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Aquarius: Adiabatic Quantum Architectures In Ultracold Systems

Researching the Elements of a Quantum Computer

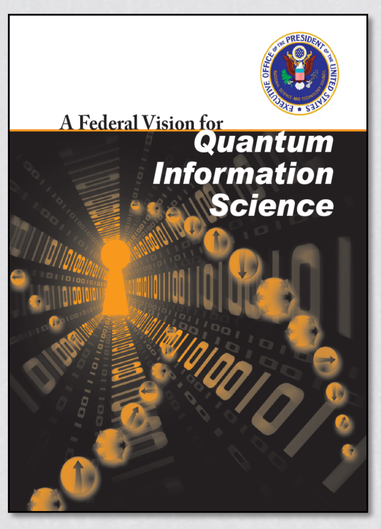
Sandia National Laboratories
Steven Rinaldi, Andrew Landahl

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

NNSA National Nuclear Security Administration

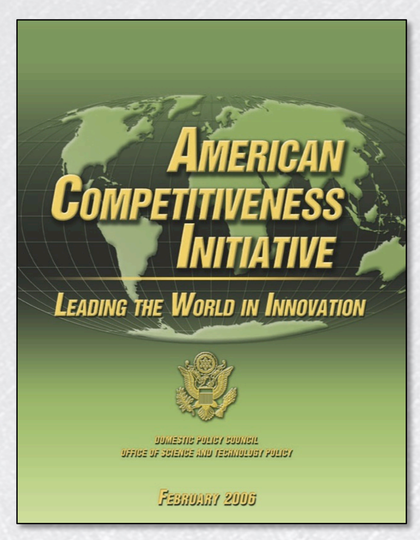
Challenges

Quantum Computing
Policy and Technical Issues



"The United States' large stake in all these potential applications warrants a cohesive national effort to achieve and maintain leadership in the rapidly emerging field of **quantum information science**."
OSTP, Federal Vision for QIS, Dec 2008

"Overcoming technological barriers to the practical use of **quantum information processing** to revolutionize fields of secure communications, as well as quantum mechanics simulations used in physics, chemistry, biology, and materials science (DoE, NIST, NSF)."
Domestic Policy Council, OSTP, 2006

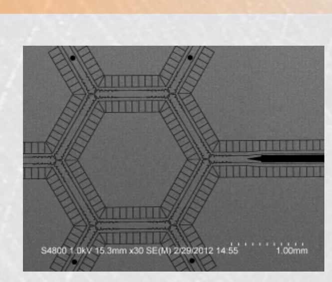


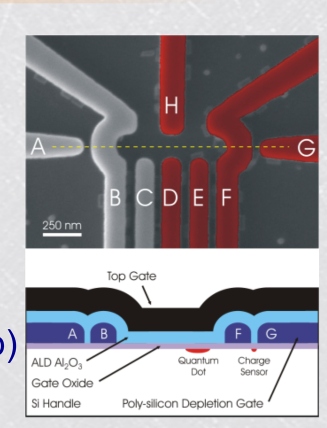
- Quantum computers promise to take computing to its ultimate quantum-coherent limit, just as lasers did for light. Multiple applications in fields like energy, medicine, and optimization are already known.
- The primary roadblock to development is exceptional noise sensitivity.
- On paper, the adiabatic quantum architecture is expected to dramatically improve robustness by maintaining a quantum computer in its lowest-energy configuration. Understanding whether this robustness is borne out in practice is an important R&D question.

Key QIS Issues

- What technology?
- What computer architecture?
- What error mitigation strategy?

Mainstream R&D focus:
- Quantum circuits (gates and qubits)
- Components good to 10^{-4}
- MASSIVE redundancy for error correction


(a)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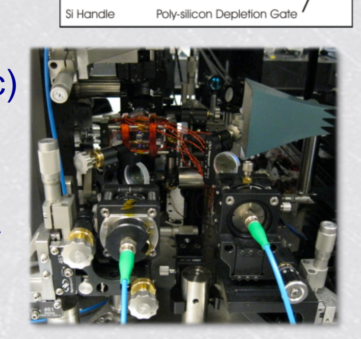

(c)

Representative qubit technologies:
(a)Trapped ions
(b)Electrons in double quantum dots
(c)Interacting neutral atoms

AQUARIUS Vision & Approach

VISION: Develop a quantum-computing architecture whose resource requirements are more achievable than conventional approaches due to the intrinsic noise immunity offered by adiabatic physics

TECHNICAL APPROACH

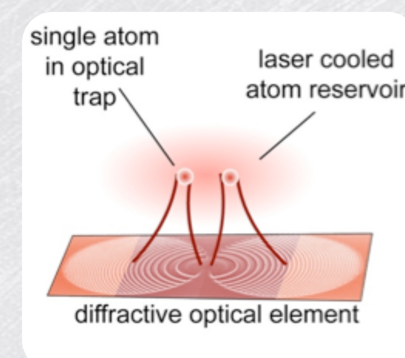
Demonstrate two-qubit *special-purpose* adiabatic quantum optimization algorithms in:
1. Neutral atoms trapped by a nanofabricated optical-trap array, and
2. Electrons trapped by semiconductor nanostructures

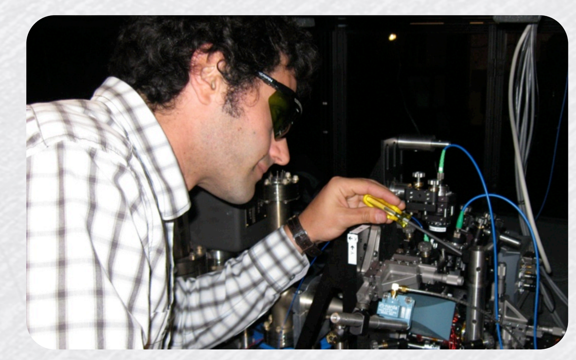
and for these technologies to:

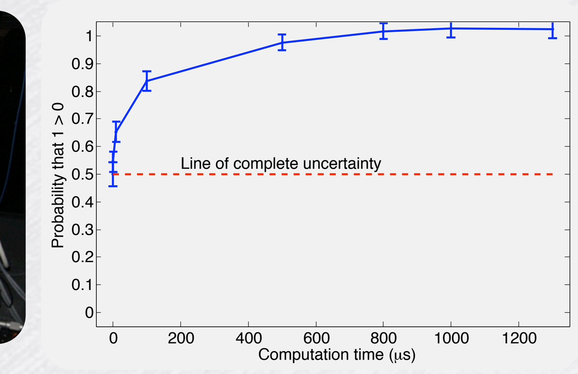
3. Evaluate the potential for fault-tolerant general-purpose adiabatic quantum computation architectures through design & simulation

Results

Neutral Atoms

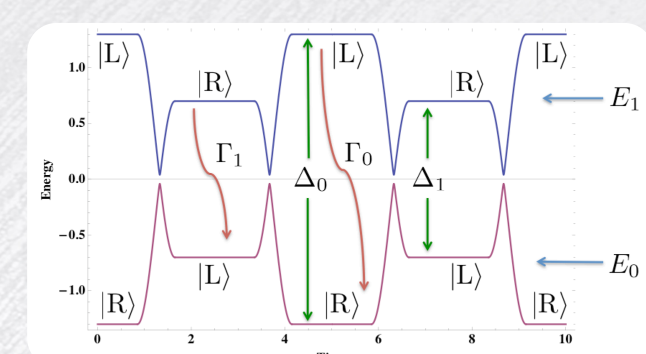


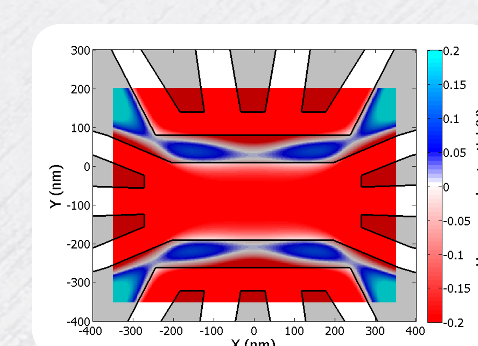




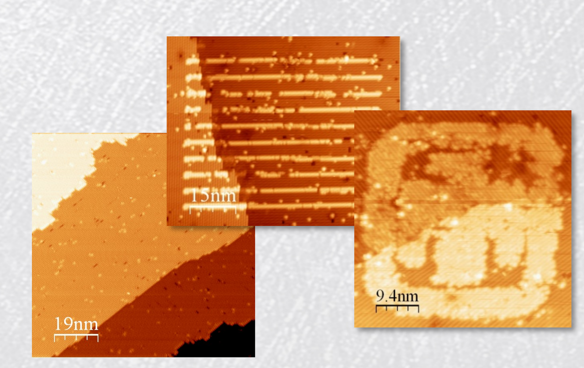
- Fabricated and used world-first diffractive optical elements for trapping and controlling individual atoms
- Built Sandia's ***first functioning one-qubit quantum processor***
  - Trapped & processed a Cs atom laser-cooled below 100 μK
  - Inaugural calculation: "1 is greater than 0 … with high probability"

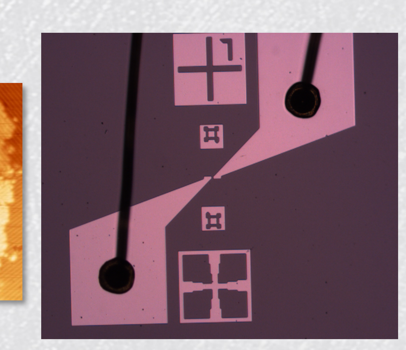
Silicon Nanostructures





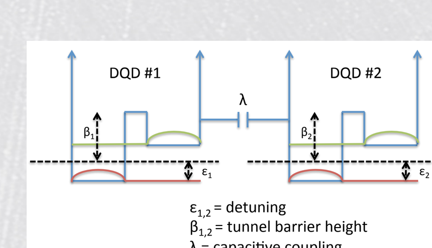
- Invented world-first semiconductor adiabatic charge qubit
- Built one- and two-qubit silicon quantum-dot devices realizing the idea
- Invented world-first benchmarking test for adiabaticity of qubits
- Developing atomic-scale fabrication capability: P donors in Si
  - Sandia will be the ***second institution worldwide*** with this capability

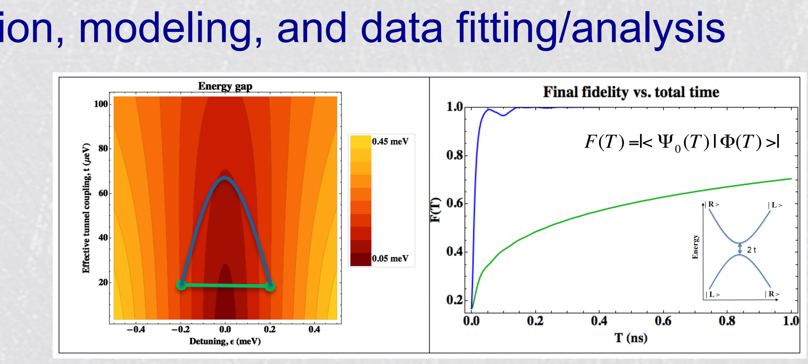




Architectures

- Developing detailed noise models and identifying critical noise sources
- Examining hardware implementations / efficacy of error suppression techniques
- Developed an error correction code family that is hardware implementable
- Providing detailed experimental support in the areas of qubit control, experimental design, simulation, modeling, and data fitting/analysis





Significance

- Developing key adiabatic quantum computing technologies – multiple world-first demonstrations focused on improving quantum architectures
- Leverages multiple SNL capabilities into a world-class QIS R&D team
- Furthers external partnerships and builds a collaborative network to address tomorrow's QIS challenges – U of New Mexico, U of Wisconsin, LANL, NASA
- Enhances and extends Sandia's capabilities to support U.S. government needs in quantum information sciences

U.S. DEPARTMENT OF ENERGY

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