Time dependence of dipole width obtained by zero-field μSR for Al and Al-0.5 at.%Si

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Al-Mg-Si aluminum alloys are widely used for vehicles, buildings, home appliances, *etc.*, because of their low weight, excellent formability and age hardenability. The mechanical strength (hardness) of the alloy depends on the density, size and structure of precipitates consisting of Mg and Si atoms; dense nano-size Mg_2Si precipitates make the alloys harder.[1–5] From various studies on Al-Mg-Si alloys, vacancy behavior is considered to play an important role in the aging process, stimulating the diffusion of solute Mg and Si atoms and the nucleation of Mg/Si/vacancy clusters. Positron annihilation spectroscopy (PAS)[3,4] and muon spin relaxation spectroscopy (μSR)[6,7] have been successfully used to investigate the behavior of vacancies and solute atoms in their clustering in Al-Mg-Si alloys. Taking advantage of high beam intensity and a high counting rate of muons at the ARGUS line, we have observed the time dependence of the dipole width (Δ) via zero-field muon spin relaxation spectroscopy in a pure (99.99%) aluminum and an Al-0.5at.%Si alloy to understand the details of the clustering process of solute atoms in Al-Mg-Si alloys.

All samples underwent heat treatment at 848 K for 1 h and subsequent quenching in ice water (STQ). Approximately 10 min after STQ, the sample was inserted into the ARGUS muon spectrometer, and then zero-field μSR measurement was started at a constant temperature. Typical spin relaxation spectra obtained for pure Al are shown in Fig. 1, in which the relaxation rate obviously decreases with time; the relaxation rate observed at 16 min after STQ (black circle) is larger than that at 378 min (blue square). The observed spin relaxation spectra were fit with the Kubo-Toyabe function using the WIMDA program,[8] and the dipole widths (Δ) deduced at three different temperatures are plotted in Fig. 2. Surprisingly, they appear to decrease linearly with time. The reduction of Δ is most likely ascribed to the annihilation of vacancies that are the main trapping sites of muons at these temperatures. The reason for the linear variation of Δ vs. t is unclear.

Figure 3 shows the time dependence of Δ in Al-0.5 at.%Si (described as Al-Si) obtained at 280 K, which seems to change on a logarithmic scale. On the Δ variation, there is obviously an effect of Si solutes that can bind vacancies. It is also noticeable that there is a change in the slope on the Δ vs. log(t) curve at approximately 300 min. For a comparison, the time dependence of Δ in the Al-1.6 at.%Mg_2Si (described as Al-Mg_2Si), which was previously reported,[9] is shown in Fig. 4. The similar change in the slope on the Δ vs. log(t) curve existed at approximately 150 min, which takes place earlier than in Al-Si. The magnitude of change of Δ in Al-Mg_2Si, however, is about one half of that in Al-Si in the same time range. The difference of the solute elements and the concentrations possibly affects the time dependence of Δ in Al-Si and Al-Mg_2Si.

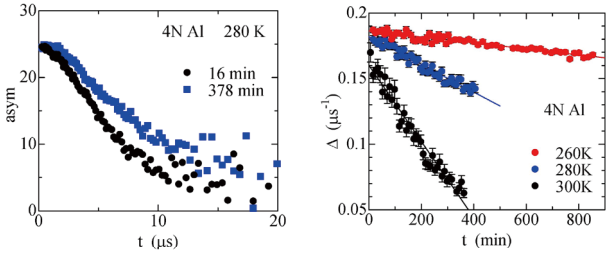

Fig. 1. (left) Zero-field muon spin relaxation spectra obtained for the pure Al sample at 280 K.

Fig. 2. (right) Time dependencies of dipole width in pure Al at 260, 280, and 300 K.

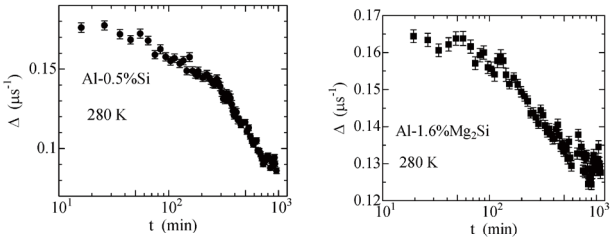

Fig. 3. (left) Time dependencies of dipole width in the Al-0.5 at.%Si alloy at 280 K.

Fig. 4. (right) Time dependencies of dipole width in the Al-1.6 at.%Mg_2Si alloy at 280 K.[9]

References
1) S. Pogatscher *et al.*, Acta Mater. **59**, 3352 (2011).
2) H. Seyedrezai *et al.*, Mater. Sci. Eng. A **525**, 186 (2009).
3) J. Banhart *et al.*, Phys. Rev. B **83**, 014101 (2011).
4) A. Somoza *et al.*, Phys. Rev. B **61**, 14454 (2000).
5) S. Pogatscher *et al.*, Phy. Rev. Lett. **112**, 225701 (2014).
6) S. Wenner *et al.*, Phys. Rev. B **86**, 104201 (2012).
7) S. Wenner *et al.*, Acta Mater. **61**, 6082 (2013).
8) F. L. Pratt, Physica (Utrecht) B **289**, 710 (2000).
9) K. Nishimura *et al.*, RIKEN Accel. Prog. Rep. **50**, 242 (2017).

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