Avoiding two-level-system losses in superconducting niobium resonators using gold capping layer

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Abstract
Superconducting resonators are critical components in various quantum technologies, including high-performance detectors and amplifiers. However, their performance is often limited by noise and sensitivity issues caused by two-level systems (TLS) originating from oxide layers, such as Nb_2O_5, in the device.
To address this challenge, we investigate a superconducting device combining a 100 nm niobium (Nb) circuit, including twelve Lumped Element Resonators (LERs) with a 10 nm gold (Au) capping layer, which effectively avoids oxide formation and reduces TLS density.
Our study explores the device's performance across a broad range of temperatures and driving powers. Compared with an uncapped device, we demonstrate that the Au capping layer maintains high internal quality factors while enhancing the kinetic inductance [1], which is crucial for the resonator response as a detector. These findings highlight the potential of Nb/Au lumped element resonators for applications where TLS noise mitigation is critical. While this work does not explore the single-photon regime, it provides valuable insights into improving resonator performance by addressing material-specific limitations, paving the way for more robust and efficient superconducting devices.

References

[1] M. C. de Ory, et al., arXiv:2401.14764v4 (2024)
[2] C. R. H. McRae, et al., *Appl. Phys. Lett.* **116**, 194003 (2020)

Figures

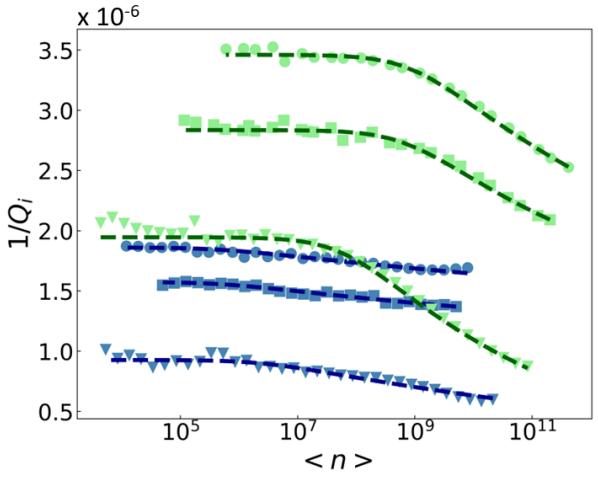

Figure 1: Inverse of the internal quality factor as a function of the number of photons for six resonators. Three resonators are made of uncapped Nb and the other three of Nb are capped with a 10 nm Au layer. Green symbols represent experimental data for the Nb resonators and blue symbols for the Nb/Au ones. Resonators sharing symbol types (circles, squares, triangles) share the same design. Dashed lines (dark green for Nb and dark blue for Nb/Au) show the fits performed using a general model for weak-field TLS loss [2] upon the experimental data. Measurements have been obtained at 10 mK.

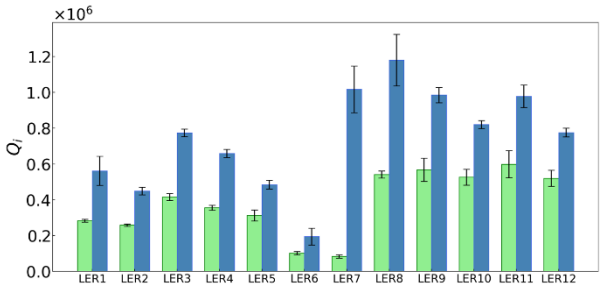

Figure 2: Internal quality factor as a function of resonator number for Nb (green) and Nb/Au (blue). The tested Au-capped device (and the witness uncapped one) consists of 12 resonators coupled to a single transmission line. The values correspond to a driving power of -100 dBm.