FERROMAGNETIC RESONANCE AND SURFACE ANISOTROPY IN IRON SINGLE CRYSTALS

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Ferromagnetic resonance and antiresonance experiments have been performed on (100) planes of iron whiskers in order to determine the value of surface anisotropy K_s. From the measurements one obtains $K_s = (0.1 \pm 0.05)$ erg cm^{-2} with the easy axis normal to the surface. This result is compared with experimental data on thin films and with the conclusions of Néel's theory.

On a free surface of a ferromagnet there exists a surface magnetic energy E_s, the density of which is dependent on the angle θ between the static magnetization vector and the surface normal direction in most cases according to the relation $E_s = K_s \sin^2\theta$; the constant K_s is called the surface anisotropy (see e.g. [1]). The aim of this work is to determine K_s for the (100) plane of iron by the method of ferromagnetic resonance and antiresonance.

Our experiments were performed on pure iron single crystals in the form of whiskers several mm long and 30–90 μm thick grown along the [010] direction. The crystals had a square cross-section with (100) lateral planes with optically perfect surfaces and were mounted into a shorted waveguide section with their axis parallel to the external static field direction. Several waveguide sets were used in order to cover the frequency interval 20–100 GHz. The microwave signal reflected from the sample holder was detected by a silicon diode. As the external magnetic field was modulated with a 115 kHz ac field of small amplitude, the ac signal proportional to the field derivative of the absorption (i.e. of the real component of sample surface impedance) appearing at the diode was amplified by means of a lock-in detector and registered on an X–Y plotter. The accuracy of both dc field intensity and microwave frequency measurements amounted to 10^{-5}.

The linewidth value ΔH (i.e. the difference between static field intensities corresponding to the extreme values of absorption derivative) was obtained with an accuracy of $\pm 2\%$ for the FMR case and of $\pm 5\%$ for the ANR case (because of the worse ANR signal/noise ratio). Using the measured field dependences of absorption derivative for a certain frequency the ΔH values were evaluated and plotted as points in fig. 1.

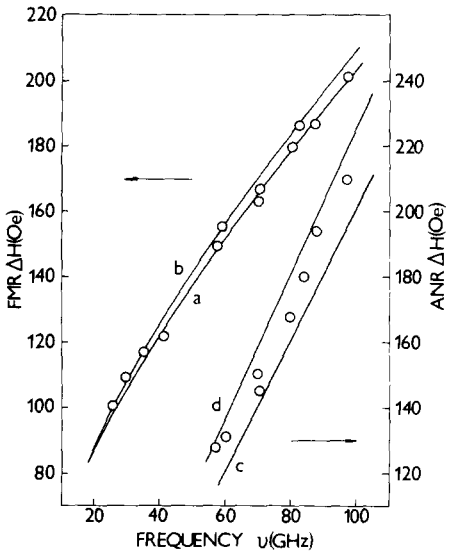

Fig. 1. Frequency dependence of linewidth values. Circles – experimental data. Curves – theory; a; FMR ($K_s = 0.15$ erg cm^{-2}, $\lambda = 5.72 \times 10^7$ rad s^{-1}); b; FMR ($K_s = 0$, $\lambda = 5.72 \times 10^7$ rad s^{-1}); c; ANR ($\lambda = 5.33 \times 10^7$ rad s^{-1}); d; ANR($\lambda = 5.96 \times 10^7$ rad s^{-1}).

The results of the measurements were evaluated by means of the electromagnetic macroscopic theory of FMR and ANR, which is based on Maxwell and Landau–Lifshitz equations and appropriate boundary conditions [4]. From the resulting formula for surface impedance [5] the FMR and ANR linewidths can be computed. Except for the relaxation parameter λ (Landau–Lifshitz constant) and the surface anisotropy K_s all quantities needed for the evaluation of the ANR linewidth for pure iron (static magnetization, g-factor, electric conductivity, exchange stiffness constant, microwave frequency) are well known [6]. As in the ANR region the penetration depth of microwave fields is much larger than in the case of FMR, the surface properties practically do not influence the antiresonance line shape (for iron the relative change of

ANR linewidth caused by a large K_s of several erg cm^{-2} is less than 1×10^{-3}). The λ value can be determined simply from the measured frequency dependence of ANR linewidths (according to our experience this method is the most suitable for λ evaluation). As this dependence is linear we have obtained λ by the method of least-squares as 5.72×10^7 rad s^{-1} (see fig. 1). In order to get K_s we compared the frequency dependence of measured FMR linewidths with data computed from theory [4, 5]. The best fit (see fig. 1) yields $K_s = (0.1 \pm 0.05)$ erg cm^{-2} (from measurements on four samples), i.e. in our samples there exists a weak surface anisotropy with easy axis direction normal to the surface planes.

By comparing our value with other experimental data available, we may first state that this is much smaller than K_s required for evaluating the standing spin wave measurements on thin (polycrystalline) iron films ([7, 8], $K_s > 1$ erg cm^{-2}) and smaller than K_s found in amorphous oligatomic Fe films (with different metallic coatings [9], $K_s \ldots 0.3$–0.7 erg cm^{-2}). The easy direction of K_s for both cases agrees with our results, the quantitative discrepancy may be explained by the usual assumption that in films prepared by evaporation there exists a gradient of magnetic parameters (magnetization, stress, local demagnetizing field) at the surface [1, 10]. The small value of K_s also agrees with the observation that in nearly perfect thin metal platelets well resolved standing spin wave spectra have not been excited [10].

Concerning the agreement with theory, there is only Néel's original work available [1], from which one predicts for the (100) plane of iron a value for K_s of 0.1 erg cm^{-2}, however, with opposite sign (easy plane type anisotropy). It is hard to compare our value with Néel's data, as K_s in iron, due to its high magnetization, may be easily influenced by a small decrease of surface magnetization (in contrast to nickel [1–3]), caused e.g. by oxygen adsorption; by using a simple theory of Wolf [11] one gets $K_s \approx 0.1$ erg cm^{-2} (> 0) for even a small (4%) decrease of magnetization in five surface atomic layers. Before making final statements about the surface anisotropy of iron one should have at ones disposal results of more modern (microscopic) theory (as for the case of nickel was worked out by Takayama et al. [12]).

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