# Atomically Precise Devices:
# Enabling Fundamentally New Devices at the Ultimate Atomic Limit

Richard Silver, Xiqiao Wang, Pradeep Namboodiri, M. D. Stewart, Jr., Roy Murray, Kai Li and Jon Wyrick

*National Institute of Standards and Technology*

Atomically precise device fabrication is poised to enable a new class of atom-based electronic devices for use in traditional and quantum information processing. Controlling the position and electronic or quantum state of individual atoms or electrons in a solid state environment enables an array of new devices such as single atom transistors, single charge sensors, and solid state qubits. Si electronic structures that rely on individual atoms precisely placed within a pristine environment further provide a path to probe individual dopant-dopant interactions and to understand the impact of individual dopants on device performance.

Deterministic placement of individual dopant atoms in the Si lattice is achieved using hydrogen-based scanning probe lithography. However, fabricating functional atom-based devices requires a number of complex steps including preparation of atomically ordered silicon surfaces in exceptional vacuum, fiducial marks, hydrogen termination, atomic resolution patterning, dopant dosing, epitaxial silicon overgrowth, and contacts to buried devices.

In this presentation we will focus on measurements and characterization of ultra-thin, atomically abrupt, highly doped low-dimensional devices in Si and our flexible strategy for contacting these buried devices. We will present low-temperature electrical measurement results from atomically abrupt wires and tunnel junctions with coplanar gates. We study the effects of process conditions on device dimensionality and performance in the context of our extensive study of delta layer formation with optimized locking layer epitaxial growth techniques to enhance the confinement of Phosphorus atoms.

We will describe our alignment strategy to contact buried devices and the use of scanning capacitance, peak force Kelvin, and optical methods in relocating devices. Optimization of multiple alignment steps capable of withstanding high processing temperatures enables subsequent ebeam patterning and metallization processes with adequate accuracy. Ultimate overlay and alignment enables the smallest contact pads minimizing STM writing time and exposure to contaminants in the UHV environment.

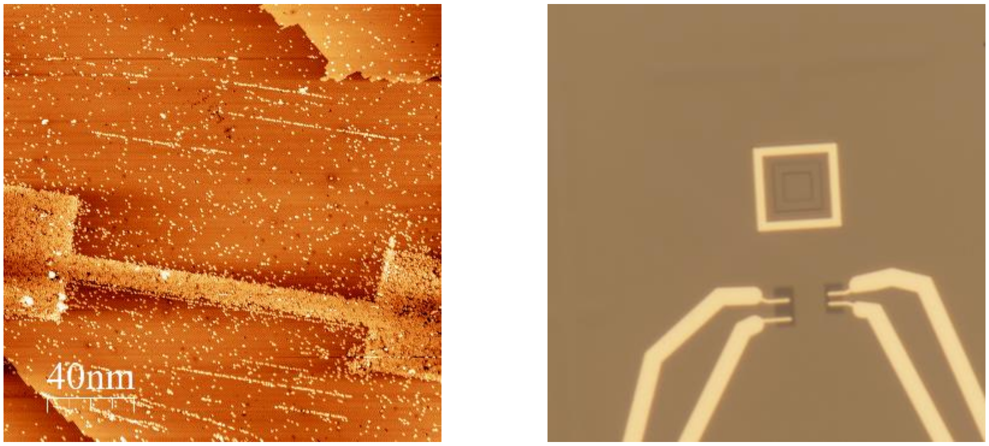


Figure 1. Atomic resolution image of 12 nm patterned line and image of ebeam patterned contacts to a buried device.

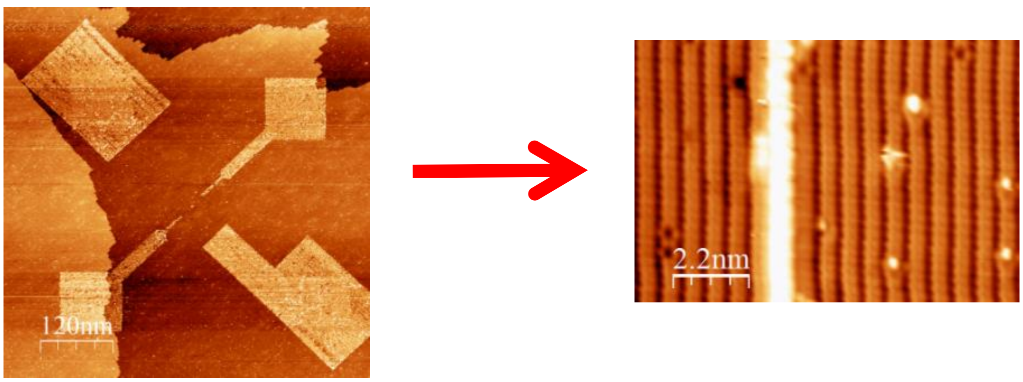


Figure 2. Atomic scale patterns on atomically ordered H-terminated surfaces dosed with phosphine resulting in P doped structures relocated by SCM and peak force Kelvin.