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Viewpoint

Domain walls riding the wave

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Theorists propose a mechanism to induce domain-wall motion in ferromagnetic nanowires that may lead to unprecedented speeds.

Subject Areas: **Nanophysics, Spintronics**

A Viewpoint on:
Minimization of Ohmic Losses for Domain Wall Motion in a Ferromagnetic Nanowire
O. A. Tretiakov, Y. Liu and Ar. Abanov
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Recent years have witnessed a rapid proliferation of electronic gadgets around the world. These devices are used for both communication and entertainment, and it is a fact that they account for a growing portion of household energy consumption and overall world consumption of electricity [1]. Increasing the energy efficiency of these devices could have a far greater and immediate impact than a gradual switch to renewable energy sources. The advances in the area of spintronics are therefore very important, as gadgets are mostly comprised of memory and logic elements. Recent developments in controlled manipulation of magnetic domains in ferromagnet nanostructures have opened opportunities for novel device architectures. This new class of memories and logic gates could soon power millions of consumer electronic devices.

The attractiveness of using domain-wall motion in electronics is due to its inherent reliability (no mechanical moving parts), scalability (3D scalable architectures such as in racetrack memory [2]), and nonvolatility (retains information in the absence of power). The remaining obstacles in widespread use of "racetrack-type" elements are the speed and the energy dissipation during the manipulation of domain walls. In their recent contribution to *Physical Review Letters*[3], Oleg Tretiakov, Yang Liu, and Artem Abanov from Texas A&M University in College Station, provide a theoretical description of domain-wall motion in nanoscale ferromagnets due to the spin-polarized currents. They find exact conditions for time-dependent resonant domain-wall movement, which could speed up the motion of domain walls while minimizing Ohmic losses.

Movement of domain walls in ferromagnetic nanowires (see Fig. 1) can be achieved by application of external magnetic fields or by passing a spin-polarized current through the nanowire itself. On the other hand, the readout of the domain state is done by measuring the resistance of the wire. Therefore, passing current through the ferromagnetic wire is the preferred method, as it combines manipulation and readout of the domain-wall state. The electrons that take part in the process of readout and manipulation of the domain-wall structure in the nanowire do so through the so-called spin transfer torque: When spin-polarized electrons in the ferromagnet nanowire pass through the domain wall they experience a nonuniform magnetization, and they try to align their spins with the local magnetic moments. The force that the electrons experience has a reaction force counterpart that "pushes" the local magnetic moments, resulting in movement of the domain wall in the direction of the electron flow through the spin-transfer torque. The forces between the electrons and the local magnetic moments in the ferromagnet also create additional electrical resistance for the electrons passing through the domain wall. By measuring resistance across a segment of the nanowire, one determines if a domain wall is present; i.e., one can read the stored information.

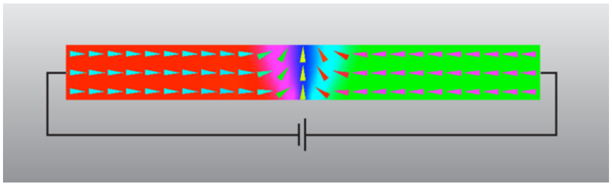

FIG. 1: Micromagnetic model of the domain wall trapped in a nanowire. The domain wall can be pushed along the wire in a controllable manner by applying an external magnetic field or by passing an electrical current through the wire. In the latter case, using optimized electric current pulses can significantly reduce Ohmic losses in the wire.

The interaction of the spin-polarized electrons with the domain wall in the ferromagnetic nanowire is not very efficient. Even for materials achieving high polarization of the free electrons, it is very difficult to

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move the magnetic domain wall. Several factors contribute to this problem, with imperfections of the ferromagnetic nanowire that cause domain-wall pinning being the dominant one. Permalloy nanowires, one of the best candidates for domain-wall-based memory and logic devices, require current densities of the order of 10^8 A/cm^2 in order to move a domain wall from a pinning well. Considering that this current has to pass through a relatively long wire, it is not very difficult to imagine that most of the energy will go to Joule heating. The efficiency of the process—the ratio of the energy converted to domain-wall motion to the total energy consumed—is comparable to that of an incandescent light bulb converting electricity to light.

A step towards more efficient domain-wall-based memory devices is the advance of using alternating currents or current pulses to drive the domain walls [4, 5]. Injection of a spin-polarized current below the threshold value necessary to move the domain wall only causes oscillation of the domain wall inside the pinning potential. Exploiting the effect of resonance, one can apply a specific current waveform to drive the oscillations of the domain wall into resonance. Resonant amplification of domain-wall oscillations will free the domain wall from the pinning well at current levels that are a fraction of the dc threshold. Currents of an order of magnitude lower than before were shown to be sufficient to manipulate domain walls, thus reducing Joule heating 100 times [4].

In their current paper, Tretiakov *et al.* provide a theoretical basis for the mechanism of resonant domain-wall motion in ferromagnetic nanowires. They solve the equation of motion for the domain wall in the presence of spin-polarized current and identify different regimes of domain-wall movement. The analytical approach they use in the paper offers physical transparency for what is usually hidden behind complex numerical micromagnetic calculations.

By minimizing the total power at fixed domain drift velocity, they find that there exists a critical velocity for domain-wall movement. Below that critical velocity, the optimal driving force is produced by a dc current. What is remarkable is that beyond this critical velocity, it is energetically advantageous to move the domain wall with an *ac* current and specific pulse duration. The authors are able to find at which domain-wall velocities these energy savings are highest, and also what kind of spin-polarized waveform and pulse duration should be used in each particular case. They also find that when driving the domain wall too fast, one approaches the dc current limit dissipation.

Thus the motion of the domain wall resembles the movement of the Maglev train—a right sequence of pulses in phase with the rocking motion of the domain wall could accelerate a domain wall to speeds close to that of Japan's Shinkansen. However, the speeds necessary in order to compete with existing technologies are comparable to that of a supersonic jet. Indeed, it has been shown that domain walls can travel with supersonic speeds in microscopic wires [6]. Achieving such speeds in planar nanowire ferromagnets remains a challenge, but equipped with the knowledge that we have gained in the last decade the solution might be just around the corner. As a complete analytical treatment of the dynamics of spin-transfer-torque-induced domain-wall motion, this manuscript is an important milestone in providing guiding principles for designing spintronic devices based on domain-wall manipulation.

References

[1] *Gadgets and Gigawatts: Policies for Energy Efficient Electronics* (OECD/IEA, Paris, 2009).
[2] S. S. P. Parkin, H. Hayashi, and L. Thomas, *Science* **320**, 190 (2008).
[3] O. A. Tretiakov, Y. Liu, and A. Abanov, *Phys. Rev. Lett.* **105**, 217203 (2010).
[4] L. Thomas, M. Hayashi, X. Jiang, R. Moriya, C. Rettner, and S. Parkin, *Science* **315**, 1553 (2007).
[5] S. Lepadatu *et al.*, *Phys. Rev. B* **81**, 060402 (2010).
[6] R. Varga, A. Zhukov, V. Zhukova, J. M. Blanco, and J. Gonzalez, *Phys. Rev. B* **76**, 132406 (2007).

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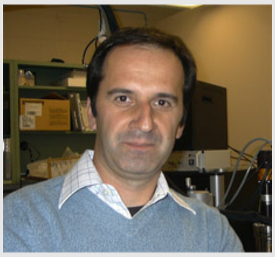

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