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LIGHTSCATTERING FROM SURFACE ACOUSTIC SPINWAVES IN FERROMAGNETS

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Lightscattering from a nonreciprocal surface spinwave which has previously been reported for EuO [1] has now also been found on thin Ni-films. For a film thickness of 1000 Å both waves propagating on the front and on the backside of the film are observed.

Lightscattering from surface acoustic spinwaves has for the first time been found on EuO [1] which is a semiconductor and orders ferromagnetically below $T_c = 69$ K. It has recently been demonstrated that the effect can also be observed from metallic ferromagnets like Ni and Fe [2]. Light-scattering thus seems to be a promising tool for the investigation of surface spinwaves.

The surface spinwaves which have up to now been found in these light-scattering experiments have theoretically been treated by Damon and Eshbach (D.E.) [3]. A thin platelet is assumed as sample shape. If the sample thickness, d, is large compared to the wavelength of the surface wave the frequency is given by

$$\nu_s = (\gamma/2\pi)(B_0 + J/2)\,, \qquad (1)$$

where $\gamma/2\pi = 0.28 \times 10^7\ \mathrm{G^{-1}\ s^{-1}}$. B_0 is the external magnetic field and J is the saturation magnetization of the sample at the given temperature. Here it is assumed that the surface wave propagates transverse to B_0 and the sample magnetization. If the wavelength is comparable to the sample thickness the frequency ν_s is lowered compared to eq. (1). In the long wavelength limit or for very small sample thicknesses, ν_s becomes equal to the frequency of the bulk spinwave, ν_b, which in this case is identical with the ferromagnetic resonance frequency:

$$\nu_b = \frac{\gamma}{2\pi}\,[B_0(B_0 + J)]^{1/2}\,. \qquad (2)$$

Although for EuO the observed frequencies of the surface wave differ from the theoretical values given by eq. (1) there is little doubt now that the assignment of the observed wave to the D.E. mode is essentially correct. This follows because in all cases where inelastic lightscattering has been found the frequency is above that of the bulk spinwave given by eq. (2). Also symmetry considerations clearly show [1] that a surface wave with nonreciprocal behaviour is observed. The D.E. mode is also nonreciprocal.

For the derivation of eq. (1) any kind of magnetic anisotropy, surface or bulk, has been neglected. For EuO, on the other hand, there are indications [1] that surface effects are present, which leads to a downshift of the frequencies of both the bulk and surface spinwave.

A surface wave is characterized by the fact that it travels parallel to the surface but its amplitude decays exponentially into the bulk of the material. In the case of the D.E. mode the penetration depth is given by $1/q_s$, where q_s is the wavevector of the surface wave. The values of q_s which can be observed in a lightscattering experiment typically range between 0.5 and $5 \times 10^5\ \mathrm{cm^{-1}}$ which according to this relation should correspond to penetration depths between 2000 and 200 Å. In the following we would like to describe an experiment which was designed to test if the penetration depth of the spinwave observed by lightscattering is given by the $1/q_s$ relation of the D.E. mode. We think that this is of particular importance when influences on the surface waves due to surface effects have to be considered.

Thin films of Ni have epitaxially been grown on cleaved (100) NaCl surfaces. Various film thicknesses between 1000 Å and 10 000 Å were chosen. Spectra of 1000 and 10 000 Å thick films are shown in fig. 1. Since the amount of elastically scattered light is very strong a five passed Fabry Perot interferometer had to be used in these experiments. The analyzer direction for the observation of the scattered light is always set perpendicular to the polarization direction of the incident laser light. The spectra in the upper and middle part show the influence of a reversal of the magnetic field. The line flips from Stokes to Antistokes when B_0 is reversed. This ensures that we are dealing with a surface spinwave because the bulk wave does not show this behaviour. Fig. 2 shows how the wavevectors of the incident light, scattered light, and surface spinwave are related to each other. In all cases the angle between incident beam and normal to the sample plane was 20° which for the 6328 Å He–Ne laser line produces a wavevector of the incident light parallel to the surface of $k_i^{\parallel} \approx 0.34 \times 10^5$ cm^{-1}. This yields 0.68×10^5 cm^{-1} for the wavevector q_s of the surface wave which is observed in the back-scattering geometry

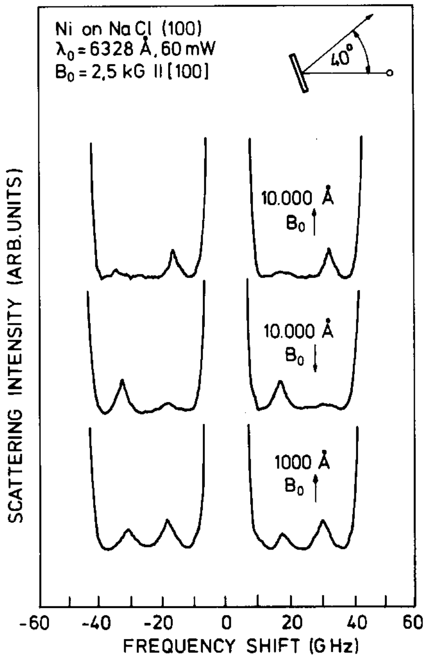

Fig. 1. Brillouin spectra from thin Ni films at room temperature.

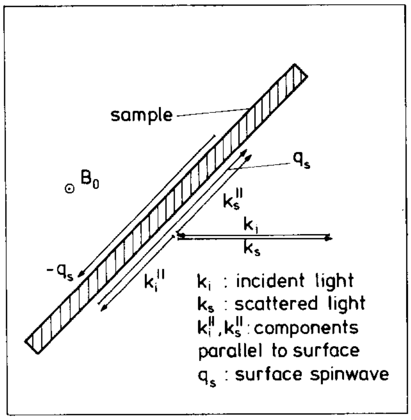

Fig. 2. The relation of the wavevectors of the incident light scattered light and surface spinwave in the backscattering configuration.

and from the D.E. Theory we expect a penetration depth of ≈1500 Å.

A film thickness of 10 000Å can still be considered as large compared to the penetration depth. However, when the film is only 1000 Å the spinwave which propagates on the backside of the film has a considerable amplitude on the frontside. The two waves travel with opposite wavevectors as indicated in fig. 2. This explains why a line appearing on the Stokes side is reproduced on the Antistokes side for a film which is only 1000 Å thick. The intensity ratio of the two lines is within the experimental error in accordance with the expected amplitude ration of 2 : 1 of both waves on the frontside. For small values of $q_s d$ the frequency of the D.E. mode should be lowered, approaching that of the ferromagnetic resonance given by eq. (2) for $q_s d = 0$. Since the saturation magnetization of Ni is comparatively low (J_{Ni} = 6.1 kG) the frequency difference between bulk and surface is also small. This explains why for the 1000 Å thick film there is only a small lowering of the frequency of the surface wave as compared to the 10 000 Å thick film. At the same time it explains why in the latter case also a weak line is observed on the other side of the elastic line. This is due to scattering from the bulk wave which is expected at a slightly lower frequency.

Evaluation of the spectra yields 15(18) GHz for the surface wave at B_0 = 1.5(2.5 kG). Eq. (1) yields 12.7 (15.5) GHz for these values of B_0. The frequency of the surface mode thus in the case of the Ni films, in fact, is observed at higher frequencies than the theoretical values for the D.E. mode. For EuO, in contrast, it was found below the theoretical values. Besides other properties, Ni differs from EuO in that exchange effects are much stronger. This can easily be seen from the Curie temperatures T_c(EuO) = 69 K, T_c(Ni) = 627 K. Wolfram and Dewames [4] predict that the frequency of the D.E. mode is increased by exchange effects. This is reasonable because these act as additional restorning forces on the spins. Also via exchange the surface mode is coupled to the bulkspinwaves which means that its lifetime decreases. In fact, we have also found larger linewidths in the case of the Ni-films as compared to EuO. This, however, might also be due to inhomogeneous broadening. Experiments on single crystal surfaces which are now in preparation should help to clarify this point in the future.

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