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STANDING WAVES IN THE MICROWAVE SPECTRA OF Ni AND NiFe SINGLE CRYSTAL DENDRITES

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Abstract. — We have performed a room temperature microwave spectroscopy experiment, at frequencies of 12 and 24 GHz, on single crystal dendritic platelets of pure nickel and nickel-iron alloys. We observe clear evidence for the formation of standing waves in these specimens, in that the spectra of the platelets show many discrete modes. From the dispersion relations and angular dependence of these modes we are able to deduce that they are mainly of magnetostatic origin, at least for the case of the nickel-iron platelets.

This paper discusses a room temperature, microwave frequency, spectroscopic investigation of small single crystal dendritic platelets. The specimens of nickel and nominally 82% nickel-18% iron are grown by a vapor transport technique [1, 2] and usually have a <100> axis normal to the plate. Multiple modes are observed in the microwave spectra, and we present evidence indicating that these modes are mainly of a magnetostatic type, previously observed only for nonmetallic ferrimagnets [3, 4]. The experiments are carried out at frequencies of 12 GHz and 24 GHz, and in the geometry in which the D. C. magnetic field $H_0$ is either along the normal (n) (perpendicular resonance), or in the plane of the platelet (parallel resonance). The microwave magnetic field is always normal to $H_0$.

We have examined spectra from samples of various shapes: squares, right triangles, long rectangular and triangular blades, and one long thin wedge. Figure 1 shows examples of the mode spectra obtained from these metallic crystals. The spectra show multiple standing waves whose intensities decrease steadily as one moves away from the main resonance. For perpendicular resonance the modes die out at a field of about $2\pi M$ below the main resonance. The main resonance, itself, is found at the usual field for ferromagnetic resonance for both parallel and perpendicular cases respectively [5].

A major feature to be noted in figure 1a for a nickel-iron platelet in perpendicular resonance is that the mode spacing decreases with increasing separation from the main resonance. The dispersion relation for this sample is shown in figure 2 for both perpendicular and parallel resonance. This effect is also clearly

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In conclusion we believe that we have demonstrated that they occur always on the low field side of the main resonance relation, with mode spacing increasing away from quadratic, at low mode numbers [7]. The mode spacing is approximately proportional to the product of this ratio and the magnetization.

From the evidence of figure 1 and the dispersion curves of figure 2 it is clear that the nickel-iron platelets and wedge are showing modes of the magnetostatic type. Although the aspect ratio of these samples is smaller, by about a factor of 3, than the samples of reference [3], the magnetization is larger by approximately the same factor. However, the nickel samples spectra cannot yet be definitely characterized as either spin wave or magnetostatic.

There are several difficulties which prevent an immediate quantitative comparison between magnetostatic mode theory and the spectra of the nickel-iron specimens. The usual theories of magnetostatic modes are for cases of simple shapes such as circular discs, square or rectangular plates. The initial observations presented here have been made on awkward or irregular geometric shapes, however, it is clear from the nature of magnetostatic modes and the calculations which have already been carried out, that this will not change the qualitative conclusions that we have been able to draw.

An example of such a qualitative comparison is given for the specimen of figure 1a. We take the simple relation for magnetostatic modes in a rectangular insulating sample.

$$H_0^1 - H_0^2 \approx \frac{b_1}{2} n (n - 1) - \frac{\omega}{\gamma} \sqrt{1 + \left(\frac{b_1/2}{\omega \gamma}\right)^2} n^2 + \frac{\omega}{\gamma} \sqrt{1 + \left(\frac{b_1/2}{\omega \gamma}\right)^2}$$

where $\omega$ is the microwave angular frequency, $\gamma$ the gyromagnetic ratio, $n$ the mode number,

$$b_1 = 2 \pi^2 M(d/L)$$

and $M$ is the magnetization. Figure 2 shows the fit of the data to this expression with $M = 850$ e.m.u. and for a ratio $L/d = 28.7$ which is the best fit to the lowest mode spacings. This approximate aspect ratio is typical for these samples.

A further difficulty for comparison between experiment and present theory lies in the metallic nature of the samples. We expect that this will not drastically change the magnetostatic mode solutions obtained for dielectric materials, but the problem is somewhat more complicated and the modes will certainly be broadened by eddy current damping effects.

In conclusion we believe that we have demonstrated
that the initial observation of standing wave spectra in single crystal metal dendrites presented here is an indication of magnetostatic mode effects, at least for the nickel-iron platelets. The pure nickel platelet spectra show weaker modes which we have not yet been able to characterize.

References