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Domain-wall pinning and depinning at magnetic soft spots in nanowires

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The controlled motion of magnetic domain walls (DWs) in nanowires is one of the fundamental issues for the realization of new concepts of high-density and ultrafast non-volatile data-storage devices [1]. Locally well-defined confining potentials, e.g., created by notches, act as pinning sites for individual DWs [2]. A spin polarized current, driven through the nanowire, yields the possibility to manipulate the magnetic configuration due to a transfer of spin-angular momentum [3]. For a reliable spin-torque induced domain-wall depinning, low threshold currents are required in order to reduce stochastic temperature effects, caused by Joule heating as well as to avoid damage to the nanowire.

Here we present a concept to create pinning sites for DWs in magnetic nanowires without geometric constrictions: The local modification of magnetic properties by means of ion irradiation (magnetic soft spots). Implantation of chromium ions into $Ni_{80}Fe_{20}$ causes a reduction of the saturation magnetization (Ms) and changes the crystalline magnetic anisotropy [4]. The application of electron beam lithography (EBL) or focused ion beam (FIB) on the other hand enables a spatial resolution below 50 nm for this kind of magnetic patterning process [5]. Pinning of DWs in magnetic soft spots is expected to be preferred compared to the environment, as the locally reduced Ms causes a decrease of the exchange energy associated with the DW. In order to verify the suitability of our concept, we fabricate magnetic soft spots into $Ni_{80}Fe_{20}$ nanowires by means of 15 kV Cr ion irradiation through an EBL shadow mask and examine the pinning characteristics for DWs.

We directly observe the field-driven pinning and depinning of a DW at magnetic soft spots in $Ni_{80}Fe_{20}$ nanowires using magnetic transmission soft x-ray microscopy (MTXM) (see Fig. 1). Starting at a fully saturated state, an external magnetic field aligned parallel to the wire is successively reversed in order to determine the specific pinning and depinning fields. Magnetic contrast is provided via x-ray magnetic circular dichroism (XMCD) at the Ni L3-absorption edge (852.7 eV). Measurements have been performed for nanowires with different widths, spot sizes, and Cr dosage, where each wire comprises two individual soft spots (A, B).

We find that pinning and subsequent depinning occurs in most of the wires. For several configurations a pinning rate (PR) of 100 % is observed for the first soft spot A (see Fig. 2). As the pinning and depinning fields exhibit a certain spread, multiple reversal measurements are required to gain information on the average and quality of the distribution (see Fig. 3). In agreement with previous results [2], the saturation fields are found to decrease with the width of the nanowires (see Fig. 4).

As expected, no pinning events are observed for nanowires without any magnetic soft spots. For all other samples, the pinning rate for the second spot B is lower than for the equivalent spot A. This can be attributed to prior depinning at spot A, involving magnetic fields that are already beyond the pinning potential of spot B.

Depending on the configuration of the nanowire (width, spot size, spot dose) we observe the following trend regarding the pinning rate and the gap between pinning and depinning field (ΔH): PR and ΔH decrease with an increasing wire width but increase with an increasing dose (see Figs. 2,3). No clear trend can be determined concerning the size of the magnetic soft spots.

In conclusion, magnetic soft spots realized via implantation of chromium are suitable as pinning sites for domain walls, avoiding a local increase of the current density in the nanowire due to supplementary spatial constriction.

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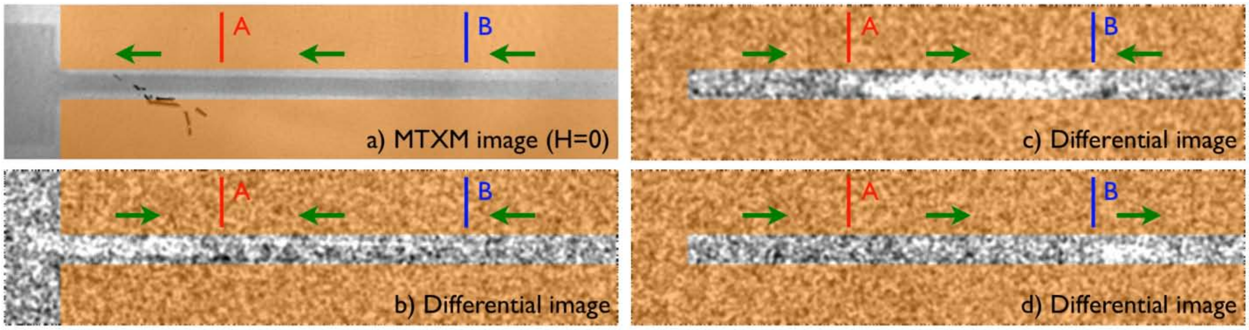

Figure 1: Reversal process of a 300 nm wide nanowire comprising two magnetic soft spots (A,B).
a) MTXM image in saturated state, where the arrows indicate the magnetization direction inside the wire.
b),c),d) Differential images at characteristic steps of the magnetization reversal.
b) pinning at spot A c) depinning A / pinning B d) depinning B

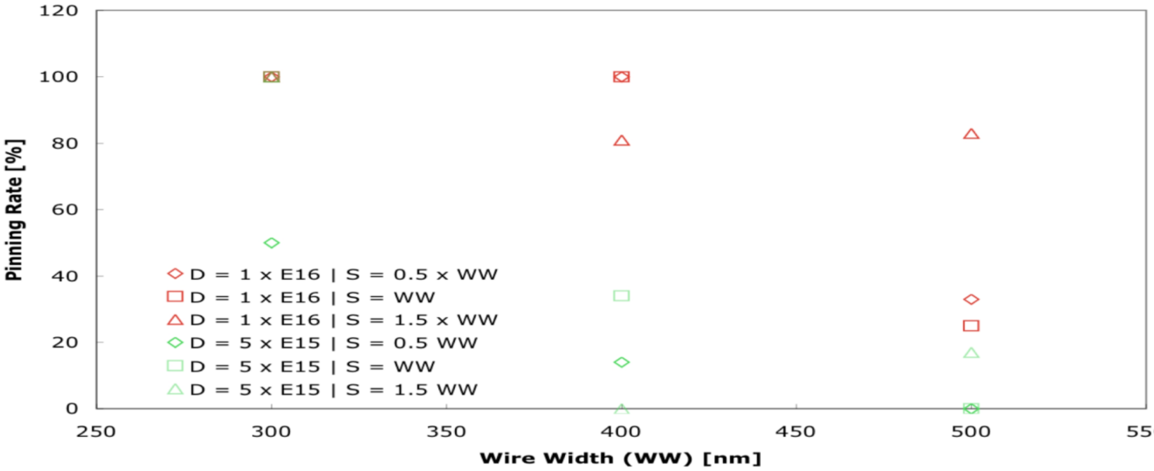

Figure 2: Average pinning rate at spot A for different wire configurations

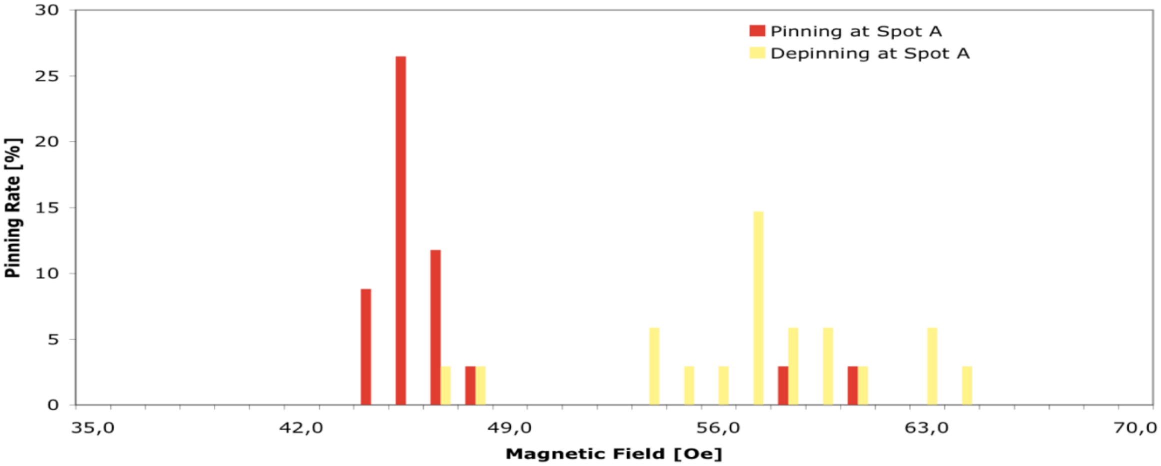

Figure 3: Typical magnetic field distribution for pinning and depinning at spot A, Wire width: 400 nm, spot size 400 nm, Cr dose 5 x 10^{15} /cm^2

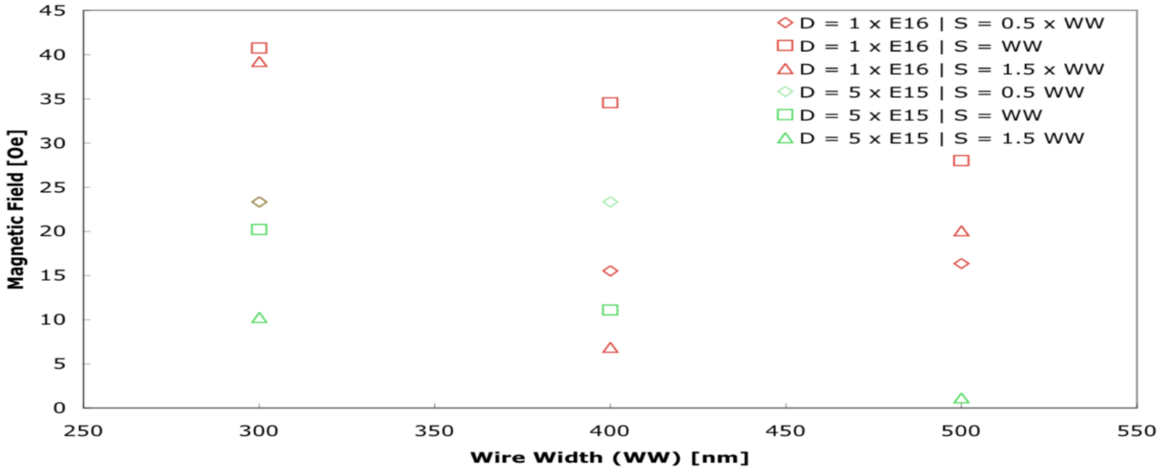

Figure 4: Average gap between pinning and depinning fields at spot A for different wire configurations