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M. Schmidt

Institute of Molecular Physics, Polish Academy of Sciences, 60-179 Poznan, ul. Smoluchowskiego 17/19, Poland

Abstract. – We analyse a continuous magnon spectrum which is excited in FMR in a ferromagnetic sample with dislocations. Calculations are presented for the moments of the uniform mode. Numerical comparisons of the moment method with literature data and the Born approximation are given for the broadening of the resonance line.

In monocrystalline ferromagnets, the dislocations have the remarkable effect on resonance behaviours. Thus the linewidths measured in dislocated samples are usually appreably larger than the highly perfect single-crystal linewidths [1, 2] and the profile of the FMR line is asymmetric [3]. The relaxation mechanism, in the Born approximation, was first considered in papers [4, 5]. The validity range of the Born approach was estimated in papers [6, 8]. It was shown that the higher terms of the perturbation series contribute in an important way to the relaxation. In the present paper, we adopt the method of the moment to FMR. Imperfections cause extra broadening of the resonance line by including local resonance frequency. We calculate the moments of the spectral density of magnon excitations in ferromagnets with dislocations. In the framework of the moment method the problem may be solved more accurately. The moment method was adopted previously to the spin-wave analysis of FMR by Schlömann [7]. In ferromagnetic resonance, the formalism [7] faces some difficulties. The higher moments calculated are too great and contributions of short-wave magnons are dominant for the higher moments. We remove the difficulties by a limitation of the calculations of the moments to the region of long-wavelength magnons of the magnon band [9]. At resonance, magnons can be excited only from a limited region of the magnon band. The magnon excitation region coincides with the DC field interval in which the signal frequency is degenerate with resonant frequencies of long-wavelength. The limitation of the region of frequencies of the magnon band is brought about in a way of cut-off wavenumbers $\mathbf{k}_1$. For a given direction of wave vectors, we calculate the cut-off wavenumber length k_1 from

$$\omega_{\mathbf{k}_1}(0) = \omega, \tag{1}$$

where ω is the signal frequency and $\omega_{\mathbf{k}_1}(0)$ denotes the magnon frequency of the nondefected ferromagnet for internal static field $H = 0$.

The resonance peak in metallic ferromagnets is given by the different factors. In strongly dislocated Ni crystals the shape of the FMR line is determined predominantly by dislocations [1]. We consider the case when dislocations exert the predominant influence on the shape of the resonance line.

The moments are calculated for the Hamiltonian, where the cut-off is introduced [9]. The width of the resonance line is discussed for a case where the calculations can be performed analytically. We neglect effects given by inhomogeneous magnetization at the dislocation line and for strong DC fields. The matrix elements $P(0,\ \mathbf{k})$ of magnon scattering has the form (see e.g. [5])

$$P(0,\ \mathbf{k}) = \frac{3\lambda\gamma}{2M_0}\frac{1}{V}\int_V \mathrm{d}\mathbf{r}\left(\sigma_{xx} + \sigma_{yy} - 2\sigma_{zz}\right)\,\mathrm{e}^{-i\mathbf{kr}}, \tag{2}$$

here the z-axis is the direction of the static magnetization in the sample, M_0 – the saturation magnetization, λ – the magnetostrictive constant, γ – the magnetomechanical ratio, and σ_{ij} – the stress component of dislocations.

The lower-order moments of the uniform mode, taken with respect to the center of gravity, ω_g are given

$$\mu_0 = 1, \tag{3a}$$

$$\mu_1 = \omega_g - \left\{\omega_0 - \sum_{\mathbf{k}}\frac{|Q(0,\ \mathbf{k})|^2}{\omega_0 + \omega_{\mathbf{k}}} - \sum_{\mathbf{k}>k_1}\frac{|P(0,\ \mathbf{k})|^2}{\omega_{\mathbf{k}} - \omega_0}\right\} = 0, \tag{3b}$$

$$\mu_2 = \sum_{\mathbf{q}\le k_1}|P(0,\ \mathbf{q})|^2, \tag{3c}$$

$$\mu_3 \cong \sum_{\mathbf{q}\le k_1}\left(\omega_{\mathbf{q}}(\mathrm{H}) - \omega_g\right)|P(0,\ \mathbf{q})|^2, \tag{3d}$$

where $\omega_{\mathbf{k}}$ is the frequency of magnons of the nondefected ferromagnet. The matrix elements $Q(0,\ \mathbf{k})$ describe the elliptical scattering of magnons by dislocations. The amplitudes of the moments are limited by the cut-off condition for the wave vector in contrast to the [7] where the higher moments of the uniform mode ($\mathbf{k} = 0$) are too big.

The square root of the second moment is a measure of the broadening of the resonance line

$$\Delta\omega = \sqrt{\sum_{\mathbf{k} \leq k_1} |P(0,\ \mathbf{k})|^2}. \qquad (4)$$

The higher moments have the influence on the resonance linewidth. For better approximation, we can take into account more moments. It is possible in the recursion method [9]. If the dislocation density is not extremely high, the result (4) depends weakly on the limit k_1. In this case, the equation (4) is converted to Schlömann's result

$$\frac{\Delta\omega}{\gamma} = \frac{3\,|\lambda|}{2M_0}\sqrt{\frac{1}{V}\int_V \mathrm{dr}\,(\sigma_{xx} + \sigma_{yy} - 2\sigma_{zz})^2}. \qquad (5)$$

The linewidth, as given by equation (5), is for screw dislocations

$$\frac{\Delta\omega}{\gamma} = \frac{9\,|\lambda|\,\mu b}{4M_0}\sin 2\varphi\sqrt{(d\,/\,\pi)\ \ln\ (r_1\,/r_0)}, \qquad (6)$$

and in the case of edge dislocations

$$\frac{\Delta\omega}{\gamma} = \frac{9\,|\gamma|\,\mu b}{2M_0\,(1-\nu)}\sqrt{(d\,/\,\pi)\ \ln\ (r_1\,/r_0)}\times$$
$$\times\sqrt{\left(1 + \nu - 3\nu\cos^2\varphi - 4.5\sin^2\varphi\right)}$$
$$\times\sqrt{(1 + \nu - 3\nu\cos^2\varphi) + \frac{45}{8}\sin^4\varphi}. \qquad (7)$$

Here, μ is the shear modulus, b – the length of the Burgers vector, ν – the Poisson coefficient, φ – the angle between the magnetization and dislocation line, d – the dislocation density. The parameter r_0 is the radius of the dislocation core in the hollow model of the core, r_1 the range of the stress field of the dislocation. This result, in the Schlömann approximation, is in good agreement with the experimental data [1] for the dislocation density corresponding to a stage II of work-hardening. The discrepancy between the dependence $\Delta\omega \propto d^{1/2}$ and the experimental data appears for extremely high density, where we should apply the cut-off condition for the wave vector. See [3] for experimental data. In the Born approximation, the broadening is proportional to the dislocation density [5]. The angular dependence (7) of the linewidth agrees with the experimental results. In the skin depth, a region at the surface has the predominant influence on the shape of the resonance peak, where dislocation lines are perpendicular to the sample surface. The dependence (7) of the width on the angle φ for an edge dislocation is similar in shape to the broadening data of [1]. Anders and Biller [1] measured a 40 Oe broadening of the linewidth after a slight deformation, which increased the dislocation density from 3×10^6 cm^{-2} to about 10^7 cm^{-2}. Our calculation for an edge dislocation gives $\Delta\omega\,/\,\gamma = 14$ Oe. Within the Born approach, the calculations [5] leads to an increase of the FMR line $\Delta\omega\,/\,\gamma < 0.4$ Oe. In Schlömann's formalism, the width depends weakly on the core radius, but higher moments depend essentially on the model of the dislocation core. If the cut-off is introduced, the moments do not depend on the structure of the core.

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