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Stress Distribution in the Direction of 1-D Motion of an Interstitial Loop

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1. Introduction

We studied a stress distribution around a dislocation loop to know the effect of compressive stress on 1-D motion of defect clusters. And we presented the effect of 1-D motion on the radiation hardening. Two mechanisms of radiation hardening have been proposed. One is a dispersed barrier hardening mechanism[1]. This explains defect clusters as barriers to a dislocation motion. And the other is a cascade induced source hardening mechanism [2], which places emphasis on the role of defects as a Cottrell atmosphere for dislocation motions. The interaction between dislocation and defect clusters has been considered, but the self-motion of clusters was not considered. No model has given a solution to the 1-D motion of defect clusters of a size of over 2 nm. Though the 1-D motion of defect clusters was observed by many researchers[3-8], they did not consider its effect on radiation hardening. To establish the effect of a 1-D motion on radiation damage, it is important to clarify the driving force of this motion. At this time, we tried to find out stress field into the motion direction of clusters through calculations with equations suggested by T. A. Kraishi et al[9].

2. Methods and Results

2.1 Experimental

The starting material for this study was binary Fe-Cu alloys made in our laboratory and an Fe single crystal (99.98% Fe) supplied by Goodfellow. After the Fe-Cu samples were solution-treated at 1,123K for 5 hrs in a vacuum condition, they were water-quenched. Samples were isothermally aged at 773K.

For an examination in an electron microscope, discs 3 mm in diameter were punched from the aged samples. TEM samples were observed with 1.25 MeV HVEM in KBSI. The image of the clusters formation was captured at a time interval of about 2 minutes. And the motion of the clusters was recorded through a CCD camera with a time interval of 1/30 s.

2.2 1-D Motion of Defect Clusters

Defect clusters started 1-D motion when the density of clusters reached a critical value, $1.8 \times 10^{21}/ m^3$ in Fe and $2.4 \times 10^{21}/m^3$. The motion is shown in Fig. 1. The direction of motion was analyzed with diffraction patterns and HREM images. The direction was <111>, the close packed direction of BCC structure. This direction is same with the direction of 1-D motion of crowdions in results of MD calculations [11, 12]. And the plane of motion was {110}. Therefore, the motion was a kind of conservative climb of dislocation loop.

(a)

(b)

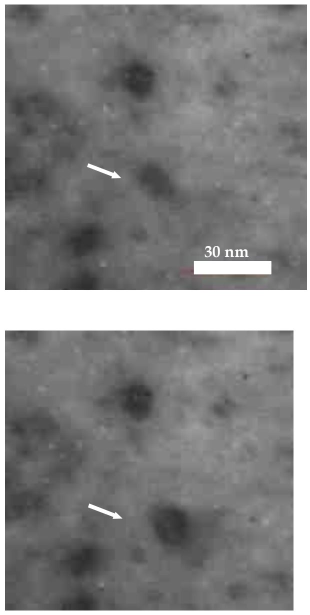

Fig. 1. 1-D motion of a dislocation loop in Fe-1.0%Cu irradiated with electrons.

2.3 Stress Field around a Dislocation Loop

Compressive stress field in the normal direction of a dislocation loop was presented at the last symposium. At the time, the motion was considered as a squeeze of dislocation clusters around the moving loop.

At this time, we considered the motion as a result of repulsive action between loops at a same {110} plane.

The material was treated as an isotropic one. To know the effect correctly, we should check the interaction between loops. But we calculated a stress field around just one loop at this time.

The Peach-Koehler equation for the self-stresses of any curved closed dislocation loop is given by the following line integral[12]. To perform the integration, a coordinate system was selected as shown in Fig. 2. The symbols are used as defined by T. A. Kraishi et al[9]. The loop radius is indicated by r_A. At first, the integration was carried out with respect to the local coordinate system (x', y', z'). And then the result was transformed into the global coordinate system (x, y, z).

The dislocation loop lies in x'y' plane and the distance from xy plane is z' , constant.

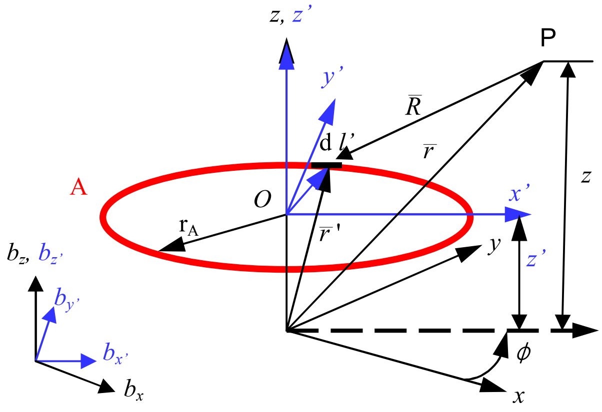

Fig. 2. The geometry of a circular dislocation loop{9}.

$$\sigma_{\alpha\beta} = -\frac{G}{8\pi}\oint_C b_m \varepsilon_{im\alpha}\frac{\partial}{\partial x'_i}\nabla'^2 R dx'_\beta - \frac{G}{8\pi}\oint_C b_m \varepsilon_{im\beta}\frac{\partial}{\partial x'_i}\nabla'^2 R dx'_\alpha - \frac{G}{4\pi(1-\nu)}\oint_C b_m \varepsilon_{imk}\left(\frac{\partial^3 R}{\partial x'_i \partial x'_\alpha \partial x'_\beta} - \delta_{\alpha\beta}\frac{\partial}{\partial x'_i}\nabla'^2 R\right)dx'_k , \quad (1)$$

where b_i is the Burgers vector, $\in$ is the permutation symbol, G is the shear modulus and ν is the Poisson's ratio. The compressive stress into [111] direction of a loop plane, σ_{yy} turns out to be

$$\sigma_{yy} = \frac{y^2}{\rho^2}\sigma_{x'x'} + \frac{2xy}{\rho^2}\sigma_{x'y'} + \frac{x^2}{\rho^2}\sigma_{y'y'} \quad (2)$$

Where

$$\sigma_{x'x'} = -\frac{Gb_{z'}}{\pi}[C_1E(k) + C_2K(k)] - \frac{Gb_{x'}}{2\pi(1-\nu)}[C_3E(k) + C_4K(k)] - \frac{Gb_{z'}}{2\pi(1-\nu)}[C_5E(k) + C_6K(k)]$$

$$\sigma_{x'y'} = -\frac{Gb_{y'}}{2\pi}[C_7E(k) + C_8K(k)] - \frac{Gb_{y'}}{2\pi(1-\nu)}[C_9E(k) + C_{10}K(k)]$$

$$\sigma_{y'y'} = -\frac{Gb_{x'}}{\pi}[C_{11}E(k) + C_{12}K(k)] - \frac{Gb_{z'}}{\pi}[C_{13}E(k) + C_{14}K(k)] - \frac{Gb_{x'}}{2\pi(1-\nu)}[C_{15}E(k) + C_{16}K(k)] - \frac{Gb_{z'}}{2\pi(1-\nu)}[C_{17}E(k) + C_{18}K(k)]$$

where the coefficients C_1 to C_{18} are given by Khraishi et al.[10]. K(k) and E(k) in above equations are complete elliptic integrals of the first and second kinds respectively.

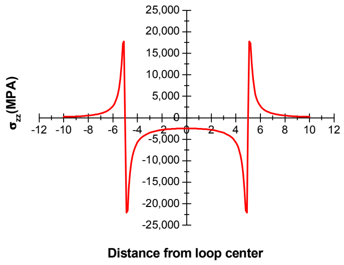

Fig. 1. σ_{zz} variation at z'=0 nm

3. Conclusion

The 1-D motion of radiation defects was observed. The motion occurred at a loop density of over $2.0x10^{21}/m^3$. The stress variation around an interstitial loop was calculated with the Peach-Koehler equation. From the calculated stress distribution, a compressive stress was applied to the direction of cluster motion..

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