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

Richard Silver, Xiqiao Wang, Pradeep Namboodiri, Xiao Deng, and Kai Li
National Institute of Standards and Technology

Abstract

Atomically precise devices will be a key, strategic direction as future computation architectures move beyond traditional technologies. Controlling the position and electronic or quantum state of individual atoms or electrons in a solid state environment has the potential to have broad impact from single atom transistors to scalable qubits. New low dimensional devices or interface-free atomic structures offer new possibilities to reduce power dissipation while improving device performance characteristics. Deterministic placement of individual dopant atoms in the Si lattice can be achieved using hydrogen-based scanning probe lithography. Fabricating devices using this methodology requires a number of complex steps including preparation of atomically ordered silicon surfaces, fiducial marks, hydrogen termination, atomic resolution patterning, dopant dosing, epitaxial silicon overgrowth, contacts amongst others.

Many of these steps require processes and temperatures that can have an effect on device dimensionality and performance. In this presentation we will describe strategies for fiducial alignment marks allowing subsequent relocation for electrical contacts. We investigate the effects of mark geometry and processing on the resulting silicon surface. Scanning tunneling microscopy and spectroscopy are used to characterize the resulting surfaces and defects such as Si vacancies or dangling bonds. Recent results will be presented on understanding low temperature epitaxial silicon overgrowth on bare silicon and hydrogen terminated surfaces intended to elucidate the growth mechanisms and opportunities to optimize epitaxy. Si surface diffusion and crystallization and key to epitaxial growth but have a strong dependence on growth temperature and growth rates. Our investigation of sub-monolayer early phase growth through 20 nm thick overlayers gives direct insight to the growth mechanism and the effects of hydrogen on silicon surface diffusion.

We will describe our atomically resolved patterning methods and subsequent dosing with phosphorus dopant atoms. There are key process steps to optimize phosphorus dosing and electrical activation. These influences are investigated using SIMS, atom probe, TEM and electrical characterization. Both transport measurements and Hall measurements are used to characterize the effective carrier concentration and mobility as a function of growth and process conditions. We will present our electrical transport studies of the effects of silicon overgrowth conditions and phosphorus dosing methodology.

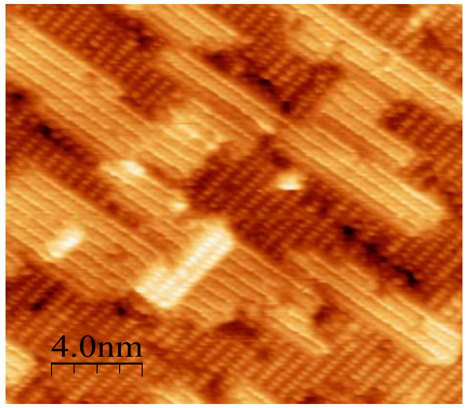


Figure 1. Atomic resolution image of 0.4 monolayers of Si overgrown on Si at 250ºC as part of a detailed Si growth study to understand low temperature epitaxial growth on hydrogen terminated silicon surfaces.

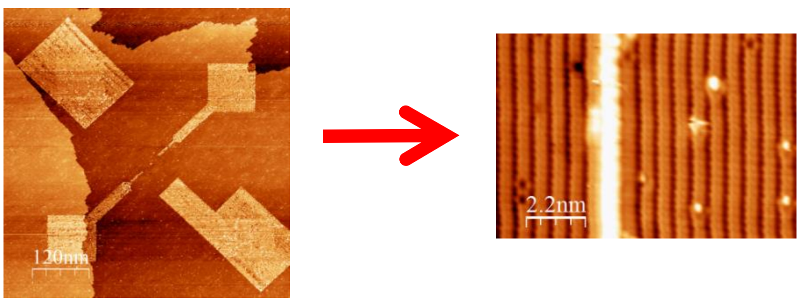


Figure 2. Atomic scale patterns on atomically ordered H-terminated surfaces were successfully dosed with phosphine resulting in P doped patterned structures.