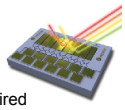
University of Sussex
Ion Quantum Technology Group

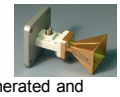
Microfabricated ion trap chip architectures for fault-tolerant operations

Microwave ion quantum technology



Lasers

- Off-resonant scattering
- Precise alignment required
- Amplitude/phase fluctuations
- Numerous mirrors and lenses required for large scale quantum logic



Microwaves

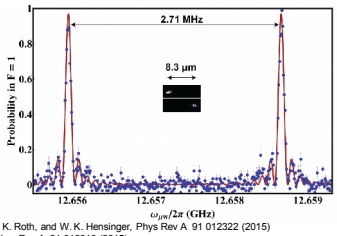
- Stable amplitude/phase
- Easily electronically generated and manipulated
- All frequencies radiated via a single horn from outside the vacuum system
- Single ion addressing and spin-motion coupling with a B-field gradient

Individual qubit addressing

Extremely **low cross-talk** of:

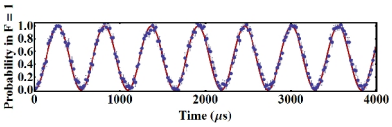
$<2.4 \times 10^{-4}$

Can be further reduced



J. Randall, S. Weidt, E. D. Standing, K. Lake, S. C. Webster, D. Murgia, T. Navickas, K. Roth, and W. K. Hensinger, Phys Rev A 91 012322 (2015)
K. Lake, S. Weidt, J. Randall, E. D. Standing, S. C. Webster, and W. K. Hensinger, Phys Rev A 91 012319 (2015)

Special long-lived qubit and qutrit



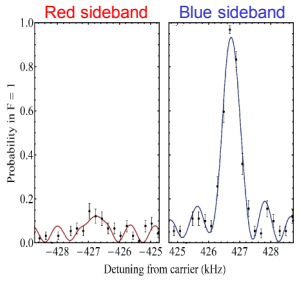
Long qubit **coherence time** of:

> 1s

Coherence time of several seconds possible!

S. C. Webster, S. Weidt, K. Lake, J. J. McLoughlin and W. K. Hensinger, Phys. Rev. Lett. 111, 140501 (2013)

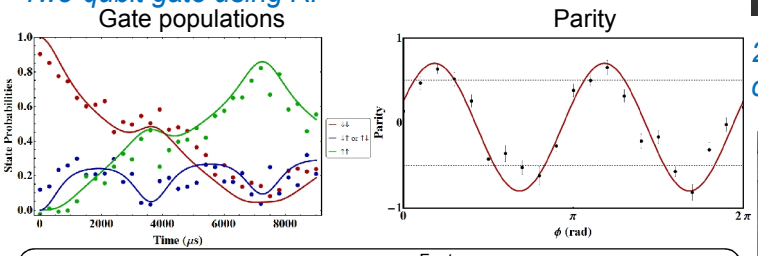
Ground-state cooling using long-wavelength radiation



After Doppler cooling:
$\bar{n} = 65(5)$
After sideband cooling:
$\bar{n} = 0.13(4)$
88% in the ground state

S. Weidt, J. Randall, S. C. Webster, E. D. Standing, A. Rodriguez, A. E. Webb, B. Lekitsch, W. K. Hensinger, arXiv:1501.01562 (2015)

Two-qubit gate using RF



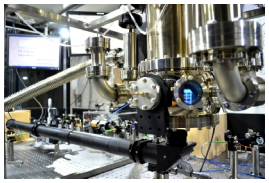
Preliminary results
Current Fidelity: 83%
Expected fidelity of >99% when fully integrated into scalable architecture

Features:
- Simple experimental setup, no ultra-stable or high-power laser systems
- Highly scalable approach

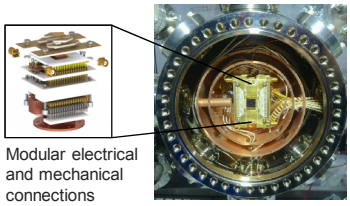
S. Weidt, J. Randall, S. Webster, K. Lake, A. Webb, E. Standing, I. Cohen, A. Retzker, and W. K. Hensinger, in preparation (2015)
I. Cohen, S. Weidt, W. K. Hensinger, A. Retzker, New J. Phys. 17, 043008 (2015)

Supporting technology

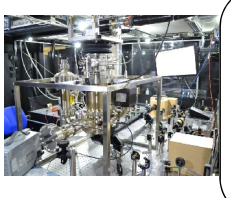
Four experimental setups capable of operating complex ion trap chips



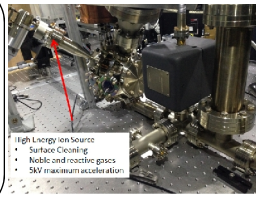
Cryogenic setup operating ion trap chips at 4 K with ultra-low vibration



Modular electrical and mechanical connections



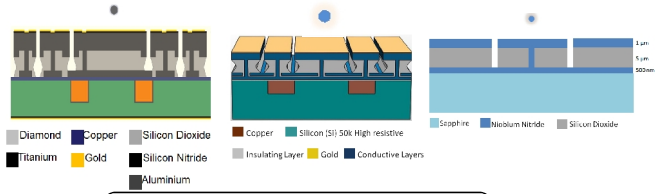
Features:
- One system at 4 K, one at 77 K and two at room temperature
- Ion sputter gun for in-situ ion trap chip cleaning
- Connections for >100 control voltages
- Connections for microwaves/RF/visible



Support for partners

- Development and fabrication of user-defined ion trap chips
- Quantum computer modules
- Microwave quantum technology

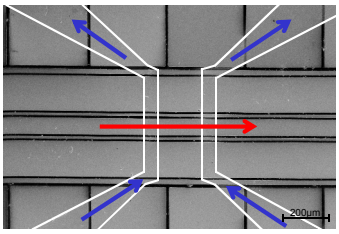
Currently used complex microfabrication processes



In excess of 1000 V can be applied to chips
Various on-chip features can be incorporated

R. C. Sterling, M. D. Hughes, C. J. Mellor and W. K. Hensinger, Appl. Phys. Lett. 103, 143504 (2013).

Strong on-chip gradients for fault-tolerant gates and quantum simulation

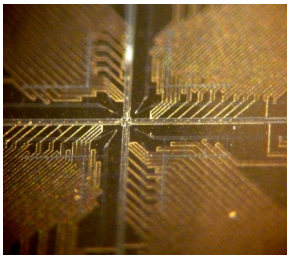


Direction of currents

Direction of magnetic field gradient

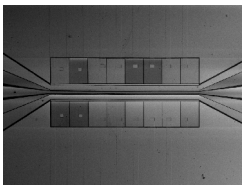
Successfully applied >10 A to our current carrying ion trap chips resulting in a gradient >150 T/m

Junction design for scalable quantum computing



Junctions are fully scalable and can **feature**:
- On-chip detection
- B- field gradients >150 T/m
- On-chip electronics
- Microwave waveguide/cavity
- On-chip loading

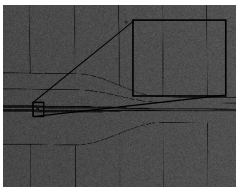
On-chip waveguides and cavities



Superconducting cavity with a **measured Q** of:

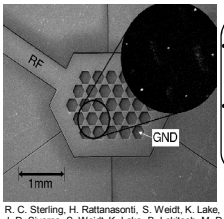
> 6000

Vertical shuttling capabilities



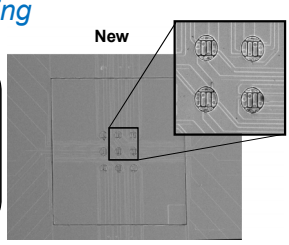
2D lattices for sensing, quantum simulation and cluster state quantum computing

Our previous result



- Ion-ion separation as low as 40 um.
- Can be scaled to many more ions

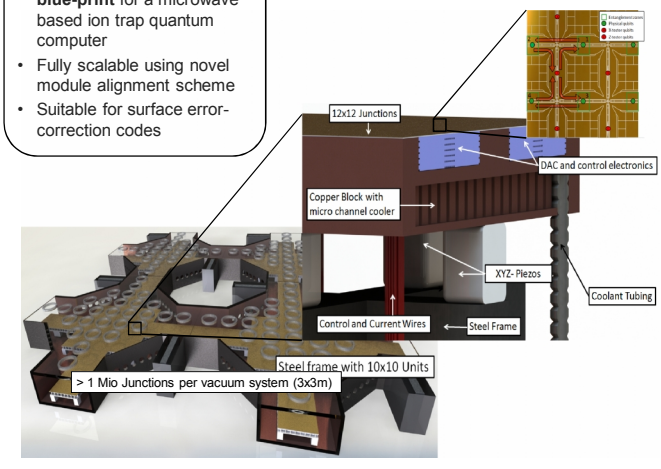
New



R. C. Sterling, H. Rattanasonti, S. Weidt, K. Lake, P. Srinivasan, M. Kraft and W. K. Hensinger, Nat. Comm. 5, 3637 (2014)
J. D. Siverns, S. Weidt, K. Lake, B. Lekitsch, M. D. Hughes and W. K. Hensinger, New J. Phys. 14, 085009, (2012)

Building a prototype microwave based ion trap quantum computer

- We have developed a **blue-print** for a microwave based ion trap quantum computer
- Fully scalable using novel module alignment scheme
- Suitable for surface error-correction codes



B. Lekitsch, S. Weidt, K. Molmer, Ch. Wunderlich, W. K. Hensinger, in preparation (2015)