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The mechanism of the magnetoresistance contribution to the magnetoimpedance effect in thin films

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We have developed a simple model [1] allowing further clarifications of the magnetoresistance (MR) contribution to the giant magnetoimpedance (GMI) effect in thin films. The theoretical considerations are the following. It is absolutely assumed that a thin film with no magnetic domain structure and a high frequency ac current $I = I_0 e^{i\omega t}$ flowing parallel to the Z direction in the plane of the film. The sample has the thickness 2a in the X direction, thus the Y direction in the plane of the sample and perpendicular to the current direction. The transverse permeability μ_Y in the Y direction is uniform. In the case of GMI effect, the total impedance $\boldsymbol{Z} = \boldsymbol{R} + i\boldsymbol{X}$ can be written as

$$\frac{Z}{R_{DC}} = (i)^{1/2}\theta \coth\left[(i)^{1/2}\theta\right] \tag{1}$$

where i= $(-1)^{1/2}$, R_{DC} is the dc resistance, θ^2 is the normalized frequency $\theta^2 = a^2\sigma\mu\omega \propto (\rho_{DC})^{-1}$ and σ in the conductivity, ω is the circular frequency, $\rho = \sigma^{-1}$ is the sample resistivity.
Now, taking into account in the case of the low-frequency limit as $\theta^2 \ll 1$, then we obtain

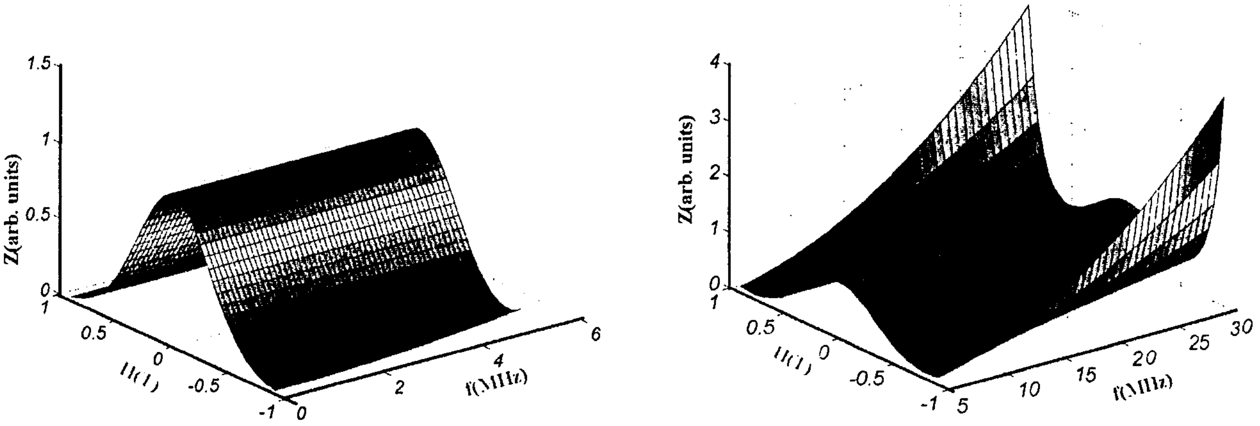
$$\begin{gathered} R \approx R_{DC}(1+\frac{\theta^4}{45}) \propto \rho(1+A\rho^{-2}) \text{ with } A = a^4\mu_Y^2\omega^2/45; \\ X \approx R_{DC}\frac{\theta^2}{3} \propto \rho^{-1}; \\ |Z| \approx R_{DC}(1+\left(\frac{7}{90}\right)\theta^4) \propto \rho(1+B\rho^{-2}) \text{ with } B = \frac{7a^4\mu_Y^2\omega^2}{90} \end{gathered} \tag{2}$$

If the parameters are given of 2a ≈ 1 mm, $\mu_Y \approx 10^4\mu_0$, $\sigma \approx 10^7\Omega^{-1}m^{-1}$ and a region of frequencies up to 30 MHz, then the impedance R and Z can be calculated using Eq (2). The calculations show that the MR contribution to the total impedance plays an important role in the low frequency regime f = 0-5 MHz (see the left panel of Figure). Because in the fact that in this frequency region the change in the skin depth due to the change in μ_Y is small and thus the MI is of the same order as the MR.

In the high frequency limit, $\theta^2 \gg 1$, the expression in Eq (1) can be rewritten as

$$|Z| \approx R_{DC}\theta \propto \rho^{1/2} \tag{3}$$

As continuously increased to frequencies f = 5-30 MHz, we have found that there is no considerable MR contribution to the total MI, but the Z(H) curve start to occur the drastic change in its shape as frequency further increases (see the right panel of Figure). It is attributed to the contribution of the inductance to the MI in this frequency region. The completion between domain wall motion and magnetization rotation processes is pointed out in consideration [2].



The magneto-impedance changes as a function of magnetic field at various frequencies (the left to right) up to 30 MHz.

In summary, the only contribution of the MR to the total impedance and thus the GMI effect in the low-frequency regime, and this contribution can be neglected at relatively high frequencies. This study allows one to interpret the increase in the GMI effect of recently investigated amorphous ribbons [3-5] as frequency increases from 100 kHz to 5MHz and its reduction at higher frequencies.

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