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Enhancing niobium films for SRF and quantum applications

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Niobium films are crucial for superconducting radiofrequency cavities and two-dimensional superconducting transmon qubits. However, performance issues such as the medium-field Q-slope in Nb film cavities and microwave dissipation in qubits persist. To identify the limiting factors in Nb film performance, we used DC biased high-power impulse magnetron sputtering to deposit niobium films onto a 1.3 GHz single-cell elliptical bulk niobium cavity. By systematically modifying the material properties and microstructure through annealing, we identified the key limiting parameters. Annealing at 340℃ raised the quench field from 10.0 to 12.5 MV/m, while treatments at 600 ℃ and 800 ℃ for 3 hours increased it to 15.3 MV/m. Extending to 6 hours at 800 ℃ further improved the quench field to 17.5 MV/m. Reduced field-dependent losses were linked to the mitigation of hydrides, local misorientation, and defects. Using the same cavity to isolate Nb film losses from other materials in the qubit allowed us to pinpoint losses due to the Nb film and the metal-air interface. Operating the cavity in the quantum regime, we correlated RF losses to material parameters. The microwave dissipation mimicked the high intrinsic Q0 of bulk Nb cavities, with lifetimes extending into seconds. Nb film microstructure and impurity levels had minimal impact, with the oxide layer being the primary limitation in qubit performance. These findings advance efficient SRF technologies and extend qubit coherence times.

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Footnotes

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