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TITLE: Determination of the strain-impedance gauge factor of Si-cantilever-based giant magnetoimpedance sensors

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ABSTRACT BODY:

Digest Body: Magnetoresistive sensors are currently widely investigated for flexible electronics and strain-sensing applications by employing magnetostrictive materials in GMR, TMR and giant magnetoimpedance (GMI) devices [1-3]. A true comparison of the three underlying effects for strain detection was so far not possible, because GMI strain sensors have so far been reported only on low-quality polymer substrates or Si wafers. Deposition on strongly bendable Si-cantilevers has only been reported very recently [4].

In this report a fabrication process and its effect on the magnetic and transport properties of GMI sensors integrated onto Si cantilevers are discussed. A strong change of permeability and therefore an impedance change is induced by the dry etching plasma processes needed to release the cantilevers from a 20 µm thick Si membrane. It softens the sensors magnetically. The downsizing of the GMI strain sensor required to deposit it on a cantilever allows accurate finite element simulations of induced stress/strain in the magnetostrictive layers ($Ni_{82}Fe_{18}$). As a result the strain-impedance gauge factor could be determined to be almost 200 at an ac current frequency of 2 GHz (Fig. 1). In consideration of the small dimensions, the consequently small magnetic field sensitivity and the low maximum GMI ratio of this device and due to the low-magnetostrictive NiFe employed in multilayer system, much higher strain gauge factors are assumed to be possible for GMI sensors. They could even surpass TMR strain-gauge factors. In addition, the highest strain gauge factor of the present device was measured in the ferromagnetic resonance regime. GMI ratios beyond 500% have already been reported for bigger NiFe multilayer GMI field sensors in the skin-effect regime and when magnetization rotation is the dominating reversal mechanism in the low-field regime. In the present case, complex domain-wall annihilations and creations dominate the reversal in the low-field regime and even lead to domain-wall resonances (DWR) in a distinct frequency regime. This could be proven by magneto-optical widefield microscopy and corresponding micromagnetic simulations of the magnetization dynamics.

By optimizing the NiFe ratio of the sputtering target and the deposition parameters a nearly zero magnetostriction ($Ni_{80}Fe_{20}$) was realized for the sensor material. In contrast to low-magnetostrictive $Ni_{82}Fe_{18}$ (Fig. 2) the effective anisotropy field is not changing when applying compressive and tensile strain. This proves that even for thin film NiFe, which has been microstructured by means of lithography and which contains thin Ti spacer layers to bypass the critical thickness of emerging stripe domains, nearly zero magnetostriction can be reached. Therefore, ultraflexible GMI magnetic field sensors can be fabricated without the need of employing materials with high spin polarization and a high magnetostriction such as Co and Fe alloys, which are often deposited in TMR and GMR sensors. Additionally, no high-quality MgO or Al_2O_3 interfaces are necessary.

In conclusion we show that thin-film GMI sensors have a very promising but not completely known potential on flexible substrates. Further optimization of the geometry is necessary and especially highly permeable materials with higher magnetostriction coefficient than that of NiFe ought to be investigated to analyze their full potential for strain or hybrid magnetic field and strain detection.

References: [1] A. Tavassolizadeh et al., Appl. Phys. Lett. 102(15), 153104 (2013)

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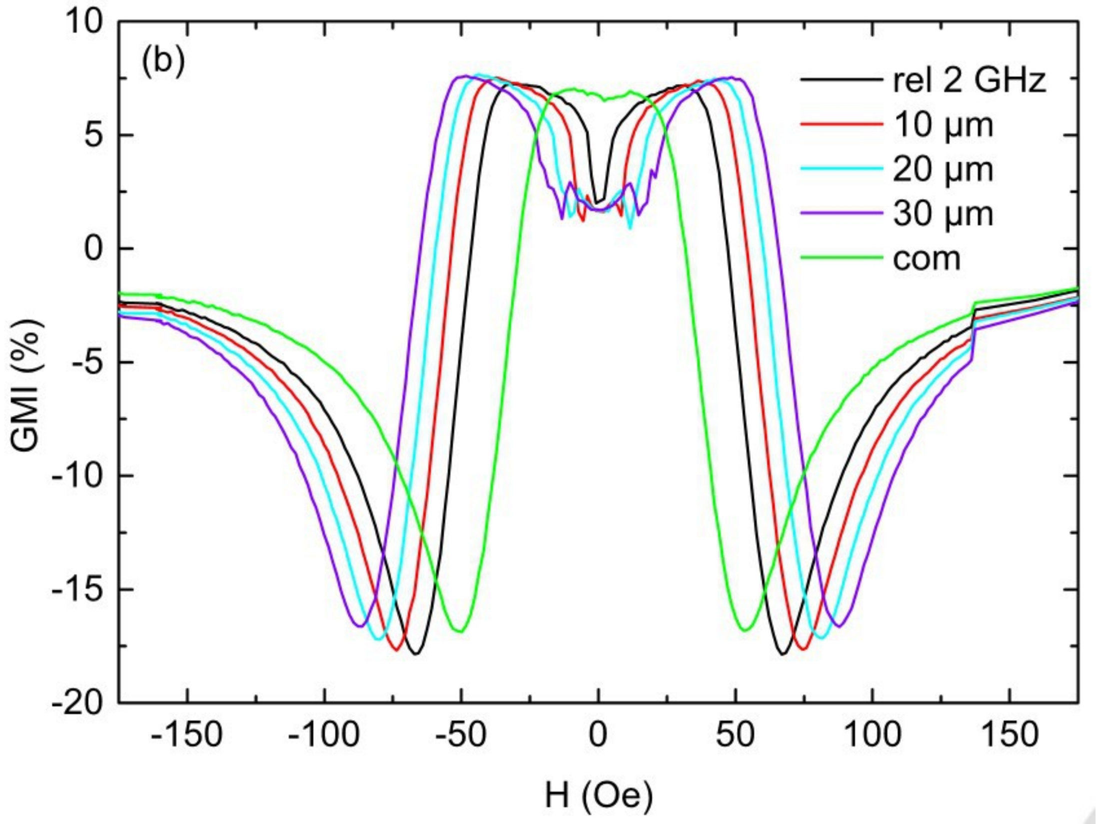
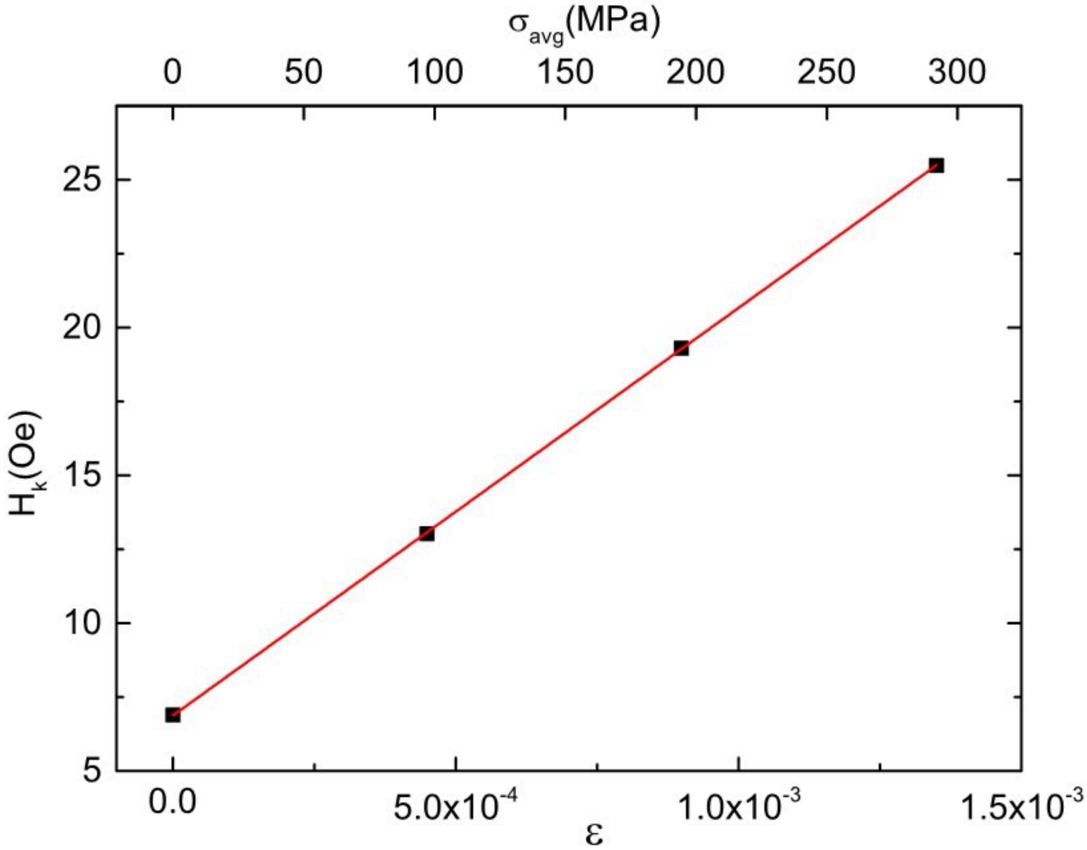
[4] G. Buettel et al., Appl. Phys. Lett. 111, 232401 (2017)

KEYWORDS: giant magnetoimpedance, MEMS, magnetostrictive sensor, magnetic field sensor.



Transport measurement for the cantilever in the relaxed (rel) and in a 10, 20, 30 µm tensely and 30 µm compressively (com) deflected state at an ac current frequency of 2 GHz in the FMR regime.



Change of the effective anisotropy field under tensile stress/strain. The data was deduced from the shift of the peaks of the GMI curve in the skin-effect regime at an ac current frequency of 0.3 GHz.

IMAGE CAPTION: Transport measurement for the cantilever in the relaxed (rel) and in a 10, 20, 30 µm tensely and 30 µm compressively (com) deflected state at an ac current frequency of 2 GHz in the FMR regime. Change of the effective anisotropy field under tensile stress/strain. The data was deduced from the shift of the peaks of the GMI curve in the skin-effect regime at an ac current frequency of 0.3 GHz.

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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.