Spin Polarized Electron Transport Near the Si/SiO$_2$ Interface

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1. Introduction

To integrate semiconductor spintronics into current MOSFET technology, it is important to realize lateral spin transport in silicon and study its phenomena near the semiconductor/oxide interface as well as in bulk. Previously, lateral spin transport in silicon has been demonstrated over 1μm using non-local detection geometry [1], and it has been carried out even over 2mm distance [2]. Besides the spin transport through bare silicon, the effect of the buried Si/SiO2 interface on the spin transport is of interest because it can be an important part of spin-based silicon field-effect devices such as gating. In this study, we have explored electron spin transport near the Si/SiO$_2$ interface using hot electron injection/detection technique.

2. Experimental method

To fabricate the hot electron injection/detection device, first, ultra-high vacuum metal film wafer bonding was carried out to assemble a semiconductor-metal-semiconductor hot-electron spin detector; two different semiconductor-on insulator(SOI) wafers, one with a 10 μm single-crystal (100) float zone (FZ) silicon layer and the other with a 3μm phosphorous doped n-type layer were bonded together with a Ni$_{80}$Fe$_{20}$ (4 nm)/ Cu (4nm) bilayer. Both wafers have a 1μm thick thermally-oxidized SiO$_2$ layer as an insulator. Then, the detector composed of the 3 μm n-type silicon layer was patterned and the 10 μm FZ silicon transport layer was exposed by conventional photolithography and wet-etching techniques. To remove residual metal silicide formed at and under the surface of 10 μm FZ silicon layer[3], ion-milling was performed. A hot-electron spin injector was built with a ferromagnetic emitter oxide tunnel junction, Al (40 nm)/Co$_{84}$Fe$_{16}$ (10 nm)/Al$_2$O$_3$/Al (5 nm)/Cu (5 nm) on the 10 μm FZ-Si layer. To confirm lateral spin transport in our silicon device, the collector 2 current (I_{C2}) at the detector was measured applying an external magnetic field parallel to transport layer (spin-valve effect) and perpendicular to the layer as well (Hanle effect) at 60 K. Clear spin precessional signals obtained in Hanle effect measurement of our device firmly prove the realization of lateral spin transport in silicon. To have electron transport near the interface, the gating voltage was applied between injector base and handle wafer.

3. Results

As injected hot electron approaches the interface of Si/SiO$_2$, we have observed reduction in the measured values of all three properties; spin polarization, spin transit time, and spin dephasing. Having the empirical spin current transit-time distribution recovered and using a simple one dimensional two-stage drift-diffusion model[4], we found that spin lifetime is reduced by over two orders of magnitude from its bulk transport value.

4. Discussion

We identify strong interface-induced spin depolarization as the consistent cause of this severe spin lifetime reduction phenomena. The microscopic cause of the observed phenomena is not clear yet. It could be from the nature of broken lattice inversion symmetry at the interface causing a D'yakonov-Perel type spin depolarization mechanism or localized spin momentum exchange with paramagnetic defects and dangling bonds created at the interface of Si/SiO_2.

5. Conclusion

Using long-distance lateral devices, spin transport near the interface of Si and its native oxide (SiO_2) is studied by spin-valve measurements in an in-plane magnetic field and spin precession measurements in a perpendicular magnetic field at 60K. As electrons are attracted to the interface by an electrostatic gate, we observe shorter average spin transit times and an increase in spin coherence, despite a reduction in total spin polarization. This behavior, which is in contrast to the expected exponential depolarization seen in bulk transport devices, is explained using a transform method to recover the empirical spin current transit-time distribution and a simple two-stage drift-diffusion model. We identify strong interface-induced spin depolarization (reducing the spin lifetime by over two orders of magnitude from its bulk transport value) as the consistent cause of these phenomena[5].

6. References

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