Magnetic losses and domain wall dynamics in amorphous ribbons with longitudinally-induced anisotropy: theory and experiments.

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We discuss the broadband (DC – 1 MHz) magnetic loss properties of longitudinal field-annealed Co-based amorphous ribbons. The field-treated samples exhibit a sharp longitudinal anisotropy, enforcing a corresponding array of antiparallel domains. They display a very high permeability, making them suitable for applications like current transformers, magnetic amplifiers, and cores for power electronics. With their rectangular hysteresis loop and abruptly attained saturation, they can be seen as a counterpart of the transverse field-annealed samples and the related smooth increase of the energy loss with frequency. We characterize in this work 17 μm thick $Co_{71}Fe_4B_{15}Si_{10}$ amorphous ribbons, stress-relieved and annealed 12 hours at 280 °C under a longitudinal saturating field, both as single strips and tapewound ring samples. The broadband loss versus frequency analysis, carried out in conjunction with dynamic magnetooptical observations of the domain structure, puts in evidence the rise of the skin effect at high frequencies. This is accounted for, in the framework of the loss decomposition method, by numerical modeling of the domain wall bowing versus frequency.

Keywords: Amorphous ribbons; Magnetic losses; Induced anisotropy; Domain wall bowing.

1. Introduction

The amorphous (AM) and nanocrystalline (NC) ribbons generally display a thickness in the 10 – 25 μm range, relatively high resistivity, and weak dependence of the magnetic properties on temperature. Combined with high saturation polarization, these properties engender a significant volume reduction and lower losses than soft ferrites [1]. The amorphous alloys, susceptible to field annealing and the related induced anisotropy, further show great flexibility of their magnetic properties. For example, transverse field-annealed (TA) samples exhibit the lowest high-frequency losses, largely reduced with respect to the longitudinal field-annealed (LA) samples, and the permeability cutoff is generally displaced beyond some 100 kHz, because the rotations are the dominating magnetization process [1]. The behaviour of the TA samples appears to depend quite linearly from the peak polarization J_p and one can successfully address their loss properties by identifying the magnetic constitutive equation via the Landau–Lifshitz–Gilbert equation and applying Maxwell's diffusion equation at high frequencies [2], [3].

The LA materials can nevertheless offer very high permeability values, making them useful in high-frequency transformer applications [4]. Their appropriate use at high frequencies requires a good understanding of the loss process up to the MHz range.

2. Results and discussion

Magnetic domain wall (DW) observations, both under static and dynamic conditions, have been performed using a stroboscopic Kerr effect apparatus. They show that the anisotropy induced by longitudinal field annealing is high enough to create a regular antiparallel domain structure with extended 180° DWs, as sketched in Fig. 1. The DW spacing is around 0.5 mm, much higher than the ribbon thickness, thereby filling the conditions where the simplification offered by the Pry&Bean model and the assumption of independently oscillating walls, can be accepted [5].

The dynamic Kerr observations, carried out up to about 1 MHz, show limited to negligible DW multiplication, at least for J_p values far from the knee of the magnetization curve.

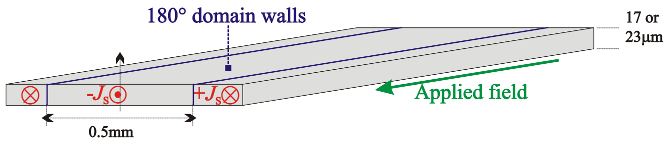

Figure 1: Sketch of the domain structure following the LA treatment

This would imply a linear dependence of the dynamic loss $W_{dyn}(f)$ on frequency, in accordance with the Pry&Bean model or, equivalently, with the Statistical Theory of Losses in the absence of evolving number of Magnetic Objects. The example in Figure 2 shows, however, that a deviation of $W_{dyn}(f)$ from such a law occurs at J_p = 50 mT beyond about 10 kHz. This behaviour is accounted for by means of Bishop's DW bowing model [6], a straightforward approach to the skin effect in the presence of DWs. The so- calculated $W_{dyn}(f)$ is shown by the continuous line in Fig. 2.

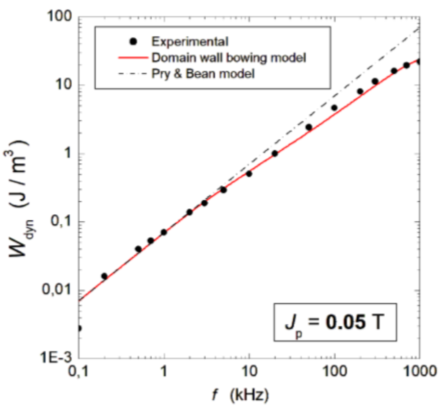

Figure 2: Dynamic loss at 50 mT up to 1 MHz

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