Determination of the magnetization distribution in soft magnetic films using microwave permeability measurements

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Soft magnetic films are important for a variety of applications. It is common to determine the microwave permeability of soft thin films using a permeameter [1]. In the case of a perfectly uniform thin film with in-plane magnetization, saturation magnetization and anisotropy can be determined from the permeability spectrum in a straightforward manner. However, in many real cases, the “all uniform” model is only an uncertain approximation, and until recently, it seemed that it was out of reach to extract simple reliable information from the permeability of complex samples. However, it has been established last year that in the case of a soft thin film with its magnetization lying in the (x, y) film plane [2]:

$$\sqrt{\langle M_x^2 \rangle} = \frac{1}{\gamma}\sqrt{\frac{2}{\pi}\int_0^{F_{\max}} \mu_y''(f).f.df}\,, \qquad (1)$$

where M_x is the magnetization component along x, μ_y the microwave permeability associated to a microwave field along y, $\langle\ \rangle$ designates the spatial average over the sample, and $\gamma \approx 3 MHz/Oe$ is the gyromagnetic ratio divided by 2π. The extensive proof will not be given again, but instead we shall insist on intuitive hints that make this expression easy to understand and to use in practice. First, it says that if one wants to probe the magnetization components along x, it is appropriate to measure the permeability with a microwave field along the y direction. This is no wonder, because the fundamental equation of magnetization dynamics says that the microwave field couples only to the magnetization component that is normal to it. Second, it tells that though the frequency response depends on magnetic parameters of the thin film (such as anisotropies and internal fields), there is a trade-off between the permeability levels that can be attained and the frequencies at which they are attained. Again, this is no wonder; in the case of ferrites this is known as “Snoek’s law”. The quantity $\sqrt{\langle M_x^2 \rangle}$ obtained from the permeability measurements using Eq. (1) should not be confused with $\langle M_x \rangle$ obtained by conventional Vibrating Sample Magnetometer (VSM) measurements. It will be shown experimentally that when a large enough static field is applied on the sample, both quantities are equal. In contrast, in the demagnetized state, the VSM is blind, while the permeameter provides useful indications. Eq. (1) can also be used to determine experimentally the saturation magnetization of thin films [3].

Performing precise measurements of $\sqrt{\langle M_x^2 \rangle}$ requires a permeameter with good absolute precision, especially at high frequencies. The hardware and calibration features of our apparatus that are important to achieve such high precision levels shall be described.

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[1] M. Ledieu and O. Acher, J. Magn. Magn. Mater. **258**, 144 (2003).

[2] O. Acher and S. Dubourg, Phys. Rev. B **77**, 104440 (2008).

[3] O. Acher, V. Dubuget and S. Dubourg, IEEE Trans. Magn. **44**, 2842 (2008).

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