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TITLE: Transport, magneto-optical and micromagnetic characterization of domain-wall resonance (DWR) in giant magnetoimpedance strain and magnetic field sensors

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ABSTRACT BODY:

Digest Body: Recently, very high strain-gauge factors have been determined on micromachined thin-film and multilayer giant magnetoimpedance sensors [1]. The observed domains walls and different magnetization reversal mechanisms are complex and difficult to predict in advance in such sensors, but strongly determine the high-frequency transport characteristics and are critical for strain and magnetic field sensitivity in the low-field regime.

In this contribution we report on observed domain walls emerging during sweeping of the external field. Domains were imaged and distinguished by longitudinal magneto-optical widefield Kerr and magnetic force microscopy. The main goal of this study was to obtain a match with micromagnetic simulations carried out by the MUMAX framework.

While typically a double peak GMI response has been reported in mm-sized NiFe multilayer thin-film and ribbon GMI sensors with a Cu core layer and surrounding NiFe layers [2], we show that in microstructured and -machined multilayers a well-pronounced fourfold peak behavior can occur. Measurements were performed by a VNA in distinct frequency regimes below the FMR frequency of the Kittel mode. Similar multi-peak effects were also reported for GMI thin-film sensors with CoNbZr in the low-MHz regime, but no explanation could be found so far [3]. The DWR depends on the actual structure of the multilayer system, on materials, post-deposition annealing processes, ac current amplitude and domain-wall types and density. The implications of DWR in GMI sensors may be dis-/advantageous in future GMI sensor applications for magnetic field/particle or strain detection. Therefore, a thorough understanding and prediction of such processes by micromagnetic simulations is very helpful.

A careful/thorough set-up of the exciting-field geometries has to be defined in the simulations to understand and verify the more or less pronounced occurrence of DWR in the MHz regime for different multilayer designs. The Oersted field that is generated by the ac current in the Cu core layer has antiparallel orientations in the surrounding bottom and top NiFe layers. For a single layer system, the dipolar coupling between the top and bottom layers adjacent to the Cu core leads to an antiparallel orientation of domain walls and opposing oscillations of the Oersted field and of vortices and anti-vortices in the single layers (Fig. 1). For a double layer system, experimentally and in micromagnetic simulations, the amount of vortex structures is strongly reduced and the DWR peaks in the GMI curve are less pronounced (Fig. 2). This can be qualitatively understood by a very weak antiparallel dipolar coupling of bottom and top double layers and by the antiparallel coupling of the single NiFe layers in each surrounding double layer. This leads to a damping of strong oscillations/DWR as the Oersted field is parallel and antiparallel to the single layers below and on top of the Cu core. In addition, the domain walls of the individual layers of the double-layer system are much stronger coupled by dipolar interactions. Both aspects can be experimentally verified by an identical shape of MOKE-recorded hysteresis curves from the top of the double layer and VSM hysteresis curves of the whole multilayer stack.

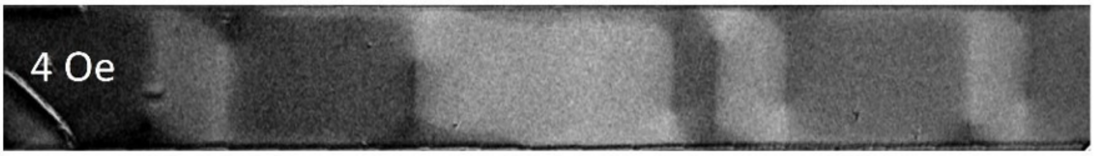
By applying tensile strain to such double layer GMI sensors, the field regime exhibiting DWR increases as well as the number of domain wall annihilations/nucleations in the low-field regime before the magnetization rotates towards the saturated state. This further proves that a high density of domain walls in microscaled GMI sensors strongly influences or dominates the change of permeability and impedance in the skin-effect regime far below the FMR frequency regime. This may lead to fundamental scaling limits for GMI sensors or it may stimulate new design and materials concepts, when a rotation of magnetization in the low-field regime cannot be established.

In conclusion, we show that micromagnetic simulations, not presented so far for GMI devices, are a powerful tool for

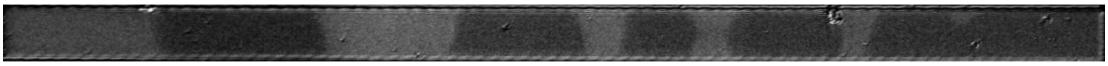
the prediction of DWR in relatively large GMI devices with odd and even numbers of NiFe layers and alternating changes of dipolar coupling and occurring domain walls. Thereby, optimal strain and field sensitivities can further be explored and optimized for future smaller GMI sensors.

References: [1] G. Buettel et al., Appl. Phys. Lett. 111, 232401 (2017)
[2] A. Garcia-Arribas et al., J. Magn. Magn. Mater. 400, 321 (2016)
[3] H. Kikuchi et al., J. Magn. Magn. Mater. 420, 269 (2016)

KEYWORDS: giant magnetoimpedance, domain-wall resonance, micromagnetics, sensor.



Longitudinal Kerr-microscopy image of a single system (400µm x 40µm) at 4 Oe. For zero field no vortices/anti-vortices occur in the films and no DWR in the corresponding GMI curves. The density of the vortices strongly depends on the thickness of the Cu core layer



Longitudinal Kerr-microscopy image for two double (NiFe/Ti/NiFe) layers (400µm x 20µm) surrounding the Cu Core layer at an external field of 4 Oe. Due to the large size and soft magnetic properties of NiFe only a qualitative match (shape, density) to the micromagnetic simulations can be reached. Vortices/anti-vortices do not occur in the double layer system as well as flux closure domains parallel to the longitudinal axis of the GMI structures in comparison to single layers.

IMAGE CAPTION: Longitudinal Kerr-microscopy image of a single system (400µm x 40µm) at 4 Oe. For zero field no vortices/anti-vortices occur in the films and no DWR in the corresponding GMI curves. The density of the vortices strongly depends on the thickness of the Cu core layer Longitudinal Kerr-microscopy image for two double (NiFe/Ti/NiFe) layers (400µm x 20µm) surrounding the Cu Core layer at an external field of 4 Oe. Due to the large size and soft magnetic properties of NiFe only a qualitative match (shape, density) to the micromagnetic simulations can be reached. Vortices/anti-vortices do not occur in the double layer system as well as flux closure domains parallel to the longitudinal axis of the GMI structures in comparison to single layers.

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AWARDS:

Previous Presentation: Yes

Manuscript?: Undecided

Attendance at Conference: I acknowledge that I have read the above statement regarding the requirement that an author of this presentation must attend the conference to present the paper.