THE FMR LINEWIDTH OF IRON-NICKEL ALLOYS IN HIGH MAGNETIC FIELDS

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INTRODUCTION

It is well known from measurements at microwave frequencies that the linewidth of metallic ferromagnets contains a term which is linear in frequency, called the Landau-Lifshitz damping term. In order to check the validity of this linear relationship up to the far infrared, we measured ferromagnetic resonances (FMR) on plates and films of Fe-Ni alloys, using far infrared lasers and pulsed magnetic fields. These measurements were performed at temperatures between 4 K and room temperature. They generally confirm the microwave results.

Several features of these results are explained by a model proposed originally by Kambersky (1), describing the Landau-Lifshitz relaxation as an interaction between magnons and electronic exitations in the conduction band. However, there remain discrepancies between the theory by Kambersky and the experimental results, mainly regarding the temperature dependence of the linewidth.

THE EXPERIMENTAL SETUP

The main components of the apparatus are the far infrared (FIR) laser, the light pipe containing the sample, the pulsed field magnet and the FIR detector. Our FIR laser consists of a 50 W CO_2 pump laser and an oversized waveguide laser with methanol or formic acid as the active medium. This combination allows us to tune the FIR source to several lines. The most prominent are the 699 μm and 570 μm in methanol and the 513 μm, 432 μm and 393 μm in formic acid. The output power is typically a few milliwatt.

The FIR radiation is guided through a light pipe to the sample which consists of a thin film or a thin plate of iron, nickel or an alloy of 67 % iron and 33 % nickel. The sample is either a tightly wound spiral of a metal-insulator sandwich or it is mounted as the sidewall of a stripline.

The magnet is a coil wound of copper wire with rectangular cross section, insulated by glass fiber cloth and reinforced with steel wire and an outer steel cylinder. The field pulse is generated by a capacitor discharge. The discharge time is of the order of 10 ms and the peak field which can be generated without coil destruction is 45 Tesla. The magnet is pre-cooled by liquid nitrogen. During each shot its temperature increases above room temperature and it requires a 15 min. cooling period. The central bore of the magnet is 20 mm in diameter. The sample is mounted in a stainless steel tube which is thermally disconnected from the magnet (fig. 1). It is cooled by a flow of helium gas. The sample temperature can be stabilised at any desired value between 5 K and 250 K.

The detector, shown in fig. 1, is an In-Sb hot electron detector mounted at the end of the light pipe in a metal chamber which is immersed in the liquid helium of a bath cryostat. The noise background of the detector signal is mainly due to FIR laser instabilities and is typically a few percent of the laser power. This limits the range of electron spin resonances that can be investigated. However, the intensity of the FMR signals is sufficient to obtain signal to noise ratios higher than 10. A typical resonance signal, as recorded during the field pulse by a fast transient recorder, is shown in fig. 2.

ABSORPTION OF FIR POWER IN A METALLIC FERROMAGNET

The linewidth and lineshape of the FMR signal is determined by the interplay between exchange- and conductivity effects as well as by the high frequency susceptibility. This follows from the theory of power absorption in a metallic ferromagnet which has been treated by many authors, in particular by Wolfram and De Wames (2).

The essential feature which distinguishes FMR in metals different from that in insulators is the existence of a conductivity term dominating the dielectric displacement term in Maxwell's equation. Thus there exist two competing solutions for the wave vector k. k_1 and k_2 can be obtained from the equation of motion of the magnetisation, i.e., the Bloch equation, and the equations of Maxwell.

Both k_1 and k_2 have real and imaginary parts which are comparable in magnitude and vary as a function of the magnetic field. The variation in power absorption caused by k_1 is called the 'ferromagnetic resonance background' and the variation of k_2 determines the so called 'standing spin wave modes'. The observed FMR absorption line is the sum of these two solutions.

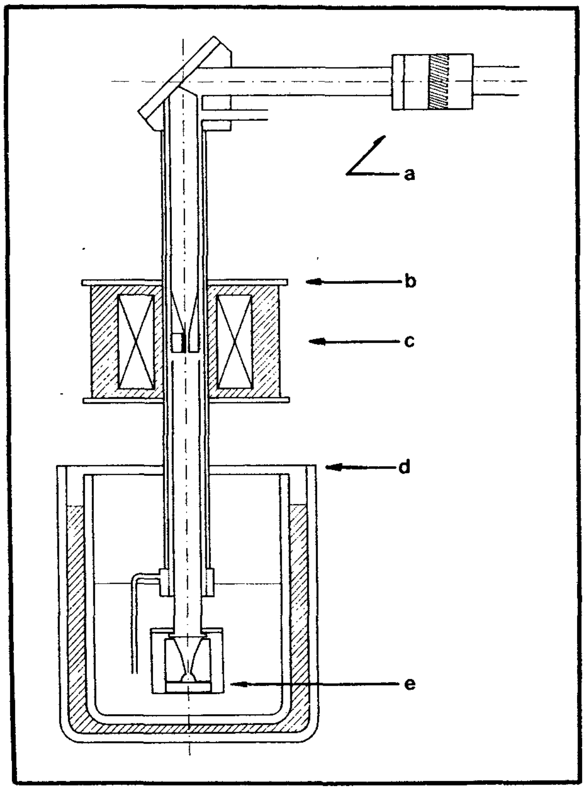

Figure 1 : Experimental setup.
a : beamsplitter for laser monitoring.
b : coil in liquid nitrogen. c : sample position. d : helium bath cryostat.
e : In-Sb detector.

The intrinsic parameters such as the damping term are determined by computer simulation. This procedure is time consuming but straightforward and allows an accurate determination of the physical parameters.

THE FMR LINEWIDTH AS A FUNCTION OF FREQUENCY

The linewidth of FMR in metallic ferromagnets is a sum of three terms : an intrinsic linewidth due to magnon-magnon scattering, an exchange-conductivity linewidth and a 'Landau-Lifshitz' damping term.

The magnon-magnon scattering contribution is a constant, independent

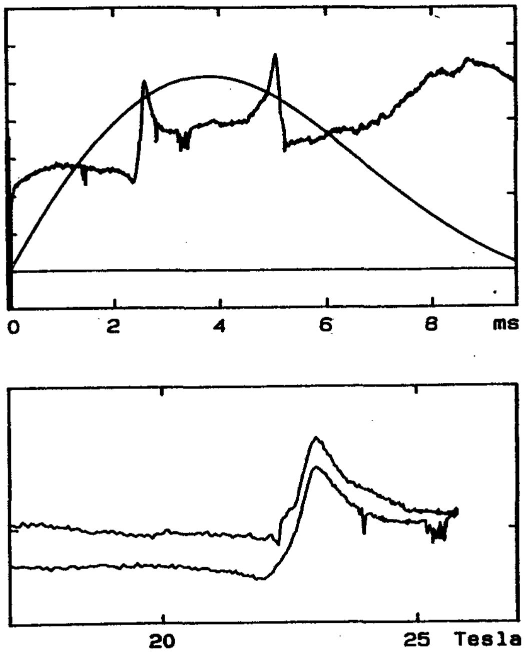

Figure 2 : Typical resonance signal.
The upper figure shows the detector signal and the magnetic field as a function of time. In the lower figure the detector signal is plotted versus the magnetic field.

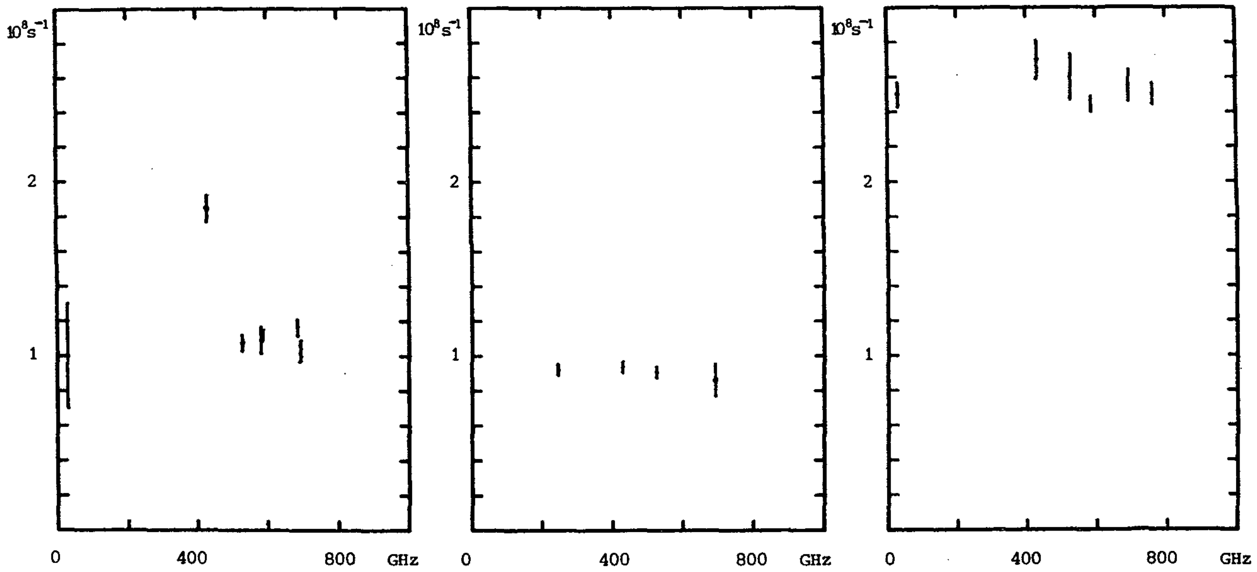

Figure 3 : Landau-Lifshitz damping frequency as a function of FIR frequency.
a : Iron. b : Iron-nickel alloy (67 % - 33 %). c : Nickel.

of frequency and temperature (3).

The exchange-conductivity contribution can be expressed under the condition of high magnetic fields as $\omega\sigma\mu_0 D$ where ω is the frequency of the FIR radiation, σ the conductivity of the medium, μ_0 the permeability and D an exchange constant (Dk^2 is an exchange frequency). This exchange-conductivity contribution is linear in frequency and has the same temperature dependence as the conductivity (4,5).

The Landau-Lifshitz damping term is usually written as $\omega\lambda/\gamma M_s$ where γ is the gyromagnetic ratio, M_s is the saturation magnetisation and λ is a parameter (6,7,8). All the results obtained up to now indicate that λ is independent of frequency. This has been established by several authors (9,10) for the microwave range and is confirmed by our measurements as shown in fig. 3.

These data confirm that λ is a constant over a very broad frequency range.

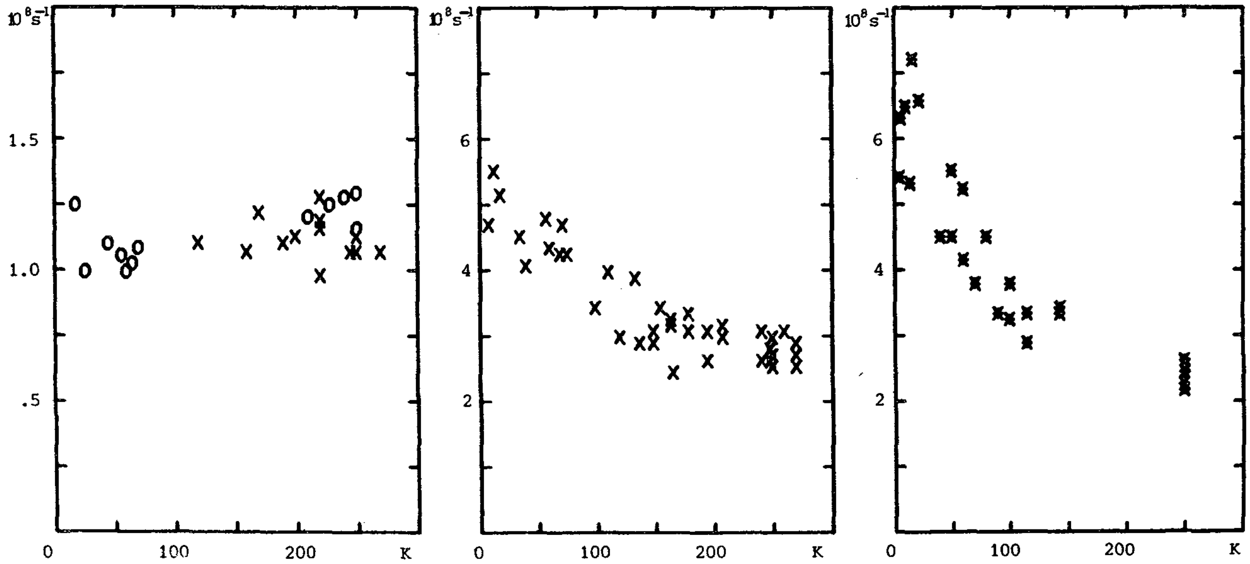

Figure 4 : Landau-Lifshitz damping frequency as a function of temperature.
a : Iron at 584 GHz. b : Nickel at 693 GHz. c : Nickel at 425 GHz.

There is one point out of line in fig. 3a but this is almost certainly caused by noise since it is a single discrepancy, occuring for the thinnest film where the signal to noise ratio is very small. λ is also found to be the largest for the metal with the largest magnetostriction. This indicates that the damping is most probably connected with the spin-orbit coupling, as put forward in the Kambersky model.

THE FMR LINEWIDTH AS A FUNCTION OF TEMPERATURE

As shown in fig. 4 there is no measurable temperature dependence of λ for Fe and only a very small decrease of λ with temperature for Ni. In some of the measurements at microwave frequencies (9) the negative slopes of the $\lambda(T)$ curves are more pronounced but this is not sufficient to fit the values predicted by the Kambersky model (1). This model introduces three mechanisms : in one mechanism the phonons, scattering on conduction electrons, cause spin flips via spin-orbit coupling; in the other an anisotropy of spin-orbit coupling combined with the precession of the magnetisation, causes repopulation effects of the spin sub-bands via ordinary (non-spin-flip) scattering.

The first mechanism predicts an increase of the linewidth with temperature between liquid nitrogen and room temperature. This is at variance with all known results. The second mechanism predicts a decrease of the linewidth with increasing temperature but the estimated order of magnitude is too low by a factor of ten. Kambersky gives a rough estimate of the λ-value for Ni : $3\cdot10^7 s^{-1}$, whereas the experimental value is $2.5\cdot10^8 s^{-1}$.

CONCLUSION

In high magnetic fields, the main contribution to the linewidth of FMR in iron, nickel and iron-nickel alloy is due to the Landau-Lifshitz damping. Our results confirm that the Landau-Lifshitz constant is independent of frequency. A temperature dependence was only found in the nickel samples. This temperature dependence is smaller at high magnetic fields.

The Kambersky model couples the motion of the magnetisation to the orbital motion via spin-orbit interaction. This interaction is the origin of magnetostriction. Thus far, the model is in agreement with the experimental results, i.e. the relaxation is proportional to the magnetostriction and has a linear frequency dependence. For the relaxation of the orbital motion, Kambersky proposes two mechanisms but none of these can explain the temperature dependence.

While our results confirm the first part of the model, another damping mechanism for the orbital motion must be introduced.

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