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AQUARIUS: Adiabatic Quantum Architectures in Ultracold Systems

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Problem

- Adiabatic quantum computation (AQC) is an alternative approach to the standard "circuit" model for performing quantum computation. How promising is it?

Objectives

- Demonstrate two-qubit special-purpose adiabatic quantum optimization algorithms in two systems:
  1. Neutral atoms trapped in a nanofabricated optical array
  2. Electrons trapped in semiconductor nanostructures
- Evaluate the potential for universal fault-tolerant adiabatic quantum computation architectures through simulation

Approach

- In AQC, one encodes the solution of problem as the ground state (GS) of some Hamiltonian H_{prob}
- Initialize in GS of initial Hamiltonian H_{init}
- Slowly deform the Hamiltonian into the final Hamiltonian, $H_{\text{init}} \to H_{\text{prob}}$
- If Hamiltonian deformation sufficiently slow, by adiabatic theorem system remains in GS
- Measure final state to read out solution

AQC vs. traditional gate model for QC:

Though formally equivalent, AQC and circuit model demand distinct resources:

Circuit model:

- Requires coherence times long compared to the computation, consequently fast gates

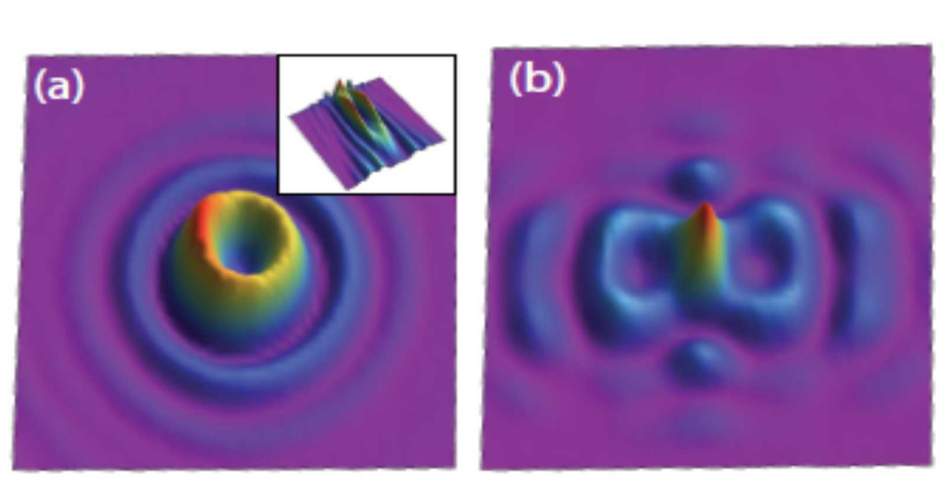
AQC:

- Requires system to remain in ground state (GS) or in a state correctable to the GS
- Coherence time in the energy eigenbasis permitted to be short compared to the computation
- Sensitive to thermal effects and errors in Hamiltonian implementation

Results

Neutral atoms:

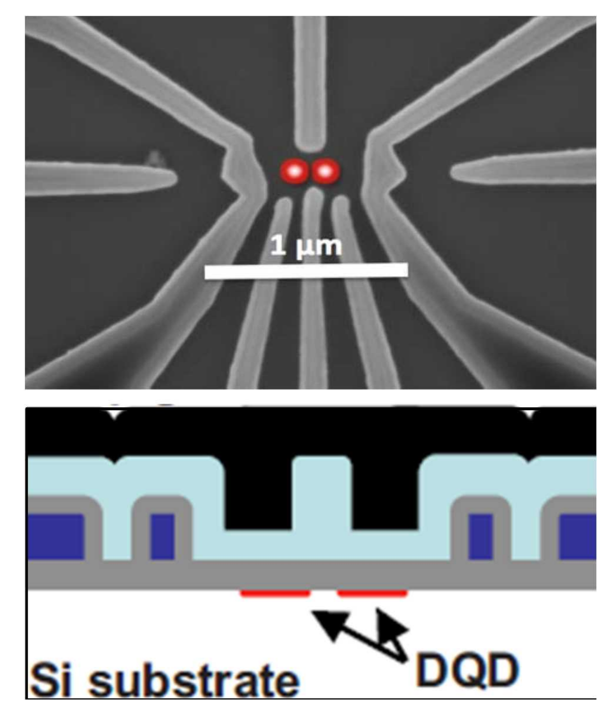
- Developed optics for trapping Cs atoms in bottle-beam traps
- Observed and characterized strength of two-qubit interactions



Single and double bottle-beam traps

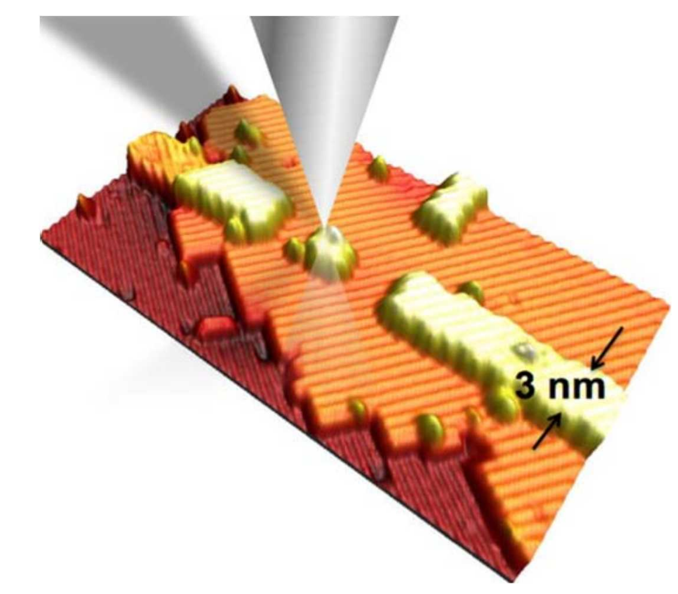
Semiconductor nanostructures:

Gate-defined quantum dots



Developed methods for characterizing qubit-environment interactions

Donor atoms in Silicon

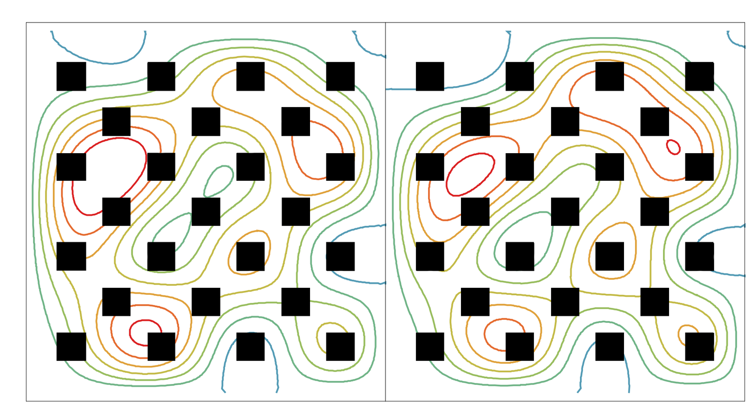


Developed capability at Sandia to place phosphorus donors into silicon with atomic precision

Algorithms

Adiabatic quantum optimization (AQO)

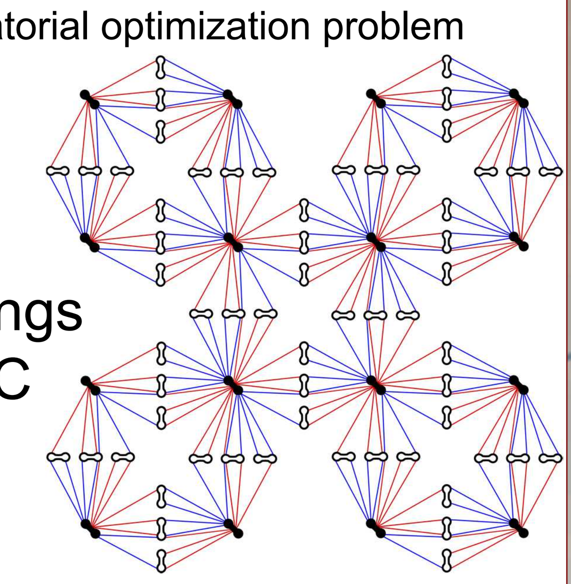
- Developed a mapping that enables linear PDE-constrained combinatorial optimization to be performed with AQO



Optimal/best suboptimal solutions for Poisson equation-constrained combinatorial optimization problem

Universal AQC

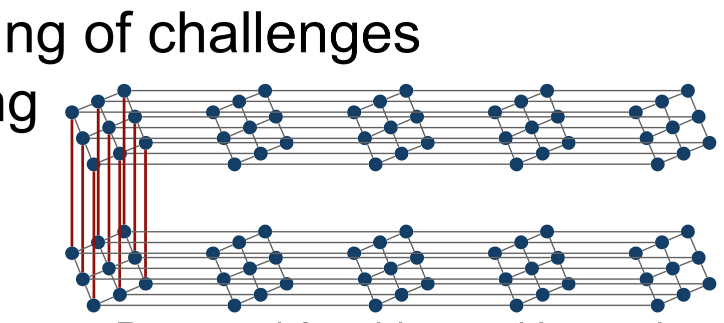
- Any quantum circuit maps to an AQC problem
- Requires richer set of inter-qubit couplings
- Developed approach for realizing UAQC Hamiltonians with quantum dots



Proposed charge qubit layout for UAQC with double quantum dots

Error correction/suppression

- Scalability requires robustness to errors
- Developed new family of quantum error detecting codes for error *suppression*
- Developed better understanding of challenges and limitations of implementing error *correction* in AQC



Proposed 9-qubit repetition code

Significance

- The work of AQUARIUS is relevant for helping to define the technological and architectural avenues that should be taken in the field of quantum computing.
- Made numerous hardware innovations for advanced neutral atom and semiconductor device implementations.
- Developed a deeper understanding of challenges and limitations of the AQC architecture, including improved theoretical tools for studying these systems.
- Laid the theoretical groundwork and the technological infrastructure that will contribute to the development of future QIP capabilities at Sandia.

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