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Disaccommodation of Silicon-Iron Single Crystal with Frame Type*

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Time decrease of magnetic permeability due to 180° wall movement after demagnetization for a Si-Fe frame type single crystal was studied. Measuring alternating magnetic field with 1 kc/s was changed between 0.1 and 100 milli-oersteds, and the temperature was varied from −9°C to −30°C. Amount of disaccommodation was influenced by these measuring amplitudes and it became negligible for larger amplitude which corresponds to the zero curvature of 180° wall potential energy originated in interstitial carbon atoms. From these measurements stabilization field strength for 180° wall was estimated to be nearly 15 mOe at temperatures of interest. These results for 180° wall movement will not be explained by Snoek's magnetostrictive theory, but support Néel's theory of direct dipole-dipole type interation between iron atoms.

Introduction

Disaccommodation (D.A.) of a magnetic permeability means that the potential energy of domain walls in ferromagnetic materials changes with time after demagnetization treatment. Motion of the walls tends to be fixed through this energy, which reaches a constant value after an infinitly long time.

As is well known, Snoek's[1] theory for the origin of this potential energy is essentially of magnetostrictive. Néel[2] proposed, on the other hand, the pseudo dipole interaction between iron atoms is more dominant which cancels out in the case of exact cubic symmetry, when the interstitial carbon atoms occupy preferentially a certain direction in iron.

According to Néel, the potential energies take different forms for 90°-and 180°-walls. For 180°-walls, the energy is increased with the displacement from the center of walls and becomes to constant value when the displacement is larger than that of the order of wall width, whereas for 90°-walls, the energy goes on increasing even for the displacement of larger distances than the wall width.

This implies that when we measure the permeability with various measuring amplitude of magnetic field, amount of D.A. is changed as the amplitude is increased and finally D.A. should not be observed for 180°-walls, corresponding to zero curvature of 180°-wall energy.

For the purpose of studying the effect of measuring magnetic field on D.A. for 180°-wall, a frame-type specimen having almost 180°-walls only in it will be fitted. In the frame-type silicon-iron single crystal of ⟨100⟩ direction, the effect of magnetostriction on D.A. can hardly be expected to occur.

Experimental Procedure

1.23% Si-Fe single crystal was kindly lent us by Prof. E. Tatsumoto of Hiroshima University. Its size, crystal orientation and chemical compositions are shown in Table I. Permeability was measured by using an alternating current bridge, which was the same instrument used in previous work on polycrystal silicon-iron.[3] Measuring field was changed from the minimum 0.1 mOe to the maximum 10^2 mOe of 1 kc/s and the vari-

Table I.

Orientation of 1.23% Si-Fe Single Crystal with Frame Type						
(001) — <100>						
Cross Section						
1.05 mm²						
Outside						
76 mm × 30 mm						
Inside						
65 mm × 2.2 mm						
Chemical Compositions						
	Si	C	Mn	P	S	Cu
wt%	1.23	0.09	0.24	0.010	0.043	0.25

* This work was done at Hokkaido University.

ation of D.A. with these amplitudes of a.c. field was observed. Hysteresis curve was measured by a recording d.c. magnetic flux-meter of Cioffi's type and the effect of the several ways of demagnetization on initial magnetization process was examined. No a-symmetry of *B-H* curves about *H*-axis was seen by each way of demagnetization, so this indirectly proved the simplest domain structure as expected.

To keep the temperature of the specimen constant for a few days, it was set in a Dewar-bottle with dry-ice in it. By changing the height of the specimen in the Dewar-bottle, a desired temperature between $-19°C$ and $-30°C$ could be obtained within the error of $\pm 0.01°C$.

Results

Time decrease at several points of temperature is seen in Fig. 1 and Fig. 2. After Rathenau *et al.*[4], we assume the decrease with respect to time should be represented as

$$r_t = r_0 + r_a(gt \exp -E/kT)$$

where $r_t = \mu_t^{-1}$ is the inverse permeability at time t after demagnetization, r_0, r_a the constant values and $g = (r_t - r_0)/(r_\infty - r_0)$

Fig. 3 shows that up to $g=0.9$, a linear relationship is valid. From the slope of Fig. 3, the activation energy E is found to be $E = 0.86 \pm 0.05$ eV. This value will correspond to that of diffusion process of carbon in silicon-iron, causing the relaxation of the wall motion.

Next, we measured the 180°-wall stabilization field from the variation of D.A. with measuring field. *B-H* curve from the initial magnetization range was obtained from Fig. 4 at (1) immediately after demagnetization treatment and at (2) after an infinity of time actually about 30 hours. The stabilization field for 180°-wall was defined as the difference of measuring field (H_0) for the same value of B at (1) and (2).[5] By Néel's theory[2],

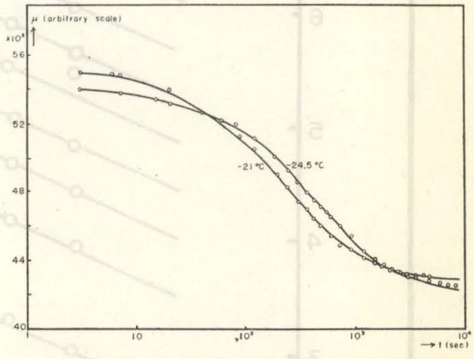

Fig. 1. Time Decrease of Permeability in 1.23% Si-Fe Single Crystal at −21.0°C and −24.5°C.

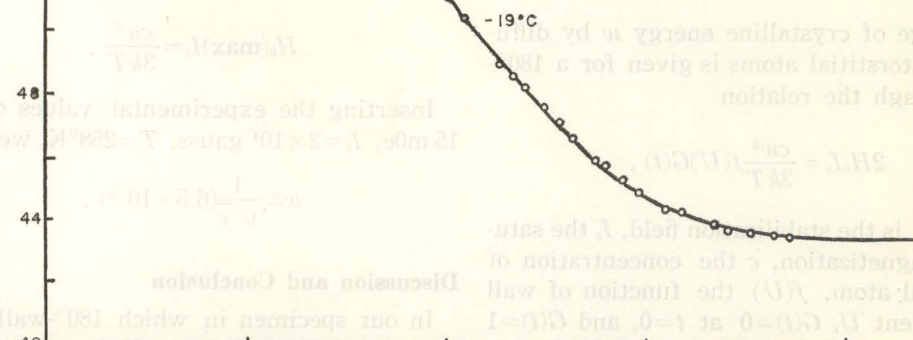

Fig. 2. Time Decrease of Permeability in 1.23%Si-Fe Single Crystal at −19.0°C

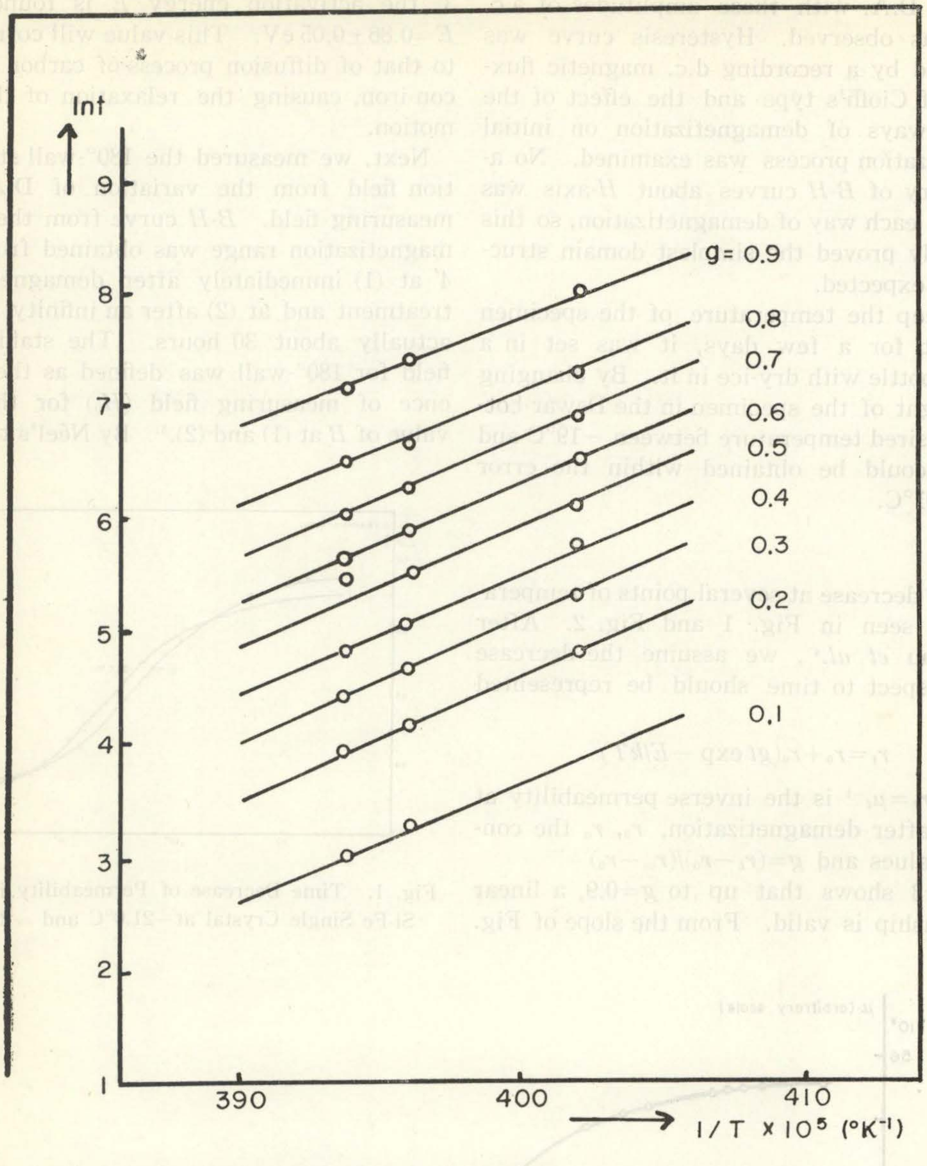

Fig. 3. Determination of the Activation Energy from D. A. Measurement.

the change of crystalline energy w by diffusion of interstitial atoms is given for a 180°-wall through the relation

$$2H_0I_s=\frac{cw^2}{3kT}f(U)G(t)\ ,$$

where H_0 is the stabilization field, I_s the saturation magnetization, c the concentration of interstitial atom, $f(U)$ the function of wall displacement U, $G(t)=0$ at $t=0$, and $G(t)=1$ at $t=\infty$.

In our case, if we take the maximum value of $f(U)=2$ and $G(t)=1$, then

$$H_0(\max)I_s=\frac{cw^2}{3kT}\ .$$

Inserting the experimental values of $H_0=$ 15 mOe, $I_s=2\times10^4$ gauss, $T=258$°K, we obtain

$$w\doteqdot\frac{1}{\sqrt{c}}(6.5\times10^{-6})\ .$$

Discussion and Conclusion

In our specimen in which 180°-walls exist dominantly, the result of the stabilization field experiment might not be explained essentially on the basis of above cited ideas of

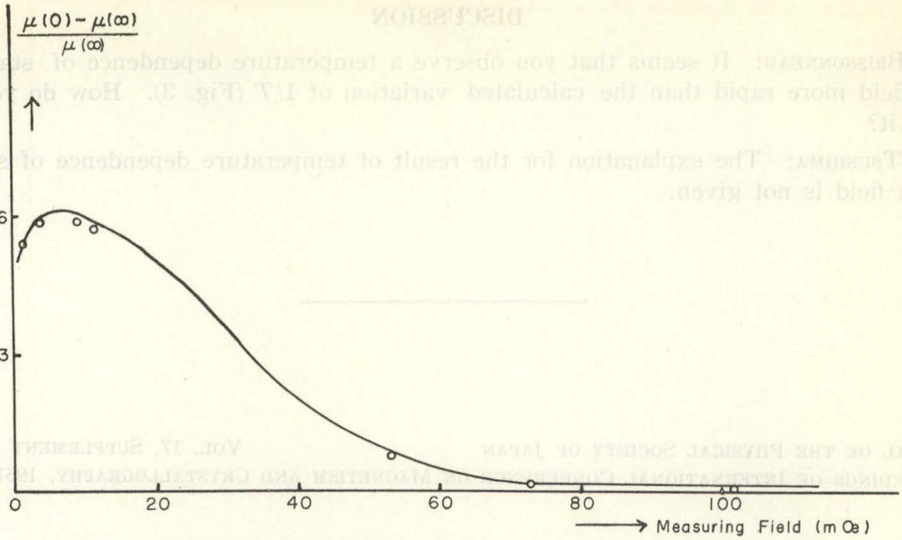

Fig. 4. Variation of D. A. with Measuring Field at −15°C.

Snoek, *i.e.*, the effect of magnetostriction of silicon-iron on D.A. can hardly be expected to occur.

The result of stabilization field experiment of Rathenau *et al.*[6] for a single crystal of silicon-iron (but not with frame type) coincides with ours.

The variation of D.A. with silicon compositions in silicon-iron polycrystal by Bosman[7] and by us[8] also indicates none of the effect of magnetostriction, and supports Néel's theory.

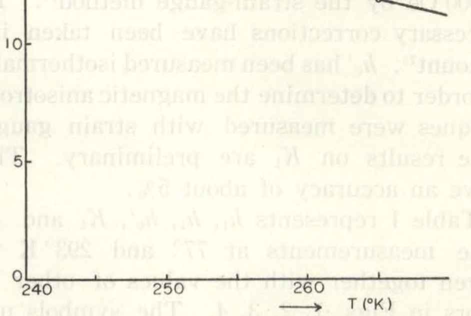

Fig. 5. Temperature Dependence of 180°—wall Stabilization Field.

Acknowledgement

The author wishes cordial thanks to Prof. S. Miyahara for discussions and encouragement since the beginning of this work and to Prof. E. Tatsumoto of Hiroshima University for lending him the single crystal frame type specimen of 1.23% Si-Fe.

He also expresses sincere thanks to Dr. T. Yamadaya for valuable advice about D.A. and the measuring method and to members of Research Laboratory of Magnetism of Hokkaido University for many discussions and criticisms.

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DISCUSSION

P. BRISSONNEAU: It seems that you observe a temperature dependence of stabilization field more rapid than the calculated variation of $1/T$ (Fig. 3). How do you explain it?

K. TSUSHIMA: The explanation for the result of temperature dependence of stabilization field is not given.

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Single-Crystal Magnetostriction Measurement on Dilute Iron Alloys

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The single-crystal magnetostriction constants of iron and of dilute alloys of iron with some non-transition elements have been measured in the temperature region 4-300°K. The variations of the constants with temperature, with composition and with degree of ordering are separately discussed. Preliminary results on magnetic anisotropy are also given.

It seemed of interest to measure single-crystal magnetostriction constants[2] at low temperatures as functions of temperature in order to test the applicability of the equation of Kittel and van Vleck[1] to metals and alloys.

It also seemed worthwhile to investigate the specific influence of non-transition elements added as dilute solutes to iron. It is well known that silicon and aluminum in additions up to about 10 atomic % act as simple diluents of iron when judged from the saturation change. Similar behaviour is found for the alloys of iron with other non-transition elements, which we have measured (Sn, see reference 2). Part of this program has already been carried out by others[3][4][5][6].

Experimental and results

The iron crystal was produced from Ferrovac E iron (impurities about 0.05 at %, except O, C, N, of which C and N had been removed). The alloy crystals have also been prepared from Ferrovac E or purer iron and high-purity solute elements. The crystals were homogenized. No inhomogeneities were revealed by micrographic inspection. Since no single crystal of an Sn-Fe alloy has been obtained, the measurements in this case were done on a polycrystalline specimen with a strong texture.

Magnetostriction was measured at 10000 and 20000 Oe by the strain-gauge method[7]. The necessary corrections have been taken into account[7]. h_0' has been measured isothermally. In order to determine the magnetic anisotropy, torques were measured with strain gauges. The results on K_1 are preliminary. They have an accuracy of about 5%.

Table I represents h_1, h_2, h_0', K_1 and M_s. The measurements at 77° and 293° K are given together with the values of other authors in Figs. 1, 2, 3, 4. The symbols used are defined in reference 2.

Discussion

The measurements, though far from being