2D and 3D Racetrack Memory

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The growing demand for more powerful and energy-efficient computing devices, driven especially by artificial intelligence (AI), requires novel data-centric technologies. Racetrack Memory is an innovative memory-storage technology that encodes data in magnetic domain walls (DWs) that are moved along nanoscopic magnetic “tracks” using spin torques derived from spin currents. The movement of the encoded data distinguishes Racetrack Memory from other solid-state memories. Moreover, Racetrack Memory has the potential to store vast amounts of data because each racetrack can be designed to accommodate many DWs, perhaps a hundred or more. Here we demonstrate that DWs, a few nanometers wide, can be moved smoothly along 2D magnetic conduits just 50 nm wide, can be positioned with an accuracy of ~30 nm, and can be placed ~100 nm apart.[1] Such dimensions are just those needed to allow for Racetrack Memory technologies with storage capacities that are competitive with today’s magnetic hard disk drives, the repository of much of today’s digital data.

The greatest potential of Racetrack Memory lies in building three-dimensional (3D) forms of the magnetic racetracks.[2] Using freestanding membranes, just a few nanometers thick, that are comprised of complex thin film magnetic heterostructures that form the racetrack, we recently demonstrated the first 3D Racetrack Memory.[3] The membranes are floated off a substrate and positioned on pre-patterned surfaces with micron sized protrusions, thereby forming 3D structures in which we demonstrated current induced DW motion with high velocities.

More complex 3D racetracks can be formed by using 3D printing techniques. We have developed a custom-designed, multiphoton lithography 3D printing instrument based on a modified super-resolution microscope with a 50 nm voxel size. Using this system, we have fabricated 3D polymeric scaffolds with variable clockwise and, anti-clockwise, chiral twists. These have very smooth surfaces on which we then deposited thin film heterostructures to form magnetic racetracks. We show that DWs can either pass through the ribbon or are impeded, depending on their chirality and configuration (up/down or down/up) and the geometrical chiral twist of the ribbon.[4] The interplay of spin and geometrical chirality results in a non-reciprocal DW motion, namely a DW filter or diode. These findings show how the interplay between geometrical and spin chiralities can lead to novel functionalities that allow for innovative chiral spintronics.

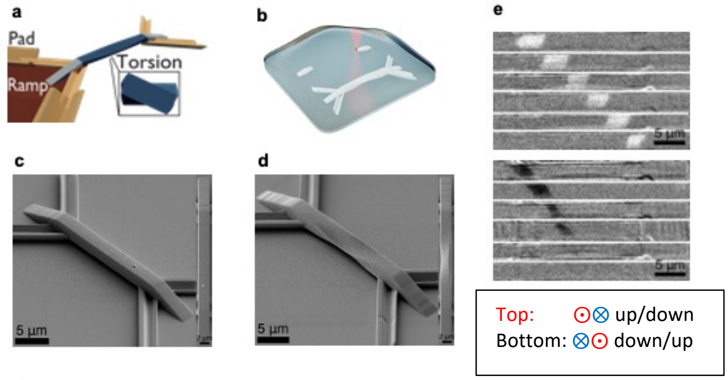

Figure 1. 3D Racetrack Device. **a**, A schematic of a 3D Racetrack (blue) with electrical contacts. **b**, Schematic of the 3D multiphoton fabrication lithography process. **c**,**d**, Scanning electron microscopy images of devices with twist angles of $\zeta=0°$ (**c**) and $\zeta=45°$ (**d**). **e**, Kerr microscope snapshot images of current driven DW motion on a 3D twisted ribbon with $\zeta=+11°$ as a function of time. The ⊙⊗ DW passes through the entire ribbon (upper panel) while the ⊗⊙ DW is stuck in the middle of 3D twisted ribbon (lower panel).

References

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