Strain-controlled Domain Wall injection into nanowires for sensor applications

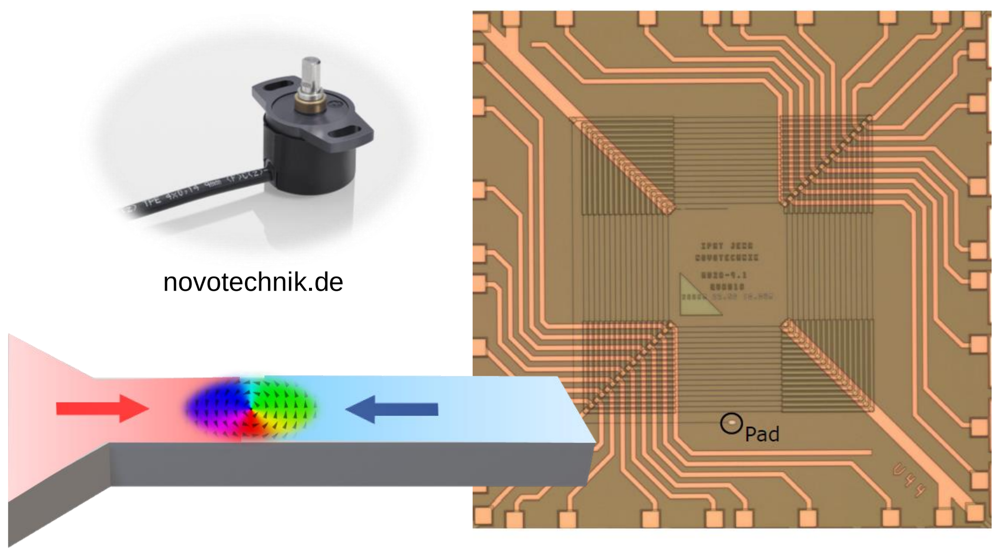
G. Masciocchi[1,2] *(gmascioc@uni-mainz.de)*, M. Fattouhi[3], A. Kehlberger[1], L. Lopez-Diaz[3], M.-A. Syskaki[2,4] and M. Kläui[2]

1 Sensitec GmbH, 55130 Mainz, Germany, 2 Institute of Physics, Johannes Gutenberg -University Mainz, 55099 Mainz, Germany, 3 Universidad de Salamanca, Department of Applied Physics, E-37008 Salamanca, Spain and 4 Singulus Technologies AG, 63796 Kahl am Main, Germany.

BACKGROUND and OBJECTIVES

Magnetoresistive (MR) sensors are usually composed of thin magnetic films forming micro/nano- structures and adopted in the detection and measurement of magnetic fields, electric current, rotation in industrial, automotive, and even aerospace application [1,2].

The impact of the **strain**, intrinsically present in thin crystalline materials, is of fundamental importance for the **performance of devices** like sensors based on magnetic domain wall motion [3].



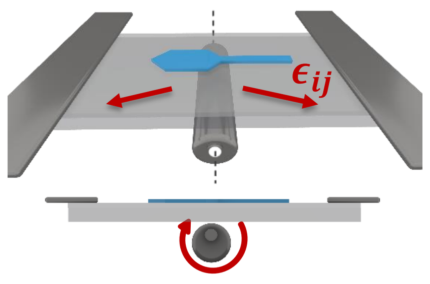
In the work presented here, we address this well-known challenge in magnetic sensor industry.

We investigate experimentally and with simulations, the impact of externally applied strain on the injection of a **180° domain wall** (DW) from a nucleation pad in a magnetic nanowire, as typically used for domain wall-based sensors.

MATERIAL PREPARATION

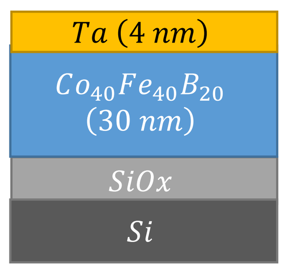
It is known how the magnetization is coupled to the uniform macroscopic strain (ϵ_{ii}) in the expression of the anisotropy [4]:

$$K_{ME} = \frac{3}{2}\lambda_s Y \left|\epsilon_{xx} - \epsilon_{yy}\right|$$



We deposited ferromagnetic layers with different **magnetostriction** (λ_s) to explore strain effects.

In our samples made of $Co_{40}Fe_{40}B_{20}$ the effective anisotropy of the device can be additionally tailored by **annealing in a magnetic field** (K_{film}) [5].



METHODS

We study the **injection of a domain wall** from a nucleation pad into a nanowire (figure 1 and 2), as typically used for domain wall-based sensors.

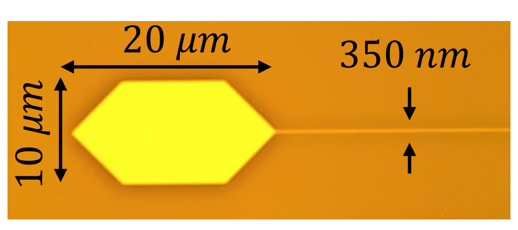


Figure 1: optical microscope image.

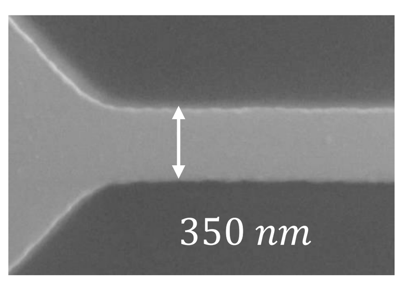


Figure 2: SEM image of the device.

To apply **uniaxial strain** to our devices, the substrate ($SiOx$) was bent mechanically.

We employ **magneto-optical Kerr effect** (MOKE) microscopy to image the DW creation, pinning and injection from the pad for different external strain configurations.

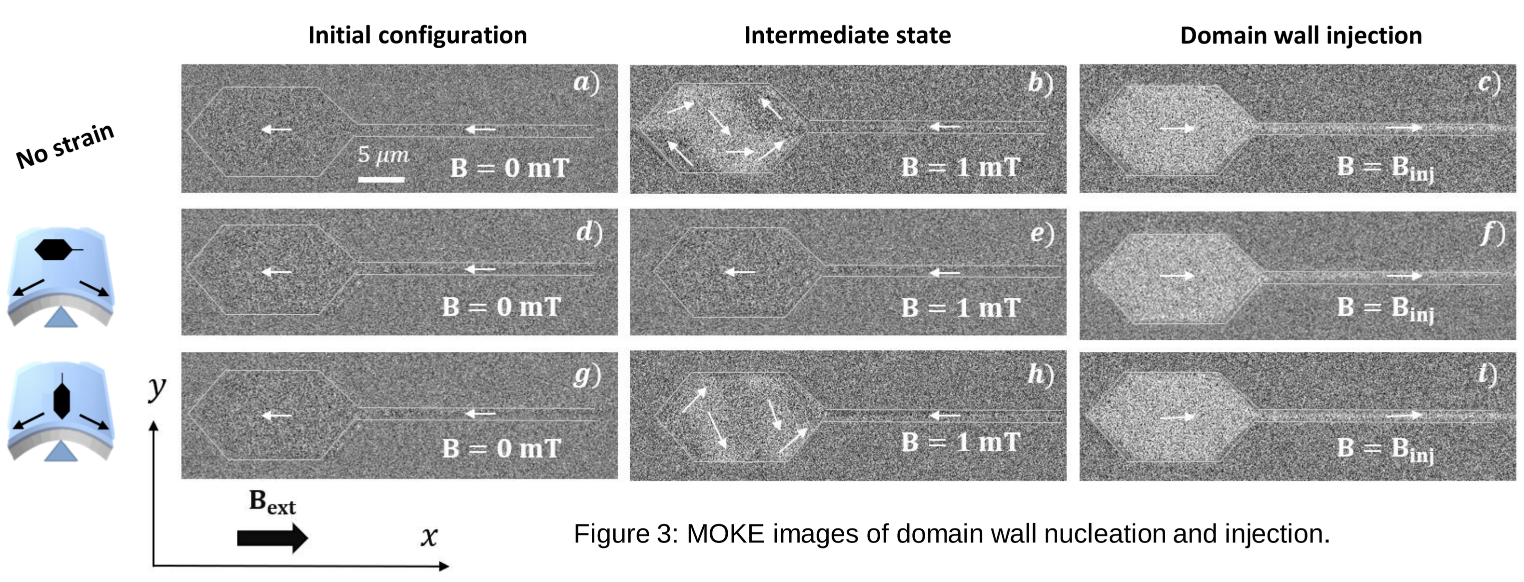


Figure 3: MOKE images of domain wall nucleation and injection.

The domain configuration and the switching mechanism in the injection pad depend strongly on the direction of the magnetic anisotropy induced by strain with respect to the wire axis.

RESULTS and DISCUSSION

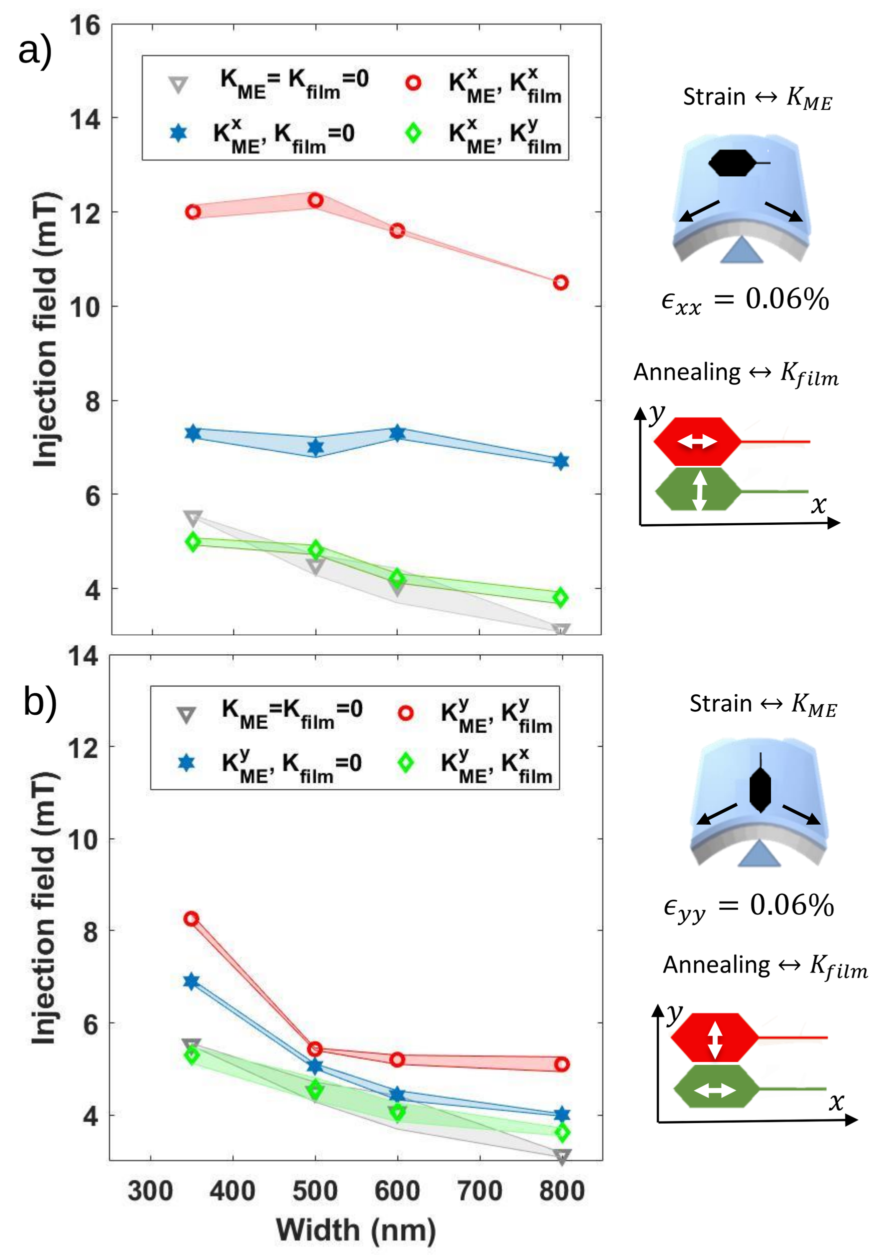


Figure 4: experimental data for $Co_{40}Fe_{40}B_{20}$: the domain wall injection field is plotted as function of the nanowire width.

We first measure the domain wall injection field (B_{inj}) in absence of strain (grey triangles).

I. We find that strain (ϵ_{ii}), regardless of its direction, **increases** B_{inj} (blue stars).

The effects of strain are proportional to the **magnetoelastic coupling** of the magnetic layer.

II. An additional anisotropy term (K_{film}) can increase (red circles) or reduce (green diamonds) the effects of mechanical strain on B_{inj}. This happens, respectively, if the magnetic uniaxial anisotropy K_{film} is parallel or perpendicular to the strain-induced easy axis K_{ME}.

This means, a **magnetostrictive free behavior** of the device (grey triangles), can even be reached in systems with finite magnetostriction.

SIMULATIONS

Mumax3 simulations [6,7] are used to identify the **switching mechanism** and the spin structure of a pinned DW, just before the injection into the wire.

Our simulations are in good agreement with the experimental data for the injection field, as we observe a **dominant effect of tensile uniaxial strain.**

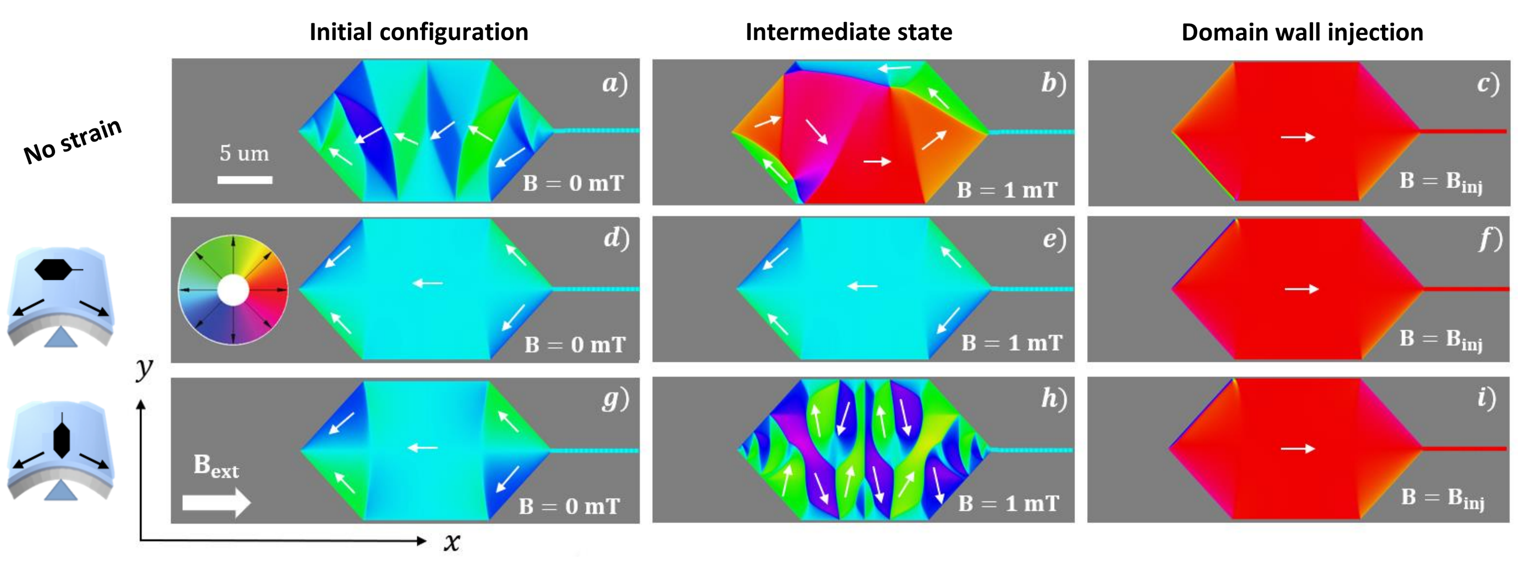


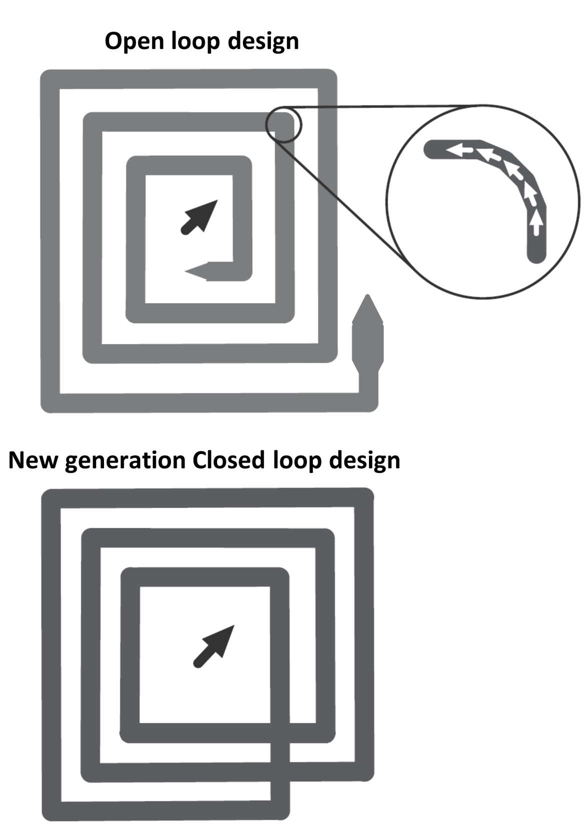
Figure 5: snapshots during simulations of domain wall nucleation and injection.

CONCLUSION and OUTLOOK

We unambiguously show that in a real domain wall sensor the effects of **strain can play a significant role.**

Tailoring the effective anisotropy in the sensor offers a way to improve the **robustness of these type of devices** against strain disturbances and fosters the development of innovative and more capable devices [8].

Our future studies will focus on the dynamics of DW in **more complex geometries.** Our goal is to use the strain to reliably drive a spin structure at the intersection of two nanowires, thus enabling a new generation of DW based rotation counters [9].



REFERENCES and ACKNOWLEDGEMENTS

[1] L. Jogschies et al., *Sensors* 15.11 28665-28689 (2015).
[2] M. Diegel et al., *Sensor Letters* 5, 118–122 (2007).
[3] N. Lei et al., *Nature Communications* 4.1, 1-7 (2013).
[4] A. Bur et al., *Journal of Applied Physics* 109, 123903 (2011).
[5] Y. Zhang et al., *Applied Physics Letters* 98.4 042506 (2011).
[6] A. Vansteenkiste, et al., *AIP Advances* **4,** 107133 (2014).
[7] R. Yanes et al., *Applied Physics Letters* 115, 132401 (2019).
[8] M. Foerster et al., *Handbook of Spintronics*, Springer (2015).
[9] B. Borie et al., *Physical Review Applied* 8, 044004 (2017).

Cite this work as: Journal of Applied Physics 130, 183903 (2021)

KLÄUI-LAB

magnefi.c2n.u-psud.fr

klaeui-lab.physik.uni-mainz.de

MagnEFi

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 860060 "Magnetism and the effects of Electric Field" (MagnEFi).