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Magnetic Relaxation in Silicon Iron under Irradiation by Neutrons

H. D. DIETZE AND E. BALTHESEN
Technische Hochschule Aachen und Kernforschungsanlage Jülich, Germany

In silicon iron with 3% silicon the magnetic relaxation was investigated at temperatures above 200°C under simultaneous irradiation by fast neutrons. The experiments can be explained by diffusion of vacancies into the domain walls. The results yield informations on the production and annihilation of vacancies during irradiation by fast neutrons.

In silicon iron a magnetic relaxation is observed at temperatures above 350°C which was investigated for the first time by Fahlenbrach[1] and co-workers[2),3)] and recently by Biorci, Ferro and Montalenti[4]. Dietze[5] proposed as a mechanism for this relaxation the diffusion of vacancies into the domain walls. There is an interaction energy between a vacancy and the wall, resulting, after demagnetization, in a diffusion of the vacancies into the wall. In this way an additional potential well for the domain walls is created which then gives rise to the well known phenomena of magnetic relaxation. Biorci *et al.*[4] proposed a different model for this relaxation. They assume that the energy of solute atom pairs is a function of their orientation relative to the direction of magnetization. This gives rise to a theory which is very similar to Néel's[6] theory of relaxation by interstitials.

In this paper results are presented which were obtained when the samples were simultaneously irradiated with fast neutrons. The experimental set-up is described by Dietze and Balthesen[7]. The evaluation of the experiments was performed according to the theory of vacancy diffusion into the domain walls[5),7)]. This theory yields the following expression for the time rate of change of the reciprocal of the initial permeability directly after demagnetization:

$$\left(\frac{d}{dt}\frac{1}{\mu_a(t)}\right)_{t=0}=L(T)nD\,.$$

Here D is the diffusion constant of the vacancies, n the concentration of the vacancies and $L(T)=(A_2/4)\cdot(1/4\pi J_s^2)\cdot(\varepsilon_1^2/kT)\cdot(b/\delta^3)$ (J_s: saturation magnetization, b: distance of the domain walls, δ: thickness of a wall, ε_1: elementary interaction energy between a vacancy and a domain wall, T: absolute temperature, k: Boltzmann constant, A_2: a numerical constant). Fig. 1 shows schematically the results for a fast neutron flux of about 10^{11} neutrons/cm^2 sec. (L_0 is the value of the temperature function $L(T)$ at 400°C). Above 400°C practically no deviation from the experiments without irradiation is observed. At these temperatures the vacancies are mainly produced by the thermal movement. In thermal equilibrium their concentration is in this case $n=N\exp(-Q_b/kT)$ (N: number of lattice sites per unit of volume, Q_b: enthalpy of formation of a vacancy). The diffusion constant depends exponentially on the temperature: $D=D_0\exp(-Q_w/kT)$ (Q_w: enthalpy of activation for the motion of vacancies).

This leads, in Fig. 1, to a straight line with slope Q_b+Q_w. At temperatures below 400°C most of the vacancies are produced by irradiation. The equilibrium between production by irradiation and annihilation determines the vacancy concentration n. Fig. 1 shows that the rate of annihilation depends on the irradiation time. After irradiation times of more than $20h$ nD becomes independent of temperature. The reason for the decrease of nD at temperatures below 270°C is probably that in this temperature range the equilibrium between production and annihilation is no longer reached. This was also

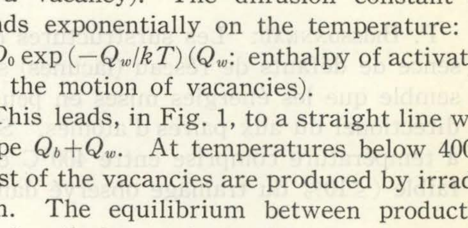

Fig. 1. Schematic plot of nD versus temperature

proved experimentally. Dienes and Damask[8] measured nD in α-brass under simultaneous irradiation by a totally different method. Above a certain temperature they observed an increase with the activation energy of self-diffusion. Below this temperature nD is independent of temperature. They explain this phenomenon according to a theory of Lomer[9] in which the temperature independence of nD is explained by the diffusion of the vacancies to fixed sinks. In this case n is inversely proportional to D and, therefore, nD is independent of temperature. Our experiments indicate that these fixed sinks are built up during the irradiation. Dienes and Damask[8] could not find this effect as their method was by far not so sensitive as our magnetic method. At the moment, a detailed model for the annihilation of the vacancies at the different irradiation times can not yet be given. The authors did not succeed in finding a simple explanation of these phenomena on the basis of the theory of Biorci *et al.*[4].

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DISCUSSION

P. BRISSONNEAU: Les surstructures d'orientation et le traînage de diffusion en présence de défauts de réseau (lacunes) sont des phénomenes très intéressants, mais il semble que les énergies mises en peu soient beaucoup plus faibles que dans l'ordre directionel dû aux paires d'atomes. Sur un fer purifié par melting zone on a observé à température comprise entre 400°C et 500°C un champ de traînage d'amplitude très faible ($\leq$10% du traînage observé dans l'alliage Fe-Si habituel).