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# Improved Magnetic Domain-wall Control with Transverse Fields

Andrew Kunz

Marquette University, [andrew.kunz@marquette.edu](mailto:andrew.kunz@marquette.edu)

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# Improved magnetic domain-wall control with transverse fields

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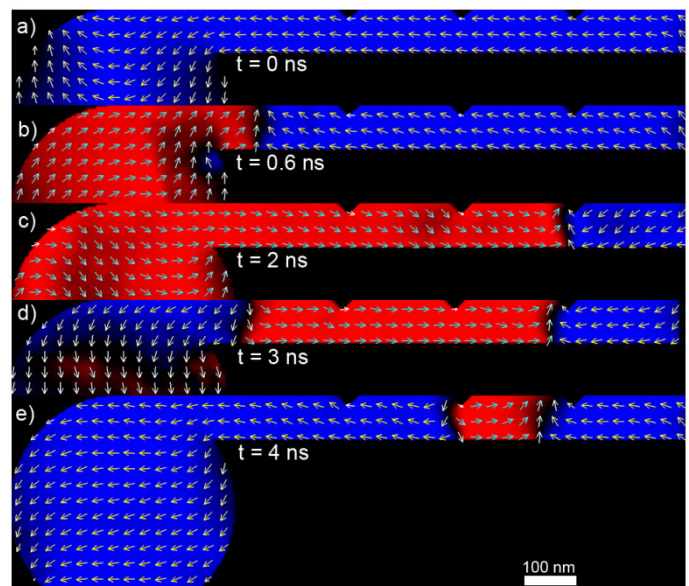
*Full control of fast, high-density, nonvolatile data-storage devices enables reliable injection, motion, and positioning of domain walls.*

Understanding the motion of domain walls along planar nanowires is of interest because of their potential for creating new nonvolatile, fast, high-density memory and logic devices.<sup>1,2</sup> The viability of such devices depends on our ability to quickly and reliably control an individual domain wall from creation to storage in the presence of other domain walls. Control is possible when the system's structure is known. This knowledge is crucial for avoiding Walker breakdown,<sup>3</sup> which occurs at a critical driving field and limits the domain-wall speed by altering its magnetic structure.

To avoid Walker breakdown, the process of injecting, moving, and storing the structure must be completed by applying small magnetic fields to the system. Unfortunately, large magnetic fields are typically necessary for injection into the wire. In addition, when two domain walls are placed into a wire, they move in opposite directions because of the magnetic field. To avoid these difficulties, we show how an additional in-plane field component, applied perpendicularly to the driving field, can be used in combination with pads and notches placed along the wire, to quickly and reliably control individual domain walls.

The additional, transverse magnetic-field component gives rise to a significant improvement in our ability to control these structures. We use the transverse field to create a domain wall with a known magnetic configuration.<sup>4</sup> Knowing the magnetic state is necessary because it is possible to speed up the system by maintaining the transverse field parallel to the magnetic moments within the wall, and to slow it down by configuring the transverse field antiparallel.<sup>5</sup> Controlling the speed of the system enables precise placement of the wall along the wire.

Figure 1 shows our nanopad and wire structure, as well as the simulated magnetic-field configuration (represented by arrows). A domain wall is found in the region between oppositely oriented domains (represented by the red and blue shading). Starting with the magnetic state shown in Figure 1(a), we apply

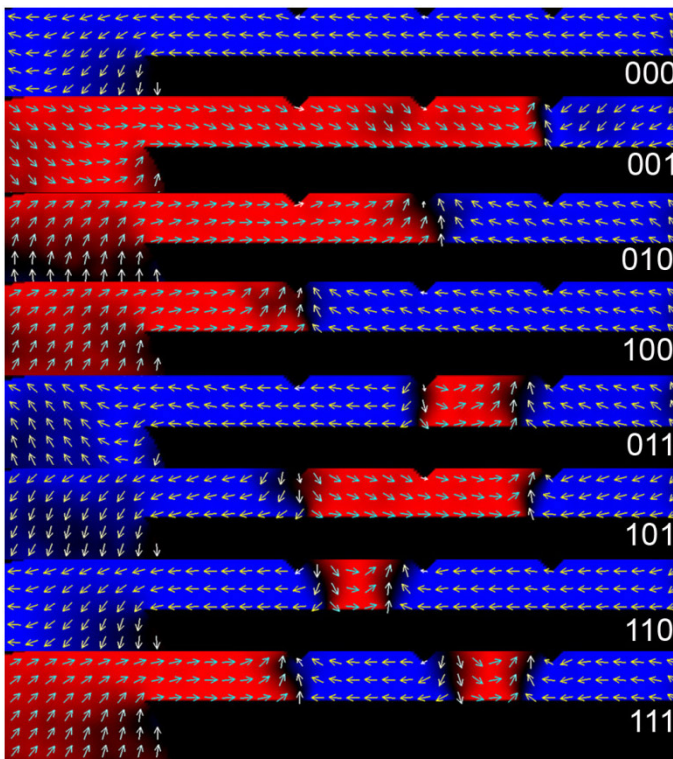


**Figure 1.** Physical nanopad and nanowire, with arrows representing the magnetic-field structure. The red and blue shading is primarily intended to orient the eye to domain-wall transitions. A combination of magnetic fields is used to control the fast injection, motion, and positioning of domain walls in the wire.  $t$ : Time.

a transverse field oriented upward and a small driving field pointing to the right. The field combination and structural shape facilitate fast injection of a domain wall with a magnetic configuration pointing upward: see Figure 1(b).

We use the notches along the top edge of the nanowire to capture the domain wall for storage. A fast-moving system has enough energy to overcome the potential-energy barriers set by the notches. By maintaining a transverse field oriented upward, the structure's speed remains high until it has passed the first and second notch. Removal or reversal of the transverse field leads to a decrease in domain-wall speed. Figure 1(c) shows that the wall is captured at the center notch.

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**Figure 2.** The three-notch configuration leads to eight distinct magnetic states. We arbitrarily assign a ‘1’ if a domain wall is captured at a notch and a ‘0’ otherwise. Transverse fields can be used to assist a fast transition between states with the same number of domain walls (e.g., 101  $\rightarrow$  011).

Once a domain wall is captured at a notch, a reversal of the transverse and driving fields allows injection of a second domain wall—see Figure 1(d)—and to move it to its desired location: see Figure 1(e). Importantly, the combination of field reversals leaves the original domain wall in its location as the new systems are injected and moved around. The three-notch configuration enables eight different magnetic states (see Figure 2), each of which can be quickly created from the original state.

In summary, a driving field is necessary to quickly move a domain wall along the axis of a planar nanowire, but for accurate control a transverse field is essential. Application of a transverse field leads to a significant reduction in the injection field needed to create the system (thus avoiding Walker breakdown), guarantees the magnetic structure of the domain wall (which improves our control of the structure’s speed), and enables control of its final resting site in the wire. This improved level of control for field-driven domain walls impacts the potential for high-speed data storage. We continue to work on optimizing the scaling and improving timing.

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#### Author Information

**Andrew Kunz**  
Marquette University  
Milwaukee, WI

Andrew Kunz received his PhD from the University of Minnesota in 2000 and is currently an assistant professor of physics. His expertise is in magnetization dynamics using micromagnetic simulation. He has six refereed articles in the last two years with undergraduate-student co-authors related to domain-wall motion.

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