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Electrical Manipulation of Magnetization in Nanomagnet

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The manipulation of magnetization by spin currents is a key technology for future spintronics. The underlying physics is that spin currents can apply a torque on the magnetic moment when the spin direction of the conduction electrons has a relative angle to the local magnetic moment. This leads us to a general concept that any type of spin structure with spatial variation can be excited by a spin-polarized current in a ferromagnet. We confirmed this concept for two typical noncollinear spin structures: a magnetic domain wall (DW) and a magnetic vortex.

The direction of magnetic moments gradually changes in a DW. Since the spin direction of conduction electrons changes when the electrons cross the DW, spin transfer from electrons to the DW occurs and torqueis exerted on the DW. In consequence, an electric current can displace the DW [1]. Magnetic force microscopy observation of the current-driven DW displacement in submicron magnetic wires can provide quantitative information such as magnetic DW structure and the displacement as a function of the intensity and the duration of the pulsed-current [2, 3].Uni-directional motion of a domain wall in a magnetic wire with asymmetric structures, which could be called a magnetic ratchet effect, is also presented [4].

The spin transfer torque is also expected to be active in a magnetic vortex, in which a curling magnetic structure with a nanometer-scale core is realized [5]. We show that a magnetic vortex core in a ferromagnetic circular dot can be resonantly excited by an AC current through the dot when the current frequency is tuned to the resonance frequency originating from the confinement of the vortex core in the dot [6]. The core is efficiently excited by the AC current due to the resonant nature and the resonance frequency is tunable by the dot shape. We also demonstrate that the direction of a vortex core can be switched by utilizing the current-driven resonant dynamics of the vortex. [7].

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Spin Tunnel Contact to Silicon with Interfacial Nanolayers

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Proper spin contacts to semiconductor are essential to realize next generation spintronic devices combining ferromagnetic properties and semiconductor characteristics. Besides a large tunnel spin polarization (TSP), the resistance-area (RA) product of spin-tunnel contacts is critical for many applications, including spin-injection into semiconductors.

We present a novel approach to control the RA product of spin-tunnel contacts using interfacial nanolayers with low work function. For the experimental observation of spin-injection from ferromagnetic metals (FM) into GaAs, insertion of a tunnel barrier has been a key aspect to overcome the conductivity mismatch. Unfortunately, no positive results have yet been obtained with Si. This is due to Schottky barrier formation, leading to three major obstacles for electrical spin injection into silicon: (i) low current due to a (reverse biased) Schottky barrier, (ii) electrons tunnel into or out of states at elevated energy, for which the TSP is strongly reduced, and (iii) a huge conductivity mismatch of many orders of magnitude between Si and tunnel contacts with ferromagnetic metals such as Co and NiFe alloys.

We find that the conventional method to control the tunnel conductance, adjusting the tunnel barrier thickness, cannot provide a solution. Hence, magnetoresistance cannot be observed in a Si spin-MOSFET unless the spin-lifetime in Si is more than seconds. We present a radically different approach for spin-tunneling resistance control using low work function ferromagnets, inserted as an ultrathin (sub-nm) interlayer at the FM/tunnel barrier interface. We demonstrate that in this way the RA product of FM/Al_2O_3/Si contacts can be tuned over 8 orders of magnitude. Equally important, complementary tunnel magnetoresistance data show that a reasonable TSP is simultaneously maintained over the full range. We compare the TSP and RAwith those required for a Si spin-MOSFET, and show that spin-tunnel contacts with low work function ferromagnets qualify as conductivity-matched source and drain electrodes that will allow the observation of magnetoresistive response even for sub-nanosecond spin-lifetime in Si. The results raise prospects for Si-based spintronics and present a new category of ferromagnetic materials for spin-tunnel contacts with low RA product.

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