Towards Definitive Electrical Identification of Single Paramagnetic Donors in Nano-Structured Devices

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Preliminary work towards the electrical detection of the (spin) magnetic resonance from a small number of phosphorus donor atoms in nano-structured (50-150nm) silicon devices is presented.

Keywords- magnetic resonance, silicon nano-wires, coherent transport

I. Introduction

The electron paramagnetic resonance (or EPR) technique has been widely used to study paramagnetic defects and impurities in semiconductors with its first reported application to silicon in 1953 [1]. It is a powerful experimental technique able to study the properties of electronic states in insulators and semiconductors alike with an ability to resolve energy shifts, arising from neighboring nuclear spins or crystal fields, as small as 1neV.

The sensitivity of a conventional EPR measurement in semiconductors is limited, requiring samples with $\sim 10^{10}$ donor spins or more. This poses a significant problem for nano-structured semiconductors whose entire device region may contain fewer atoms than the detection limit of this technique. This problem can be overcome by detecting magnetic resonance via the effects of spin selection rules on other observables, such as charge transport. Sensitivity to as few as ~100 spins has been reported using the *so called* electrically detected magnetic resonance technique (EDMR) [2].

In order for scalable, solid-state quantum logic gates to be constructed, one needs to be able to *readout* the single spin state of the quantum bit (qubit). Advances in single-shot readout of electron spins associated with phosphorus qubits in silicon have recently been reported [4]. However, definitive identification of single, deterministically implanted and activated phosphorus donors has proven elusive. One of the few techniques compatible with transport measurements of nano-structured devices that is also able to provide an unambiguous spectroscopic signature for dopants is EDMR.

II. EDMR Experimental Details

In this work, we describe the use of quasi-one dimensional (fabricated) transport nano-structures for the detection and identification of a small number of phosphorus dopant atoms. With channel dimensions ranging from ~50 to 150nm, it is hoped that a sensitivity to low numbers of donors may be achieved using this technique. Work towards the deterministic (i.e. counted ion) doping of these nano-channels is also presented since low energy phosphorus ions can give rise to abrupt changes in the channel conductance with each ion impact [5].

Results from two different device formats will be presented. The first is based on the well known FinFET geometry [6] while the second employs CVD-grown, freestanding silicon nano-wires. The proximity of surface oxide defects (i.e. P_b's) in both cases is expected to significantly enhance the donor resonance signal via spin dependent recombination/scattering processes [7].

These device geometries also lend themselves to the study of low temperature conduction mechanisms under static magnetic fields such as the nearest neighbour, spin dependent hopping mechanism. It should also be possible to directly correlate the device transport performance with defect densities where the defects are also spectroscopically identified [8].

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