Electrical and magnetic properties of Permalloy- and iron-based magnetoimpedance sensors at the mm to nm and kHz to GHz scales

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In recent years, the giant magnetoimpedance (GMI) effect has attracted interest as an ultrasensitive and easy-to-implement effect for the detection of magnetic nanoparticles, of picotesla magnetic fields, for biomedical applications, and for the detection of inverse magnetostriction [1]. Furthermore, the origin of the GMI effect needs to be investigated to provide an important guideline for experimental research [2].

The talk will give an overview on the potential and limits of Permalloy- and iron-based devices, which are promising to be used for high-sensitive magnetic field and strain sensors. We especially focus on the underlying physics and scaling behavior of the GMI effect and on how magnetic domains and domain walls determine the transport properties of such materials in different frequency regimes [3, 4, 5]. Therefore, a whole spectrum of magnetometric and magneto-optical methods is employed in combination with theoretical and micromagnetic simulations to derive a holistic understanding of such processes.

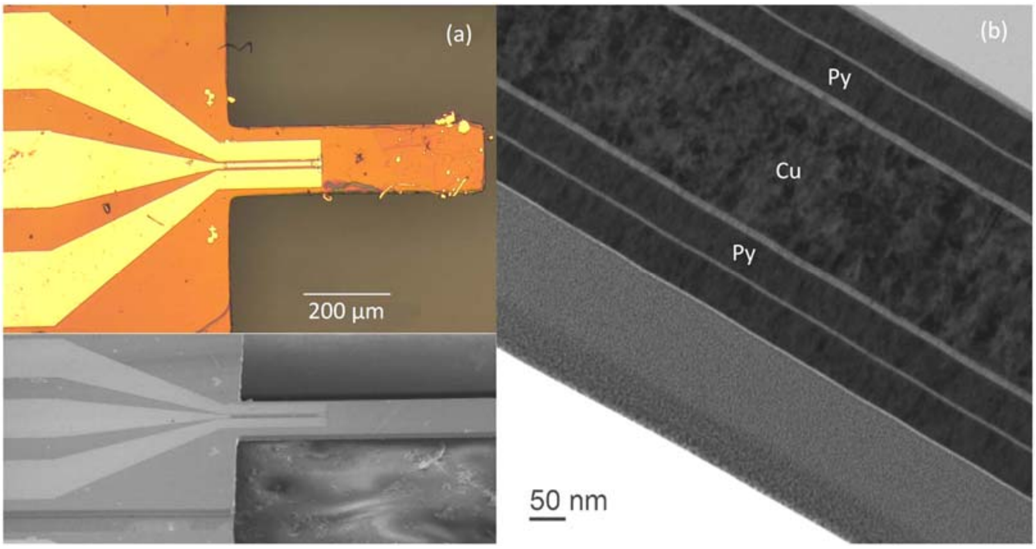

Figure 1: (a) Top-view optical micrograph and tilted-view greyscale scanning electron microscopy images of a Si cantilever with an integrated GMI sensor. The whole magnetostrictive element was positioned onto the cantilever in a way such that a maximum strain results at a minimum deflection. (b) Transmission electron microscopy cross-sectional view of the multilayer structure [4].

The GMI sensors were fabricated using sputter deposition and electron beam lithography techniques with various aspect ratios of the magnetic multilayer. Figure 1 shows a typical example of a magnetostrictive GMI sensor. All relevant characteristics of the GMI sensors, including the GMI ratio, Hysteresis curves and strain-impedance gauge factor were measured and analyzed in the range from the skin effect to ferromagnetic resonance [4]. As a comparison, iron whisker samples were fabricated and the GMI ratio of them was measured as well.

The transformations in the magnetic domains and internal structures of the domain walls of Permalloy were investigated by MOKE, MFM [5], and micromagnetic simulations using OOMMF [6] and MuMax [7] softwares. Figure 2 presents MFM images of the modification of the domain configurations of a Permalloy pattern inside an applied external magnetic field. Evolution of vortices and antivortices inside the domain walls was investigated as well.

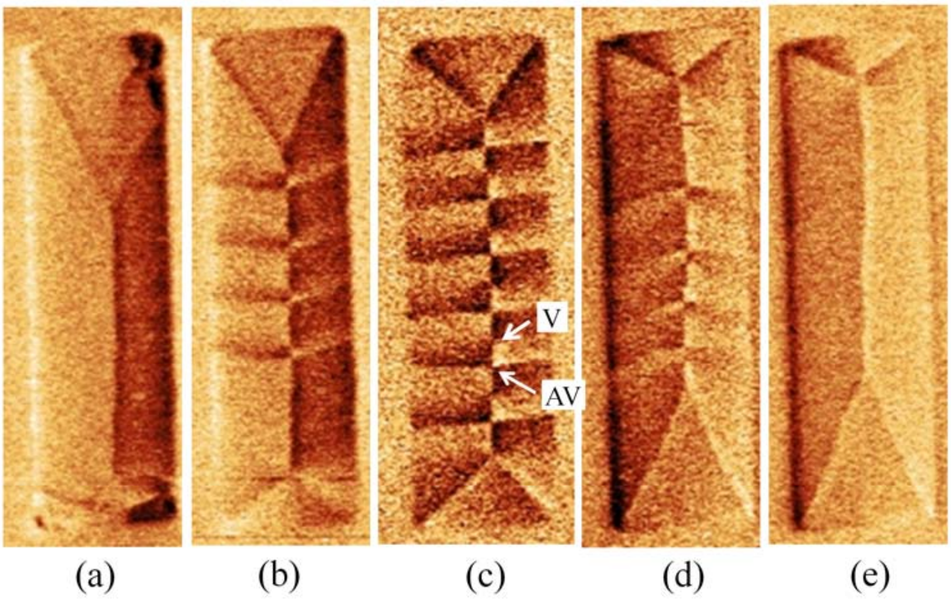

Figure 2: MFM images of domain configurations of a 50 nm thick 5 × 18 μm^2 Permalloy pattern at (a) + 4.4 mT, (b) + 3.0 mT, (c) zero (d) – 3.0 mT, and (e) – 4.6 mT, respectively. The external magnetic field was applied along the short axis of the sample. Positions of vortices (V) and antivortices (AV) are indicated.

We also show the possibly inherent potential of GMI sensors to surpass the sensitivity of XMR-based strain and field sensors and present work in progress and future options to integrate thin-film based GMI sensors with high-frequency spintronic devices to significantly reduce the fabrication costs of ordinary coil-based GMI sensors.

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