Nanoscaled Spintronics

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Spintronics has attracted considerably interest in recent decades due to its widespread use in sensor and memory applications. Our research project focuses on fabricating spintronic nanodevices as well as studying fundamental spin phenomena in these devices.

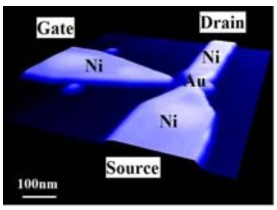
1. Introduction

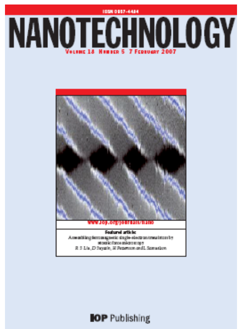
Until recently, the spin of the electron was ignored in mainstream charge-based electronics. A technology called spintronics has emerged where it is not the electron charge, but rather the electron spin that carries information. Using the spin degree of freedom opens up a possibility for new generations of devices combining standard microelectronics with spin-dependent phenomena. Our research goal is to explore such spin-related phenomena for future application in novel nano-scaled devices.

2. Research highlights

1) Spin relaxation studies of Au nanostructures

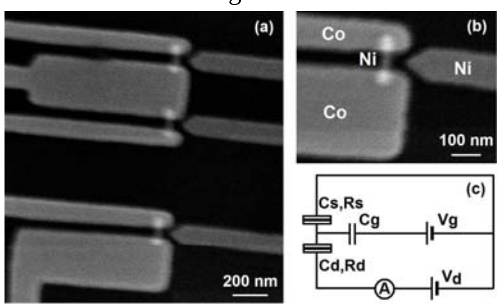
To process information with spin-coded signals, it is crucial that the spin relaxation time is long enough to ensure that the information is accurately processed and conveyed. Recently, unprecedented enhancement of the spin relaxation time in Au nanostructures was reported. To investigate this promising route for future spintronics applications, we have studied spin-relaxation phenomena in Au nanostructures with a size of about ten nanometer using Ni/Au/Ni ferromagnetic single electron devices (SET). For this we developed an innovative SET design fabricated with the tip of an atomic-force microscope (AFM) acting as a nanorobot. Ni/Au/Ni ferromagnetic SETs (left-hand figure below) have been successfully fabricated by manipulating a Au island with an AFM tip into the gap between Ni source and drain electrodes. This fabrication scheme was high-lighted as a featured article in *Nanotechnology* and the main result was also honored as a cover image in the same issue (right-hand figure). We have performed magneto-transport measurements on the devices and deduced an upper bound of the spin-relaxation time of a few nanosecs in the Au island in conjunction with spin transport calculations.



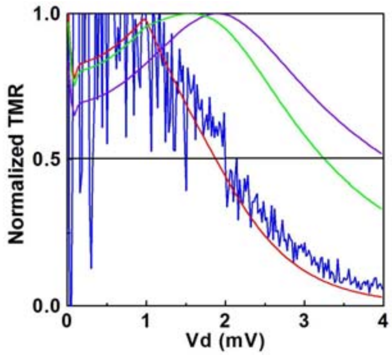


2) Spin-torque effect in Co/Ni/Co single electron transistors

Within the last several years it has been demonstrated that the transfer of electron spin angular momentum from current-carrying electrons in magnetic structures, generally referred to as the spin torque effect, can control and manipulate the magnetic states of devices, i.e. MRAM. We have observed this effect in a newly developed type of Co/Ni/Co SETs fabricated by e-beam lithography. In this fabrication scheme the source/drain electrodes and the island/gate electrodes are defined in two sequential high-precision alignment e-beam writing steps. This allows fabrication of devices with a large throughput, and also with a much larger variety of possible materials since self-oxidation is eliminated. The image below is an electron

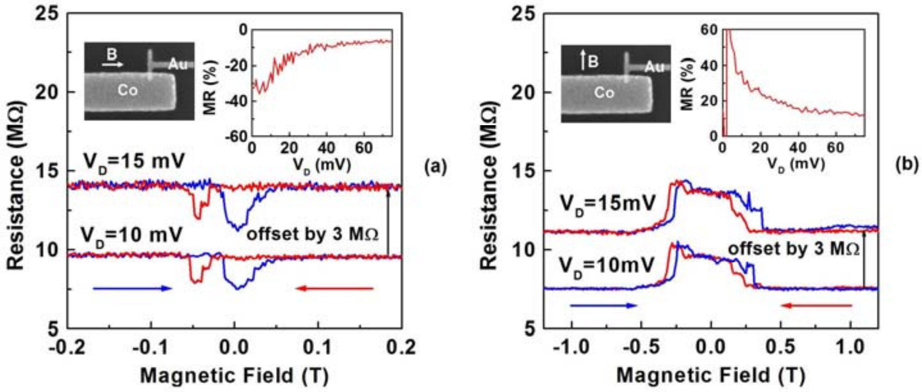


microscope image of a SET, with the Ni central island of 150 nm long, 15 nm wide and 25 nm thick. The left-hand image below shows the magnetoresistance (TMR) as a function of the drain-source bias with a maximum TMR of 18% within the Coulomb blockade regime. The TMR decreases rapidly with drain-source bias, which can be attributed to the aforementioned spin-torque effect.



3) Tunneling anisotropic magnetoresistance effect Co/AlO$_x$/Au tunnel junctions

Recently, we discovered a very interesting spin-valve-like effect in junctions with a *single* magnetic layer. The device design, shown in the two figures below, consists of a nanoscaled Co/AlO$_x$/Au sandwich structure. The observed tunnel magnetoresistance is anisotropic and depends on the relative orientation of the magnetization direction of the Co electrode with respect to the current direction as shown in the



two figures. A high magnetoresistance is observed when the current is parallel to the magnetization of the Co electrode (left figure), in contrast to the low magnetoresistance found for orthogonal orientation of the current relative to the magnetization (right figure). We attribute this effect to a two-step magnetization reversal and an anisotropic density of states resulting from spin-orbit interaction. These interesting results points to future applications in spintronics devices involving only one ferromagnetic layer.

Publications

"Assembling Ferromagnetic Single-Electron Transistors by Atomic Force Microscopy"
R. S. Liu, D. Suyatin, H. Pettersson and L. Samuelson
Nanotechnology 18, 055302 (2007). (Cover Page Paper)

"Probing Spin Accumulation in Ni/Au/Ni Single-Electron Transistors with Efficient Spin Injection and Detection Electrodes"
R. S. Liu, H. Pettersson, L. Michalak, C. M. Canali and L. Samuelson,
Nano Lett. 7, 81(2007).

"Large Magnetoresistance in Co/Ni/Co Ferromagnetic Single Electron Transistors"
R. S. Liu, H. Pettersson, L. Michalak, C. M. Canali, D. Suyatin and L. Samuelson
Appl. Phys. Lett 90, 123111 (2007).

"Tunneling Anisotropic Magnetoresistance in Co/Al$_x$O/Au tunnel junctions"
R. S. Liu, L. Michalak, C. M. Canali, L. Samuelson and H. Pettersson
Nano Lett. **8**, 848 (2008).