Solid State, Atom-based Devices for Analog Quantum Simulation

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NIST is using atomically precise fabrication to develop devices for use in quantum information processing. We are using hydrogen-based scanning probe lithography for deterministic placement of individual dopant atoms with atomically aligned gates to fabricate single/few atom transistors, few-donor/quantum dot devices for spin manipulation, and arrayed few-donor devices for analog quantum simulation.

Recently we have fabricated arrays of few atomic clusters in silicon for the analog quantum simulation of an extended Hubbard model. The long-term goal of these experiments is to explore the Hubbard phase space by fabricating atomically engineered quantum materials whose properties, such as magnetic ordering or Mott insulator, depend on the detailed parameters of the atomic configurations. Details of the STM-fabrication will be described as well as quantum transport measurements from several arrays of few atom clusters ranging from 1x2 double dots to a multi-gate 3×3 dot array.

These atomic clusters form the sites of a Hubbard model array in the strong interaction regime, where we vary the tunnel coupling with atomic precision between nearby dots from a weakly to strongly tunnel coupled regime. We explore the impact of site-by-site disorder on charge occupation and the Hubbard band structure. Numerical simulations of the model reveal charge distributions and magnetic correlations for different parameter sets. We quantify the electron addition energy spectrum through Coulomb blockade and charge stability analysis and demonstrate tuning of the array's energy spectrum using gates. We map the Hamiltonian parameters to the physical system to tune the charge occupation, the spatial distribution of the eigenstates, localization/delocalization transition, and Hubbard band structure.