High-Q Ta-based microwave resonators for quantum applications

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Abstract: High-Q Ta-based microwave resonators are key elements for qubit development. We have designed, realized and tested a number of such devices, using different materials and substrates, obtaining Q values in excess of 10^6.

We aim at developing thin film superconducting resonators for application to quantum technologies with the goal of obtaining high-quality factors in the few photon regime. We employ non-traditional materials, such as tantalum, to design and fabricate the resonator structures. We have designed and simulated, in the frequency range 4 to 8 GHz, the response of several λ/4 coplanar resonators, each coupled to a common coplanar transmission line through interdigital capacitors. We have fabricated a number of test chips using as substrates single crystal C-plane Sapphire. We realized samples with a single 200 nm Ta layer and a with a 20/200 Nb/Ta bilayer.The Ta samples were fabricated on the high-vacuum system with a cryogenic pump and equipped with two chambers separated by vacuum door. The main chamber contains three DC magnetron sputtering sources, namely, Nb, Ta and Al. The Nb underlayer was deposited with thickness of 20 nm. The 200 nm Ta layer was deposited in situ with a deposition rate of 2.0 nm/s at room temperature. The resonator geometry was patterned by the Reactive Ion Etching process in CF_4/O_2 mixture plasma.

The superconducting devices have been characterized in a 300mK ^{3}He cryostat equipped with microwave feeds having 18 GHz bandwidth. The RF circuit include cryogenic attenuators to limit the number of photons fed in the cavity, a circulator, a 4K HEMT and a room temperature low noise amplifier to insulate and amplify the device output signal. The frequency response of the resonators has been measured using a 26 GHz Vector Network Analyzer and the complex S21 curves fitted to remove the effects of delay and attenuations due to the feeding circuitry, as well as the effect of the coupling capacitor and to compute the intrinsic Q of the cavity.

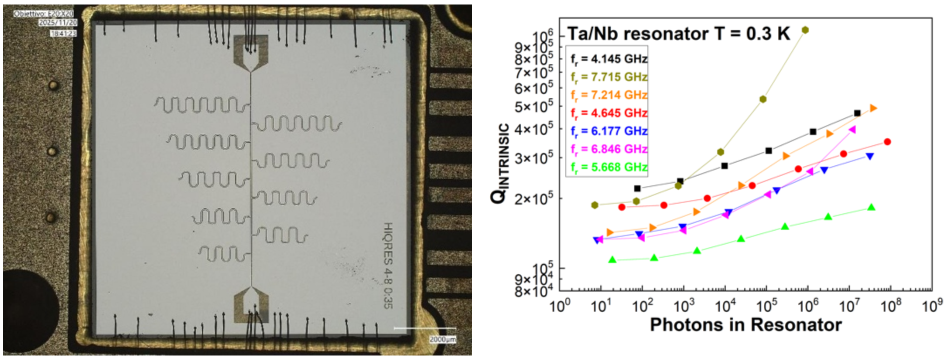

Fig. 1 (Left) Chip mounted in the sample holder and consisting of a coplanar line capacitively coupled to 9 coplanar λ/4 resonators. The resonator frequencies range from 4 to 8 GHz in 0.5 GHz steps. (Right) Measured intrinsic quality factor of the different resonators in a Nb/Ta bilayer sample at T = 0.3 K.

In Fig.1 left is shown one of the tested Ta resonator chips mounted on the chip holder and wire bonded to the RF feed lines. Fig. 1 right shows the measured intrinsic quality factor of a resonator chip for various input powers, corresponding to different number of photons in the cavity. In this case the resonators were formed by the Nb/Ta bilayer and has shown quality factor reaching 10^6 even after several months since fabrication and storage in air. This is remarkable, considering the strong decrease in performances exhibited by Al and Ta based resonators due to surface oxidation when left in ambient conditions.