The theoretical quantum computer is computationally superior to conventional binary computers, but practical hardware to implement it does not yet exist. One of the proposed hardware implementations uses the nuclear spin of single silicon-29 atoms as qubits. Fabrication of this structure requires placing a straight single-atom wide row of silicon-29 atoms on the surface of a substrate composed of silicon-28, which has no nuclear spin. A single NiFe magnet and a phosphorous atom are then placed on the ends of the silicon-29 row to generate the necessary magnetic field and also to initialize and readout the qubits after computations. Using mechanical, chemical, and electrical processes, we present a procedure to prepare the silicon-28 (111) 7x7 surface for growth of the silicon-29 atom row. By mechanical and chemical polishing of the silicon-28 substrate at a 1-degree tilt, ascending steps are produced on the surface, which are then straightened by DC annealing. The resulting substrate surface is confirmed and characterized by scanning tunneling microscopy imaging and profiling. By creating straight, single-bilayer tall steps on the silicon-28 (111) 7x7 substrate, the dangling bonds present on the step edges make the silicon-28 an effective substrate on which silicon-29 nanowires and other more complicated nanostructures may be fabricated.
Manipulation of Nanostructures on Silicon (111) 7x7 Surface for Applications in Quantum Computing

Michael Chien\textsuperscript{a,b}, Tomoya Arai\textsuperscript{b}, Shing-Chiang Huang\textsuperscript{b}, and Kohei M. Itoh\textsuperscript{b}

\textsuperscript{a} NanoJapan Program, Rice University & Department of Physics, University of Pennsylvania
\textsuperscript{b} Department of Applied Physics and Physio-Informatics, Keio University, Yokohama, Japan

\textbf{P R O P O S E}

The All-Silicon Quantum Computer\textsuperscript{1}

Silicon-29 has nuclear spin which serve as qubits
Silicon-28 substrate has no nuclear spin
Phosphorous-31 used for initialization and readout of spin after quantum computations
NiFe Magnet generates a steep magnetic field gradient needed to maintain spins

Advantages of All-Silicon System
- Long decoherence time for nuclear spin of \textsuperscript{29}Si
- Scalability of solid state hardware
- Existing technologies for silicon fabrication

\textbf{B A C K G R O U N D}

Silicon (111) 7x7 Surface Structure\textsuperscript{2}

Regular pattern and rigid unit-cell on surface allows for mechanical manipulation
Reduction of dangling bonds from 49 to 19 per unit cell allows for finer control of deposition onto the substrate

\textbf{M E T H O D S & R E S U L T S}

\textbf{Silicon (111) 7x7 Substrate Preparation}

1. Mechanical & Chemical Polishing
   Fine polishing at 1° tilt in (1 1 1) direction and 3° tilt in azimuthal direction produces kinked steps on silicon surface

2. Direct Current (DC) Annealing
   Current in kink-up direction causes electromigration of atoms that straightens kinks in the steps

3. Molecular Beam Epitaxy Growth
   Solid silicon is evaporated and deposited onto substrate in ultra-high vacuum

\textbf{R E S U L T S (C O N T ’ D )}

Scanning Tunneling Spectroscopy (STS)
STS spectra\textsuperscript{*} of deposited atoms reasonably matches that of original Si (111) 7x7 adatoms

Deposition of natSi

Deposition of Phosphorous by STS.
Finer control of deposition (vary temperature, etc.).

\textbf{F U T U R E W O R K}

Confirmation of deposited Phosphorous by STS.
Finer control of deposition (vary temperature, etc.).

\textbf{R E F E R E N C E S}


This work was supported by the National Science Foundation under Grant No. OISE - 0530220.
http://nanojapan.rice.edu

Research conducted in the Itoh Laboratory of Keio University as a participant in the NanoJapan Program 2009, sponsored by Rice University and the NSF-PIRE grant.

Sincere appreciation is due to Prof. Junichiro Kono, Dr. Cheryl Matherly, Prof. Christopher Stanton, Sarah Phillips, and Keiko Packard for making the NanoJapan Program possible, and to Tomoya Arai for his tireless and careful guidance, both in and out of the lab. Thanks to Omicron also, for making highly reliable STMs. *Some STM & STS images courtesy of Tomoya Arai. **Some diagrams courtesy of Takeharu Sekiguchi.