Domain wall devices for nanomagnetic logic

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Introduction

As electronics continue to scale down, they face challenges such as increasing heat production and interference between components. To prolong the trend of Moore’s Law, technology looks to alternatives such as magnetics. Many magnetic memory solutions have emerged (MRAM, racetrack memory), and for computer logic, Nanomagnetic Logic (NML) promises to surpass some of the limits of electronics, combining low power, nonvolatility, and radiation hardness.

Practical application of NML as Beyond-Moore technology requires an efficient clocking scheme, and an interface with external electronics. For both, we propose solutions using another magnetic entity: a magnetic domain wall in a nanowire.

Nanomagnetic Logic

In Nanomagnetic Logic, nanoscopic thin rectangular magnets transport information (left) and perform operations (below). Its advantages include:

- nonvolatility: no energy is required to maintain state
- energy efficiency: little to no heat dissipation
- speed: limited only by magnetic precession speed
- radiation hardness: not affected by EM fields

Spintronics & domain walls

Spintronics joins electronics and magnetism. The spin property of an electron in a current has the power to rotate or even switch the magnetization of a magnetic structure. STT-MRAM exploits this phenomenon for fast nonvolatile memory applications.

Regions with magnetizations parallel and antiparallel to the structure’s preferential direction are called domains. The borders between these regions are called domain walls, nanoscale entities in their own right.

NML with DW reset

Instead of the all-consuming and thus inefficient magnetic field of the above scheme, a domain wall in a nanowire running underneath the NML array can induce efficient signal transportation.

The nanowire running underneath the magnets has out-of- and into-the-plane magnetization regions, with magnetic field lines at their border (domain wall) that can reset each magnet one-by-one. We imaged the magnetic state of such devices using Magnetic Force Microscopy before and after a DW passed underneath the NML array. The horizontal magnet serves to provide Breset, DW reset is successfully demonstrated for up to two magnets.

NML with DW magneto-electrical interface

Interfacing of NML with external electronics can also be done with domain walls. The nanomagnet state determines whether a DW will pass it or not, which alters the wire resistance, leading to electronic output. Also, a trapped DW can serve as input by biasing the first magnet with its field lines.

Conclusions

- Nanomagnetic logic forms a low-power and nonvolatile alternative to transistor-based computation for Beyond-Moore technology.
- Magnetic domain walls solve some of NML’s challenges:
  - DWs can reset magnets in an NML chain one-by-one, experimentally demonstrated for two-magnet devices.
  - DWs can serve as I/O interface between electronic and magnetic components.

Further reading & contact


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