Abstract Title: Multimodal electron microscopy for unravelling structure-coherence relationship in superconducting quantum materials and systems

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Abstract

The quest of building quantum computers requires concert discoveries in materials science, device fabrication and quantum architecture. Recently superconducting qubits (transmons) have achieved millisecond coherence time; however, it is still far from demonstrating a reliable and high-fidelity quantum supremacy. The difficulties in understanding the structure-coherence relationship in a transmon stem from the complex nature of different interfaces in the device, such as metal-air interface in a 3D cavity and superconducting lead-substrate interface in a 2D Josephson Junction, which eventually entangle into a variety of two-level-system loss channels.

This talk presents our recent efforts in understanding the structure-coherence relationship in two most important components of a niobium-based transmon, using multimodal electron microscopy. The first part of my talk concerns defects in Nb thin films, namely niobium oxide and niobium hydride, which are commonly found during the material synthesis and processing and are considered as typical sources of loss in a superconducting qubit. We use 4D-STEM to unravel the nanoscopic distribution of these two phases in Nb polycrystalline thin films, especially dynamics of niobium hydride’s phase transformation at cryogenic (LHe) temperature. Secondly, I will show a combination study using core-loss EELS and 4D-STEM to investigate chemical composition, bonding environment, and nanoscale structure of amorphous materials at Al-AlOx-Al and Al-Si substrate interfaces in a Josephson Junction. Our electron microscopy findings are correlated with macroscopic measurements,
such as X-ray diffraction, X-ray reflectivity and electrical characterizations to provide a comprehensive understanding of potential influences of atomic-scale quantum disorders in superconducting materials on the coherence time of superconducting qubits. Our multimodal electron microscopy approach presents atomic-scale insight that can help inform efforts to mitigate decoherence sources in superconducting qubit devices.