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High-frequency permeability of thin amorphous wires with various anisotropic fields

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Abstract

The permeability of amorphous glass-covered Co-based microwires with various anisotropic field has been investigated up to 18 GHz. The measured permeability parallel to the direction of the wires is estimated by the Bloch–Bloembergen equation. It is shown that the gyromagnetic resonance is affected by the inhomogeneity of the anisotropic field inside the microwires. © 1999 Elsevier Science B.V. All rights reserved.

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The permeability of amorphous microwires has been intensively investigated up to several MHz [1]. Several studies of the circumferencial permeability in the GHz range have been reported [2]. In contrast, few works have been done on the investigation of the longitudinal permeability [3]. Recently, an original broad band method has been developed to determine the parallel permeability of wires between 0.1 and 18 GHz [4]. The permeability of the microwire μ_a is related to the permeability of the composite by

$$\mu_{\|} = qA\mu_a + (1 - q)\mu_m, \tag{1}$$

were q is the wire volume fraction in the sample, A the function of attenuation of the wire subject to an applied magnetic field and μ_m the permeability of the insulating and non-magnetic matrix. This method allows us to study the permeability of negative magnetostrictive amorphous microwire in the gyromagnetic resonance region.

The experimental measurement method consists to wind the microwires into a torus and to measure the permeability and permittivity of this sample using a coaxial line. The reflexion and transmission coefficients of the transverse electromagnetic mode on such a sample give us the permeability of the composite $\mu_{\|}$ in the direction of the microwires between 0.1 and 18 GHz [4]. Amorphous negative magnetostrictive microwires with nominal composition $(Co_{92.5}Mn_{7.5})_{75}B_{15}Si_{10}$ were produced by the Taylor's method [5]. The radius a of the metallic core ranges from 3 to 4.5 μm, the thickness of the glass is between 1 and 3 μm. The electrical resistivity ρ is about 100 μΩ cm. The anisotropic field H_a and saturation magnetization $4\pi M_s$ of the glass-covered microwires determined by conventional hysteresismeter measurement range respectively from 1.5–10 and 6000–9000 Oe.

At low frequency (between 100 MHz and 1.6 GHz), the apparent permeability μ_a of the microwires can also be determined using a single-coil measurement parameter [3]. This method has been applied to samples formed by parallel microwires 18 mm length glued on a glass plate. As one can see in Fig. 1, the two methods give comparable values of the permeability $\mu_{\|}$. However, the precision of the high-frequency method is better than 3% over all the frequency range whereas calibration of the parameter is made with an uncertainty of about 20% below 1 GHz and higher above. The stress due to the microwire

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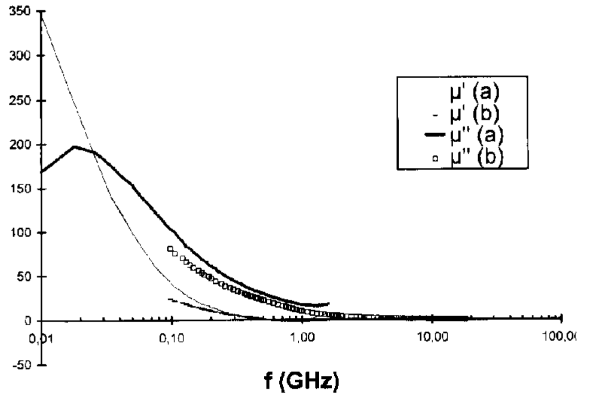

Fig. 1. Measured parallel permeability $\mu_{\parallel}$ ($a = 4.5\ \mu\text{m}$, $H_a = 1.5$ Oe) obtained by (a) the single-coil measurement and by (b) the coaxial-line measurement.

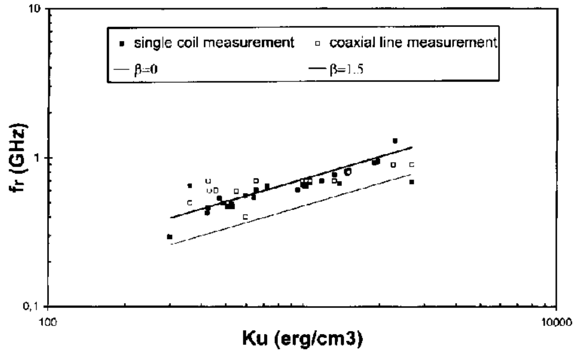

Fig. 2. Resonance frequency f_r as a function of the anisotropy constant K_u. The lines correspond respectively to a damping factor of $\beta = 1.5$ and 0.

bending inside the torus do not seem to affect the parallel permeability of the microwires. For sample with negative magnetostriction it has been shown that the outer domain structure has an orthoradial magnetization [6]. Thus if the anisotropic field is constant inside the microwire, then the apparent permeability of the microwire is given by

$$\mu_a = \frac{2}{k_i a}\frac{J_1(k_i a)}{J_0(k_i a)}\mu_i, \tag{2}$$

where a is the wire radius. $k_i = \sqrt{-j\omega\mu_0\mu_i/\rho}$ and μ_i are calculated by the Bloch–Bloembrgen model [3]. The resonance frequency f_r (defined by $\mu' = 1$) depends on the microwire anisotropy constant K_u:

$$f_r \approx \frac{\gamma}{\sqrt{1-\beta^2/4}}\sqrt{8\pi K_u}, \tag{3}$$

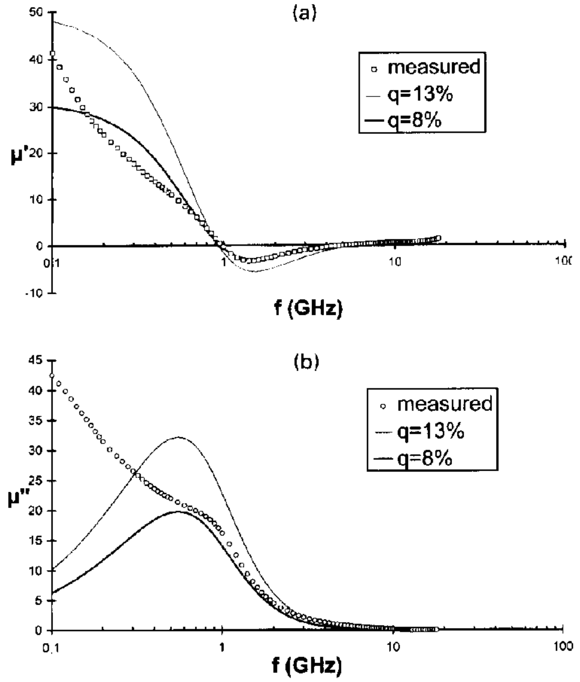

Fig. 3. Parallel permeability $\mu_{\parallel}$ measured (points) and given by the model with respectively $q = 13$ and 8%, (a) is the real part and (b) the imaginary part ($a = 3.5\ \mu\text{m}$, $H_a = 8.4$ Oe, $4\pi M_s = 7000$ Oe).

where γ equal to 3 MHz/Oe is the gyromagnetic factor and β is the damping factor. The evolution of the resonance frequency as a function of the anisotropy constant (cf. Fig. 2) can be interpreted by Eq. (3) taking the damping factor β equal to about 1.5. If the damping is neglected the resonance frequency is underestimated.

The composite measured parallel permeability $\mu_{\parallel}$ has been compared to the prediction of the model (cf. Fig. 3) using experimental values of M_s and H_a. It is found that the position of the gyromagnetic peak is well predicted by the model but the magnitudes of the permeability disagree. This discrepancy can be eliminated supposing the wire volume fraction is smaller than the experimental one ($q = 8\%$ instead of 13%). However, at low frequency, the measured permeability is still much higher than the calculated permeability. The presence in the microwire of regions with lower anisotropy field can account for those large values of the permeability. The inhomogeneity of the anisotropic field may result from the inhomogeneity of the stress inside the microwire [7,8]. This interpretation is also supported by the large value obtained for the damping factor β which is indicative of inhomogeneous broadening.

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