From Transistors to Qubits

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Since the invention of the first bipolar transistor, integrated circuits have evolved to incredibly complex, ultra-scaled devices with on the order of 10^9 transistors per chip. Even if these devices no longer rely on bipolar technology, excellent control of highly doped regions is still a critical factor for device performance. Moreover, single dopant atoms in a silicon crystal or nanoscale silicon transistors are thought to be candidates for spin qubits with a long spin lifetime.

The hydrogen resist lithography technique is capable of preparing atomic scale planar dopant devices. This is enabled by a large difference in chemical reactivity of the bare and hydrogen passivated Si (001): 2x1 surface. Using a scanning tunneling microscope (STM), the hydrogen layer of the H:Si (001) surface is locally desorbed with nanometer precision leaving behind exposed areas of reactive Si. When a gaseous dopant precursor such as phosphine or diborane is introduced, the hydrogen layer acts as a resist and the dopants stick only to the desorbed areas. Compared to conventional fabrication methods, hydrogen resist lithography enables degenerate delta-doping with sub-nanometer lateral resolution and highly abrupt doping profiles.

In the first part of my talk I'll present results on how an STM fabricated 6 x 6 nm n-type quantum dot in the Coulomb blockade regime can be used to characterize nanoscale barriers between dopant contacts [1]. We have since extended the hydrogen-resist technique to p-type doping with diborane and I'll show initial electrical transport measurements on p-type dopant wires and a simple planar pn-junction fabricated by STM patterning. In addition, I'll also outline our efforts to simplify the slow STM-based device fabrication with UHV-compatible pre-patterned SOI chips that do not require in-situ surface preparation and can be reintegrated into a CMOS process flow.

In a second part I'll give an outlook on how dopants and field effect transistors can also be used as qubits and I'll discuss ideas on how we would like to integrate such silicon based qubits with IBM's superconducting qubit technology.

[1]N. Pascher, S. Hennel, S. Mueller, and A. Fuhrer. *Tunnel barrier design in donor nanostructures defined by hydrogen-resist lithography.* New Journal of Physics, **18**, 083001 (2016).