Studying Individual Group V Donors in Silicon

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I will describe the work of the Low Temperature Scanning Tunnelling Microscopy group at the London Centre for Nanotechnology. In particular, I will focus on the group's involvement in the Coherent Optical and Microwave Physics for Atomic-Scale Spintronics in Silicon (COMPASSS) research program. The goal of the program is to utilize the properties of single Group V dopant atoms (which are electron donors) in silicon for storage and manipulation of quantum information. In the COMPASSS scheme, the outer shell electrons of deep level donors in silicon act as quantum bits (qubits), with qubit entanglement mediated via the excited orbital states of shallower level donors (control atoms). The technique of STM patterned hydrogen resist lithography will be used to fabricate donor devices for the demonstration of qubit entanglement and quantum control.

Our initial work on the COMPASSS project has involved the study of individual Group V donors in silicon, spectroscopically, at 77 K. We find that at the cleaved Si(111)2x1 surface, the structural and electronic properties of Group V donors depend critically on their atomic mass and the substitutional site they occupy. Surprisingly it is possible for the same donor to induce either a positive or negative local charge state in the surface. This phenomena results from the donor occupation of non-equivalent sites in the surface, is explained by an electron counting argument and is subtly different from that of other charging effects seen on Si and GaAs surfaces.

Traditional scanning tunnelling spectroscopy can be used to extract information on the magnetic properties of dopants only indirectly, by extracting their impact on the LDOS. A much more direct approach is to measure the low energy excitation spectrum of the dopant structures using spin-sensitive inelastic electron tunnelling spectroscopy (IETS). To date, IETS has predominately been used for studying individual atoms and molecules on thin decoupling surfaces above metals and I will briefly show recent examples of such measurements from our group. However if we perform analogous experiments for dopants in silicon we will be able to directly measure the magnetic anisotropy for an individual dopant; the spin coupling between dopants, and the interplay between the local spin and the surrounding conduction electron, i.e. the Kondo screening. I will discuss the challenge of performing such measurements and outline a possible scheme for doing so.