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Quantum Computing and Nanoscience Integration

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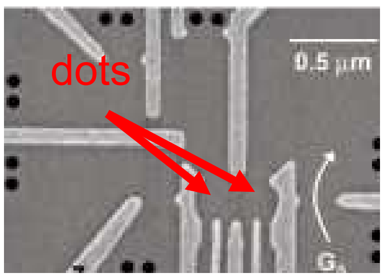
Solid State Technologies

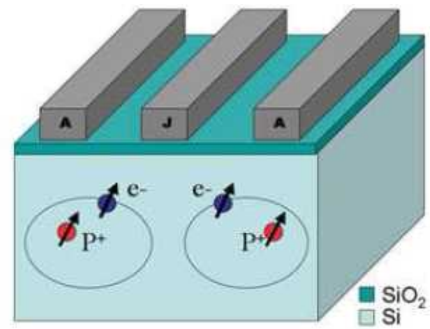
Quantum computing is expected to be extremely efficient for certain problems such as quantum simulations, searching and factoring.

Electrostatically gated quantum dots



Petta, J.R., et al., Science, 2005. **309**(5744): p. 2180-2184.

Single phosphorus dopants for single electron manipulation



University Partners:	Mark Eriksson at U. of Wisconsin
	Sankar Das Sarma, U. of Maryland
	Australian Centre for Quantum Computing Technology
	Steve Lyon, Princeton (CINT user)
	Jason Petta, Princeton (potential CINT user)

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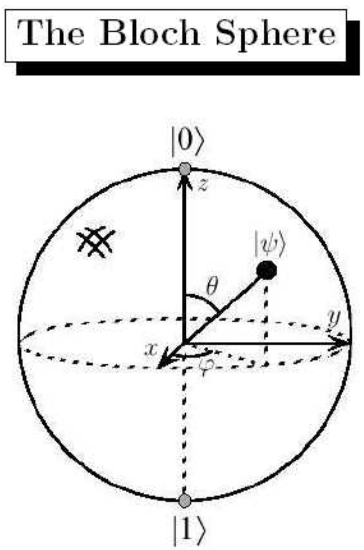
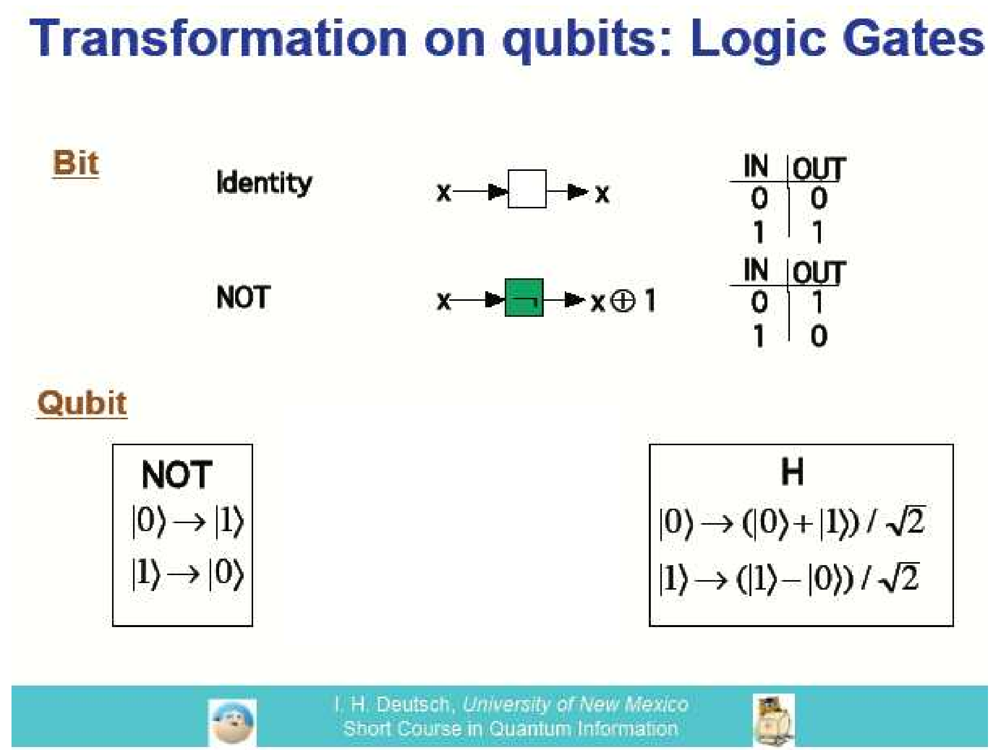
Qubits and Single Qubit Gates





- A quantum bit can be any system that has two energy levels
- The QC information is described with a | 0 > and | 1 > basis
- A Bloch sphere is used to help picture the possible qubit states
- Single qubit gates produce superposition of the eigenstates who have non-zero probability amplitudes in each eigenstate

Entanglement & Quantum Parallelism

Multiple Qubits: The Space Grows Exponentially

E.g. 3-qubits, dim=8

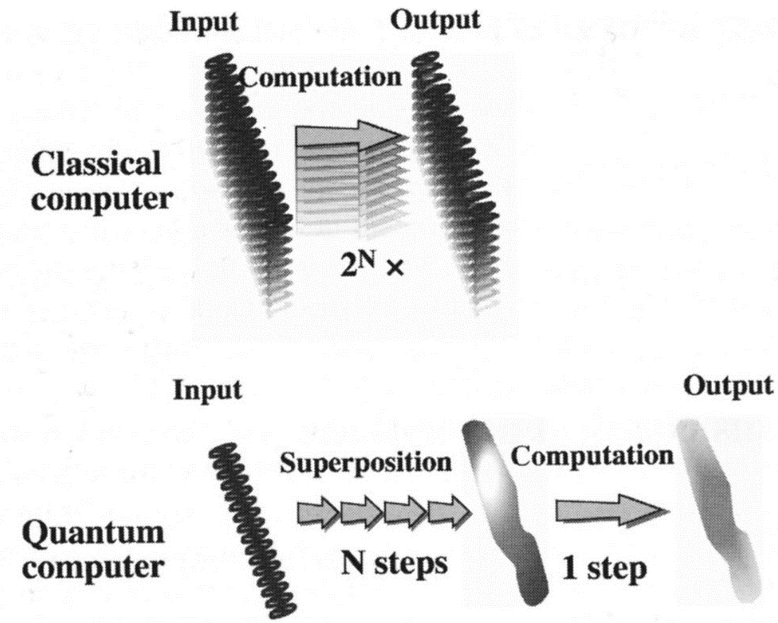
$$|0\rangle = |0\rangle|0\rangle|0\rangle \quad |1\rangle = |0\rangle|0\rangle|1\rangle \quad |2\rangle = |0\rangle|1\rangle|0\rangle \quad |3\rangle = |0\rangle|1\rangle|1\rangle$$

$$|4\rangle = |1\rangle|0\rangle|0\rangle \quad |5\rangle = |1\rangle|0\rangle|1\rangle \quad |6\rangle = |1\rangle|1\rangle|0\rangle \quad |7\rangle = |1\rangle|1\rangle|1\rangle$$

General state: $|\psi\rangle = \sum_{x=0}^{2^n-1} c_x |x\rangle$

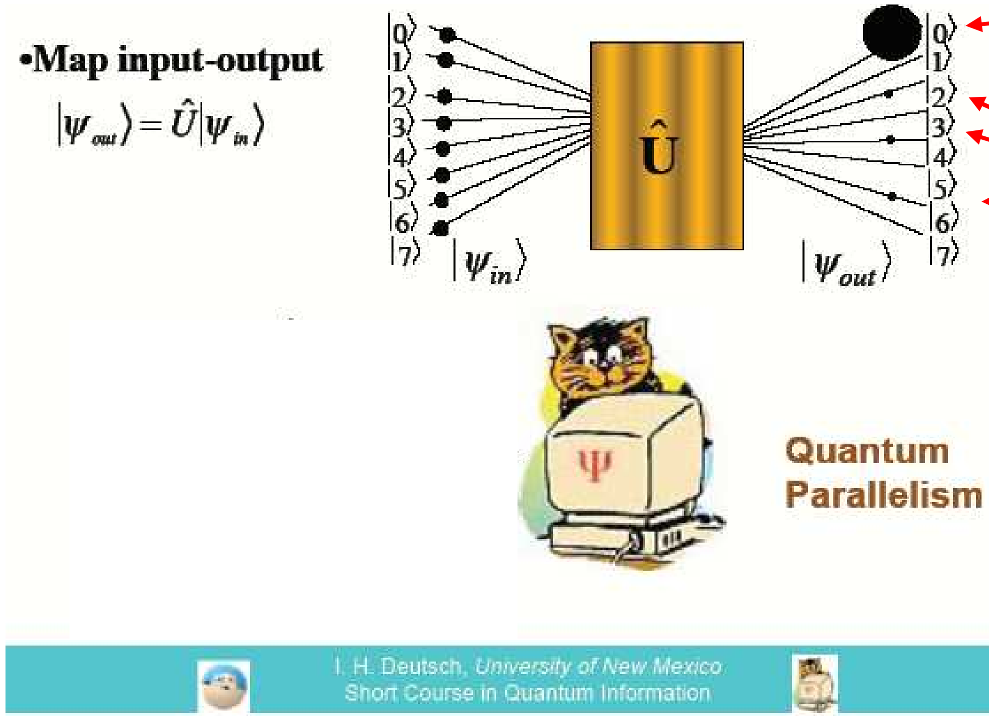
n-qubits: 2^n alternatives

I. H. Deutsch, *University of New Mexico*
Short Course in Quantum Information



- Multiple qubits may be entangled using two qubit gates
- An entangled qubit register (n qubits) can have non-zero probability amplitude in as many as 2^n basis states ***simultaneously!***
- In contrast a classical register with n bits represents 100% probability amplitude in one basis state out of 2^n possible states

Probability Amplification



result (high probability)

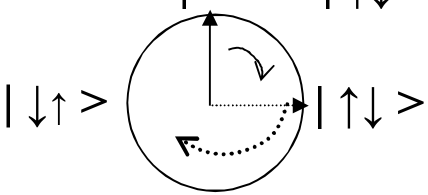
Incorrect search results – check rapidly & discard

- Quantum algorithms can be designed to solve problems more efficiently than classical ones
- Examples are quantum simulations, searches and factoring
- The algorithms are designed to converge on a probabilistic result

GaAs Double Quantum Dot Qubits

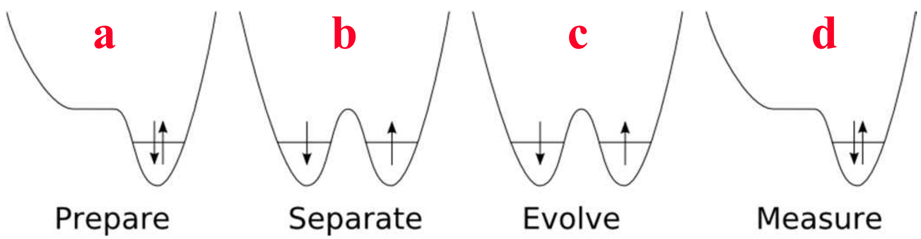
Two Electron Spin Wavefunction

$$|T\rangle = |\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle$$

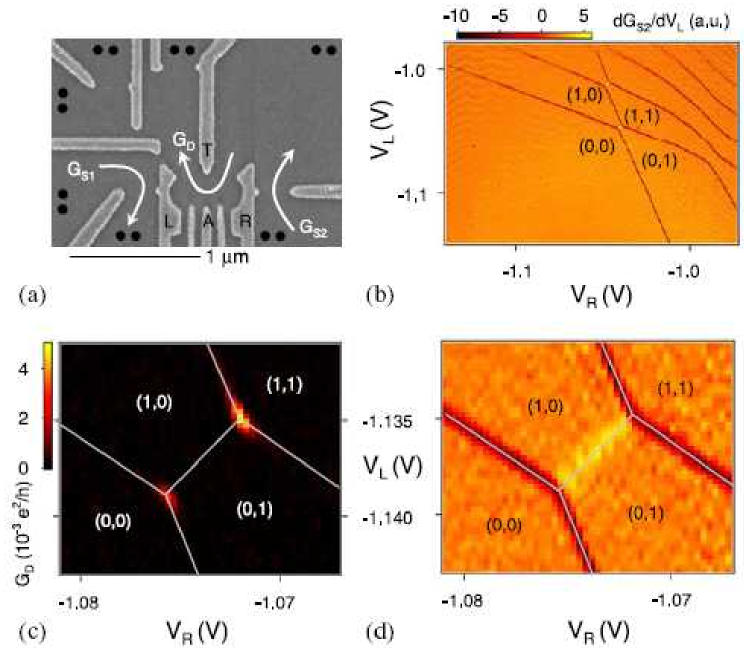


$$|S\rangle = |\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$

Singlet Evolution



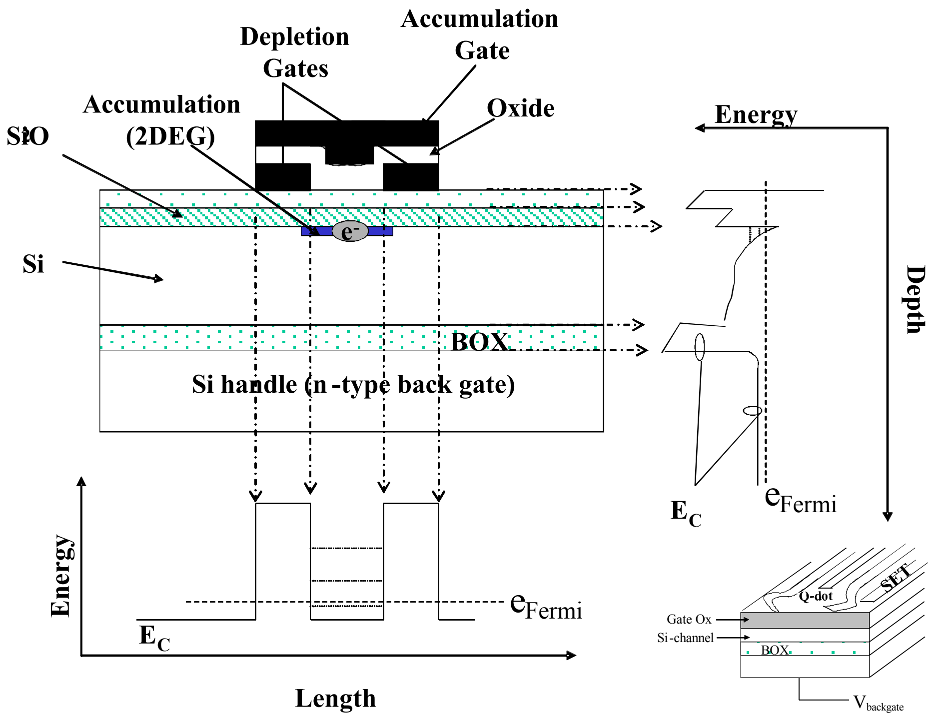
Petta et al., Nature 2005



- **GaAs community showed a singlet-triplet DQD qubit in 2005**
- **Sequence of pulses (a => d) used to initialize and read-out**
- **The state is detected through single charge electrometry**

Problem: short decoherence times (~ 1 µs)!

Electrostatic Gated Si Qubit



- Potential advantages of structure over previous approaches:
  - Gates very close to 2DEG (sharp confinement)
  - Oxide barrier predicted to have larger valley splitting
  - Standard CMOS and high purity (low noise) material integration possible

Si decoherence times are much longer (~60 ms)

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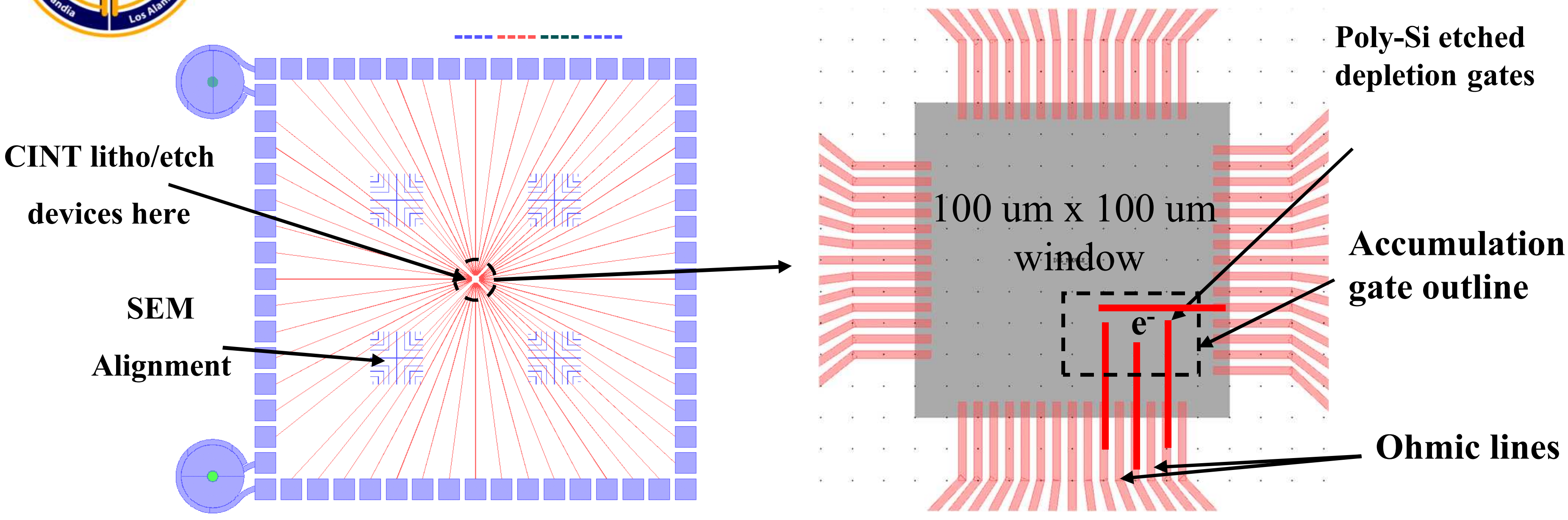
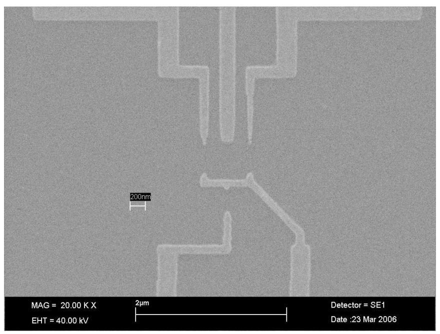
Integration with CINT Discovery Platforms™



- Silicon fab "front-end" creates MOSFET-like structures
- Nanolithography forms quantum dots
- Oxide deposition combined with top metal completes device
- Ohmic contacts are made with buried n^+ layers that the accumulation gate overlaps

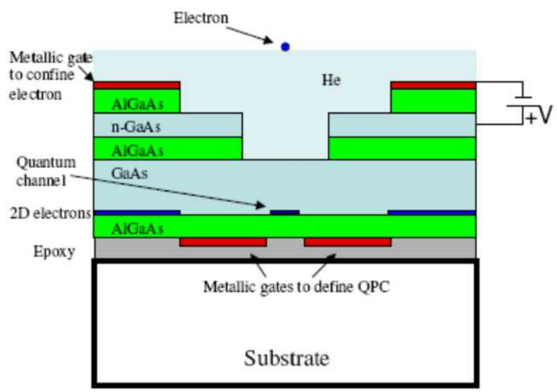
What are we doing today?

CINT Science



- Coupled nanoelectronics
- Electrometers
- Vertical quantum dots

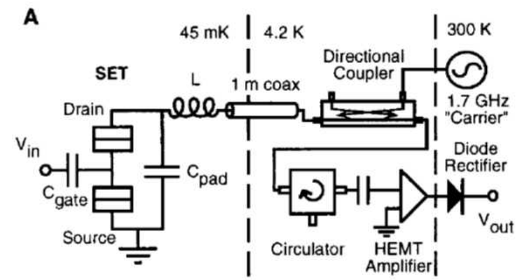
CINT Users



Steve Lyon, *Princeton*

Electron detection on the surface of liquid helium using GaAs quantum wires

CINT Capabilities

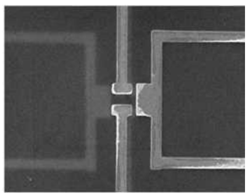


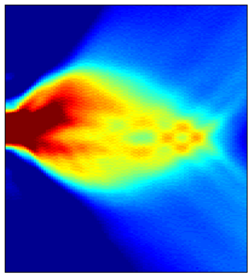
Schoelkopf, Science 1998
rf-SET

Working with our QC collaborators we are setting up capabilities for fast single charge measurements.

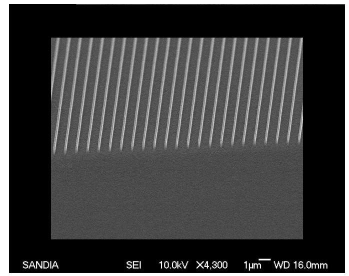
Potential CINT Collaboration

Nanoelectronics for single charge manipulation

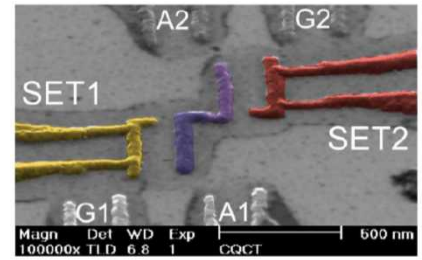




Nanofabrication

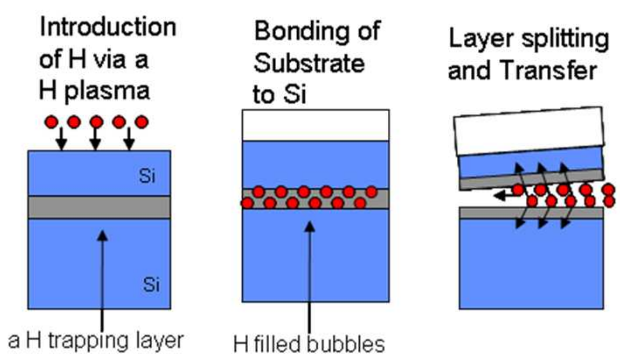


Integration



Center for Quantum Computing Technology (Australia)

Materials, Interfaces and Oxides

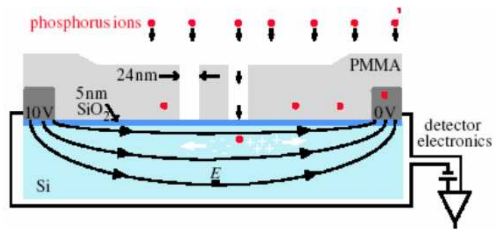


Nanoscale characterization

Potential CINT Collaboration

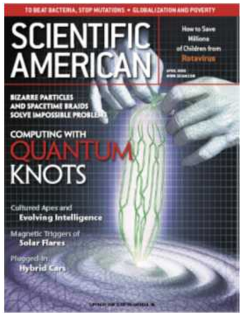
Integration of classical electronics and nanoscale phenomena

- *JFET ion detector*

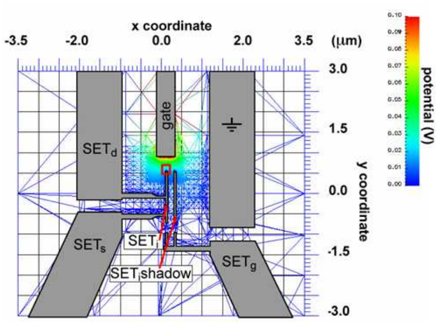


- *On-chip electronic for speed, precision and performance*

High mobility GaAs for measurements and novel approaches



Simulations



Courtesy of CQCT - Australia

CINT Users

- Discovery platform - extend CMOS foundry to nanoscale regime
- Spring 2007 call: Jason Petta, *Princeton*
- Wide range of quantum computing community.

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