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LETTER TO THE EDITOR

Effects of impurities on the positron trapping efficiency of dislocations in deformed aluminium

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Abstract. Positron lifetime and Doppler-broadening measurements have been made on deformed aluminium ($\simeq$99.95–$\simeq$99.9999% purity) and Al–0.01 at.% Si alloy. It has been found that impurities even in trace amounts can reduce the positron trapping efficiency of dislocations.

A large number of studies have been made on the interaction of positrons with dislocations in metals, since it was first realized that positrons are sensitive to defects introduced by deformation. However, for many metals, a specific trapping rate μ_d into the dislocations has not yet been confirmed although it is important in our understanding of the dislocation core structure and positron potential. For example, a large spread in μ_d values, ($\simeq$0.066–$\simeq$2) $\times 10^{-4}$ m^2 s^{-1}, exists for aluminium (Cotterill *et al* 1972, Aldi *et al* 1982, Segers *et al* 1985, Jensen *et al* 1988, Hashimoto *et al* 1992).

In recent experiments (Hidalgo *et al* 1987, Hashimoto and Kino 1991), it has been shown that the positron–dislocation interaction can be well described in terms of a model where positrons initially trapped at dislocation lines (shallow traps) can either be transferred into associated deep traps (e.g. jogs) or become thermally detrapped (Smedskjaer *et al* 1980). Then the large spread in μ_d values noted above indicates that properties other than the line density influence the trapping rate, e.g. the density of jogs or impurities trapped at the dislocation line. In this letter, we present a study of the effect of impurities on the positron trapping efficiency of dislocations in aluminium.

Positron-annihilation measurements were made on deformed aluminium ($\simeq$99.95–$\simeq$99.9999% purity) and Al–0.01 at.% Si alloy. Polycrystalline samples were annealed in vacuum ($\simeq 10^{-4}$ Pa) at 873 K for 6 h, and deformed at room temperature by rolling to various extents of thickness reduction. The deformed samples thus prepared were squares of side 15 mm and $\simeq$0.8–$\simeq$1.2 mm thickness.

Positron lifetime measurements were performed at room temperature using a fast-fast timing spectrometer with a resolution of 217 ps (FWHM). A ^{22}Na positron source was made by evaporating about 1.5×10^6 Bq aqueous ^{22}NaCl solution onto a Kapton foil. The component due to annihilations in the salt and foil, was obtained from positron-lifetime spectra acquired on well annealed samples. The spectra could be decomposed into two components characterized by two different lifetimes: $\tau_1 \simeq$ 160 ps (bulk lifetime τ_f in Al) and $\tau_2 \simeq 400$ ps. This longer-lifetime component with intensity ≃10% was attributed to the source effect, and subtracted in the analysis of the time measurements on the deformed samples. The analyses were made by the POSITRONFIT program (Kirkegaad and Eldrup 1974).

Doppler-broadening measurements were carried out as a function of temperature between 4.2 and 270 K with a Ge detector system with a resolution of 1.69 keV at 1.33 MeV. The shape of the Doppler-broadened photopeaks was characterized by a conventional peak-height (S) parameter.

The dislocation density N_d in the deformed sample actually used in the positron measurement was determined from the residual resistivities at liquid helium temperature: $N_d = (\rho - \rho_0)/\rho_d$, where ρ and ρ_0 are the residual resistivities before and after annealing in vacuum at 573 K for 2 h, respectively, and ρ_d is the resistivity per unit density of dislocations at liquid-helium temperature. The residual resistivity was measured with a superconducting chopper amplifier having a voltage sensitivity better than 5 pV (Ueda *et al* 1988). The ρ_d value of $1.2 \times 10^{-25}\ \Omega\ m^3$ has been obtained for dislocations in aluminium (Kino *et al* 1974).

A two-component analysis gave satisfactory fits of the lifetime spectra for all the samples studied. The effective trapping rate κ_{eff} at dislocations may, therefore, be obtained from the following formula: $\kappa_{eff} = \lambda_f(\bar{\tau} - \tau_f)/(\tau_2 - \bar{\tau})$, where λ_f is the rate of free annihilation in the bulk and $\bar{\tau}$ is the mean lifetime calculated from the two trapping components (τ_1, τ_2) and the corresponding intensities (I_1, I_2). The longer positron lifetime τ_2 was, within the statistical error, independent of the sample, with a value of about 235 ps. This value is in agreement with those previously quoted for dislocations in aluminium.

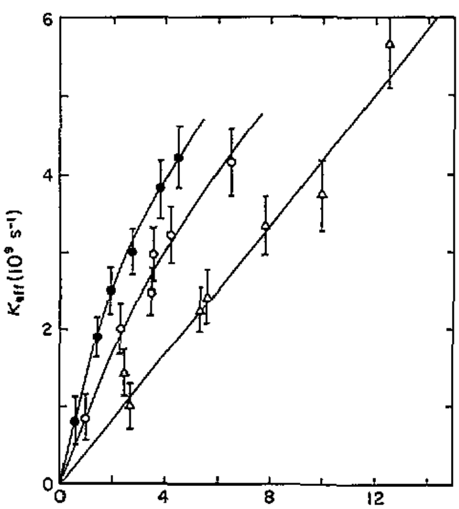

Figure 1. The effective trapping rate κ_{eff} plotted as a function of the dislocation density N_d for deformed aluminium of 99.95% (△), 99.999% (○) and 99.9999% (●) purity. The curves are drawn to guide the eye.

Figure 1 shows κ_{eff} plotted as a function of the dislocation density N_d for deformed aluminium with different impurity contents. The results clearly show that impurities even in trace amounts can reduce the trapping efficiency of dislocations.

For example, the specific trapping rates $\mu_d (= \kappa_{eff}/N_d)$ obtained for low dislocation densities are 0.42×10^{-4}, 0.88×10^{-4} and 1.5×10^{-4} m^2 s^{-1} for the samples of 99.95%, 99.999% and 99.9999% purity, respectively. For higher-purity samples, it is found that the trapping efficiency decreases with increasing dislocation density N_d, namely, degree of deformation. This may be due to a development of relatively long straight dislocation lines (shallow traps) during recovery at room temperature after deformation. Thus the observed value of 1.5×10^{-4} m^2 s^{-1} must be a lower limit for the correct value for μ_d in aluminium. Note that the μ_d value above is significantly larger than the value of 0.12×10^{-4} m^2 s^{-1} recently calculated by Häkkinen *et al* (1989) using molecular dynamics and a local density approximation.

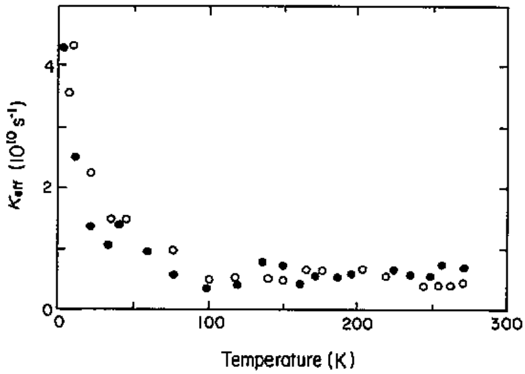

Figure 2. The effective trapping rate κ_{eff} plotted as a function of temperature for deformed aluminium of 99.995% purity (○) and Al–0.01 at.% Si alloy (●).

Figure 2 shows κ_{eff} plotted as a function of temperature for deformed aluminium (99.995% purity) and Al–0.01 at.% Si alloy with dislocation densities N_d of $\simeq 8 \times 10^{13}$ and $\simeq 3 \times 10^{14}$ m^{-2}, respectively. The trapping rate κ_{eff} decreases rapidly with increasing temperature up to about 100 K. This temperature dependence is consistent with the temperature dependence of μ_d calculated by Smedskjaer *et al* (1980) for low binding energies between a positron and a dislocation line. Besides, despite the large difference in N_d noted above, the trapping rate κ_{eff} and its temperature dependence are nearly the same for both samples. These results may suggest that in the Al–0.01 at.% Si sample only some of the dislocations can provide shallow traps for positrons and can be a precursor state for deeper traps (e.g. jogs), while the remainder have no contribution to positron trapping.

In this letter, it has been clearly shown that even trace amounts of impurities can reduce the positron trapping efficiency of dislocations. The results suggest the importance of high-purity metals in experimental studies of the positron–dislocation interaction. In order to clarify the origin of the effect of impurities, further studies, both experimental and theoretical, are required.

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