Atom by Atom Fabrication of Single Dopant and Single Electron Transistors for Quantum Technologies

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Atomically precise fabrication has an important role to play in developing atom-based electronic devices for use in quantum information processing, quantum materials research and quantum sensing. Atom by atom fabrication has the potential to enable precise control over tunnel coupling, exchange coupling, on-site charging energies, and other key properties of basic devices needed for solid state quantum computing and analog quantum simulation. Using hydrogen-based scanning probe lithography we deterministically place individual dopant atoms with atomically aligned contacts and gates to build single electron transistors (Figure 1) and have demonstrated an operational single atom transistor (Figure 2).

We have developed robust lithography, device relocation, and contact processes that enable routine electrical measurement of atomically precise devices with an emphasis on minimizing process-induced dopant movement. Our low temperature palladium silicide contact process provides low-resistance ohmic contacts with yield better than 98%.

This presentation will cover fabrication and characterization of STM patterned nanometer scale wire devices and tunnel junctions to investigate low dimensional transport. We will present the design and characterization of multiple single electron transistors that demonstrate stable coulomb blockade oscillations. We will report measurements of the electronic properties and tunnel coupling in single electron transistors where the tunnel gap is varied at the dimer row scale, Figure 3. This presentation will include spectroscopic measurements of an atomically precise, single atom transistor.

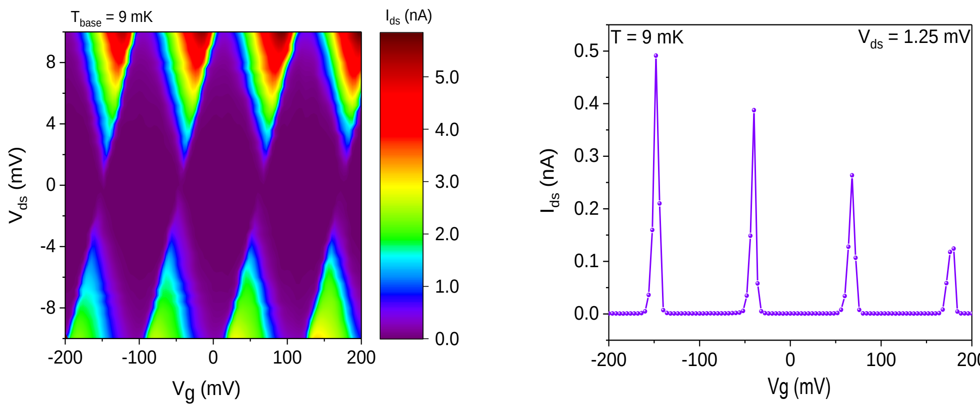

Figure 1. Coulomb blockade diamonds observed in the charge stability diagram of a single electron transistor fabricated using STM lithography. The data on the right show periodic Coulomb blockade oscillations as a function of plunger gate voltage, source drain bias 1.25 mV.

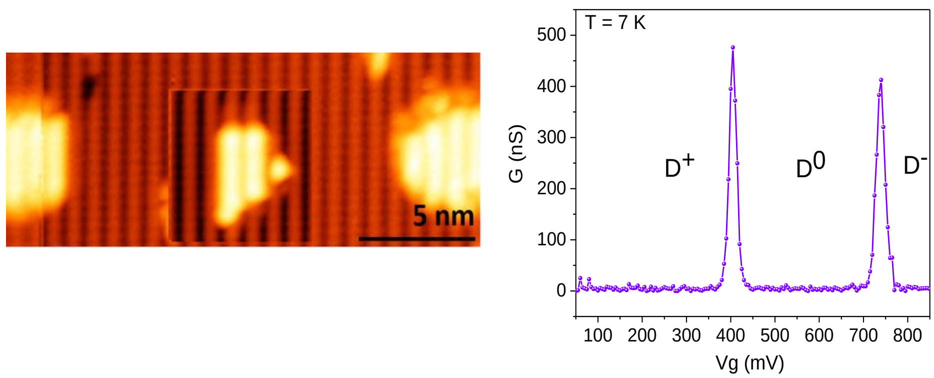

Figure 2. Atom-scale STM patterning shown after H-depassivation. The bright regions are dangling Si bonds that define the P doped regions. The low temperature transport data on the right show the transition signature from a single ionized D^+ donor to the neutral D^o state followed by the two-electron D^- state.

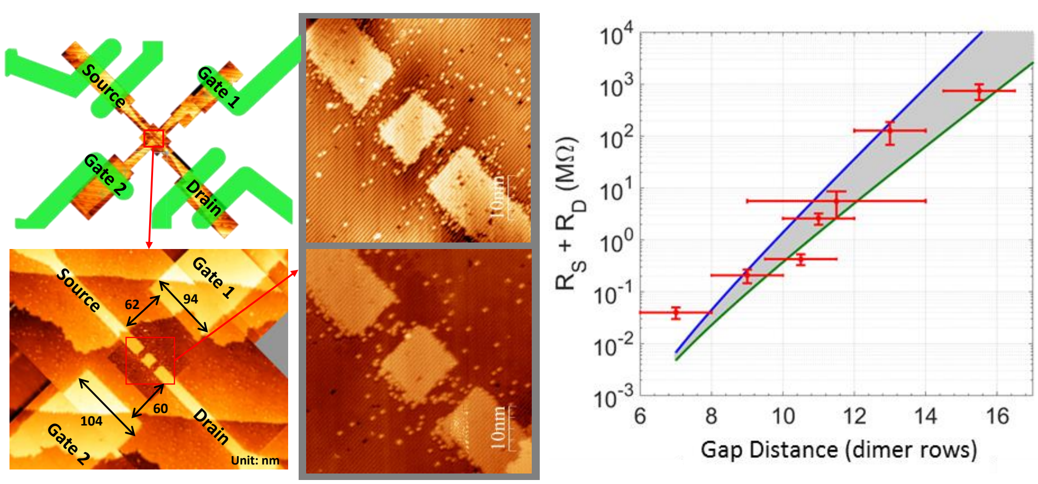

Figure 3. Layout for contacts, source, drain and plunger gates on left. Also shown are two atomically precise single electron transistor devices. Right image shows exponential dependence of tunnel resistance on gap for several devices in agreement with the WKB model.