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Characterization of Nanoscale Precipitates in an Al-Zn-Mg-Cu Alloy Using STEM-HAADF Imaging

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Al-Zn-Mg(-Cu) alloys are heat-treatable alloys widely used in the aerospace and automotive industry. Adding Cu to the ternary Al-Zn-Mg alloy changes the age hardening response; most notably, it promotes rapid hardening during the early stages of aging and enhances the peak strength during the later stages of aging. Nevertheless, it is generally agreed that the aging sequence remains the same as compared to the Al-Zn-Mg alloys, and can be roughly described as follows:

$$\text{Solid solution} \rightarrow \text{GP zones} \rightarrow \eta' \rightarrow \text{equilibrium } \eta\ (MgZn_2) \qquad [1]$$

The metastable particles, GP zones and η' phase, in both Al-Zn-Mg and Al-Zn-Mg-Cu alloys have been widely studied; but, the actual structure and composition of the metastable phases is still vigorously disputed [2-7]. High-angle annular dark field (HAADF) imaging has been shown to be a powerful tool for understanding both the chemical and the structural aspects of small particles in other aluminum alloys [8].

This work addresses the unresolved issues regarding the structure of the metastable particles in an alloy with a composition of 8.52% Zn, 1.75% Mg and 2.3% Cu (in wt%) provided by Chung-Shan Institute of Science and Technology (Taiwan). The alloy was solution treated at 485°C for 90 min followed by water quenched and then aged at 120°C. Microstructure examination was performed on FEI Titan 80-300 with c_s-correction of the probe operated at 300kV. Disk-shaped particles lying on {111} planes have been observed for a range of aging times. At earliest stages, particles grow laterally and are 7 layers thick. Considering the alloy composition, the brighter layers should be Zn- or Cu-rich, while darker layers are expected to be Mg-rich layers. Contrast suggests a compositionally layered structure with 5 Mg layers alternating with 5 Zn- or Cu-rich atom layers comprising the center of the disks, and a Zn- or Cu-rich layer on the top and bottom interfaces with matrix. The HAADF images in our study are not consistent with the η' crystal structures proposed previously. These competing hypotheses for 7 layer particles are compared via HAADF image simulations using the Kirkland multislice code [9]. At later stages (24 hours), some particles thicken to 11 layers with accommodating misfit dislocations on side faces. The 7 layered particles may be considered as the possible smallest η' phase and the 11 layered particles could be considered as the smallest equilibrium η phase [10]. Almost no particles below 7 layers and between 7 and 11 layers were found [11].

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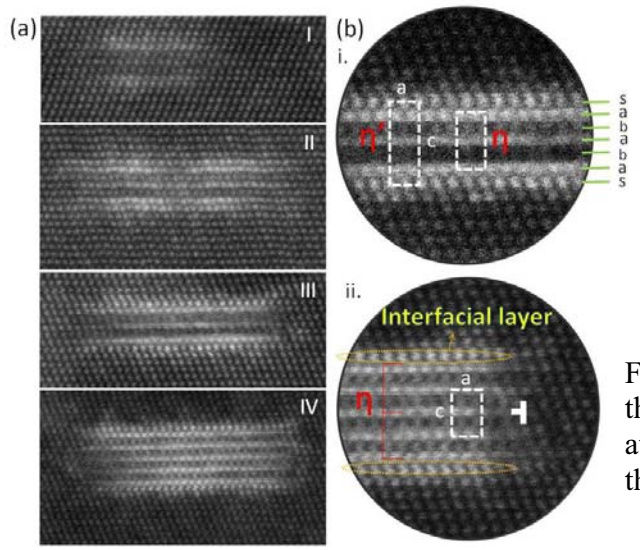

FIG. 1. The HAADF images show (a) the evolution of platelet particles aged at 120˚C and (b) detailed structure of thin (i) and thick (ii) particles.

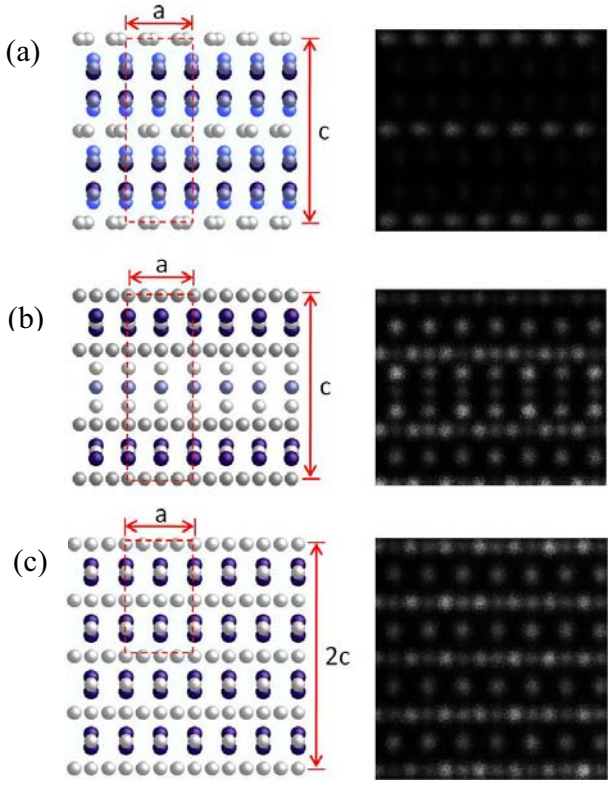

FIG. 2. η' crystal structure proposed by (a) Li et al.[2] and (b) Auld and Cousland [3]; (c) the crystal structure of η phase. On the left are the crystal structures created by CrystalMaker; on the right side are their corresponding simulated HAADF images caculated by Kirkland program[9]. All the projections are operated toward the $<10\text{-}10>_{\eta',\ \text{or}\ \eta}$. (Elements: Zn, 2/3 Zn + 1/3□, Zn or Al, Al, Mg)

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