Dislocation damping during electron irradiation

In a recent paper [1] we discussed the application of the Granato–Lücke [2] model of dislocation damping to the results obtained by Simpson *et al.* [3] during electron irradiation. We were able to show qualitatively that at low frequencies, the change in internal friction during electron irradiation could be explained by the vibration of dislocation loops about pinning points rather than the defect dragging mechanism which was postulated by Simpson *et al.* It is now possible to take the theory a little further and obtain quantitative information from the results. In the earlier paper, the following rate equations were set up,

$$\frac{dc}{dt} = At^{-1/2} - CD\Lambda \tag{1}$$

$$\frac{dn}{dt} = Bt^{1/2}\left(\frac{D}{T}\right)^{1/2}\frac{dc}{dt} - Kn, \tag{2}$$

assuming that the number of defects produced in the lattice by electron irradiation is proportional to the square root of the dose [4] and that the defects move to dislocations at a rate governed by the Cottrell–Bilby equation. The exponent in this equation is taken to be 0.5 [5]. In Equations 1 and 2 the concentration of defects in the lattice is C; n is the number of defects trapped at the dislocations, K is the rate at which defects diffuse along dislocations to nodal points, D is the diffusion coefficient in the lattice, Λ is the dislocation density and A and B are constants.

The solution of Equation 1 and 2 is,

$$n = Z\left(\frac{D}{T}\right)^{1/2} t\left[1 - kt + \frac{(kt)^2}{6} - \ldots\right] \tag{3}$$

which for small values of kT can be reduced to

$$n = Z(D/T)^{1/2} t e^{-\alpha kt} \tag{4}$$

where α is a constant approximately equal to 0.46.

According to the Granato–Lücke theory [2], n is related to the damping by the equation,

$$n = \left(\frac{\Delta\delta}{\Delta\delta_0}\right)^{-1/4} - 1 \tag{5}$$

where

$$\frac{\Delta\delta}{\Delta\delta_0} = \frac{\delta_t - \delta_s}{\delta_0 - \delta_s}$$

and δ_0, δ_s are the intial and saturation values of the damping and δ_t is the damping after time t.

From Equation 4, a plot of $\ln(n/t)$ versus t should be a straight line of slope equal to αK and intercept equal to $\ln\{Z(D/T)^{1/2}\}$. Fig. 1 shows such a plot of the results obtained by Simpson and Sosin [3] during the electron irradiation of copper at temperatures between 310 and 410 K. The plots are indeed linear and both the slope and the intercept increase with irradiation temperature. Let the intercept and slope be I and S, respectively. Then from Equation 4

$$S = \alpha K$$

$$I = Z(D/T)^{1/2}.$$

Now $K = K_0 e^{-Q'/RT}$ where Q' is the activation energy for diffusion of the defect along the dislocation line and $D = D_0 e^{-Q/RT}$ where Q is the activation energy for diffusion of the defect to the dislocation. Therefore,

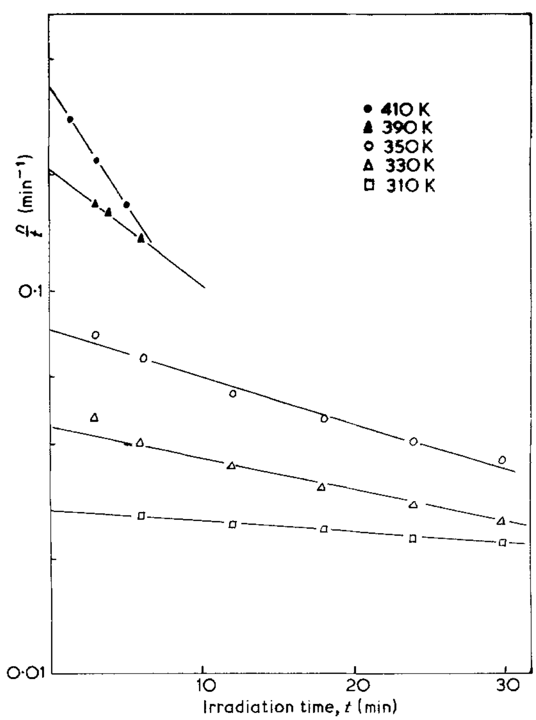

Figure 1 $\ln n/t$ versus t for the temperature range 310 to 410 K (after Simpson *et al.* [3]).

and

$$\ln(S) = \ln(\alpha K_0) - Q'/RT$$
$$\ln(I.T^{1/2}) = \ln(Z.D_0) - \frac{Q}{2RT} \quad (6)$$

Plots of $\ln(S)$ and $\ln(I.T^{1/2})$ versus $1/T$ should be linear with slopes proportional to the activation energies for diffusion along and to the dislocation line, respectively. Fig. 2 illustrates these plots and from which

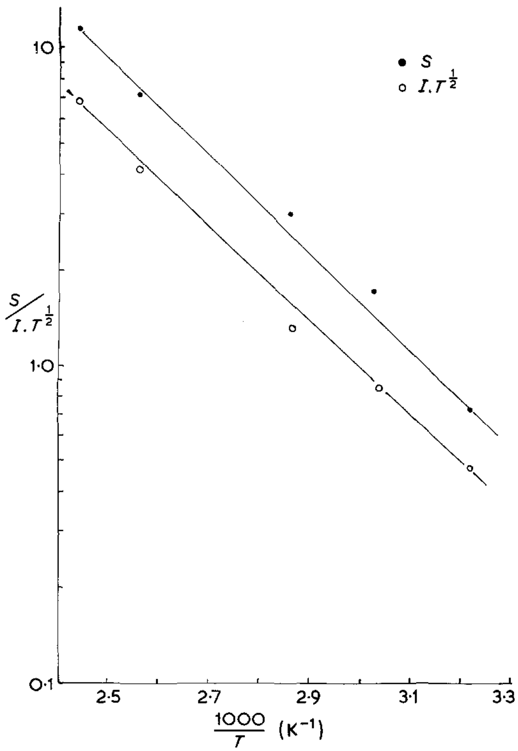

Figure 2 Intercept times $T^{1/2}$ and slopes from Fig. 1. versus T^{-1}.

and

$$Q' = 0.3\,\text{eV}$$
$$Q = 0.6\,\text{eV}.$$

Thompson reports several papers in which a lattice energy and pipe diffusion energy of 0.64 and 0.4 eV, respectively, have been obtained.

The results obtained by Simpson and Sosin can, therefore, be explained in terms of the Granato–Lücke model of dislocation on damping. This has been achieved by modifying the Cottrell–Bilby equation to take into account the continuing production of point defects during irradiation. Pipe diffusion of the defect along the dislocation has also been included in the theory. From the results, the activation energies for diffusion to and along dislocations have been obtained and are in agreement with other workers.

References

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Growth sector boundaries and their influence on quartz resonator performance

The influence of crystal defects on quartz resonator performance has been the subject of some interest in the recent past [1, 2]. In the present paper, the occurrence of boundaries between regions having differences in their impurity incorporations contained in the central part of quartz reasonator plates is indentified with the malfunctioning of the crystals. These boundaries are thought to be growth sector boundaries (gsbs) [3–6] and growth cell boundaries [3].

The inclination of the plane of a quartz resonator plate relative to the crystallographic axes of the material is a sensitive function of its frequency–temperature behaviour [2]. The variation of the fractional change in frequency, $\Delta f/f$, with temperature for normally functioning AT-cut [7] resonators is shown in Fig. 1. This figure also