Materials and Processes for Quantum Computing Focus Topic
Room 203A - Session MP+AM+EM+NS-MoA
Systems and Devices for Quantum Computing II

Moderator: Josh Mutus, Google Inc

1:20pm **MP+AM+EM+NS-MoA-1 Quantum Engineering of Superconducting Qubits**, ***William Oliver,*** MIT Lincoln Laboratory **INVITED**

Superconducting qubits are coherent artificial atoms assembled from electrical circuit elements and microwave optical components. Their lithographic scalability, compatibility with microwave control, and operability at nanosecond time scales all converge to make the superconducting qubit a highly attractive candidate for the constituent logical elements of a quantum information processor. Over the past decade, spectacular improvement in the manufacturing and control of these devices has moved superconducting qubits from the realm of scientific curiosity to the threshold of technical reality. In this talk, we review this progress and our own work at MIT that are creating a future of engineered quantum systems.

2:00pm **MP+AM+EM+NS-MoA-3 The Quantum Socket: A Wiring Method for Superconducting Quantum Computing**, ***Matteo Mariantoni,*** University of Waterloo, Canada **INVITED**

I will provide a brief introduction to the main technological and scientific challenges to be faced in order to build a practical quantum computer, with emphasis on the case of superconducting quantum computing. I will then delve into a detailed explanation of a method to address the wiring of a two-dimensional array of superconducting quantum bit (qubits): The quantum socket [1]. Next, I will show how the quantum socket can be extended to a medium-scale quantum computer and how it can help mitigate coherent leakage errors due to qubits interacting with spurious cavity modes [2]. I will then show thermocompression bonding technology [3], a method that allows us to further protect qubits from the environment. In particular, I will propose a new qubit design based on our experimental implementation of thermocompression bonded chips, where vacuum gap capacitors are used to reduce dissipation due to so-called two-level state defects in amorphous dielectrics, which are the insulators presently use in our qubits.

[1] J.H. Béjanin, T.G. McConkey, J.R. Rinehart, J.D. Bateman, C.T. Earnest, C.H. McRae, Y. Rohanizadegan, *D. Shiri*, B. Penava, P. Breul, S. Royak, M. Zapatka, A.G. Fowler, and **M. Mariantoni**, Three-Dimensional Wiring for Extensible Quantum Computing: The Quantum Socket, Phys. Rev. Applied **6**, 044010 (2016)

[2] T.G. McConkey, J.H. Béjanin, C.T. Earnest, C.R.H. McRae, Z. Pagel, J.R. Rinehart, **M. Mariantoni**, Mitigating Coherent Leakage of Superconducting Qubits in a Large-Scale Quantum Socket, Quantum Sci. Technol. 10.1088/2058-9565/aabd41 (2018)

[3] C.R.H. McRae, J. H. Béjanin, Z. Pagel, A.O. Abdallah, T.G. McConkey, C.T. Earnest, J.R. Rinehart, and **M. Mariantoni**, Thermocompression Bonding Technology for Multilayer Superconducting Quantum Circuits, Appl. Phys. Lett. **111**, 123501 (2017)

2:40pm **MP+AM+EM+NS-MoA-5 Pogo Pin Packaging for High Coherence Qubits**, ***Nicholas Bronn***, *V Adiga, S Olivadese, O Jinka,* IBM, T.J. Watson Research Center*; X Wu,* National Institute of Standards and Technology*; J Chow,* IBM, T.J. Watson Research Center*; D Pappas,* National Institute of Standards and Technology

The connectivity between qubits in large superconducting quantum processors prevents the qubits from being addressed by control lines routed to the edge of the chip. In these nontrivial circuit topologies, internal qubits must instead be coupled to control and measurement electronics by a nonplanar technique. Here we present a pogo package consisting of commercially available parts and requiring modest machining tolerances. Through careful engineering of the package for cryogenic and microwave considerations, we measure high coherence times and gate fidelities for qubits in a quantum processor connected by pogo pins. This work was supported by IARPA under contract W911NF-16-1-0114-FE.

3:00pm **MP+AM+EM+NS-MoA-6 50 Ohm Superconducting Kinetic Inductance Traveling-Wave Amplifier with flexible pump frequency for Four Wave Mixing and Three Wave Mixing**, ***Xian Wu***, *M Bal, J Long, H Ku, R Lake, D Pappas,* National Institute of Standards and Technology

We developed a 50 Ohm transmission-line based superconducting kinetic inductance traveling-wave (KIT) amplifier using high inductance material NbTiN. The nonlinearity originates from the kinetic inductance of the superconductor and enables amplification. Often, the impedance of the transmission line is significantly higher than the 50 Ohm microwave environment due to the dominance of kinetic inductance over geometric inductance at micron size scales. To address this impedance mismatch, we engineered "fingers" on each side of the original coplanar waveguide KIT [1] to introduce extra capacitance that decreases the impedance to approximately 50 Ohm [2,3]. Those extra "fingers" also function to create a band stop at higher frequency to bend the dispersion relation between wave vector (k) and frequency (f), which allows us to apply the pump frequency within a wide span of a few GHz and achieve several GHz gain bandwidth for chosen pump frequency. Another advantage of this structure is that it significantly reduces the phase velocity, hence shortening the physical length of this device. Gain measurements based on both four wave mixing and three wave mixing will be presented.

[1] Appl. Phys. Lett. **108**, 012601 (2016); https://doi.org/10.1063/1.4937922

[2] Journal of Applied Physics **119**, 083901 (2016); https://doi.org/10.1063/1.4942362

[3] Appl. Phys. Lett. **110**, 152601 (2017); https://doi.org/10.1063/1.4980102

3:40pm **MP+AM+EM+NS-MoA-8 Near Term Development of Short Depth Quantum Processors**, ***Jerry Chow,*** IBM Research Division, T.J. Watson Research Center **INVITED**

Quantum processors are currently in their infancy though the community is poised to explore bringing them to a state where they can outperform classical computations in relevant application. The challenges that lie ahead are plentiful and touch all aspects of the quantum computer, ranging from finding algorithms to building control software and control hardware as well as engineering and fabricating and testing the quantum hardware. In an effort to accelerate the development of quantum computing IBM launched the IBM Q experience. The Q Experience is a cloud-based platform which allows anyone to get familiar with quantum computing. It allows users to run experiments on actual quantum hardware.

In this talk I will focus on the development and characterization of short depth superconducting quantum hardware. Crosstalk and decoherence are some of the most pressing issues that we face today. Decoherence limits the number of operations that can be performed on the hardware (the depth of the circuit) whereas crosstalk can limit what operations can be performed in parallel on the circuit. The processors featured on the IBM Q experience are based on fixed frequency transmon qubits with a cross-resonance based two qubit gate. For this platform only a very narrow frequency range for the qubits is possible. This leads to problems related to frequency crowding and spurious interactions. Methods for characterizing and addressing both the frequency allocation and characterizing crosstalk will be discussed.

4:20pm **MP+AM+EM+NS-MoA-10 Frequency Crowding in Lattices of Transmon Qubits**, ***Sami Rosenblatt***, *J Hertzberg, J Chavez-Garcia, N Bronn, H Paik, M Sandberg, E Magesan, J Smolin, J Yau, V Adiga, M Brink, J Chow,* IBM, T.J. Watson Research Center

A key goal in quantum computing is to develop scalable fault-tolerant quantum logic circuits. One promising architecture involves lattices of fixed-frequency transmon qubits coupled via cross-resonance gates. Fixed-frequency qubits offer high coherence and the all-microwave gate reduces circuit complexity. To optimize gate performance, excitation energies of neighboring qubits must be similar but non-degenerate. This architecture is thus sensitive to any variation in device parameters affecting transmon frequency. In this talk we will discuss a statistical model for the resulting 'frequency crowding' behavior, and suggest improvements in both architecture design and qubit fabrication in order to achieve scalable circuits with good gate fidelity.

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