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Characterization of Dislocations in Single-Crystalline Ag_3Sn Intermetallic Alloys

H. Yu[1], Y. Sun[1], S-W. Lee[1], P.C. Canfield[2] and M. Aindow[1]

[1.] Department of Materials Science and Engineering, Institute of Materials Science, University of Connecticut, Storrs, CT, USA
[2.] Ames Laboratory & Department of Physics and Astronomy, Iowa State University, Ames, IA, USA

The intermetallic compound Ag_3Sn is an important component phase present in both dental amalgams [1] and lead-free solders for microelectronic applications [2]. Ag_3Sn exhibits the $D0_a$ Cu_3Ti-type structure, which is an ordered orthorhombic form of the HCP structure [3]. The phase is unusually ductile for an intermetallic compound, but there have been very few studies on the defects and deformation mechanisms in Ag_3Sn due to the difficulty of making high quality single phase samples [4]. Early studies [3] suggested that deformation in Ag_3Sn can proceed by {011}-type twinning, and this is consistent with the results of micro-hardness indentation studies [5]. In a recent study [6] we characterized defect structures in a Ag_3Sn-Cu_3Sn pseudo-binary alloy deformed in compression. A high density of dislocations was generated in the Ag_3Sn grains, but no deformation twinning was observed. However, the character of these dislocations was not analyzed in detail. In the present study, we have examined the dislocations structures in deformed single-crystal Ag_3Sn and the operative deformation mechanisms were considered.

Single-phase Ag_3Sn crystals several millimeters in size were produced by a solution growth method [7]. The single-crystal specimens were deformed by bending at room temperature, and the microstructures of the deformed crystals were evaluated using transmission electron microscopy (TEM). Cross-sectional TEM specimens through the (001) free surface were prepared using an FEI Helios Nanolab 460F1 dual-beam focused ion beam (FIB) instrument following the procedures described by Yu et al. [4]. The TEM specimens were examined in an FEI Talos F200X S/TEM operating at accelerating voltage of 200 kV.

The deformed Ag_3Sn crystals contained both twins and dislocations, and particular attention was paid to the character of the dislocations. Figure 1 is a bright-field (BF) TEM image from a typical area in deformed Ag_3Sn taken under two-beam conditions with **g** = 040, where **g** is the reciprocal lattice vector of the diffracting planes. The beam direction is close to [100]. Many parallel dislocations are present, and these extend for up to 1.5 μm within the specimen volume. The average dislocation density was calculated as $\rho = 10^9\text{-}10^{10}\ cm^{-2}$ based on such images. The Burgers vectors, **b**, were determined by diffraction contrast analyses using the **g•b** = 0 criterion, and it was found all the segments are edge dislocations having Burgers vectors, **b**, parallel to [010]. Since the line directions of the defects are approximately [001], this is consistent with deformation on the [010](100) slip system. It is noted that most of the dislocations were present as dislocation pairs, with a separation of up to 30 nm. To determine if these paired dislocations are partial dislocations or dislocation dipoles, BF TEM images were taken with ±**g** (**g** = 040), as presented in Figure 2. Significant changes in spacing between these dislocation pairs were noticed on reversing the sign of **g**. This inside/outside contrast reveals that these dislocation pairs are actually dipoles. Such dipoles are probably formed by two dislocations with opposite Burgers vectors (i.e. [010] and $[0\bar{1}0]$) gliding in opposite directions on adjacent (100) planes and being trapped when their strain fields interact. We note that this slip system has not been reported previously for any $D0_a$ phase, and the activation of this system in addition to twinning could help to explain the extraordinary ductility exhibited by the Ag_3Sn phase [8].

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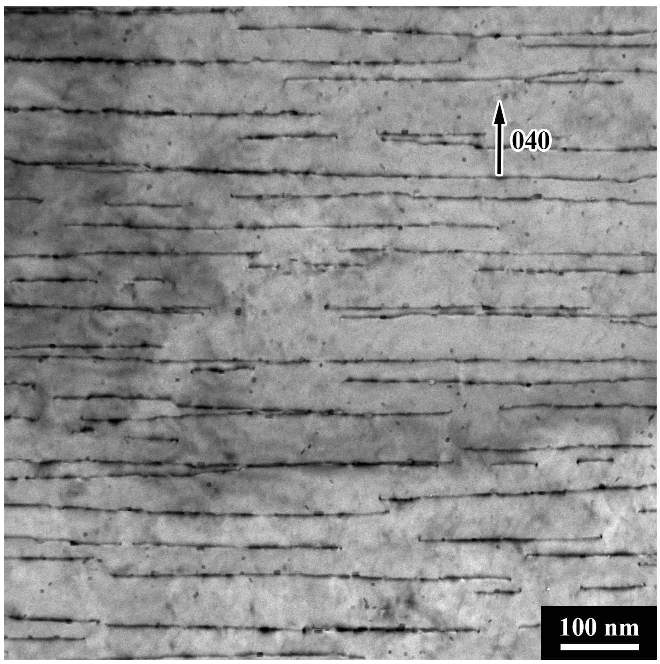

Figure 1. Bright-field TEM image of [010] dislocations in deformed single-crystalline Ag_3Sn taken under two beam conditions with **g** = 040, beam direction close to [100].

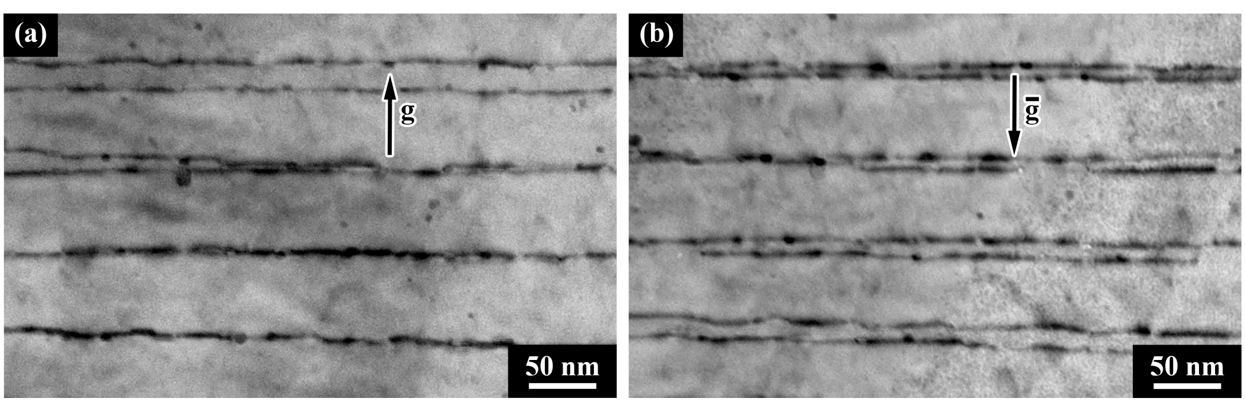

Figure 2. Images of dislocation dipoles showing inside/outside contrast on reversing **g** (±040).

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