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COMMENT

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Reply to the 'Comment on "Ultralow magnetostrictive flexible ferromagnetic nanowires"' by D. Faurie, N. Challab, M. Haboussi, and F. Zighem, *Nanoscale*, 2022, 14, DOI: 10.1039/D1NR01773J

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In the comment to our paper, D. Faurie *et al.* have carried out simulations on Co-nanowires subjected to tensile stress perpendicular to the length of the nanowires. According to their simulation, the low effective magnetostriction constant of the Co nanowires results from a very low transfer of stress. They suggest that a higher transfer of stress would be obtained if the wires are bent along the length of the nanowires. Here we compare the result of magneto-optical experiments conducted by bending the nanowires both along and perpendicular to their long axis. The obtained effective magnetostriction of the Co-nanowires is, within the experimental resolution, independent of the bending direction.

In the comment by Faurie *et al.*, simulations were performed on Co-nanowires [Ti (3 nm)/Co (30 nm)/Al (4 nm)] using a model published by Challab *et al.*[1] Compared to our bending experiments, in these simulations, stress is induced by stretching the substrate perpendicular to the length of the nanowires. The flexible PEN substrate is also thinner, 5 μm compared to 125 μm in our experimental sample. Interestingly, the simulations result in an inhomogeneous distribution of the stress across the substrate. In accordance, when the stress is applied perpendicular to the nanowires, a lower strain is localized in regions of the polymer covered by the magnetic material (being more rigid), and the stress is shown to be concentrated in the areas where the magnetic material is missing. The average stress value within the Co-nanowires is only 3% of the stress applied to the PEN substrate. This results in low effective magnetostriction for the perpendicular configuration. On the other hand, simulations performed applying the stress along the length of the nanowires suggest that 45% of the applied stress is transferred to the Co-nanowires. Hence, Faurie *et al.* suggest that a significantly higher effective magnetostriction constant should be obtained in experiments conducted by bending the samples along the length of the nanowires.

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The experiments reported in our paper[2] were carried out with stress applied perpendicular to the long edge of the nanowires. Nevertheless, we have also performed magneto-optical Kerr effect (MOKE) experiments in the longitudinal geometry, *i.e.*, by bending along the long axis of the nanowires. Our experiments performed on two sets of nanowire samples did not yield any difference between tensile stress applied perpendicular to the nanowires and the equivalent compressive stress applied at 90°, *i.e.*, parallel to the nanowires, similar to the observations for the continuous thin films. Fig. 1 shows examples of $M(H)$ curves measured at room temperature in both geometrical configurations [panel (a) and (b)], as well as the corresponding coercivity values as a function of the applied external stress [panel (c)]. The $M(H)$ loops were measured along the easy axis of nanowires (NWs) in all the cases.

According to the procedure used in the published manuscript,[2] we can analyze the data with the formula eqn (1)

$$\mu_0 H_C = \mu_0 H_C^0 + \frac{3}{M_S}\lambda_\sigma \sigma \tag{1}$$

where H_C^0 is the original intrinsic coercivity, M_S = 1.4 MA m^{-1} is the saturation magnetization, σ is the applied external stress, and λ_σ is the magnetostriction constant, which is the only free parameter. As we reported earlier in our publication, in Fig. 1c, fitting eqn (1) to the data collected with tensile stress perpendicular to the NWs yields $\lambda_\sigma = -9(2) \times 10^{-7}$ and fitting the data measured with compressive stress parallel to the NWs results in $\lambda_\sigma = -8(5) \times 10^{-7}$. The two values of magne-

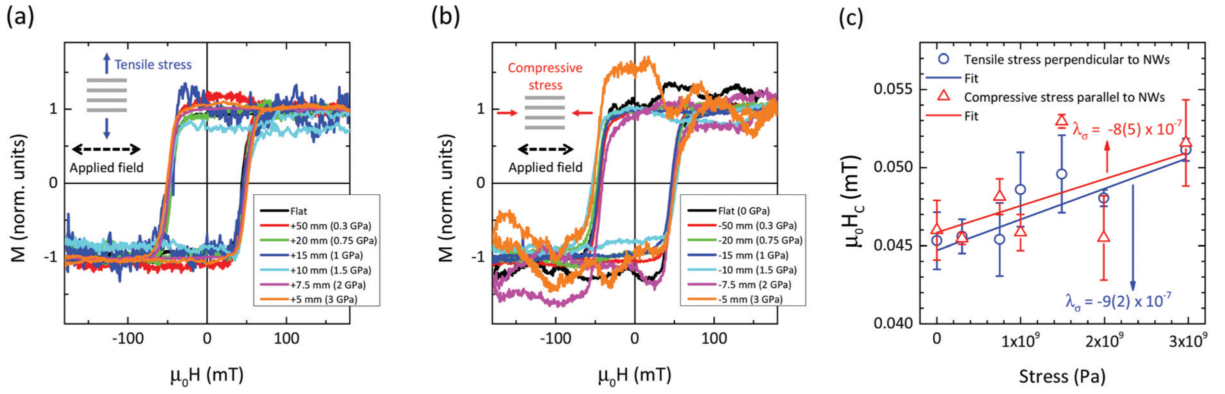

Fig. 1 Example of $M(H)$ curves for (a) tensile stress applied perpendicularly and (b) compressive stress applied parallel to the nanowire length as a function of the radius of curvature/stress, as illustrated in the inset sketches of each panel. (c) The corresponding values of coercivity *vs.* applied stress for tensile stress applied perpendicular to the nanowires (blue circles, data provided in the original published manuscript) and compressive stress applied parallel to the nanowires (red triangles). The lines represent the fit of eqn (1) to the experimental data.

tostriction are reasonable within the experimental error. Due to the geometrical configuration, the longitudinal curvature of the sample led to noisier data, as the reflected laser light was spread over a large area, making it difficult to focus it on the photo-detector efficiently. Therefore, we selected to present the perpendicular curvature geometry for greater reliability.[2]

Differences between experiments and simulations

Experimentally, stretching (the whole substrate elongates) and bending (outer surface elongation supported by inner layers of the substrate) processes could have varying experimental consequences. Unlike the stretching used in the simulations, we bend the substrate using stable 3D printed curvature molds in our experiments. It is worth noting that the nanowires did not flake off or undergo permanent deformation attaining plasticity since the post bending magnetic properties, such as coercivity and magnetization, would have been significantly different in that case (see Fig. 6 in our manuscript[2]).

To conclude, the essential points that require further investigations are related to the effect of bending *vs.* stretching of nanostructures and how the substrate (material and thickness) and the choice of buffer and capping layers influence the magneto-mechanical properties. A better understanding of magneto-mechanical phenomena at the nanoscale will lead to new opportunities in the field of flexible spintronics and magneto-electronics.

Conflicts of interest

There are no conflicts to declare.

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