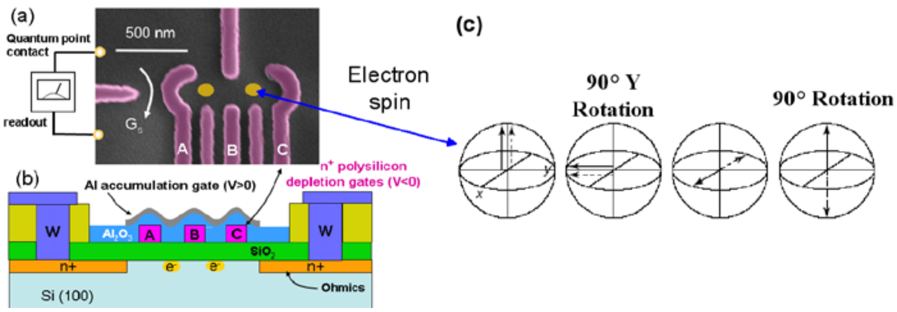
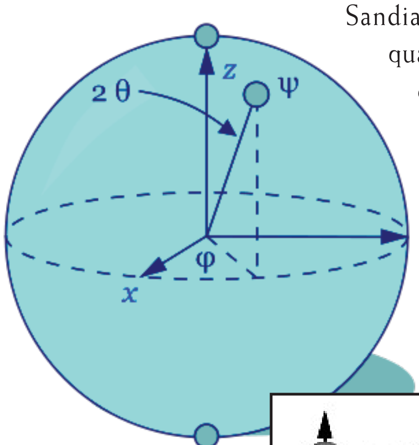
Silicon-Based Quantum Information Sciences Grand Challenge

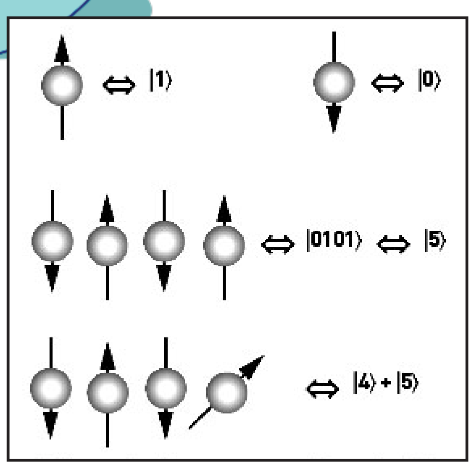
The Quantum Information Science and Technology (QIST) Grand Challenge is a three-year research effort aimed at producing the world's first silicon spin based quantum bit (qubit). Qubits are the basic information storage elements of quantum computers, which perform quantum information processing and offer the opportunity to efficiently solve problems that are numerically challenging for classical computers. Quantum computers, therefore, may someday augment conventional classical computers by employing some of the unusual properties of quantum systems to speed up computation.



(a) scanning electron microscope image of Sandia's dual quantum dot structure fabricated in silicon (the dots suggest the approximate location of the electron position); (b) schematic cross section of the quantum dot structure showing the position of the single electron locations; and (c) schematic representation of spin manipulation using rotation and precession of two different spins.



Sandia is engaged in basic quantum information sciences research motivated by advanced computing architectures and the fact that future engineered systems will require increased understanding of quantum effects.



Qubits are made up of controlled particles and the means of control (e.g. devices that trap particles and switch them from one state to another).

Sandia's Unique Approach

A critical challenge in building a quantum information processing system is the need to couple and manipulate tiny quantum dots as qubits in the form of a quantum circuit that produces a useful function. Sandia researchers are focused on the basic questions related to the feasibility of manufacturing a simple qubit and simple quantum circuits – a task that includes demonstrating a silicon qubit, integrating the qubit with classical CMOS (Complementary Metal Oxide Semiconductor) technology, and designing quantum error correction circuits that are tuned to the physical qubit's unique properties. Sandia's approach is to physically encode quantum information in the spin state of an electron that is confined in a silicon dual quantum dot (DQD). Although gallium arsenide quantum dots have been demonstrated, quantum dots made from silicon are expected to have longer decoherence times and improved integration with silicon-based classical circuitry. A significant challenge is to engineer the Si qubit and the surrounding electronics all operating at ~ 0.1K (0.1 degrees above absolute zero).

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Why Quantum Dots in Silicon?

Isotopically pure silicon-28 has the potential to provide a much more robust physical qubit because it has zero nuclear spin, resulting in better performance (by comparison to gallium arsenide). A spin-encoded qubit state has finite duration, and will eventually change direction (decoherence), thereby also corrupting the information encoded into that qubit; the zero nuclear spin of pure silicon-28 is expected to minimize the effect of nuclear spin on qubit spin state, thereby increasing the duration (qubit decoherence time) over which a qubit will maintain its correctly encoded spin state. Hence Sandia's pursuit of silicon-28 quantum dots is a key step in rendering a viable qubit.

What are the Technical Objectives of QIST?

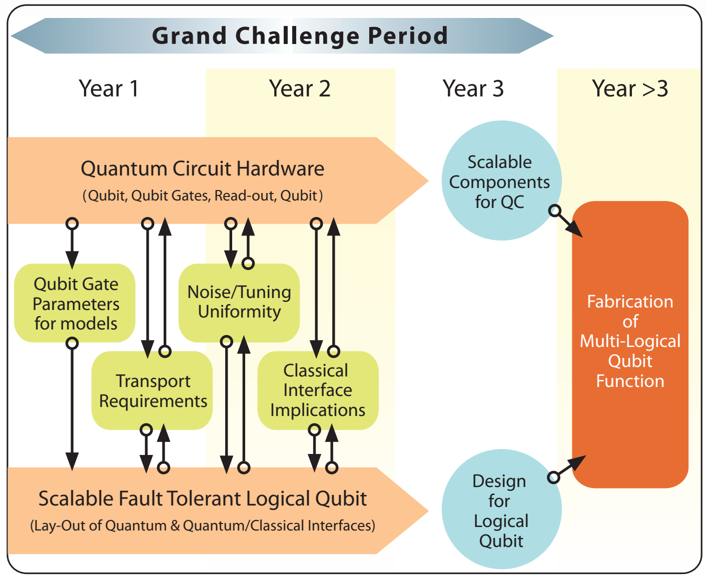
- Fabricate silicon-based double quantum dots (DQDs) and associated nano-electronics for qubit initialization, manipulation, and read-out.
- Simulate and model electrical observations and qubit dynamics
- Design a self-sustained error-corrected Qubit
- Develop novel classical circuit design that facilitates classical-quantum electronics interface

In addition to the silicon quantum-dot qubits, themselves, Sandia researchers must also engineer the silicon circuitry required to operate with qubits. And although the CMOS (Complementary Metal Oxide Semiconductor) technology that is required for such circuitry is well-known, for a silicon quantum dot qubit, the circuitry must operate at a temperature of 0.1 K, very close to absolute zero. This enormous challenge is necessary in order to minimize the disruptive effects of random thermal motion to this computational circuitry.

In physical qubits, such as the silicon DQD qubit, it is impossible to eliminate all sources of error. Therefore, the project is also designing a "logical qubit" that incorporates error correction algorithms and architecture design attributes that add fault tolerance.

Will Quantum Computing be a Standalone Technology?

No. Given the difficulty and expense of cryogenic (extremely low-temperature) operation, it will partner with and supplement/ augment classical computing, rather than replacing it.



Two Parallel Paths to Technical Success of QIST

What Type of Computational Problems Would Benefit ?

Because of the large number of different states that a single qubit can assume, a succession of qubits has the capacity to encode a huge amount of information. For this reason, as Richard Feynman observed in 1982, a quantum computer can model materials at the quantum dynamical level much more efficiently than a classical computer.

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