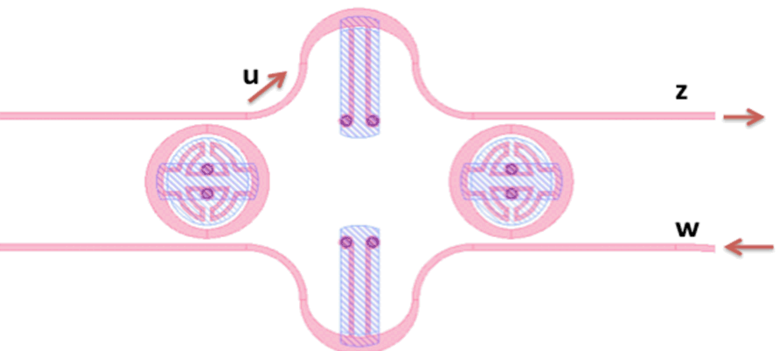
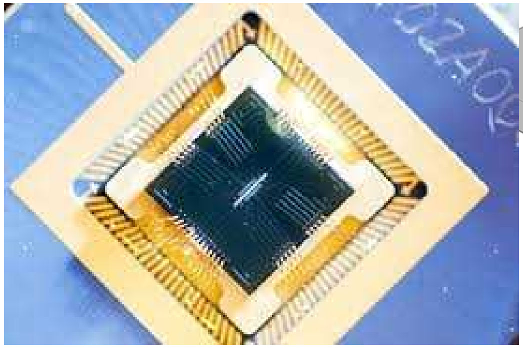
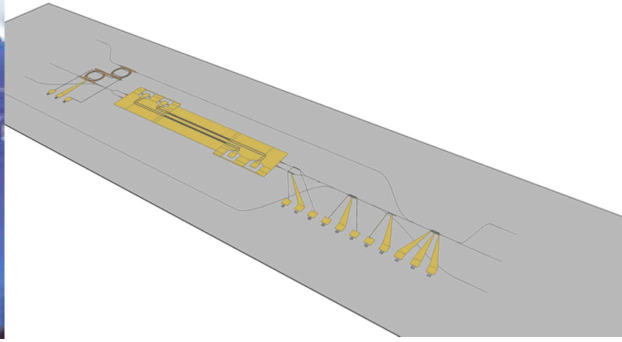
SAND2015-4926PE

Exceptional service in the national interest

Sandia National Laboratories







Quantum Information Sciences at Sandia

Mohan Sarovar

Digital & Quantum Information Systems Department

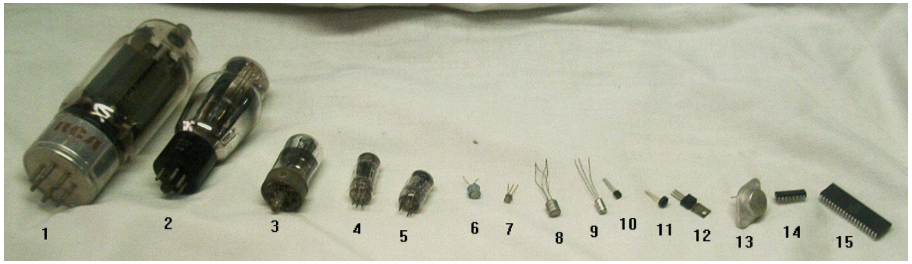
(Postdoc at UC Berkeley 2006-2011)

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

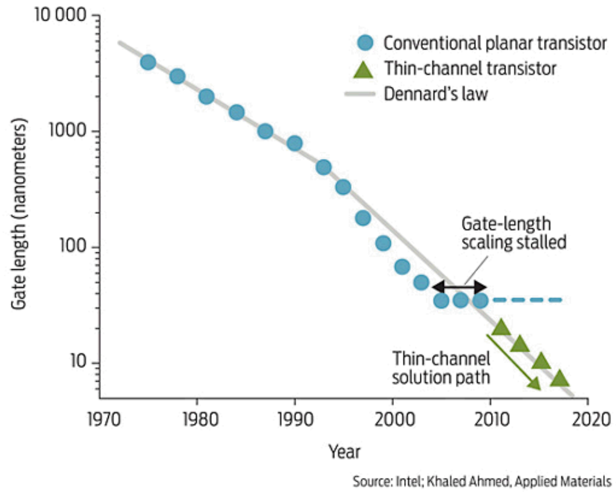
Quantum Information Sciences (QIS)

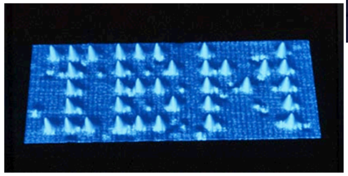
- Evolution of information technology:



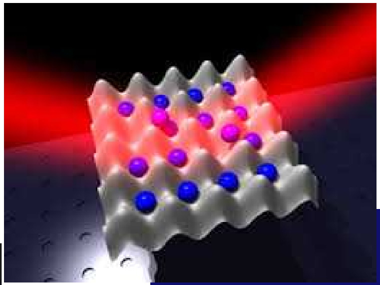
Museum of Maritime Navigation and Communication

- Smallest engineerable feature size is rapidly decreasing to ultimate limits:

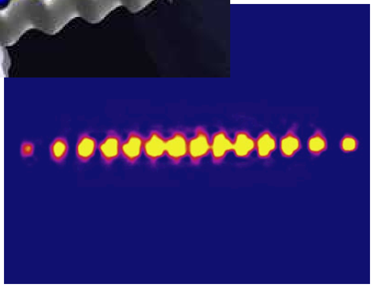




Individual atoms deposited



Individual atoms cooled and trapped



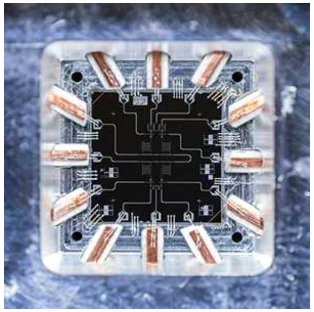
Individual ions trapped

Energy quantization, the superposition principle, the uncertainty principle and other quantum effects can be important or even dominate physics at these scales

Quantum Information Sciences (QIS)

Sandia National Laboratories

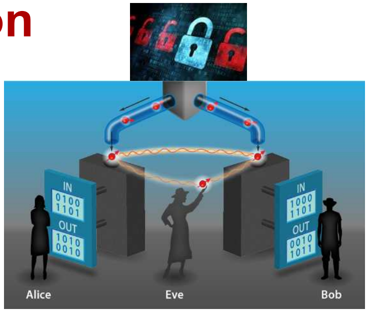
Quantum computing



Utilize quantum properties of microscopic (or specially designed mesoscopic) materials to perform certain computations much more efficiently than CMOS-based computers.

A path to **Beyond-Moore** computation.

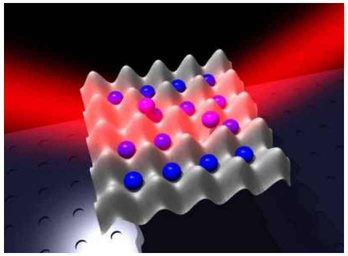
Quantum communication



Utilize quantum properties of photons to achieve perfectly secure communication (security based on the laws of physics).

The promise of **unbreakable encryption**.

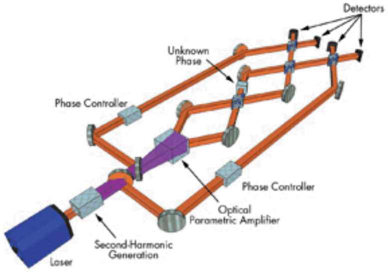
Quantum simulation



Utilize precisely designed arrays of quantum particles to simulate the behavior of difficult many-body models of interest to physics and chemistry.

Physics and chemistry simulations (e.g. materials) unfeasible in CMOS

Quantum sensing/metrology



Utilize correlations unique to collections of quantum particles to sense physical objects, fields with greater precision.

Ultra-precise sensing

QIS at UC Berkeley

Professors at Cal active in QIS:

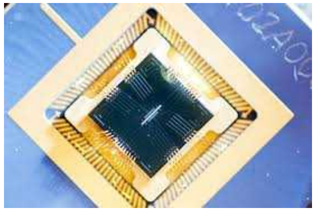
Jeff Bokor (EECS)
John Clarke (Physics)
Michael Crommie (Physics)
Graham Fleming (Chemistry)
Hartmut Haffner (Physics)
John Kubiatowicz (EECS)
Joel Moore (Physics)
Shankar Sastry (EECS)
Irfan Siddiqi (Physics)
Dan Stamper-Kurn (Physics)
Umesh Vazirani (EECS)
Ashvin Vishwanath (Physics)
Birgitta Whaley (Chemistry)
Eli Yablonovitch (EECS)
Alex Zettl (Physics)

Have active collaborations with staff at Sandia Livermore

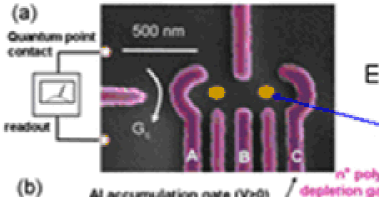
QIS at Sandia

Quantum computing

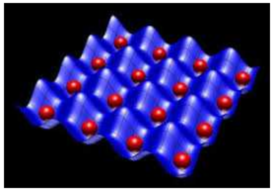
- Qubit technologies in silicon, trapped ions, neutral atoms



Sandia on-chip ion trap



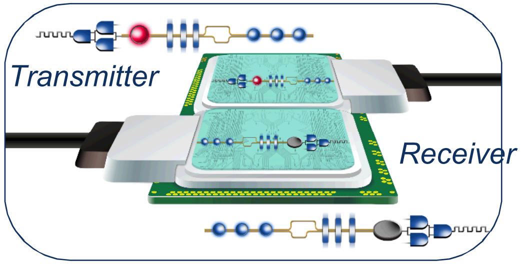
Sandia quantum dot qubit



Neutral atoms in an optical lattice

Quantum communication & quantum optics

- Nonclassical sources of light
- Scalable quantum key distribution



Quantum theory

- Quantum control theory
- Modeling and simulation of complex quantum systems and devices
- Noise mitigation and error correction
- Quantum computing and simulation architectures

$$\frac{\mathrm{d}\tilde{\rho}(t)}{\mathrm{d}t} = -\frac{\mathrm{i}}{\hbar}[\bar{H}_{\mathrm{AQC}}(t), \tilde{\rho}(t)] - \frac{1}{\hbar^2}\sum_j \int_0^t \mathrm{d}\tau C_j(\tau)\tilde{E}_j(t)\tilde{\Xi}_j(t,\tau)\tilde{\rho}(t) - C_j^*(\tau)\tilde{E}_j(t)\tilde{\rho}(t)\tilde{\Xi}_j(t,\tau)$$
$$-C_j(\tau)\tilde{\Xi}_j(t,\tau)\tilde{\rho}(t)\tilde{E}_j(t) + C_j^*(\tau)\tilde{\rho}(t)\tilde{\Xi}_j(t,\tau)\check{E}_j(t), \quad (10)$$

$$\sum_i \alpha_i(t)\bar{L}_i \left(\sum_j \beta_{ij}(t)\Gamma_{ij}^{\nu}\right) |n,k;0\rangle_t = \epsilon_{n,k;\nu}(t)\,|n,k;0\rangle_t\,,$$

QIS at Sandia

In Livermore: ~ 10 researchers in QIS theory and experiment

Of all the national laboratories in the Bay Area, Sandia has the most active QIS program

We collaborate with many university groups:

- UC Berkeley
- Stanford University
- Princeton University
- University of New Mexico
- Shanghai Jiao Tong University, China
- University of Bristol, UK
- University of Waterloo, Canada

- Between academia and industry
- Should not compete with industry
- Some unique capabilities
  - Large scale fabrication, testing & computing facilities
  - Several areas of expertise within the same organization
  - Well suited to tackle **systems-level and scaling** problems

QIS at Sandia – *e.g.* adiabatic QC

Sandia National Laboratories

Quantum computing

Adiabatic quantum computing (AQC) is an important alternative model for performing quantum computing.

In principle, AQC is just as powerful and robust as conventional quantum computing (circuit model QC).

However, the property of ***fault-tolerance***, which allows one to perform reliable computation even if some components are faulty is incompatible with physically realistic AQC:

The company Dwave markets a special purpose adiabatic device

PHYSICAL REVIEW X 3, 041013 (2013)

Error Suppression and Error Correction in Adiabatic Quantum Computation: Techniques and Challenges

QIS at Sandia – *e.g.* SECANT program

Quantum communication & quantum optics

Quantum Communications

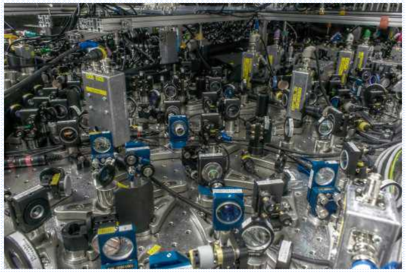
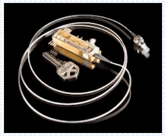
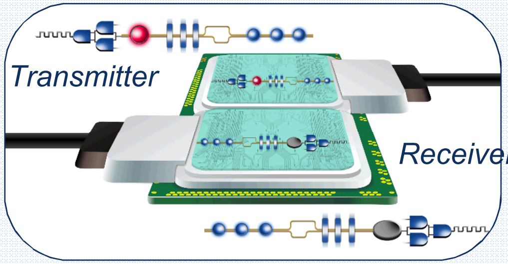


Photo: Toshiba



LANL

ID Quantique



Electronic Circuits

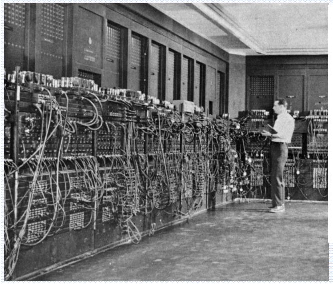


Photo: U.S Army

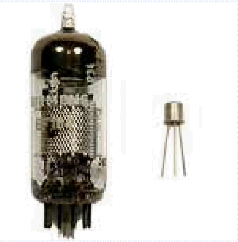


Photo: Texas Instruments

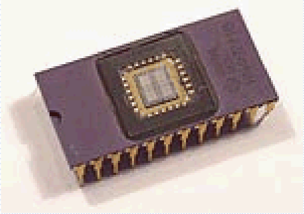


Photo: nobelprize.org

Possible models of cooperation

- **Training of students. Sandia Livermore offers:**
  - broad expertise in QIS theory and experiment
  - state-of-the-art large-scale computational facilities
  - a unique perspective on the requirements of, and challenges to, large scale QIS

- **Sandia is an established provider of government-furnished information to federal funding agencies**
  - *e.g*. iARPA looks to team up academic performers with teams at government labs who can assess the research of performers.

What else?