MANIPULATION OF NANOSTRUCTURES ON SILICON-28 (111) 7X7 SURFACE FOR APPLICATIONS IN QUANTUM COMPUTING

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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

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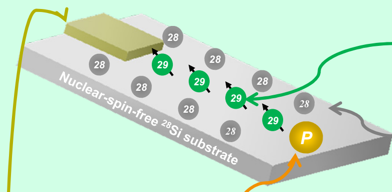
PURPOSE

The All-Silicon Quantum Computer[1]



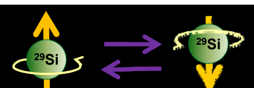
Silicon-29 has ***nuclear spin*** which serve as ***qubits***

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

Nuclear spin of ^{29}Si as qubits
Superposition

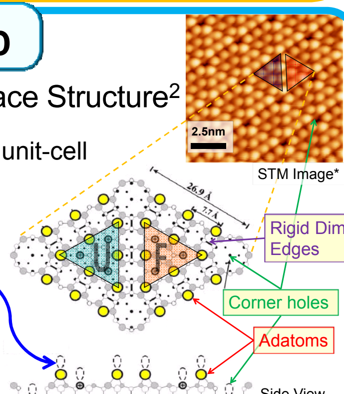


Advantages of All-Silicon System

- ***Long decoherence time*** for nuclear spin of ^{29}Si
- ***Scalability*** of solid state hardware
- ***Existing technologies*** for silicon fabrication

BACKGROUND

Silicon (111) 7x7 Surface Structure[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

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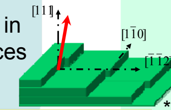
http://nanojapan.rice.edu

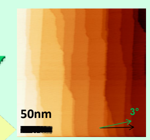
METHODS & RESULTS

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



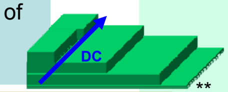


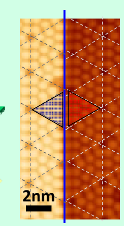
Wide range STM image of silicon surface after polishing

10 hours DC Annealing ~800°C

2. Direct Current (DC) Annealing

Current in *kink-up direction* causes electromigration of atoms that ***straightens kinks*** in the steps





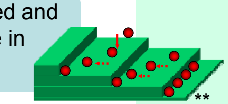
STM image of straightened step edge after DC annealing*

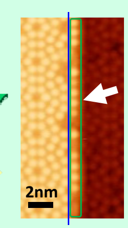
MBE Growth @ T_{sub}= 400°C ~10^{-11} torr

Deposition of ^{nat}Si

3. Molecular Beam Epitaxy Growth

Solid silicon is evaporated and deposited onto substrate in ultra-high vacuum



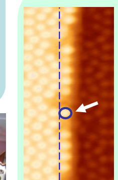


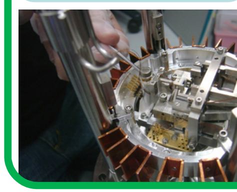
STM image of result of 0.84L Si deposition @ T_{sub}= 400° C*

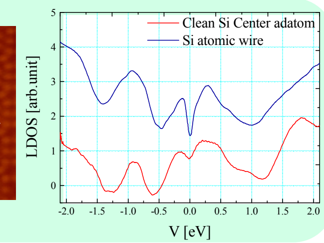
RESULTS (CONT'D)

Scanning Tunneling Spectroscopy (STS)

STS spectra* of deposited atoms reasonably matches that of original Si (111) 7x7 adatoms







Scanning Tunneling Microscope

CONCLUSIONS

Initial Steps For Realization of Quantum Computer

An effective substrate for growth of single atom wide Silicon atom row and other nanostructures can be created by polishing and DC annealing of Silicon (111) 7x7 to produce a regularly stepped vicinal surface.

Variations in polishing and annealing allow for growth of different structures, such as the single atom wide Silicon atom row or regularly spaced atoms.

Identity of deposited silicon can be confirmed by STS.

FUTURE WORK

Confirmation of deposited Phosphorous by STS.

Finer control of deposition (vary temperature, etc.).

REFERENCES

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