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TITLE:

Magneto-optical and transport characterization of micromachined Si cantilever with integrated high frequency GMI thin-film device under local compressive/tensile strain

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ABSTRACT BODY:

Digest Body: The giant magnetoimpedance (GMI) effect could open sensitivity and bandwidth regimes beyond XMR effects for field- and strain- sensing purposes. While XMR-based sensors have already been integrated onto flexible substrates and Si cantilevers [1], GMI devices have so far only been reported in the context of flexible polymer substrates and Si wafers by several groups [2-4]. However, especially for Permalloy polymers can diminish the magentoimpedance response by overheating the magnetic films during fabrication due to low thermal conductivity [2]. Therefore, such substrates do not allow for an investigation of optimal anisotropy tuning and best possible performance of strain sensing thin-film GMI devices. Also the behavior and potential under compressive and torsional strain is difficult to investigate in a controlled way employing such substrates for GMI microstructures.

We have developed a complex fabrication process to realize a 1-port 50 Ω on-chip terminated (Nichrome resistors) coplanar waveguide with a magnetic signal line on a tipless Si(27μm)/Si_3N_4(1000nm) cantilever of 500μmx100μm lateral dimensions resembling commercial scanning probes for AFM's. The signal line, consisting of a Permalloy multilayer system (400μm length, 20μm width), is located above the bending edge of the cantilever to induce a maximum local strain at a minimum mechanical deflection of the cantilever. This was exerted at the end by a nanomanipulator (135nm xyz minimum step size). A home-built longitudinal Kerr effect widefield microscope allowed for simultaneous imaging of the magnetic domains and for deducing the hysteresis curve from the change of Kerr contrast of the top layer under applied tensile, compressive and torsional stress. Fig. 1 shows the device and its magneto-optical characterization, which reveals domains transversally oriented to the longitudinal axis. The latter is induced by applying a magnetic field of 250 Oe during sputtering. VSM analysis of arrays of such structures matches well the MOKE recorded hysteresis curves as well as micromagnetic simulations based on the MUMAX framework. The latter allows time-efficient modeling of such large microstructures. Transport measurements were carried out with a VNA in a range of 0.1 to 3 GHz at 0 dbm power level to cover the skin-effect and the ferromagnetic resonance regime of the GMI effect. Deflection up to 50μm were exerted by the manipulator. Although bulk $Ni_{80}Fe_{20}$ Permalloy is not magnetostrictive, small changes of composition strongly impact magnitude and sign of the magnetostriction coefficient and a multilayer system deviates the behavior from the one of bulk. Contrary to reported results [2], Fig. 2 shows that our device conserves the typical double peak pattern and high GMI ratio after fabrication, corroborating the importance of the substrate type upon dc magnetron sputtering. Therefore the device shows a higher stress-impedance and characteristic broadening/compressing of the GMI curve peaks with applied tensile/compressive strain due to the induced change of the effective anisotropy. This is also supported by Kerr microscopy exhibiting an increasing/decreasing saturation field and a magnetization reversal mainly controlled by magnetization rotation in the strongly dipolarly coupled layers. Due to the relatively small width and thickness of the multilayer the GMI ratio is small in the skin-effect regime but increases significantly in the FMR regime. Kerr microscopy before and after the ICP-RIE dry etching process releasing the cantilever shows slight changes in the domain structures and points towards the necessity to thoroughly analyze the influence of temperature and membrane thickness on the domain structure and GMI performance.

In conclusion we show that GMI sensors might possess a huge potential as MEMS-type strain sensors based on our results with relatively thin Permalloy multilayers. GMI sensors comprise a wider choice of materials and geometrical variations and therefore a better tunability and performance than alternative magnetostrictive sensor mechanisms, especially in the high-sensitivity regime. We further discuss concepts and limits to shrink the device size even more and optimize the sensor performance. Also ways to wafer-scale fabrication are discussed. This discussion involves alternative magnetostrictive and nonmagnetic spacer materials to realize flexible GMI field- or strain- sensing devices. On the other hands, our devices also open possibilities to measure the influence of strain on magnetic parameters like Gilbert damping and the magnetostriction coefficient via analysis of the GMI curve [2] or strain-controlled VNA-FMR spectroscopy of arbitrary shaped magnetic materials that can be implemented into the signal line by e-beam

lithography.

References:

[1] Tavassolizadeh, A. et al. "Self-sensing atomic force microscopy cantilevers based on tunnel magnetoresistance sensors." *Applied Physics Letters* 102.15 (2013): 153104.

[2] Garcia-Arribas, A. et al. "Thin-Film Magnetoimpedance Structures onto Flexible Substrates as Deformation Sensors." *IEEE Transactions on Magnetics* (2016).

[3] Li, B. et al. "Flexible magnetoimpedance sensor." *Journal of Magnetism and Magnetic Materials* 378 (2015): 499-505.

[4] Miwa, Y. et al. "Basic Study of Fabricating High Sensitive Strain Sensor Using Magnetostrictive Thin Film on Si Wafer." *IEEE Transactions on Magnetics* 51.1 (2015): 1-4.)

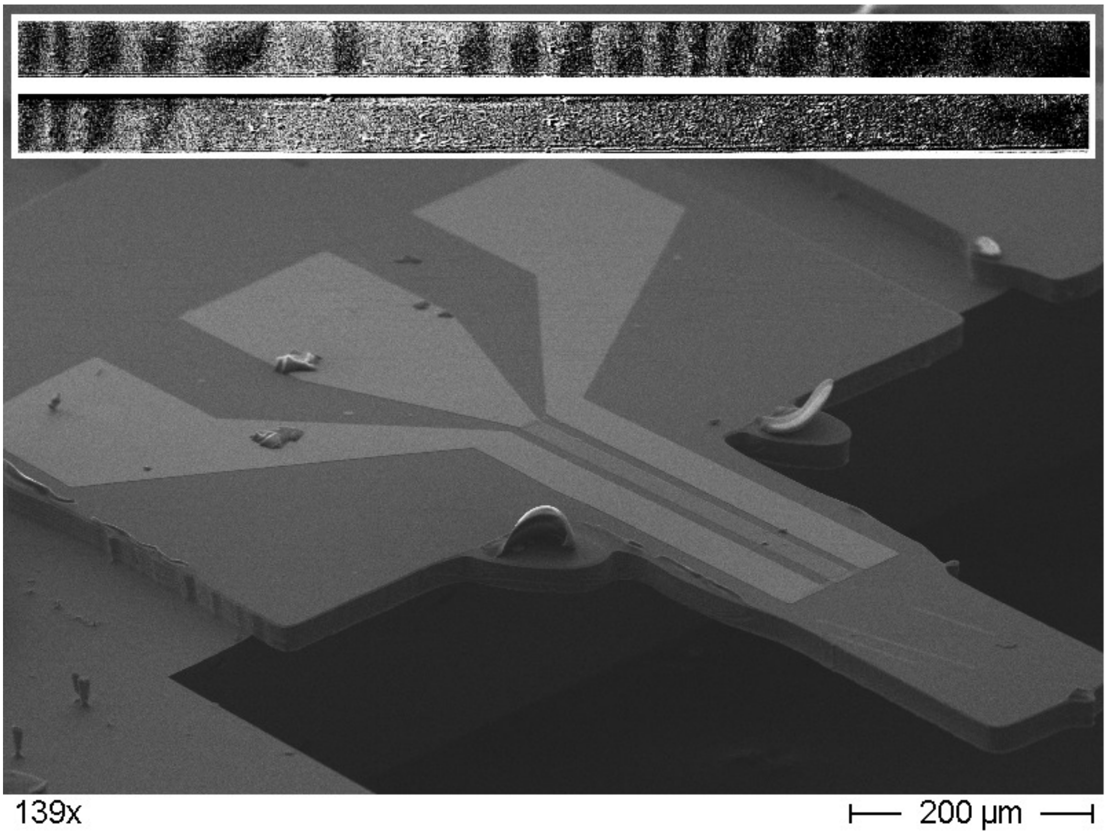

Figure 1: SEM image of a typical device after fabrication. The signal line consists of a Ti10nm[Py100nm/Ti5nm]$_2$/Cu250nm/[Ti5nm/Py100nm]$_2$ layer stack linked to Ti/Cu/Au coplanar waveguide terminated with Nichrome resistors in a multi-level lithography process. The inset shows a MOKE microscope image of transversal domains at zero external field for the cantilever in the relaxed (top) and in a 20 µm compressively deflected (bottom) state that increases the longitudinal anisotropy locally.

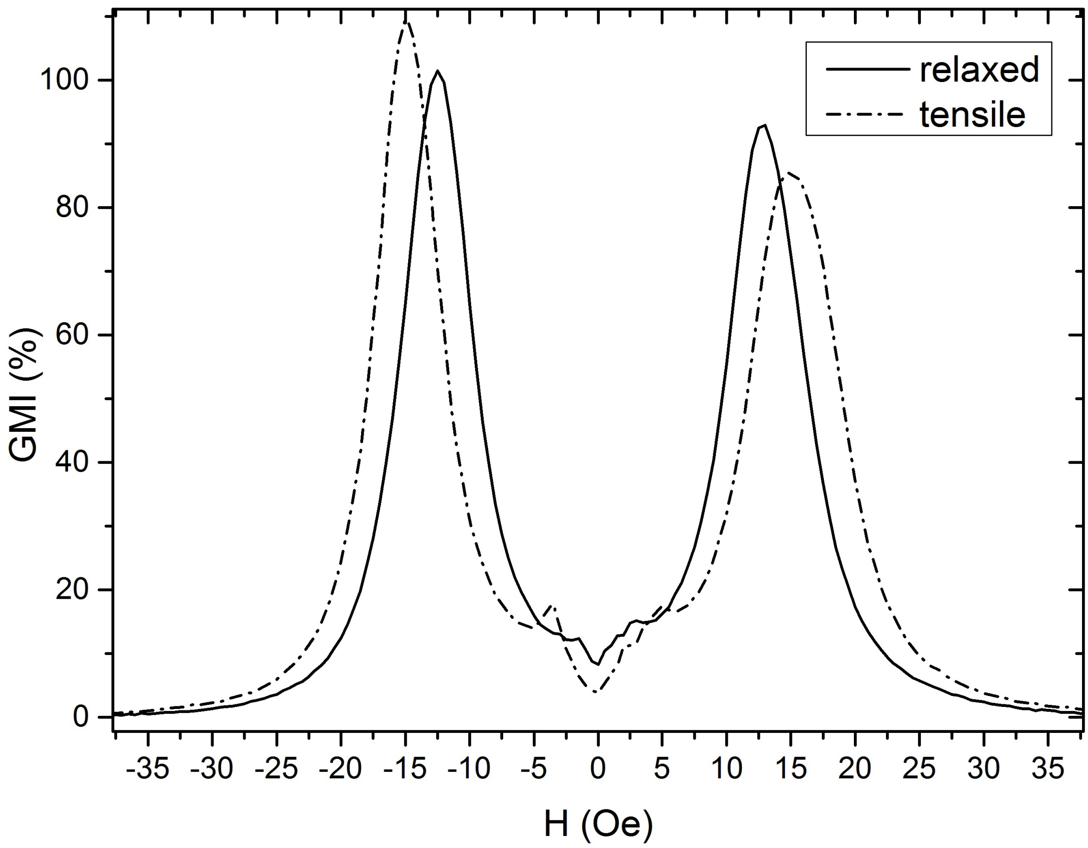

Figure 2: Normalized GMI ratio in the relaxed and in a 20 μm tensely deflected state. The ac current frequency is 1.5 GHz in the FMR regime.

IMAGE CAPTION:
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