Sandia's Foundation LDRD investment in Quantum Information Systems (QIS)

SAND2016-0511PE

QIST Quantum Information S&T

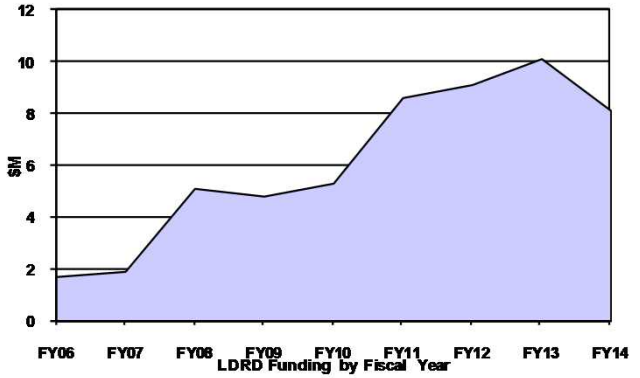
AQUARIUS™ Adiabatic quantum architectures in ultracold systems

SECANT QKD

FY08 – FY10
Si-based qubits

FY11-FY13
Architectures

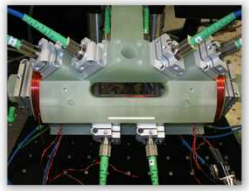
FY14-FY16
Communication

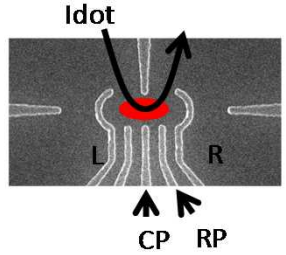


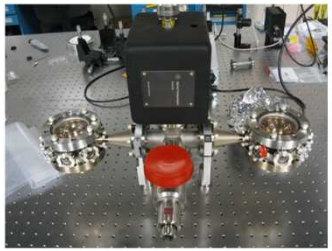
- *Build foundational capabilities while exploring novel, high risk areas*
- Focus on the materials and design challenges of QIS
- $62.6M LDRD investment, FY06-15

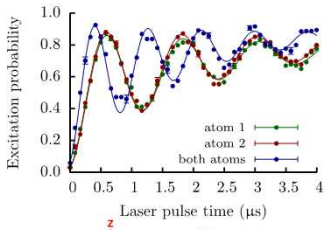
Broad and deep portfolio, spanning many facets of QIS:

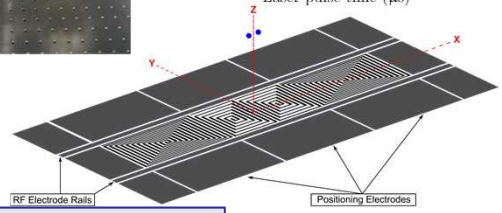
- Qubits: physical qubit development, logical qubit design, entanglement, noise modeling
- Quantum engineering: architectures, robust controls for quantum gates, on-chip microwave control of ion traps, tomography
- Algorithms/applications: demonstration of few-qubit apps, algorithm design
- Modeling: design toolkits, error correction threshold simulators
- Sensing: matter-wave sensors, atom interferometry
- Communication: Quantum key distribution, photon source development, single photon detectors











These programs have an ever expanding suite of capabilities that could be beneficial to CINT User science.

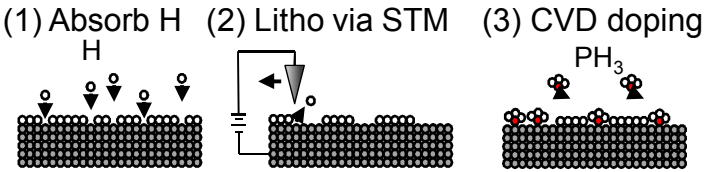
LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Exemplar 1 – Atomic Precision Fabrication
1st in US, 2nd in the world

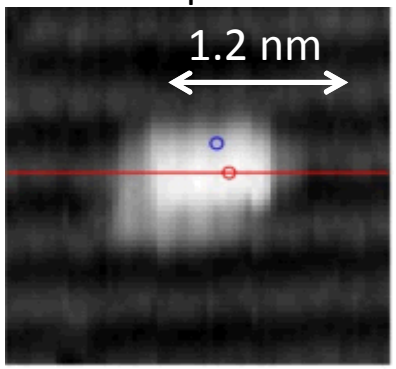
Sandia National Laboratories

World-leading capability to make controlled single atom integrated structures at CINT

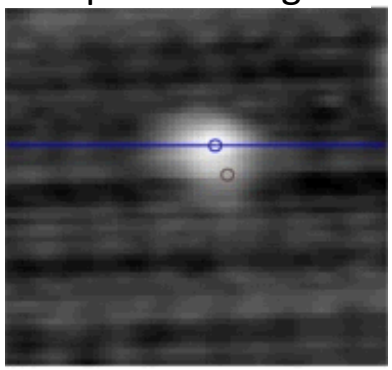
Sandia has build and demonstrated atomic precision fabrication at CINT.



STM litho pattern



Incorporated single P



In-situ capabilities under development:

- Epitaxial growth capability for Si and ^{28}Si
- Delta doping of boron
- Ge and SiGe epitaxial growth

These capabilities can be accessed by users to explore defects and devices at the single atom level!

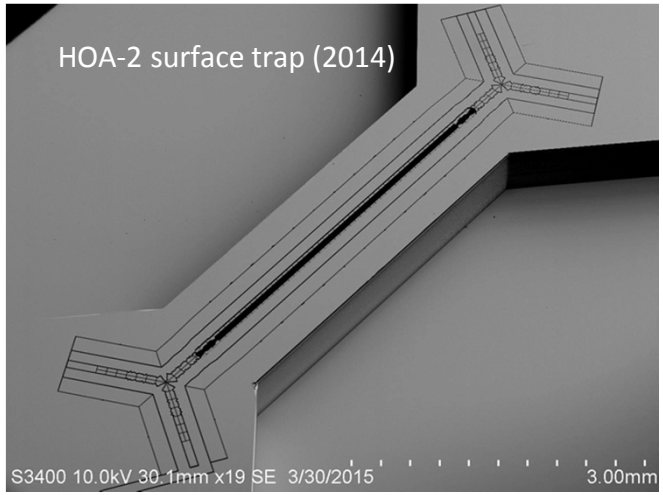
- E. Bussmann et al. Nanotechnology 26, 085701 (2015)
- W.C.T. Lee et al., Nanotechnology 25, 145302 (2014)

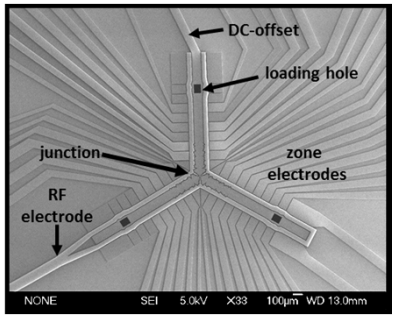
Exemplar 2 – Ion Trap Platform

Sandia National Laboratories

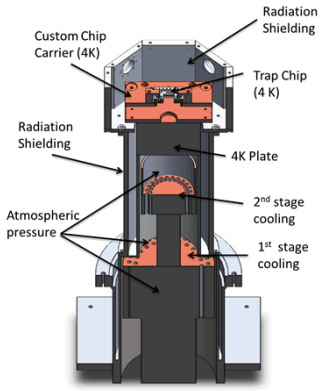
World-leading MEMS based Ion Trap platform with ion and electrical access.

- Fabrication done using SNL MESA microfabrication facility.
- High Optical Access (HOA)-2 trap: optimized for quantum information processing
  - Scalable trap with linear section and two junctions and integrated slotted section
  - Excellent optical access
  - High trapping frequencies and deep trap depth
  - Segmented electrodes close to ions for axial control
  - Trap lifetime > 90h while taking measurements
  - Trap lifetime without cooling > 10 min
  - Trap heating rates <100 quanta/s (ytterbium)





Sandia Y-junction surface trap
Dynamic shuttling of Ca^+ thru junction (>10^6 cycles)



New cryogenic ion trap chamber (2014)

- Multiple designs delivered to multiple partners
  - 12 institutions, 5 countries
  - 8 institutions have successfully trapped using SNL designs
- Traps used with Ca, Yb, Mg

C. D. Bruzewicz, et al, Phys. Rev. A 91, 041402(R) (2015)
McConnell, et al, Phys. Rev. A 92, 020302 (2015)

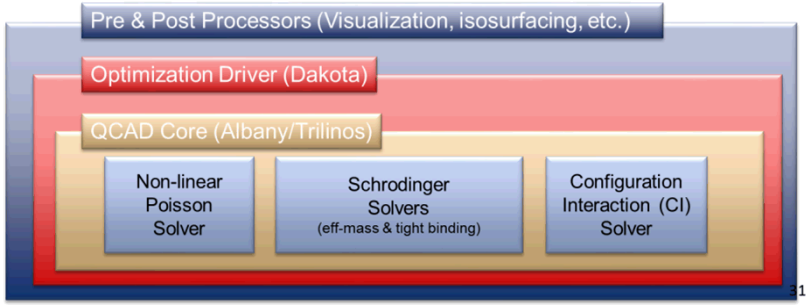
These capabilities could be accessed by CINT users to simultaneously study the optical and electrical characteristics of Bose-Einstein condensates.

Exemplar 3 – Qubit Physics Modeling

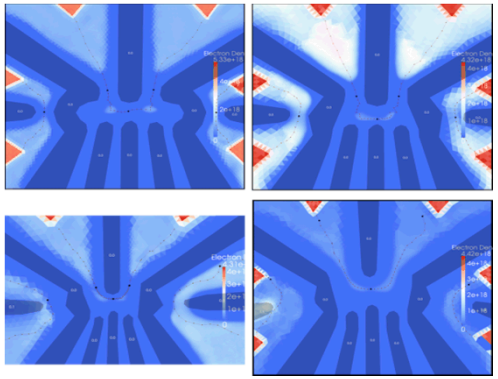
The Sandia QCAD model applies the, NNSA funded, Dakota solver to predict and evaluate the dynamic electrical performance of multi-dimensional quantum devices.

Uniqueness:

- Semiconductor quantum device simulation
  - Finite element basis
  - Semiclassical, Schrodinger-Poisson, Configuration Interaction solvers
  - Sophisticated optimization using Dakota
  - Efficient, fast, parallel
- GUI front end
  - Web based, database backed
  - Create gates using SEMs or by hand
  - Apply voltages, set optimization targets, etc.



QCAD model of Double Quantum Dot electron density



Quantum computer aided design simulation and optimization of semiconductor quantum dots, X Gao, E Nielsen, RP Muller, RW Young, AG Salinger… - Journal of Applied Physics, 2013

The Promise of Quantum Simulation, RP Muller, R Blume-Kohout - ACS nano, 2015

These capabilities could be accessed by CINT users to model their integrated quantum devices (qubit) measurements.