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MAGNETIC ANISOTROPY IN SILICON IRON

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Résumé. — La première constante d'anisotropie pour $Fe_{1-x}Si_x$ a été déterminée, par la mesure de torsion pour x jusqu'à 10 % (pour cent) atomique, dans la gamme des températures de 21 à 300 °K. Cette valeur, extrapolée jusqu'à 0 °K, varie linéairement en fonction de la teneur en silicium.

En utilisant les expressions de Keffer et de Oguchi, on prouve que K_1 à 0 °K doit varier comme $\{1 - (a + 2)x\}$ où a est le rapport de la contribution dipolaire à la valeur totale de K_1 , et égale à 1,6.

Abstract. — The first anisotropy constant for $Fe_{1-x}Si_x$ is determined by torque measurements, for x up to 10 atomic per cent, in the temperature range 21-300 °K. The values, as extrapolated to 0 °K, vary linearly with silicon content. Using the expressions obtained by Keffer and Oguchi it is shown that K_1 at 0 °K should vary as $\{1 - (a + 2)x\}$ where a is the ratio of dipole contribution to the total value of K_1 and equal to 1.6.

1. Experimental. — Single crystals of silicon iron were shaped spherically by spark erosion and subsequent polishing [1] till the departure from perfect sphericity was less than 0.002. Anisotropy measurements, in fields of 14 kOe, were performed by a torsion magnetometer along the lines developed by Aldenkamp et al. [2] and modified by Van Wyk [3]. Two perspex discs, separated by phosphor bronze torsion vanes, provides a mechanism that twists easily but resists lateral movement. The angular displacement is measured by altering the capacity between parallel metal sheets, each fixed to a disc. The capacitor is part of a stable oscillator's tuning circuit and the frequency change provides an extremely sensitive method for torque measurements. The results for K_1 , from measurements performed in the [100] plane of the crystal are depicted in the figure 1 together with the values as extrapolated to 0 °K. Both the peak and the slope values of the torsion curves were employed to determine the values of K_1 . The methods gave comparable values that were well within the limits of experimental accuracy. Some values due to Graham [4] and Arajs et al. [5] are also shown for purposes of comparison.

2. Theory. — The expressions developed by Keffer and Oguchi [6, 7], from spin wave theory, for magnetic anisotropy in a material such as pure iron, lead to the following values for the pseudo dipolar and quadrupole terms $K_{1D}(0)$ and $K_{1Q}(0)$ at 0 °K :

$$K_{1D}(0) = -\frac{15 NS}{16 Jz} D^2 S_4 ;$$

$$K_{1Q}(0) = \frac{5}{3} NS_4 Q S^2 \left(S - \frac{1}{2}\right)^2 \quad (1)$$

where N is the number of magnetic atoms ; z is the number of nearest neighbours ; J is the exchange intergal ; D and Q the dipole and quadrupole coupling constants ; S the spin value per atom ;

$$S_4 = \sum_j \left(\alpha_{ij}^2 \beta_{ij}^2 + \dots - \frac{1}{5} \right)$$

where α_{ij} , β_{ij} , γ_{ij} are the direction cosines, relative to the cubic axis, of r_{ij} , the displacement vector from the i^{th} to j^{th} atom ; $S_4 = \frac{2}{15} z$ when nearest magnetic neighbours are considered in a b.c.c. crystal.

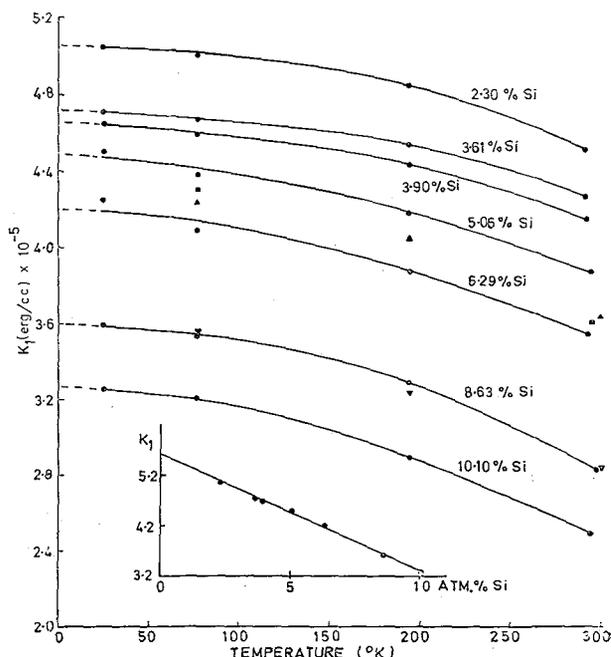


FIG. 1. — Anisotropy constant K_1 for iron-silicon alloys at different temperatures. The inset shows the linear relation between K_1 and silicon content (atm %) as extrapolated to 0 °K.

- Present measurements
- ▲ Graham's values for 6.17 % Si
- ▼ Graham's values for 9.65 % Si
- Arajs et al. values for 6.89 % Si

Assuming that the alloy $Fe_{1-x}Si_x$ may be represented by a homogeneous b.c.c. lattice, with $(1 - x)$ iron atoms on each site, the quantities N , z , and S_4 are simply multiplied by $(1 - x)$ when applying the above expressions. From saturation magnetisation measurements [8] it is known that the magnetic moment per iron atom remains virtually constant for the range of alloys dealt with here i.e. S remains unaltered. The effects of alloying on the values of J , D and Q are very difficult to estimate and it is assumed, to first approximation that they remain constant.

We have thus from equation (1)

$$[K_1(0)]_{Fe_{1-x}Si_x} = [K_{1D}(0)]_{Fe_{1-x}Si_x} + [K_{1Q}(0)]_{Fe_{1-x}Si_x}$$

$$= (1 - x)[K_{1D}(0)]_{Fe} + (1 - x)^2 [K_{1Q}(0)]_{Fe}$$

Putting

$$[|K_{1D}(0)|/K_1(0)]_{\text{Fe}} = a$$

we get

$$[K_1(0)]_{\text{Fe}_{1-x}\text{Si}_x}/[K_1(0)]_{\text{Fe}} = 1 - (a + 2)x + \dots \quad (2)$$

in which higher powers of x are discarded.

Equation (2) is derived for the case of a lattice parameter that remains constant. In practice the lattice contracts with the addition of silicon [9] and the experimental values for K_1 are corrected by utilising its pressure dependence as given by Veerman and Rathenau [10]. It is $\frac{1}{K_1} \frac{dK_1}{dp} = 0.42 \times 10^{-2}$ per kilobar per unit mass. Using this value and the bulk modulus for iron the lattice contraction due to the silicon addition can be equated to an effective applied pressure which alters the anisotropy by an amount $\frac{\Delta K_1}{K_1} = -0.5x$ where x is again the atomic percentage silicon content. Note that the above value is given for room temperature but employing it down to 0°K introduces only an error of second order of magnitude.

On applying the experimental results, as presented in the figure, to equation (2) one finds the value for $a = 1.6$. According to Joenk [11], Buslik finds a value of 2.5 from work on paramagnetic resonance line widths. Joenk [11] using experimental values of K_1 and K_2 for pure iron calculates a to be 4.6 but

this value is not reliable because of the experimental inaccuracy associated with the value of K_2 . It could in fact be comfortably reduced by half if Graham's [12] value for K_2 is employed.

It is not possible to sensibly predict to what extent J , D and Q will be effected by the addition of silicon. Since Curie point measurements [13] indicate only a slight deviation from a linear relationship, as for instance predicted by a molecular field calculation, one concludes that J is not altered appreciably.

It should be mentioned in passing that the temperature dependence of K_1 does not obey any simple power law, the power index increasing as the temperature rises. This is somewhat in qualitative agreement with Van Vlecks [14] earlier work wherein different power indices are assigned to the dipolar and quadrupolar terms and the power indices themselves are temperature dependent. It also varies with silicon content. For instance, from measurements of magnetisation taken on the same specimens that were used for the anisotropy measurements it was found, for a specimen containing 2.3 % silicon, the expression

$$K_1(T)/K_1(0) = [M(T)/M(0)]^{2.6}$$

holds at low temperature, whereas the corresponding index for a 8.6 % silicon specimen is 4.3.

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References

- [1] DURAND (J.), *Rev. Sc. Instr.*, 1959, **30**, 840.
- [2] ALDENKAMP (A.), MARKS (C.) and ZIJLSTRA (H.), *Rev. Sc. Instr.*, 1960, **31**, 454.
- [3] VAN WYK (G.), M. Sc. Thesis, 1963, University of the Orange Free State.
- [4] GRAHAM (G.), *J. Appl. Phys.*, 1960, **31**, 150S.
- [5] ARAJS (S.), CHESSIN (H.), MILLER (D.), *J. Appl. Phys.*, 1961, **32**, 857.
- [6] KEFFER (F.), *Phys. Rev.*, 1955, **100**, 1692.
- [7] KEFFER (F.) and OGUCHI (T.), *Phys. Rev.*, 1960, **117**, 718.
- [8] ALBERTS (H.), Ph. D. Thesis, Rand Afrikaans University, 1969.
- [9] PEARSON (W.), *Handbook of Lattice Spacings and Structure of Metals*, 1967, Pergamon Press.
- [10] VEERMAN (J.) and RATHENAU (G.), *Proc. Int. Conf. Mag.*, Nottingham, 1964, 737.
- [11] JOENK (R.), *Phys. Rev.*, 1963, **130**, 932.
- [12] GRAHAM (C.), *J. Appl. Phys.*, 1959, Suppl. **30**, 317S.
- [13] ARAJS (S.), *Phys. Stat. Sol.*, 1965, **11**, 121.
- [14] VAN VLECK (J.), *Phys. Rev.*, 1937, **52**, 1178.