Challenges & Opportunities for Developing Superconducting Quantum Information Systems

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Developing large-scale quantum information processors has become a major industrial goal over the last few years. Of the many quantum systems available to tackle this difficult task, superconducting circuits have shown impressive results thus far and appear to be posed to scale up rapidly. In fact, systems with over 1,000 superconducting qubits have already been built and operated. [1] Although scaling the number of qubits as well as the infrastructure to control and measure them is an outstanding challenge, it seems that individual qubit coherence still must improve in order to lower the overhead required to successfully perform quantum error correction, vital for quantum computations. About 20 years ago [2], two-level system defects were found to reside in qubit Josephson junctions: "We report spectroscopic data that show a level splitting characteristic of coupling between a two-state qubit and a two-level system. …Although two-level systems are known to exist in amorphous materials, the sensitivity of our Josephson qubit at the quantum level has allowed us to uncover individual two-level microwave resonators hidden within a 40-yearold technology. …We predict that improvements in the coherence of all Josephson qubits will require materials research directed at redistributing, reducing, or removing these resonator states." Since that time, coherence has improved tremendously, but two-level system defects not only in the tunnel junction but residing at all material interfaces continue to pose a significant challenge.

In this presentation, I will provide a basic introduction to superconducting qubits, their fabrication, measurement, and coupled operations. Then, I will focus on some of the difficulties associated with developing superconducting circuits for large scale quantum information processors. Specifically, I will provide a historical overview of early measurements that showed the influence of individual two-level system point defects on qubit operations. In addition, distributions of these defects on surfaces can also work collectively to degrade the coherence of quantum circuits. Even with these defects present, enormous progress has been made thus far in developing quantum information processors. Tackling the remaining materials science challenges associated with fabricating superconducting quantum circuits could lead to a new understanding of creating clean material systems or finding ways to engineer microwave two-level defects as coherent qubits.

[1] https://www.scientificamerican.com/article/ibm-releases-first-ever-1-000-qubit-quantum-chip/
[2] R.W. Simmonds, K.M. Lang, D. A. Hite, S. Nam, D. P. Pappas, and John M. Martinis, Phys. Rev. Lett. **93**, 077003 (2004)

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