Scanning Tunneling Microscope Fabrication of Atomically Precise Devices

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Atomically precise device fabrication with hydrogen depassivation lithography enables a new class of atom-based electronic structures with applications ranging from novel low dimensional quantum metamaterials to devices for quantum information processing. Deterministic placement of individual dopant atoms in the Si lattice is achieved using a hydrogen resist patterned by electron stimulated desorption with the scanning tunneling microscope (STM). Controlling the electronic and quantum state of deterministically placed atoms in a solid-state environment enables novel devices such as single atom transistors and solid-state qubits.

However, fabricating functional atom-based devices is particularly challenging because of the need for exceptionally ultra-high vacuum, ultra-clean processing conditions, near perfect atomic order, and low temperature epitaxial silicon overgrowth. Furthermore, electronic properties are sensitive to atomic position variability that results from thermal processing and irregularities in scanning tunneling microscope patterning.

In this presentation, we investigate methods to improve dopant confinement and their effects on epitaxial Si overgrowth. Locking layer epitaxial growth techniques that enhance the confinement of Phosphorus dopant atoms are used to optimize delta layer formation. We study the effects of varying locking layer growth parameters on device dimensionality and electrical performance as a metric for delta layer quality. We will present detailed analysis of delta layer repeatability and across chip variation. Low temperature transport and weak localization measurements are used to characterize materials properties and the effects of atomic-scale variability on transport phenomena. We use lithographically patterned delta layers and STM-patterned Si:P nanometer-scale devices, such as low dimensional Van der Pauw structures and atomically abrupt wires, as sensitive probes to characterize the Si:P material system and quantum transport properties. We have also investigated the efficiency and fidelity of scanning tunneling microscope (STM) patterning and will present a detailed analysis of atomic scale patterning fidelity and its effect on low temperature, electrical transport.