

In-Situ Study of Domain Walls Propagation and Pinning in Modulated Magnetic Nanowires.

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Further increase of memory density is very challenging with the existing 2D device structures and therefore will require novel approaches via utilizing the 3rd dimension. In case of magnetic devices, a promising concept is the so-called racetrack memory, where domain walls (DWs) are moved using spin-polarized current pulses [1]. Ordered arrays of cylindrical magnetic nanowires (NW) growing vertically to substrate inside isolating templates are attractive materials for next generation data storage devices. They can be fabricated by template-assisted electrodeposition techniques, providing a high level of control over morphology, geometry, crystal structure and packing density of the NWs [2]. Data bits could be densely packed in 3D arrays of such NWs each carrying several bits along its length in the form of magnetic domains. Following the race-track memory principle, the bits would be shifted by current-induced domain wall motion.

To realize such a concept recently we proposed a new approach – bar code cylindrical nanowires with modulation material composition along the NWs. We showed experimentally, the atomically sharp interfaces between Co and Ni segments act as an effective pinning sites for DW propagation, thus creating the periodic energy landscape which is crucial for the realization race track memory device [3]. The new material allows us to begin an intensive study of the DW dynamics in cylindrical NWs.

Numerous studies have been addressed to investigate the DW propagation behavior along flat ferromagnetic nanostripes [4]. Yet, the dynamics of the three-dimensional DW structures is still an open question. Depends on the NW material and diameter, the 3D DW could be transverse-like type similar to one in flat stripes or the spin component of the DW is allowed to curl around the wire axis forming a Bloch point structure as a topological singularity at the center, which was predicted by simulation [5] and observed experimentally [3].

The study of the DWs in cylindrical NWs (few tens of nm in diameter) is very complicated task. Traditional magneto-optical method is not suitable. The best results may be achieved by the usage of Transmission Electron microscopy (TEM). However, the dynamic measurements are limited by the speed of the digital cameras used for the record, since typically the speed of the 3D DWs motion in homogenous cylindrical nanowires is in order of 100s-1000s m/s [6]. But periodic pinning energy landscape along barcode Co/Ni nanowires [3] should slow down the DW propagation due to pinning/deepening processes at the interface.

In this study we used Titan 60-300 TEM (FEI Co) equipped with a high brightness electron gun (x-FEG), corrector of spherical aberrations (Cs) and Gatan K2-IS direct detection camera allowing the acquisition with 625 μ s time resolution (1600 frames per second). Images were recorded at 300 keV acceleration voltage in Cs corrected Lorentz mode with controllable excitation of the objective lens (from 0 to $\pm 10\%$ of max value).

Fig. 1 shows the in-situ study of the field-driven DW propagation in multisegmented Co/Ni nanowires with 80nm diameter and 30 μ m length. Our NWs have a multidomain reversal process, i.e. at certain value of the external magnetic field applied in opposite direction of the nanowire magnetization DWs nucleate and pin at certain interfaces. The change of NW magnetization can be identified in over-focused imaging conditions as a shift of the Fresnel contrast (in the middle of NW) towards one or another NW's edge. This allows us to register reliably the DWs dynamics.

At the moment of time 0 μ s the NW is in a single domain state (no DWs). Just 625 μ s after the introduction of the external magnetic field (with objective lens excitation) above the threshold level (57.0 \pm 0.5 mT) a pair of the DWs is nucleated in the Zone II and pinned at the interface: dashed lines between Zone I-II and Zone II-III, correspondingly. We can identify 3 domain state of the NW.

Thus the interaction between DWs and interfaces slows down the DW propagation to 4 mm/sec which is 6-7 orders lower than the speed of DW within uniform segments [6]. During the next frame (1250 μ s) the right DW moves to the Zone III, leaving the field of view (final, two domains state of the NW).

So for the first time the 3D DWs dynamics was demonstrated by using TEM capabilities. The field and the temperature dependence of the 3D DWs propagation are in progress.

References:

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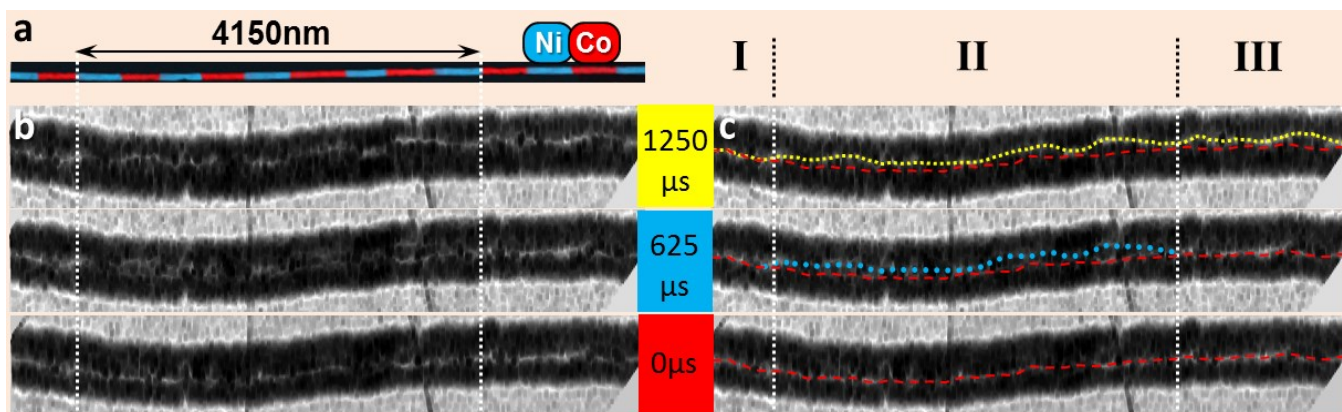


Figure 1. Domain wall dynamics in Ni/Co nanowire under external magnetic field. **a**, Compositional map of the nanowire obtained by EELS. **b**, Time development of DWs propagation in the nanowire obtained by Lorentz TEM imaging in Fresnel mode. **c**, Same as **b**, but with marked position of DWs pinned at interfaces. Images in **b** and **c** are stretched vertically by 600% for better visualization.