Spintronic devices for nonvolatile memory and logic

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Spintronic materials and devices take advantage of the electron's spin to create novel nano-devices. Examples include magnetoresistive sensors, in particular, the giant magnetoresistive spin-valve, based on spin-dependent scattering in magnetic metallic multilayers, and the magnetic tunneling junction (MTJ), based on spin-dependent tunneling across ultra thin dielectric layers. These spintronic devices facilitated a thousand-fold increase in the storage capacity of magnetic hard disk drives since their first use in commercial products in late 1997. A magnetic random access memory (MRAM) using MTJ storage elements, developed over the past decade, promises a solid state memory with an unrivaled combination of non-volatility, performance and cost, which is likely to enter the marketplace later this year.

In this talk, future directions for spintronic technologies are discussed. In particular, a proposal for a novel storage-class memory is described in which magnetic domains are used to store information in a "magnetic race-track".[1] The magnetic race-track shift register storage memory promises a solid state memory with storage capacities and cost rivaling that of magnetic disk drives but with much improved performance and reliability.

The magnetic race track is comprised of tall columns of magnetic material arranged perpendicularly to the surface of a silicon wafer. The domains are moved up and down the race-track by nanosecond long current pulses using the phenomenon of spin momentum transfer: experiments exploring the current induced motion and depinning of domain walls in magnetic nanowires with artificial pinning sites will be discussed. The domain wall structure, whether vortex or transverse, and the magnitude of the pinning potential are shown to have surprisingly little effect on the current driven dynamics of the domain wall motion. By contrast, the domain wall motion varies in an oscillatory fashion with the current pulse amplitude and length (with a characteristic frequency of a few hundred MHz). The domain walls in the magnetic race-track are read using magnetic tunnel junction magnetoresistive sensing devices arranged in the silicon substrate.

Recent progress in developing magnetic tunnel junction devices with giant tunneling magneto-resistance exceeding 350% at room temperature will also be discussed.[2] These devices involve sandwiches of thin ferromagnetic layers separated by ultrathin insulating layers through which spin polarized electrons tunnel. By electron wavefunction engineering and via control of the chemical bonding at the interfaces between the ferromagnetic and insulating layers [2, 3] dramatic increases in the degree of spin polarization of the tunneling current is possible even for conventional transition metal ferromagnets. Engineering thin film heterostructures at the atomic level promises novel spintronic materials with unforeseen properties.

1. S. S. P. Parkin, US Patent # 6,834,005 (2004).
2. S. S. P. Parkin, C. Kaiser, A. Panchula, P. Rice, B. Hughes, M. Samant, and S.-H. Yang, *Nature Mater*. **3,** 862 (2004).
3. C. Kaiser, A. Panchula, and S. S. P Parkin, *Phys. Rev. Lett.* **95**, 047202 (2005) and C. Kaiser, S. van Dijken, S.H. Yang, H. Yang, and S.S.P. Parkin, *Phys. Rev. Lett.* **94**, 247203 (2005).