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To cite this version:
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<jpa-00220981>

HAL Id: jpa-00220981
https://hal.archives-ouvertes.fr/jpa-00220981
Submitted on 1 Jan 1981

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TRAPPING OF SELF-INTERSTITIALS AT OVERSIZED IMPURITIES IN Al-Mg AND Cu-In AND UNDERSIZED IMPURITIES IN Al-Fe

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Abstract. - Several IF-peaks have been observed in Al-0.04 at% Fe, Al-0.01 at% Mg and Cu-0.025 at% In after electron irradiations. These peaks can all be related to reorientation processes of point-defect complexes consisting of self-interstitial and impurity atoms. The activation energies and preexponential factors are found in a range which is characteristic for interstitial-atom jumps. The peak behaviour during thermal annealing treatments reveal the trapping-strength of impurity atoms for migrating self-interstitial-atoms.

Introduction. - Trapping of migrating self-interstitials (S) at impurity atoms (I) is frequently observed in alloys under irradiation /1/. It results in the formation of so-called SI-complexes which are agglomerates of one or more S and one or more I.

The formation and properties of SI-complexes have attracted considerable attention in the past and many alloys have been studied.

The present IF-studies on Cu-In have been initiated because of a controversy which arose in the interpretation of damage rate studies /2/ and Perturbed Angular Correlation-studies /3/ on the same alloy namely about the question after the thermal stability of the SI-complexes in Cu-In.

A further aim of the present work was to compare the results on Cu-In with analogous IF-results on Al-Mg and Al-Fe. It was thought that this might give insight into the range of validity of theoretical models developed recently /4,5/.

Experimental. - Cu samples containing 250 atppm In and Al samples containing 125 atppm Mg and 400 atppm Fe, respectively, have been irradiated at 4.5K with 3 MeV electrons at the low temperature irradiation facility of KFA Jülich. The subsequent internal friction measurements of Al-Fe and Al-Mg were carried out in a low frequency torsion pendulum, the measurements on Cu-In in a vibrating reed apparatus. The defect concentrations introduced by the irradiation were monitored by simultaneously irradiated resistivity samples.

Results. - Six IF-peaks were observed in Cu-In, five in Al-Mg and six peaks in Al-Fe. The characteristics of these peaks are summarised in table 1, except for two of them in Al-Fe, which were too small in order to be analyzed in greater detail.
Table 1 shows the peak temperature, $T_p$, at about 80 Hz, the activation energy, $H_R$, for the reorientation and the preexponential of the relaxation time, $\tau_0$. Practically all of the values listed in table 1 fall in a range which is typical for reorientation jumps of single or multiple self-interstitials /6,7,8/.

Of particular interest is the annealing behaviour of the IF-peaks, because they directly reflect the formation- and annihilation processes of the various individual SI-complexes present in the samples. The results are shown in fig. 1, where the peak heights normalized to their maximum height, $Q_0^{-1}$, obtained during the tempering treatment are plotted as a function of the tempering temperatures.

**Discussion:**
1. Peak characteristics: The peaks characterized in table 1 are only observed in the specified alloys and not in pure Al or pure Cu. Therefore the peaks have to be attributed to the stress induced reorientation of SI-complexes. Of particular interest in respect to the peak characteristics are the two peaks occurring below 10K in Al-Fe and Cu-In. The atomic jump mechanism underlying the 8K-peak in Al-Fe is described in detail in another contribution to this conference /8/. There it is shown, that the peak results from a motion of an interstitial-Fe-atom like in a cage inside a unit cell of the fcc lattice. A specific model for the low temperature peak observed in Cu-In has not yet been developed.
2.) Number of IF-peak: The number of IF-peaks observed in each of the three different samples is apparently large inspite of the small S- and I-concentrations in the samples. This multiplicity may have two different origins: (i) One given defect type may give rise to more than one IF-peaks via different relaxation modes. An example of this is the pair of the 8K and 22K peak in Al-Fe /8/. (ii) Several different SI-complexes may be present in the sample. These two cases may be distinguished from each other from the annealing behaviour of the peaks: If peaks are being formed or disappear at different annealing temperatures, they must as a necessity be attributed to different types of SI-complexes. With this criterion, in Al-Fe at least three different SI-complexes have been observed, at least two in Al-Mg and at least five in Cu-In, as can be seen from fig. 1. For Cu-In it has been shown that this observation can be explained by a SI-complex ensemble, which consists of differently large SI-complexes, namely complexes containing from one to five S bound at one I-atom /9/. A similar defect ensemble may also account for the several peaks observed in Al-Fe and Al-Mg.

3.) Binding energies: The most stable SI-complexes disappear in Al-Mg and Cu-In at annealing temperatures of about 150K. In accordance with the interpretation of damage rate measurements on Al-Mg /10/ and Cu-In /2/ this recovery is attributed to dissociation process of the most stable SI-complexes. If this assignment is correct, binding energies of about 0.35 eV can be deduced for these complexes /1/.

The SI-complexes in Al-Fe are much more stable. They remain in the sample up to about 200K, where they are annihilated by migrating vacancies (stage III). Therefore
only a lower limit for the binding- or for the migration energies of these SI-complexes can be given which is 0.5 eV/1/.

4.) Comparison with theory: So far there is only one model available which accounts for the differences in trapping properties of different solute atoms in terms of a simple physical parameter. This parameter is the so-called volume misfit, $\delta$, which is the relative relaxation volume of the I in solution. If $\delta > 0$, solutes are called oversized and if $\delta < 0$, undersized.

In accordance with what is expected from the model it has been found in several cases that undersized I settle down into interstitial sites upon trapping a S /1/. In fig. 2a a configuration is shown where there are 24 equivalent sites for the interstitial I establishing a cage in which the I-atom jumps around. This is only one example of many /8/, which explains the occurrence of IF-peaks from undersized solute atoms having trapped a self-interstitial atom.

If oversized I encounter a Fig. 2: (a) Cage model of a SI-complex containing an undersized solute atom. (b) Jump model which explains jumps of self-interstitial dumbbells around an oversized impurity atom.

Conclusions.- In each of the three irradiated alloys, Al-Fe, Al-Mg and Cu-In an ensemble of differently structured self-interstitial-impurity atom complexes exists. This means that even at a low concentration ratio of $c_S/c_I \approx 0.1 \ldots 0.2$ not only one dominant defect is being formed but a distribution of various SI-complexes. The trapping strength may be different for different I, i.e. final detrapping occurs in Cu-In at 140K, in Al-Mg at 160K and beyond 200K in Al-Fe.
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