientation analyzed by EBSD. In the grain, necking and a lot of slip lines were observed at the surface of the specimen.

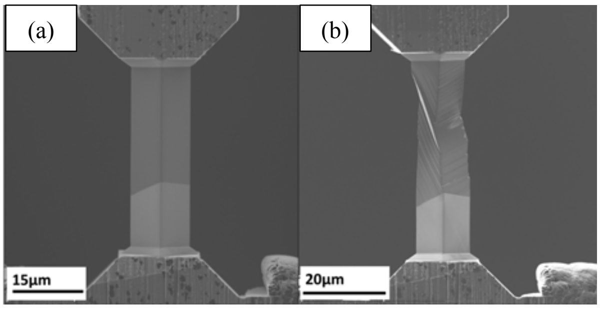

Fig.3. SIM images of the Cu-Ni-Si alloy micro-tensile specimens (a) before and (b) after the micro-tensile test.

Fig.4 shows engineering stress-engineering strain curves of the micro-tensile testing and bulk tensile test. The bulk specimen showed smooth curves and the work hardening behavior considered as a result of precipitation hardening of the Cu-Ni-Si alloy [7]. The curves of the micro-tensile specimen showed the typical serrations and load drops during the plastic deformation and the work hardening behavior. This 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 [6].

The micro-tensile specimen showed 0.2% yield stress of 210 MPa, which was lower than the bulk tensile test. There was only one grain boundary in the micro-tensile specimen. Thus, the boundary strengthening did not occur effectively as compared with large amount of grain boundaries in the bulk specimen.

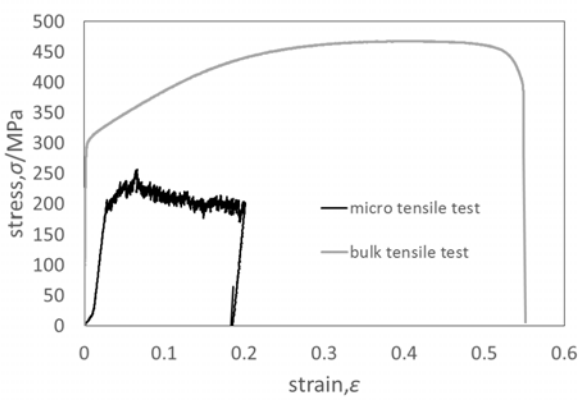

Fig.4. Engineering stress-true strain curves of the Cu-Ni-Si alloy obtained from the micro-tensile test and the bulk tensile test.

As shown in Fig. 5, EBSD pattern of the upper grain after the micro-tensile test showed a continual rotation of grain orientation at the necking point. Loading direction at the upper grain was [313] hence the grain rotated from [313] to <111>, which is the slip direction of fcc materials. In a previous study [6], the micro-tensile tests of single crystal Ni showed a few drops on the stress-strain, which are considered as a result in difference of the Schmid factor. However, this characteristic deformation was not observed in this Cu-Ni-Si alloy. This alloy is known to be a precipitation strengthening-type Cu alloy, and Araki et al reported occurrence of a deformation twinning in this alloy [8]. Thus, the rotation of the grain orientation could be originated from the microstructure, such as nano-twinning.

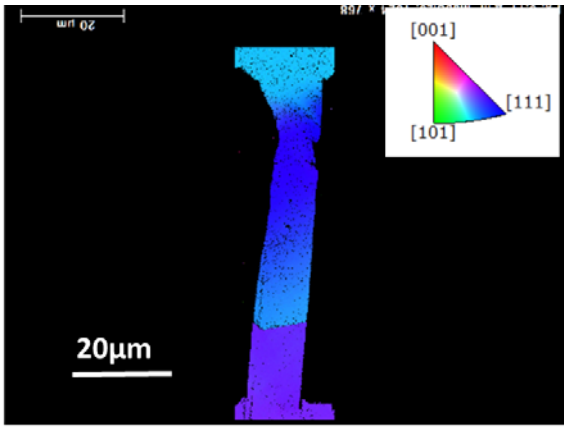

Fig.5. An EBSD image showing cross-section of the micro tensile specimen after the micro-tensile test.

4. Conclusions

A micro-tensile test was conducted for the Cu-Ni-Si alloy. A characteristic necking with concentrated slip lines and a continual rotation of grain orientation were observed. The yield stress was lower than that of the bulk sample. This characteristic deformation was suggested to come from the precipitation in the alloy.

References

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