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MIGRATION OF THE INTERSTITIAL-IMPURITY MIXED <100> DUMBBELL CONFIGURATION IN Al-Zn

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Abstract: From measurements of ultrasonic attenuation and velocity in alloys with different atomic Zn concentrations (.01%, 0.1%, and 0.5%), we obtain positive evidence that the Al-Zn dumbbell migrates as a unit. From measurements in specimens containing 1000 ppm Zn and 70 ppm of Fe it is found that only 3% of the dumbbells dissociate at the annealing temperature near 140 K for Al -0.1% Zn. In the present measurements it is found that the annealing temperature decreases with increasing zinc concentration. A possible migration mechanism involving looping of the interstitial which leads to long range migration of the dumbbell is developed, and dumbbell migration and interstitial escape energies of U_m = 0.36 eV and U_E = 0.46 eV are obtained.

We have made measurements of ultrasonic attenuation and velocity changes at 10 and 30 MHz on a number of electron irradiated aluminum alloys, looking for systematic trends and relationships. The surprising result is that there is little relationship between systems; rather each system seems to have its own characteristic pattern of relaxation peaks. The most useful information obtained from the measurements is symmetry information, but the hope one may have had originally from resistivity, channeling and Mossbauer measurements of finding single characteristic defects is largely urealized. In general, several relaxation peaks are obtained, which usually correlate with resistivity stages, but which correspond to different defect configurations, as determined by their annealing behavior.

Our most detailed studies of interstitial-impurity dipolar defects are on Al-Zn [1]. We have irradiated specimens containing 0.5, 0.1, and 0.01 atomic percent of zinc in aluminum at 65 K. A defect with <111> symmetry is found at 103 K which anneals during the measurement, while another with <100> symmetry is found at 5 K which anneals at 135 K. The measurements for the 5 K peak provide the first strong experimental evidence for the theoretically much discussed and expected caged mixed dumbbell configuration [2]. In addition, the surprising result is found that the defect tunnels between the equivalent states. The evidence for the mixed caged configuration arises mainly from the polarization dependence of the dielastic and paraelastic ultrasonic response of the defect. A large diaelastic effect in C_{44} anneals with this defect, while the paraelastic response occurs entirely in the C' elastic constant, as would be expected for this symmetry. We will have nothing further to say about the configuration, or the tunneling, of the defect here. Instead, we describe evidence that this defect migrates as a unit through the lattice. The evidence is obtained by examining the annealing behavior of Al-Zn for different concentrations of Zn and in the presence of Fe impurities at lower concentrations.

In Al -100 ppm Fe specimens irradiated to ~2 ppm FP, three peaks were found [3] in the C_{44} mode at T = 19, 43, and 97 K at 10 MHz. A peak in C' is also found at 20 K. The C' peak was not seen in earlier lower frequency measurements by Rehn, Robrock and Jacques [4], but the C_{44} peaks correspond well with the lower frequency measurements. All the peaks disappear in Stage III. The dielastic effect is -36 for C' and -5 for C_{44}. Although Fe and Mn have similar mass and size differences with Al, the results are very different, contrary to expectations from existing theory [2] based on size difference considerations. Additional symmetry information for the system comes from Mossbauer measurements by Petry, Vogl and Mansel [5], but there is not yet good agreement on a detailed model [3]. Nevertheless, the prominent Al-Fe peak can be exploited as a deep trap which should hold interstitials leaving weaker traps at temperatures below 200 K.

In Fig. 1, the decrement at a function of temperature is shown for an irradiated specimen containing 1000 ppm of Zn and 70 ppm of Fe. Both the Al-Zn peak at 5 K and the Al-Fe peaks near 20 K are found but the Al-Fe peaks are much smaller (about 14 times smaller) than they would be without the Zn. On annealing, as indicated by the dashed lines, the Al-Zn peak decreases near 140 K, but the Al-Fe peaks do not increase by a factor of 14, as could be expected if the interstitials dissociated at 140 K, with the interstial migrating to the stronger Fe traps. Instead, the Al-Fe peak grows by about 40%. This shows that dumbbell dissociation is only a small component of the annealing of this defect.

For Al-Zn specimens of different Zn concentrations, it was found that the annealing temperature depends upon the Zn concentration, with the highest annealing temperature occurring for the lowest concentration. This is expected for an annealing mechanism where migrating mixed dumbbells are trapped at substitutional zinc atoms, so that more migration jumps are required in more dilute alloys.

We have developed a simple migration model, illustrated in Figs. 2 and 3, in which the interstitial can follow two paths. One leads to an apparent 180° rotation of the mixed dumbbell which allows the Zn to migrate out of the cage by a looping process [2]. The other leads to dumbbell dissociation. Rate equations allowing for both these processes are easily written and by fitting the results to the data, one finds U_m = 0.36 eV for the migration energy and U_E = 0.46 eV for the escape energy. These results are in fair agreement with calculations by Lam, et al [6].

In addition, measurements of changes of the height of the Al-Zn peak in a 100 ppm Zn alloy after repeated irradiation and annealing experiments gave results supporting a model of depletion of Zn traps above the Zn annealing temperature.

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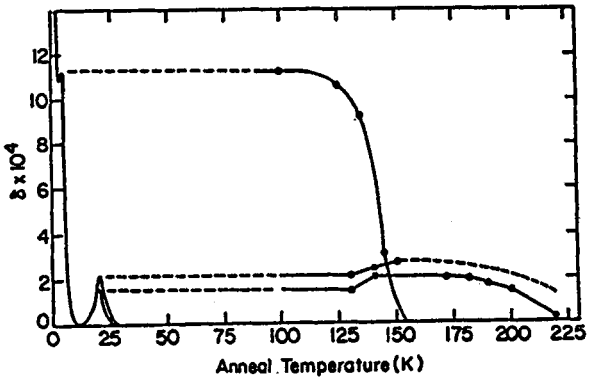

Fig. 1. Decrement as a function of temperature in Al-1000 ppm Zn-70 ppm Fe alloy. The dashed line indicates the annealing behavior of the Al-Zn peak at 5 K and the Al-Fe peaks near 20 K.

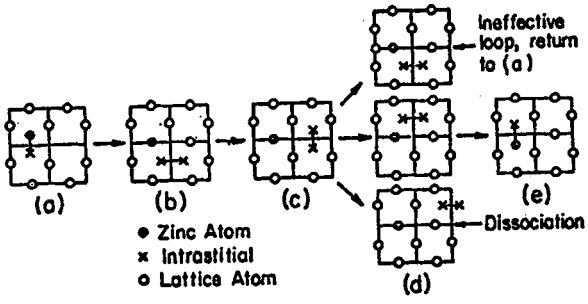

Fig. 2. Schematic diagram for a mixed Al-Zn caged mixed ⟨100⟩ dumbbell migrating by a looping process and dissociating.

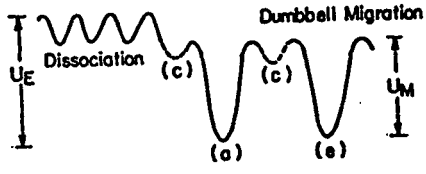

Fig. 3. Schematic potential energy diagram for the interstitial atom in configurations indicated in Fig. 2.