Quantitative analysis of precipitate crystal structure evolution in Al-Mg-Si-Cu alloys using scanning precession electron diffraction

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Here we present a methodology for evaluating the structural transformation of Al-Mg-Si-Cu precipitates with improved statistics using a combination of scanning precession electron diffraction (SPED), machine learning and high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM).

Age-hardenable Al-Mg-Si(-Cu) (6xxx) alloys are widely used in industry due to their favourable combination of properties including high strength-to-weight ratio, good formability and high corrosion resistance. The strengthening is caused by a large number of nano-sized, metastable precipitates that form during thermal ageing. By varying the alloy composition and the thermomechanical processing (TMP) applied to the material, there exists a great variety in the distribution and types of precipitate phases forming [1,2]. Each alloy is tailored to its specific application, and to this point it is crucial to have a detailed understanding of the effects of different element additions and TMP routes. This requires detailed microstructure analysis, which encompasses high-resolution studies of the interplay of phases forming, in addition to sufficient statistics for providing a reliable assessment of the average precipitate phase fractions.

We will demonstrate that SPED combined with data analysis including machine learning can give more accurate precipitate phase fractions in Al-Mg-Si-Cu alloys than obtained using other methods. By improving the data processing routines, which build on non-negative matrix factorization (NMF) decomposition of SPED data, we have been able to substantially extend the number of precipitates analysed compared to earlier work [3]. 1000s of precipitates can now be identified (**Figure 1**), labelled and the distribution plotted (**Figure 2**). Coexisting phases within individual precipitates were also assessed by HAADF-STEM lattice imaging, which enabled verification of the SPED results. The research objective is to increase the understanding of the precipitate crystal structure evolution in Al-Mg-Si-Cu alloys during overageing.

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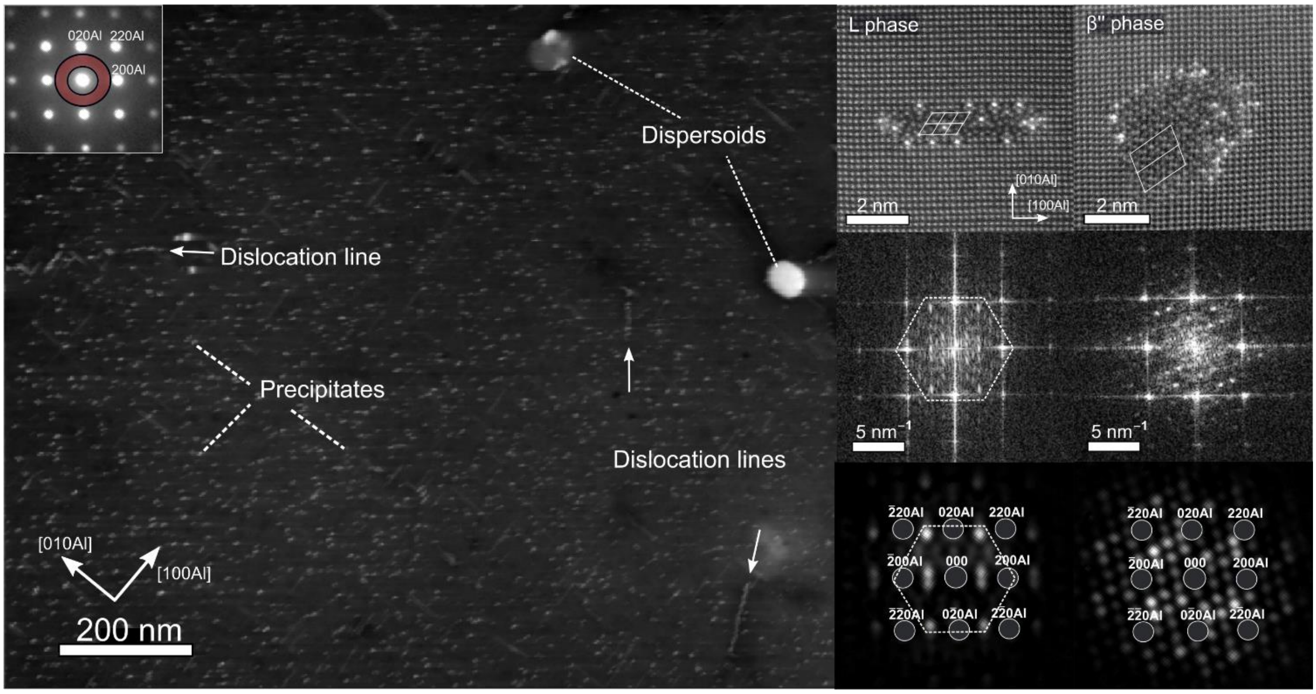

Figure 1: Virtual dark-field image formed from a <001>$_{Al}$ SPED scan using precipitate diffraction spots covered by the highlighted annulus (insert). The scan covers 1.34 μm^2 in 550x450 pixels and contains over 3700 precipitates. The second and third columns depict example HAADF-STEM images of the two main precipitate types observed, fast fourier transforms of the lattice images and NMF machine learning component patterns matched with the corresponding precipitate types.

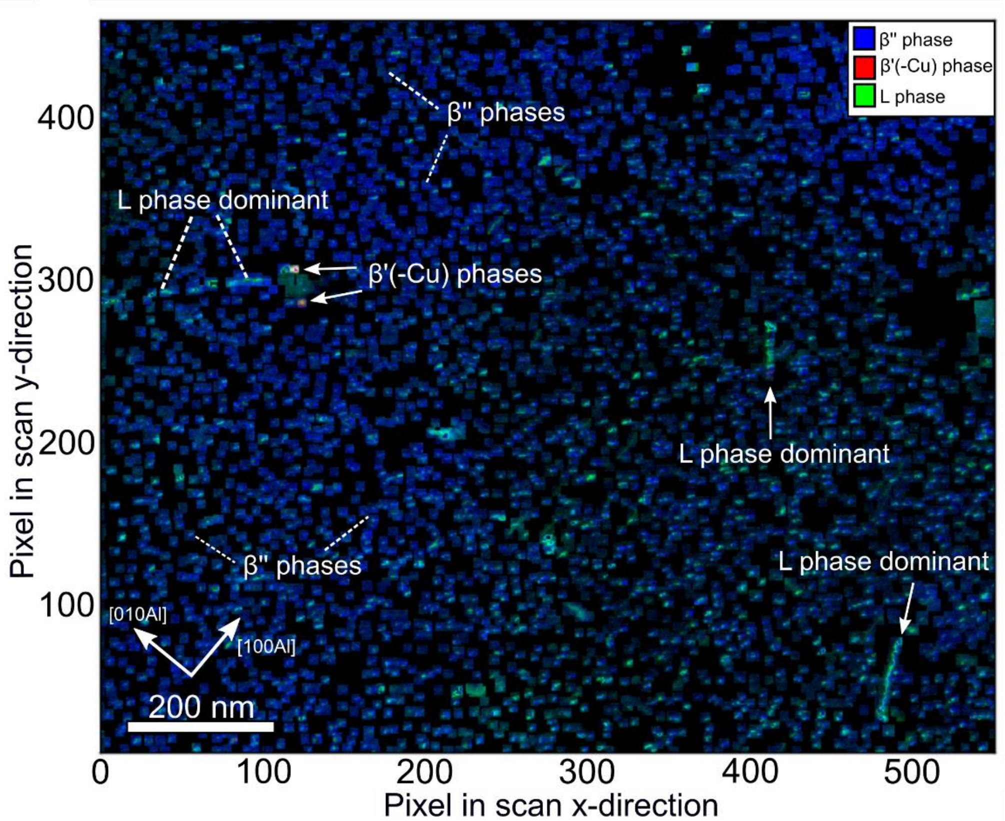

Figure 2: Colour-map showing the precipitate phase distribution in the scanned area.