Van der Waals Materials for Superconducting Quantum Technology

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Abstract

Van der Waals (vdW) materials – a family of layered materials including semi-metals, insulators, semiconductors, ferromagnetic materials, superconductors, and topological insulators - can be assembled in specific arrangements to create new electronic devices called vdW heterostructures. The extraordinary and versatile electronic properties of these heterostructures, in combination with their epitaxial precision, make vdW-based devices a promising alternative for constructing key elements of novel solid-state quantum computing platforms. In this talk, I will discuss hybrid superconducting quantum circuits made with vdW heterostructures, with relevance to advancing or complementing existing quantum technologies. In particular, we study the dielectric loss of hexagonal boron nitride (hBN) thin films in the microwave regime by measuring the quality factor of parallel-plate capacitors (PPCs) made of $NbSe_2$-hBN-$NbSe_2$ heterostructures integrated into superconducting circuits. The extracted microwave loss tangent of hBN is bounded to be at most in the mid-10^{-6} range in the low temperature, single-photon regime. We integrate hBN PPCs with aluminum Josephson junctions to realize transmon qubits with coherence times reaching 25 μs, consistent with the hBN loss tangent inferred from resonator measurements. The hBN PPC reduces the qubit feature size by at least two-orders of magnitude compared to conventional all-aluminum coplanar transmons, while exhibiting a high energy participation that helps to reduce unwanted qubit cross-talk. Such a lumped element device made with vdW materials is elemental for building all-vdW, merged-element qubits for extensible quantum computing schemes.

References

[1] J. I-J. Wang, D. Rodan-Legrain et al., Nature Nanotechnology **14** (2019) 120-125.

[2] J. I-J. Wang, M. A. Yamoah et al., Nature Materials **21** (2022) 398–403.

Figures

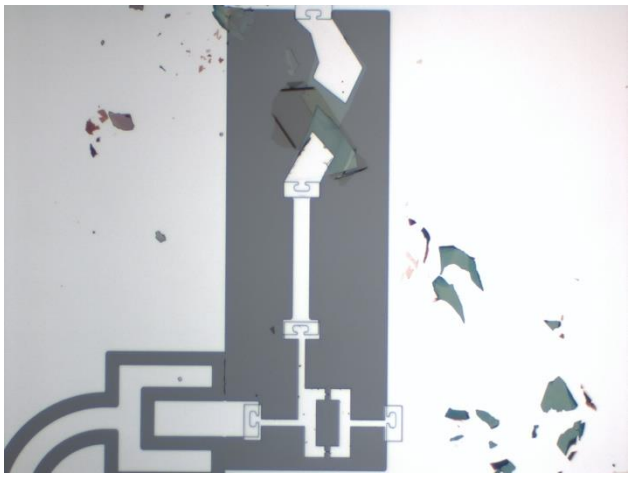

Figure 1: Parallel plate capacitor (PPC) made with $NbSe_2$-hBN-$NbSe_2$ heterostructures. The lumped element device serves as a shunt capacitor for a transmon qubit.