Domain wall pinning dependent on nanomagnet state

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Introduction
Magnetic domain walls (DWs) transcend their function as the border between magnetic domains and become versatile nanoscale entities that can be manipulated by field and/or current and used for applications in logic and memory. Their position in a film or nanowire can be controlled by pinning through methods ranging from geometrical constrictions to modification of magnetic properties through irradiation.

In this work an in-plane rectangular nanomagnet (NM) effects a pinning site in a nanowire with perpendicular magnetic anisotropy (PMA). We show that the pinning site strength notably depends on the nanomagnet state and support the asymmetry with an analytical model. Finally, we propose applications in logic and memory that exploit this phenomenon.

Experimental setup
PMA nanowires are CoNi multilayers of widths ranging from 50-140nm, patterned by e-beam lithography and ion milling. Above a nanowire sits a permalloy nanomagnet (NM), separated by a non-magnetic layer. A depinning field measurement consists of:
1. A current pulse through the injection line injects a domain wall (DW) by locally reversing the magnetization.
2. A gradually increasing out-of-plane field first propagates the DW to the pinning site underneath the nanomagnet and eventually depins it from there.
3. Changes in both anisotropic magnetoresistance (AMR) and Hall bar signals register the depinning event.

Results
The depinning field $H_{\text{dep}}$ is measured for both states of the nanomagnet’s (NM's) magnetization (→ and ←). The difference between the depinning fields can differ by 10mT.

If a field between $H_{\text{dep}}$ and $H_{\text{dep}}$ is applied to a nanowire with a DW pinned underneath the NM, the DW will exit the wire only if the (configurable) NM state is →. The phenomenon can thus be exploited for:
- Readout of NM state. It is for example applicable as magnetic-electronic interface in nanomagnetic logic systems, where it is even possible to read out multiple NMs.
- DW logic. The NM state gates the DW passage.

Modeling
To quantify $\Delta H_{\text{dep}}$, vs. wire width, a 1D analytical model does the following:
1. Draw the energy landscape, taking into account NM/DW interaction and DW internal energy, where the DW width and chirality can vary to minimize the total energy at each position.
2. Calculate $H_{\text{dep}}$ for both → and ← taking into account the DW’s probability of traversing the energy barrier by its thermal energy.

The energy landscape reveals the origin of asymmetry:
- The interaction between NM and domains returns an antisymmetric landscape that is not responsible for $\Delta H_{\text{dep}}$.
- The interaction between NM and DW fine structure adds a symmetric reduction in both landscapes so that → has a steeper energy gradient ≈ approximately proportional to $H_{\text{dep}}$ ← and thus induces $H_{\text{dep}}$ → > $H_{\text{dep}}$ ←.

Conclusion
A single in-plane NM above a PMA nanowire can pin a DW, where the pinning strength depends on the NM state. We have measured the difference between depinning fields for the two NM states for nanowires of various widths, and modeled the DW/NM interaction analytically to explain the results. Applications of the phenomenon include NM state readout for memory or a magnetic-electronic interface, or gating DW movement for use in DW logic.

Further reading