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Diffusion of Nano-Sized Liquid Pb Inclusions in Thin Aluminum Foils

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1 Introduction

The results of in-situ TEM studies of motion of nano-sized liquid Pb inclusions in thin foils of alloys of Al with about 1 at.% Pb are presented. The motion of free and attached to dislocations inclusions was investigated. Diffusion coefficients of individual inclusions were determined with high accuracy and reproducibility [1]. Their dependence on temperature and size of inclusions was studied [1, 2].

2 Experimental results and their discussion

It is shown that free liquid Pb inclusions in Al move randomly along non-localized trajectories [1]. In contrast, the inclusions attached to dislocations oscillate chaotically within a narrow region around the dislocation line [1, 3]. Fig. 1 presents the examples of the dependences of root mean squared displacement on elapsed time for motion of (1) a free inclusion and (2) of an attached inclusion in a plane perpendicular to the dislocation line. Fig. 2 shows the same for motion of attached inclusion along dislocation line.

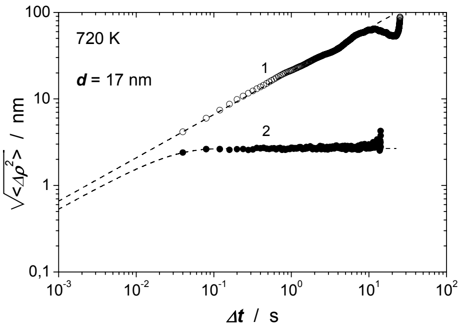

Fig. 1: Root mean squared displacement of the inclusion in the free (1) and the trapped (2) states as a function of elapsed time.

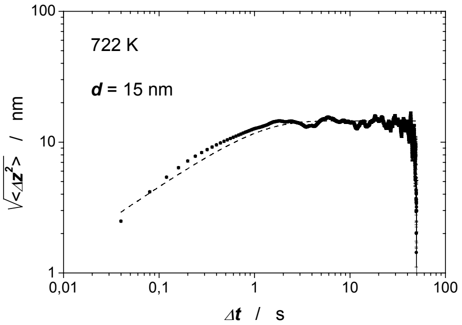

Fig. 2: Root mean squared longitudinal displacement of the trapped inclusion as a function of elapsed time.

Such dependences are used for determination of diffusion coefficients D_p of inclusions. Diffusion coefficients of free inclusions are determined using Einstein's equation for the case of 2D random walk, the dashed straight line 1 in Fig. 1. The diffusion coefficients of attached inclusions are determined using the equation derived by Smoluchowski for Brownian motion of a particle under the action of a linear elastic restoring force [1]: the curve 2 in Fig. 1 and the curve in Fig. 2 present the fitting for transverse motion and for

longitudinal motion, respectively. The diffusion coefficients of the inclusion (see Fig. 1) in the trapped state ($7.2 \cdot 10^{-17}$ m^2s^{-1}) and in the free state ($10.9 \cdot 10^{-17}$ m^2s^{-1}) obtained using Smoluchowski's and Einstein's equations, respectively, are in satisfactory agreement.
The dependence of D_p of free inclusions (the solid circles) on their diameter d is shown in Fig. 2. The linear fitting suggests the dependence $D_p \sim d^{-4}$ indicating that the mobility of the free Pb inclusions is controlled by a kinetic process at their surface [1]. The diffusion coefficients of attached inclusions well enough coincide with the size dependence of the diffusivities of free inclusions, Fig. 3. So, the effect of the dislocation on the mobility of the trapped inclusion is weak. It indicates also that the microscopic mechanism controlling the mobility of free and trapped inclusions is likely the same.

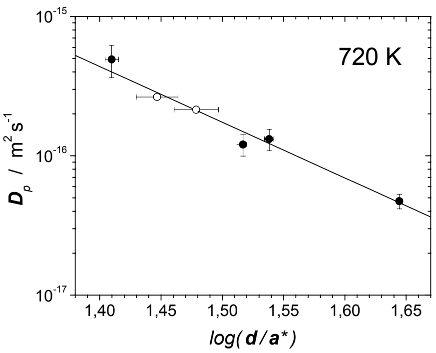

Fig. 3: Size dependence of D_p of free (●) and trapped (○) inclusions.

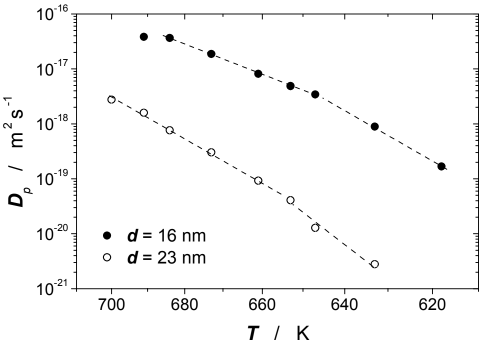

Fig. 4: Arrhenius plot of the diffusion coefficient.

The Arrhenius plot of D_p of 16 nm and 23 nm inclusions (Fig. 4) can be associated with the two different activation enthalpies: 3.5 eV and 5.8 eV at low temperature and 2.5 eV and 3.5 eV at high temperature. High values of the enthalpies and their dependence on the size of the inclusions indicate that the mobility of liquid Pb inclusions in Al is controlled by the process of dissolution of crystalline Al-matrix. The transition zone around 650 K may be related to the appearance of {111} facets on the surface of liquid Pb inclusion at the lower temperatures.

3 Conclusions

(i) The same microscopic mechanism is responsible for the mobility of free and trapped inclusions. (ii) The mobility is controlled by the process of dissolution of crystalline Al-matrix. (iii) Presumably the behaviour of the Arrhenius dependences is governed by the appearance of {111} facets on the inclusion/matrix interface.

References

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