μSR study of Al-Mg, Al-Si and Al-Mg-Si alloys†

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Al–Mg–Si alloys constitute most of the worldwide aluminium market as they have good mechanical strength and are easily formable into end products. An optimal heat treatment of alloys containing merely 1% solutes (Mg and Si) typically increases the hardness by a factor of 5 from pure aluminium. After the material is formed, an industrial hardening procedure consists of solution heat treatment (SHT), typically at 550 deg., some (unavoidable) storage at room temperature (RT) and artificial aging (AA), typically at 180 deg. Al–Mg–Si alloys quenched from SHT are unstable at RT, and atomic clusters (with Mg and Si at Al-fcc positions) form from the supersaturated solid solution.[1,2] The clusters in general are too small and coherent with the Al matrix to be observed by transmission electron microscopy (TEM).

Muons undergo interstitial diffusion inside solids. In aluminium, they have been shown to be trapped by atoms in substitutional lattice positions and by vacancies,[3-5] yielding a lower apparent muon diffusivity. In this work, we exploit this effect and identify the muon trapping behavior of Mg and Si atoms as well as vacancies in different stages of heat treatment of aluminium alloys. Due to its industrial and scientific interest, we study the ternary Al–Mg–Si system, and we also include the binary Al–Mg and Al–Si alloys mainly to isolate the ternary-specific features in the μSR data. Very dilute alloys have been probed with μSR before, and small additions of Si, Mg and Cu were found to greatly affect the muon kinetics.[6] Our previous work on the Al–Mg–Si system revealed the presence of a muon trapping peak corresponding to clustering/precipitation.[4] The main goal of the current work is to establish a connection between muon trapping rates and the microstructure of Al–Mg–Si alloys as found from TEM studies.

Observed muon spin relaxation spectra in zero-field were compared with those from a Monte Carlo simulation using four fitting parameters: the dipolar width (Δ), the trapping rate (ν_t), detrapping rate (ν_d) and the fraction of initially trapped nuons (p_0), assuming that muon spins relaxed with the single Δ value only when they were trapped. This data analysis is similar to those employed by Sato et al.[7] and Hatano et al.[8] The resulting temperature variation of the muon trapping rate is shown for eight selected samples in Fig. 1

We note the following trapping rate characteristics for Al–Mg: 1) heat treatment does not change the muon behavior much in Al–Mg alloys at temperatures up 120K.

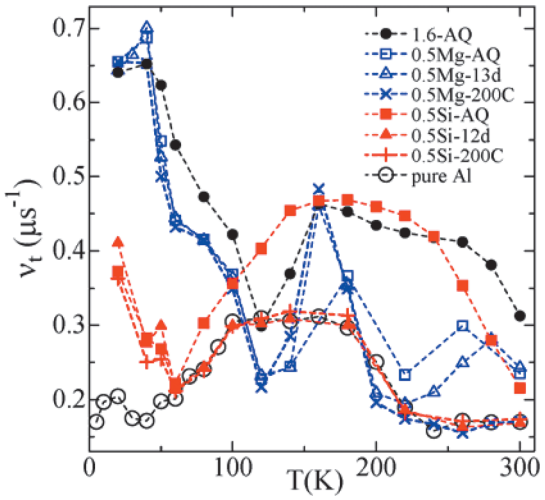

Fig. 1 Muon trapping rates (ν_t) for Al-Mg-Si, Al-Mg, Al-Si alloys and pure Al estimated using simulations.[4,5] The symbol-label of 1.6-AQ denotes the trapping rate with the Al-1.6%Mg_2Si sample quenched after SHT, those of 0.5Mg illustrate the results with the samples of Al-0.5%Mg quenched (0.5Mg-AQ), storage at RT for 13d (0.5Mg-13d), and annealed at 200 deg. for 1000 minutes (0.5Mg-200C), and the same manner used with the samples of Al-0.5%Si. The open circle presents the trapping rate observed with a pure Al (purity is 99.99%).

2) 13d and AQ samples have higher trapping rates than pure Al at temperatures of 240–300 K. This is not the case for the 200C sample. Correspondingly, for Al–Si: 3) the muon behavior in 12d and 200C samples is very similar to that in pure Al, excluding only the lowest temperatures. 4) A significant difference was observed at high temperatures between AQ and 12d (or 200C) samples. 5) The higher trapping rates of 0.5Mg-13d than those of 0.5Si-12d around RT indicate that Mg atoms tend to keep vacancies more than Si atoms.

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