Superconducting Qubit Storage and Entanglement with Nanomechanical Resonators

![Qubit diagram](http://qoqms.phys.strath.ac.uk/figures/qubit.png)

**Group 7**
AmberRose Lennox, Pin-Yi Li, Yao Li, Colin Lualdi
*Department of Physics, University of Illinois at Urbana-Champaign*
PHYS 596, December 8, 2017
Requirements for Quantum Computing Devices

Quantum computing devices need:

1) Controllable and scalable entanglement schemes of multiple qubits

N classical bits store $N$ bits of information, while $N$ qubits store up to $2^N$ “bits” of information when all qubits are fully entangled.

1) Qubits with sufficient quantum coherence lifetime (~ hundreds of ns)

\[ |c\rangle = \frac{1}{\sqrt{2}} (|0\rangle + e^{i\phi}|1\rangle) \]

Decoherence loses information to the environment

1) Qubit storage and transfer devices with sufficient quantum coherence lifetime

Motivation | Background | Previous Work | What’s New | Significance | Methods | Results | Conclusions | Critique
Using Josephson Junction as a Qubit

**Josephson Junction**

Quasi-bound states with energies $\epsilon_m$

Lowest states ($|0\rangle, |1\rangle$) define phase qubit

Tunable energy gap $\Delta E = \epsilon_1 - \epsilon_0$

Many types of resonators are candidates for this JJ-Resonator architecture:

- Mechanical/Electromagnetic/Superconducting
- Solid/Cavity
Previous Work

- Long-lived coherent oscillation between quantum states had been produced in Josephson junctions. Lifetime ~ 5μs.

- Use of electromagnetic and superconducting resonators to couple multiple Josephson junctions was proposed

- Coupling scheme between beam resonator and charge qubit was proposed
Previous Work

Motivation | Background | Previous Work | What’s New | Significance | Methods | Results | Conclusions | Critique
Novel Features of this Architecture

- Uses *piezoelectricity* - a mechanical resonator, rather than electromagnetic or superconducting.

- Use of aluminium nitride (AlN) film.

- Potential to greatly increase the quality factor.

(Quartz watches use piezoelectricity!)
Significance of Architecture

- Short quantum coherence lifetimes are one of the biggest obstacles to quantum computing.

- Want to improve the coherence time of the resonator.

- Use of integrated-circuit mechanical resonators approach allows access to smaller dimensions.
Proposed Quantum Information Architecture

Quantum Information Processing (QIP) Operations

Tuning level spacing $\Delta E$ of JJ into resonance with $\hbar \omega_0$ of resonator $\rightarrow$ electromechanical Rabi oscillations

Motivation | Background | Previous Work | What’s New | Significance | Methods | Results | Conclusions | Critique
Demonstrated large $Q$ for AlN dilatational resonator

Long energy lifetimes (300 ns) required for Quantum Information Processing operations feasible!
Simulations of Quantum Information Processing Operations

1. Qubit Storage:

- **Successful Storage**
- **Incorrect Bias Current Profile, Storage Fails**
- **Larger Resonator, Storage Performs Poorly**

*Qubit storage in resonator: probabilities of \( |10\rangle \) and \( |01\rangle \) states*
2. **Qubit Transfer:**
   a. Store JJ state into resonator.
   b. Read out same state into 2nd JJ.

3. **Qubit Entanglement:**
   a. Create $|100\rangle + |001\rangle$ superposition.
   b. Swap resonator and 2nd JJ states.
Conclusion: Architecture is Feasible

1. The feasibility of the architecture
2. Preview paper introduced the new architecture, and follow up paper discusses actually building it. The initial idea is a solid prototype of continuing research, and the following paper has been cited 1386 times.
Follow-up paper: 1386 times.
NATURE. Vol 464, 697-703. April 2010
Critique: Preview Paper Tries to “Do it All”

1. Limited discussion on noise and background analysis.

2. Needed to read a lot of extra references (not suitable for PRL).

3. Did not communicate the motive clearly.

4. The abstract is not very clear: no conclusion added and no explanation of significance for quantum information technology.

5. As a preview paper, authors tried to address too many details in too short of a paper.
Summary

- Challenge of creating scalable quantum information architectures with long coherence times may be addressed with the use of coupled Josephson Junctions.

- Nanomechanical resonators have sufficiently high quality factors to serve as coupling devices between Josephson Junctions.

- Theoretically demonstrated the feasibility of performing quantum information processing operations with this architecture.

- Good paper, but tries to accomplish too much as a preview paper.