Solid State Coherent Transport

Or, Quantum Teleportation

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MARC Talk, 2010-04-22

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Collaborators: Paul, Andrew, Jess, Changyi, Sam, Alberto, ...

Outline

Big Question: Can we demonstrate coherent transport in the solid state?

Parallel Computing

- Scalable quantum simulator
- 1 Google-sized classical simulator ∼ 66 qubits.[1]
- 100 Googles ∼ 72 qubits. 1 million Googles ∼ 86 qubits.

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nature chemistry

Towards quantum chemistry on a quantum computer

B. P. Lanyon[1,2]*, J. D. Whitfield[4], G. G. Gillett[1,2], M. E. Goggin[1,5], M. P. Almeida[1,2], I. Kassal[4], J. D. Biamonte[4†], M. Mohseni[4†], B. J. Powell[1,3], M. Barbieri[1,2†], A. Aspuru-Guzik[4]* and A. G. White[1,2]

Exact first-principles calculations of molecular properties are currently intractable because their computational cost grows exponentially with both the number of atoms and basis set size. A solution is to move to a radically different model of computing by building a quantum computer, which is a device that uses quantum systems themselves to store and process data. Here we report the application of the latest photonic quantum computer technology to calculate properties of the smallest molecular system: the hydrogen molecule in a minimal basis. We calculate the complete energy spectrum to 20 bits of precision and discuss how the technique can be expanded to solve large-scale chemical problems that lie beyond the reach of modern supercomputers. These results represent an early practical step toward a powerful tool with a broad range of quantum-chemical applications.

Lanyon, B. P. et. al, Nat Chem **2**, 106–111 (2010)

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Quantum Sensors

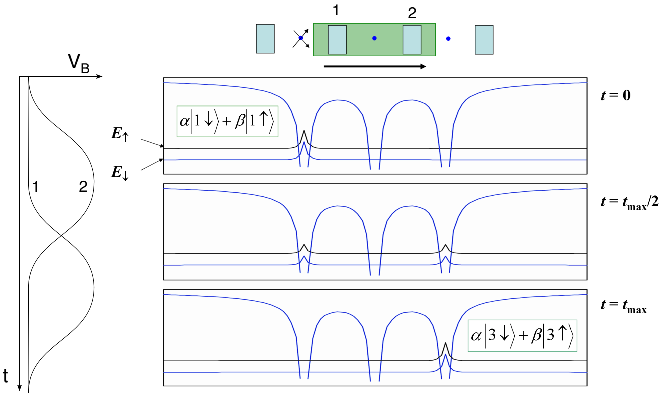
- SQUIDs – Ridiculously sensistive quantum device.
- But what else can we do with quantum sensors?
- Spin-based sensors (Diamond, trapped ion...)

Possible Architectures

Architecture	Coherence	Scalability	Transport	Interact	Manipulation	Manufacture
Kane type	9	9	1	3	4	2
NMR liquid	3	1	1	8?	8	9
Photonic	3	3	9	5	9	8
GaAs QDs	2	8	5	7	9	8
P in Si - e^{-}spin	7	9	3	7	7	3
Ion Traps	9	6	8	6	9	7
Superconductors	5	7	3	5	8	6
Diamond NV	8	7	5	3	7	6

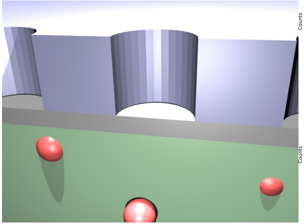
For a more thorough treatment, see the ARDA *Quantum Computation Roadmap*, last updated in 2004

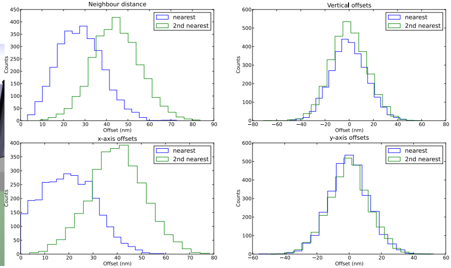
Coherent Transport by Adiabatic Passage

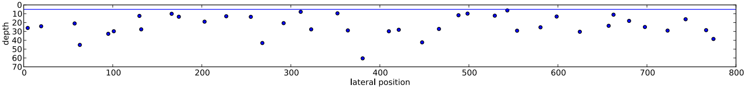


Greentree, Hamilton & Hollenberg, PRB **70**, 235317 (2004)

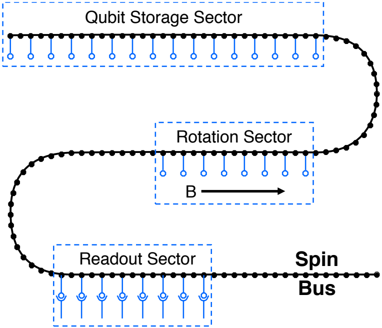
CTAP in practice







Spin Bus



- At very low temperatures, with an odd number of spins, bus state ↑↓↑↓↑ or ↓↑↓↑↓
- Much coupling to outside world?
- Possibility of coupling to many spins at once (good for initialisation)

Figure from: Frieson et. al., PRL **98**, 230503 (2007)
Original idea: Mehring and Mende, PRA **73**, 052303 (2006)

Photonic Coupling and the Flying Qubit

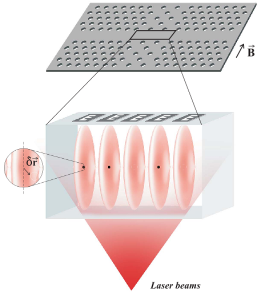
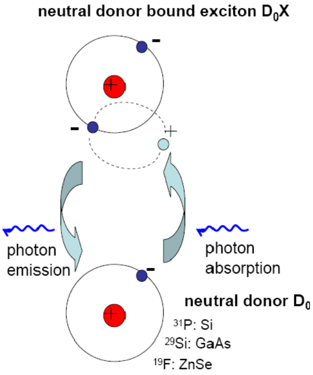


FIG. 1: **Proposed quantum-computer architecture.** Donor impurities are placed in the neighborhood of intensity maxima of a photonic crystal cavity mode, not necessarily every maximum. The donors are under the action of a uniform magnetic field **B** and electric fields **E**,



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Yamamoto et. al., *Physica Scripta* **T137**, 014010 (2009)

EDMR

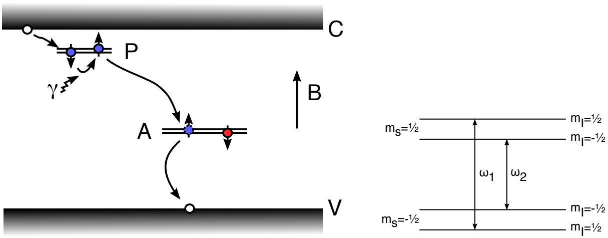


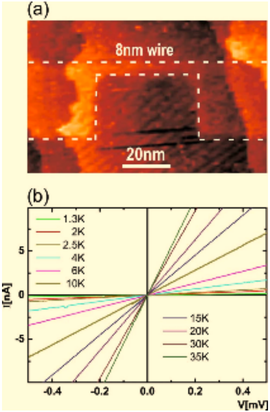
Figure: EDMR Band Structure, and first-order transitions in a spin-1/2 donor.

- Very sensitive, but no single atom yet.
- Laurens van Beverens is a pro!

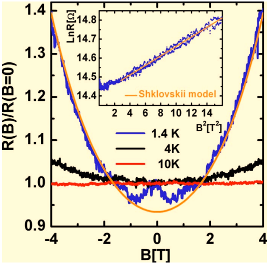
Bottom Up Nanowires

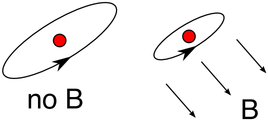
UNSW

- Measured positive (1D Hopping Model) and negative (???) magnetoresistance.



Reuß et. al., APL **92**, 052101 (2008)





- Can we do this with implanted nanowires?

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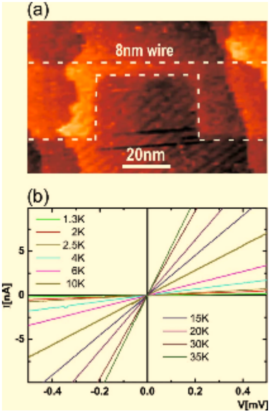

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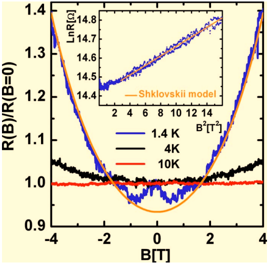

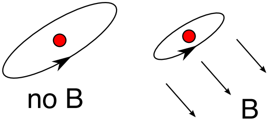

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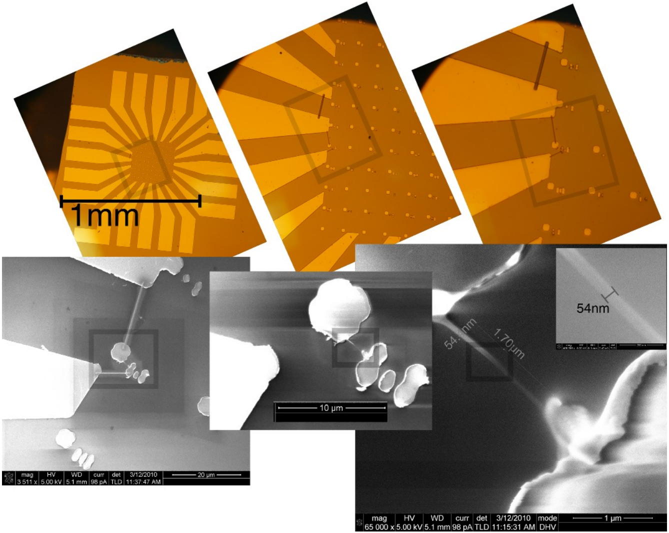
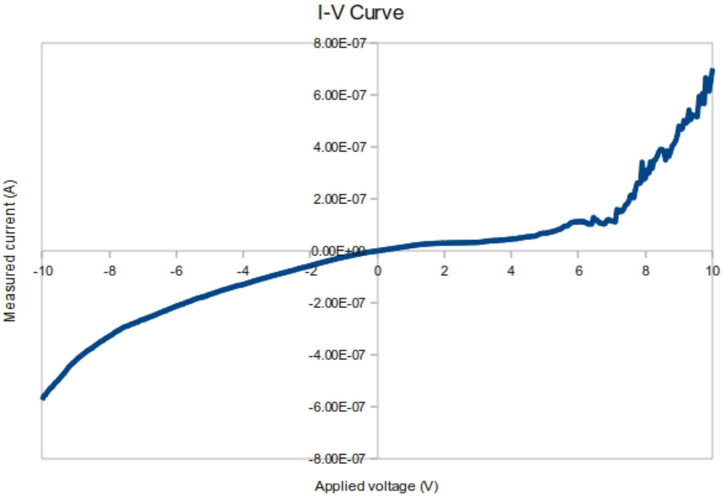
Nanowires

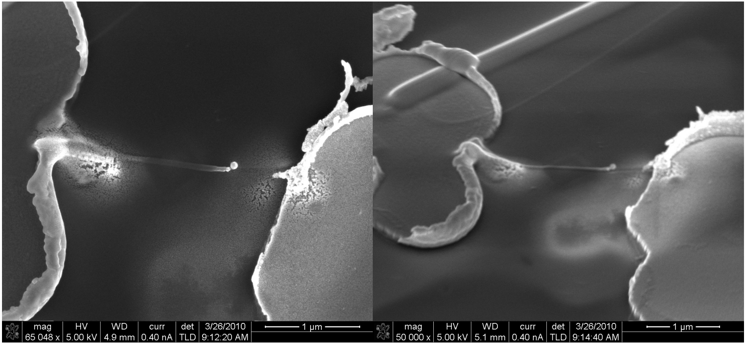


with Paul Spizziri

I-V curve


I-V Curve
8.00E-07
6.00E-07
4.00E-07
2.00E-07
0.00E+00
-2.00E-07
-4.00E-07
-6.00E-07
-8.00E-07
-10
-8
-6
-4
-2
0
2
4
6
8
10
Measured current (A)
Applied voltage (V)

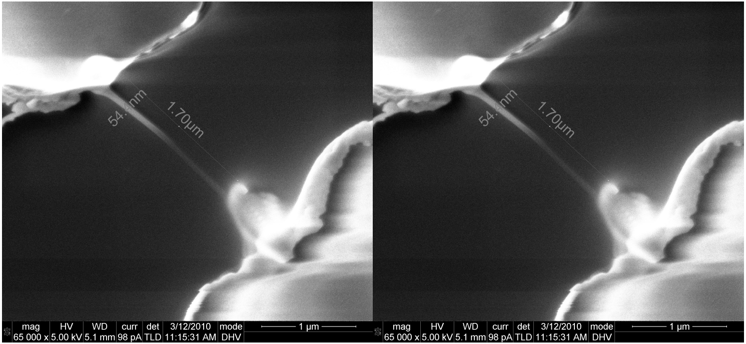
Oops



"Well, at least we know it was conducting!"

For comparison purposes

(Before the wire melted)



Summary

- Quantum Computing is very exciting and worthwhile
- Solid State methods need to demonstrate coherent transport

- Next steps
  - Something interesting with nanowires in the next month or so
  - EDMR on a single donor

Definition of quantum teleportation

Let's have a discussion

Quantum teleportation

From Wikipedia, the free encyclopedia

Quantum teleportation, or **entanglement-assisted teleportation**, is a technique used to transfer quantum information from one quantum system to another. It does not transport the system itself, nor does it allow communication of information at superluminal (faster than light) speed. Neither does it concern rearranging the particles of a macroscopic object to copy the form of another object. Its distinguishing feature is that it can transmit the information present in a quantum superposition, useful for quantum communication and computation.

More precisely, quantum teleportation is a quantum protocol by which a qubit *a* (the basic unit of quantum information) can be transmitted exactly (in principle) from one location to another. The

...

- C. H. Bennett, G. Brassard, C. Crépeau, R. Jozsa, A. Peres, W. K. Wootters, *Teleporting an Unknown Quantum State via Dual Classical and Einstein-Podolsky-Rosen Channels*, Phys. Rev. Lett. **70**, 1895-1899 (1993) (this document online). This is the seminal paper that laid out the entanglement protocol.
- L. Vaidman, *Teleportation of Quantum States*, Phys. Rev. A **49**, 1473-1476 (1994)

Definition of quantum teleportation

Some more references

- First experiments with photons:
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- First experiments with atoms:
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