TEM observation of Ni_2Si discontinuous precipitation on Cu-Ni-Si alloy having high strength and high electrical conductivity

Kim, H.[1], Han, S.Z.[2], Ahn, J.H.[2], Han, H.N.[1] and Kim, M.[1]

[1] Seoul National University, Republic of Korea, [2] Korea Institute of Materials Science, Republic of Korea

Copper alloys have been used for electric devices such as lead frame and electrical connector due to its good electrical conductivity. These materials require not only high electrical conductivity, but also high mechanical strength properties. However, in general, enhancing electrical conductivity and mechanical strength simultaneously often considered to be mutually exclusive in structural materials.

Recently, improvement of both mechanical strength and electrical conductivity by utilizing Ni_2Si discontinuous precipitation process and cold drawing on Cu-Ni-Si alloy has been reported.[1] The discontinuous precipitation is not preferred due to its unfavorable mechanical property compared to continuous precipitation, yet it can be beneficial in improving electrical conductivity by lowering the concentration of solute in matrix.[2] In addition, cold drawing induces abnormal plastic deformation of Ni_2Sinano-sized fiber-like precipitates which is attributed to the origin of mechanical strengthening of Cu-Ni-Si alloy. Therefore, it is important to examine the microstructure of Ni_2Sinano-precipitates and their interface with neighboring grains to understand the role of Ni_2Siin the mechanical properties.

In this work, samples using cold drawing to 90 % and 95 % reduction of the cross-sectional area with Cu-4Ni-0.91Si-0.05Ti, and 90 % reduction of the cross-sectional area with Cu-6Ni-1.5Si-0.1Ti alloys were investigated. The distances between Cu grains are around ~150 nm and the width of Ni_2Sifibers is in the range of a few tens of nanometers. The microstructure of these samples was studied by JEOL 2100F transmission electron microscope (TEM) equipped with a Nanomegas precession unit Digistar and Energy Dispersive Spectroscopy to obtain grain boundary misorientations and overall atomic distribution. The raw data sets of the indexed precession electron diffraction patterns were processed and analyzed further with the TSL OIM Analysis software. Using this method, we could observe that 90 % area reduction drawn sample has microstructure composed of low angle grain boundaries and twin boundaries. After drawing to 95 % area reduction, quite a few Cu matrix grain boundaries are made up of $\Sigma 7$ coincident site lattice boundaries (Fig.1). Furthermore, interfaces between Cu matrix and Ni_2Sinanofibers were examined using JEM-ARM200F Cs-corrected Scanning Transmission Electron Microscope to probe atomic configurations and chemical composition. Local strain distribution near the interfaces was obtained to correlate with theoretical calculations.

Based on these experimental observations, we performed ab initio calculations to find energetic stability of Ni_2Sinanofibers that have coherent interface with Cu matrix. We compare interface energies between Ni_2Si nanofibers and Cu matrix coherent interface under different stress. These results provide a clue on the role of relationship between Ni_2Siprecipitate and Cu grain to the mechanical behaviors. We expect that during discontinuous process, Ni_2Sinanofibers will cause Cu matrix to have specific orientation. These precipitate will act as bridge between Cu grains by making coherent interfaces with each Cu grain. As a result, coherent interface will affect the conductivity increase and mechanical strengthening at the same time.

[1] Han, S. Z. et al. Increasing strength and conductivity of Cu alloy through abnormal plastic deformation of an intermetallic compound. Sci. Rep. 6, 1 - 7 (2016).

[2] Lee, E. et al. Effect of Ti addition on tensile properties of Cu-Ni-Si alloys. Met. Mater. Int. 17, 569 - 576 (2011).

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science, ICT & Future Planning (MSIP) (NO. NRF-2015R1A5A1037627).

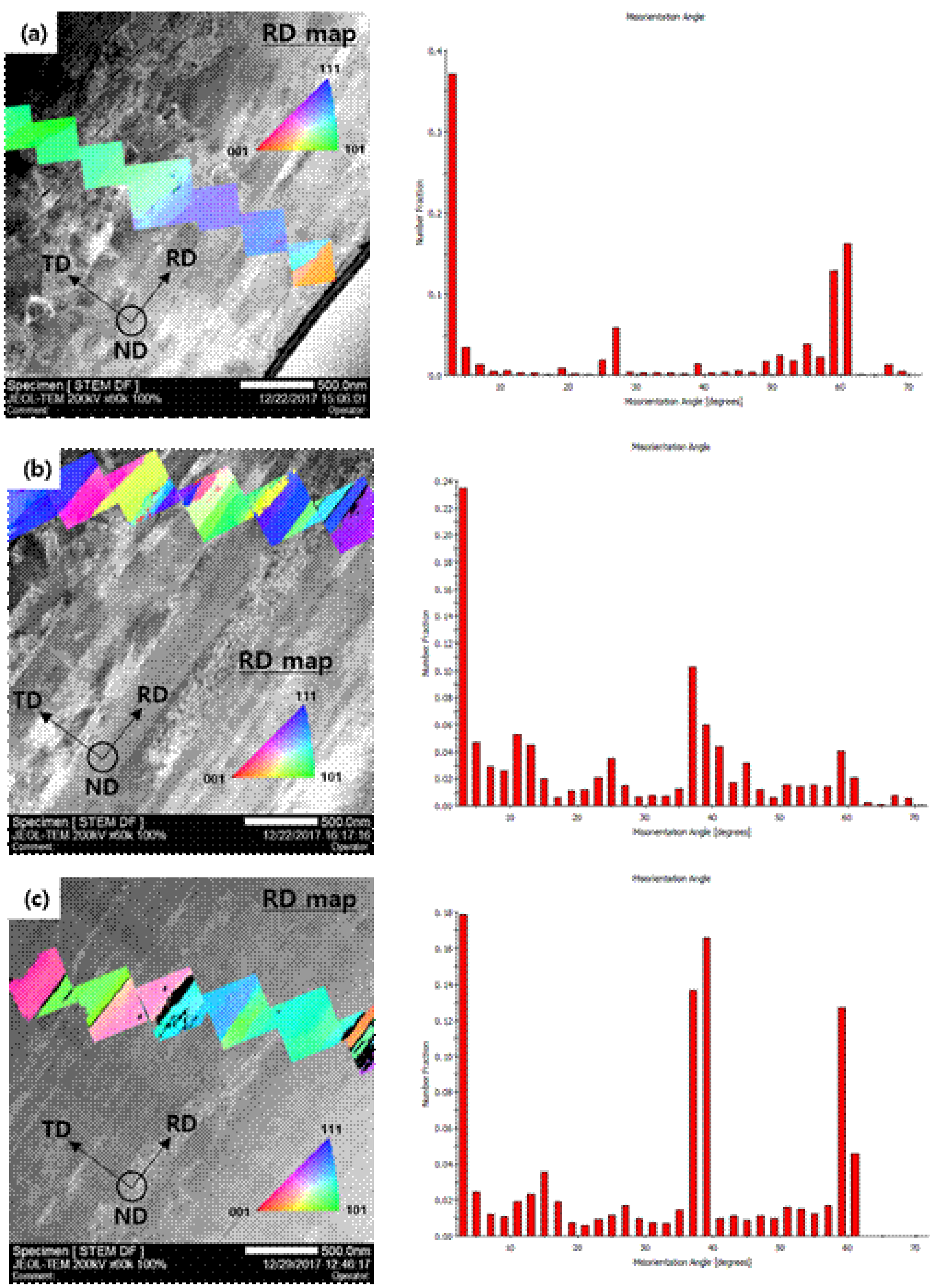

Fig 1. HAADF-STEM images overlapped with Rolling Direction inverse pole figure map and number fraction of misorientation angle distribution results. (a) Cu-4Ni-0.91Si-0.05Ti 90% drawn sample (b) Cu-4Ni-0.91Si-0.05Ti 95% drawn sample (c) Cu-6Ni-1.5Si-0.1Ti 95% drawn sample