Electrical Spin Injection & Detection in Silicon Nanowires through Oxide Tunnel Barriers

Shixiong Zhang, Shadi Dayeh & Tom Picraux (Center for Integrated Nanotechnologies, Los Alamos); Darryl Smith (Theoretical Division, Los Alamos), Yan Li & Scott Crooker (NHMFL- Los Alamos)

Introduction

Silicon (Si) is arguably the most important material for today's semiconductor technologies. In the past decade, functional one dimensional Si nanowire devices have been demonstrated for a wide variety of proof-of-concept nanoscale structures, including nanowire transistors, photon detectors, and solar cells. The successful integration of these nanowire devices into large area architectures has brought new opportunities for commercialization. However, to date most of these nanowire devices exploit only the electron's charge degree of freedom. Adding the electron's *spin* degree of freedom to such charge-based electronics is believed to add substantially more capability and to improve performance, e.g. non-volatility, increased data processing speed and decreased electric power consumption, which are of high demand in information technology applications.

Previous efforts on spin injection into Si NWs utilized metal-on-Si Schottky barriers for spin-dependent tunneling of electrons from ferromagnetic electrodes. Since the effective Schottky barrier height is generally pinned at about half the Si bandgap irrespective of the contact metal, and since the barrier thickness depends on the doping profile in the semiconductor, detailed control of the semiconductor surface doping is required in approaches using only Schottky barriers. As a result, the window for efficient spin injection may be limited. Alternatively, in planar spin transport devices oxide tunnel barriers are known to be an important ingredient in many successful electrical spin injection/detection studies and the tunneling characteristics can be readily controlled by tuning the oxide thickness alone. Considering the above points, it is thus of interest to combine these three promising aspects— silicon, oxide tunnel barriers for spin injection, and 1D nanoscale structures—into a single investigation.

Experimental

We demonstrate all-electrical spin injection, transport and detection in heavily *n*-type doped Si nanowires using ferromagnetic Co/Al_2O_3 tunnel barrier contacts. Analysis of both local and non-local spin valve signals at 4 K on the same nanowire device using a standard spin-transport model suggests that high spin injection efficiency (up to ~ 30%) and long spin diffusion lengths (up to ~6 microns) are achieved. These values exceed those reported for spin transport devices based on comparably-doped bulk Si. The spin valve signals are found to be strongly bias and temperature dependent and can invert sign with changes in the dc bias current. The influence of the nanowire morphology on field-dependent switching of the contacts is also discussed. Owing to their nanoscale geometry, approximately 5 orders of magnitude less current is required to achieve non-local spin valve voltages comparable to those attained in planar microscale spin transport devices, suggesting lower power consumption and the potential for applications of Si nanowires in nano-spintronics.

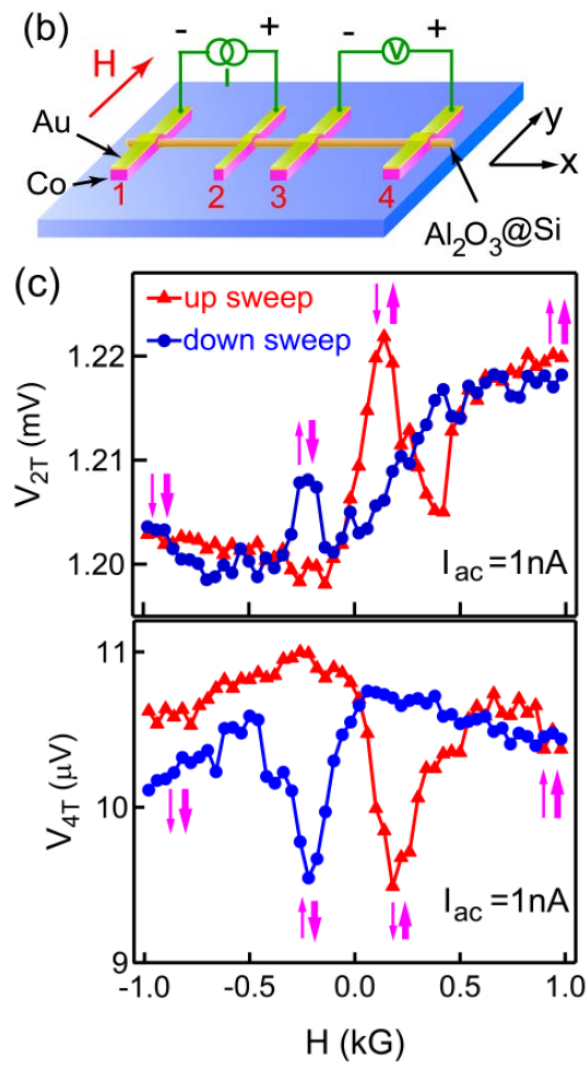

Figure 1. Schematic of the Si NW spin transport device. Lower panels show both 2-terminal (local) and 4-terminal (non-local) electrical transport measurements of this device.

This work was supported by the Los Alamos LDRD program.

[1] S. X. Zhang *et al.*, *submitted*