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Theoretical considerations on the giant magnetoimpedance effect in amorphous ribbons

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Theoretical considerations on a giant magneto-impedance (GMI) effect in amorphous ribbons (i.e., thin films) have been made in terms of the expressions of effective permeability and impedance derived in the frame of classical electrodynamics and ferromagnetism [1-3]. The dependence of GMI effect on the external dc magnetic field (H_{ext}) and the frequency of alternating current are simulated and discussed in the knowledge of energy conversion consisting of the current energy loss, the ferromagnetic energy consumption, and the magnetic energy storage in the film. The obtained results are summarized as follow:

(a) As frequency f < 20 MHz [see Fig. 1(a)], the real part of effective permeability (μ') changes slightly. The peak of the μ' curve always locates at $H_{ext} \approx H_{ani}$ - the anisotropy field. However, the peak value of μ' tends to increase with increasing frequency in the frequency range of 11–20 MHz.

(b) In the frequency range, f = 21-23 MHz, a negative peak additionally appears. Meanwhile, both the positive and negative peak values rapidly increase with increasing frequency and their peak positions shift towards a high H_{ext}.

(c) The positive peak value of μ' starts to decrease at $f \approx$ 29 MHz and its negative peak does so at about 35 MHz. Then, both peaks keep such a tendency and their peak positions move to high H_{ext} as increasing frequency.

(d) The dependence of the imaginary part of effective permeability (μ") on the external dc magnetic field and the frequency of the alternating field [see Fig. 1(b)] indicates that there is only one peak involved in μ" for the whole frequency range.

(e) The impedance vs. magnetic field curves at various frequencies show that there is a critical value of frequency around f = 18-19 MHz where the transition between two frequency regimes occurs; the one (low frequency) in which μ' predominantly contributes to the GMI effect and the other (high frequency) in which μ" determines the GMI effect.

As it stands, in the low frequency region, where the contribution of μ" to the GMI effect can be ignored, the ferromagnetic energy consumption $E_f = \omega\mu_0\mu'' h_m^2/2$ must be much smaller than the magnetic energy storage $E_m = \mu_0\mu' h_m^2/2$, hence the impedance of the ribbon mainly originates from the current energy loss $E_i = \int_V \frac{1}{2}\sigma e_m^2 dV$ and the magnetic energy storage. At high frequencies, the contribution of μ' to the GMI effect can be negligible, and thus the change in E_i and E_f safely responds to the variation of GMI effect.

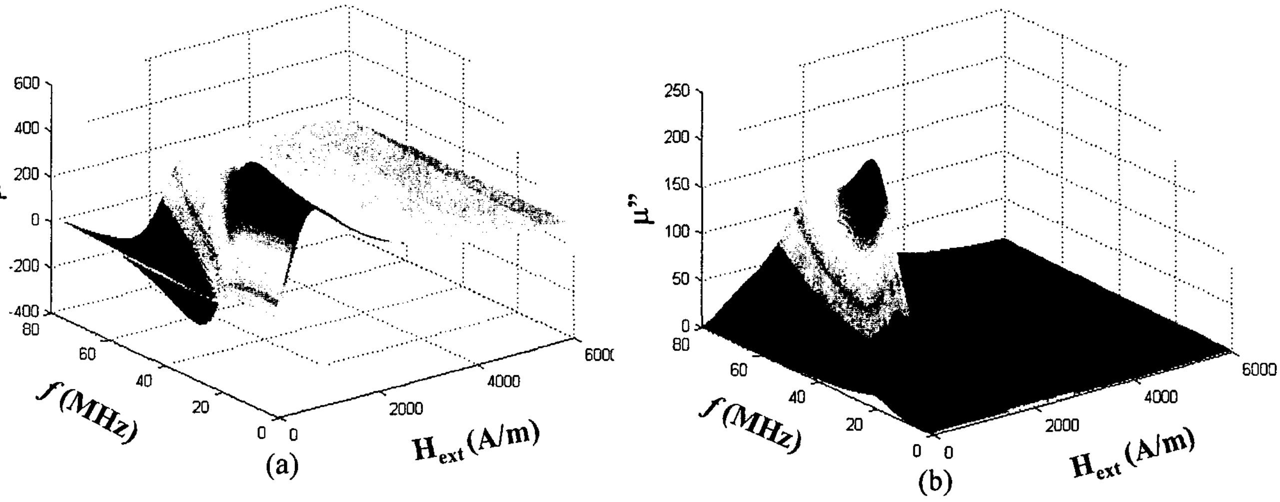

Fig. 1. *The real [μ', in (a)] and imaginary [μ", in (b)] parts of magnetic permeability versus magnetic field H_{ext} and frequency f.*

In summary, the contribution of the real and imaginary parts of permeability to the magneto-impedance effect has been clarified; in the low-frequency regime μ' predominantly contributes to the GMI effect and μ" determines the GMI effect in the high-frequency regime. Satisfactory agreement between the theoretical calculations and the experimental dependences of the impedance on magnetic field and frequency in Ref. [3,4] has been found.

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