Ultrastrong coupling and Mechanical Non-linearities at the Zero-point Motion Level

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Carbon nanotube resonators, due to their low mass and high quality factors, are excellent candidates for quantum information processing and quantum sensing. In this work, we present a quantum platform based on a suspended carbon nanotube in which a charge qubit defined in a Double Quantum Dot is coupled to the second flexural mode of the carbon nanotube, and where the qubit read-out is performed via a superconducting cavity.

We demonstrate the formation of single and double quantum dots along an ultraclean carbon nanotube [1], with readout enabled by a superconducting cavity. In addition, we explore the coupling between the qubit and mechanical modes, where the interaction with a nonlinear medium induces mechanical nonlinearities at displacements on the order of the zero-point motion. Notably, the coupling coefficient between the mechanical mode and the qubit can exceed the oscillator's mechanical frequency, opening the door to the study of the ultrastrong coupling regime [2] in the context of circuit quantum electrodynamics [3].

This regime is interesting for a wide variety of basic science experiments with direct applications in quantum computing and sensing. In particular, we discuss the use of the strong non-linearity observed in our platform for the realization of a mechanical qubit that mostly inherits the high mechanical coherence of the oscillator [4], which fundamentally differs from the mechanical qubit recently shown in [5], where the coupling is weak but the mechanical mode and the qubit are near resonance.

References

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[3] A. Blais, Rev. Mod. Phys. 93, 025005 (2021)
[4] F.Pistolesi et al, Phys. Rev. X, 11, 031027 (2021)
[5] Y.Yang et al, Science, Vol 386, issue 6723 (2024)

Figures

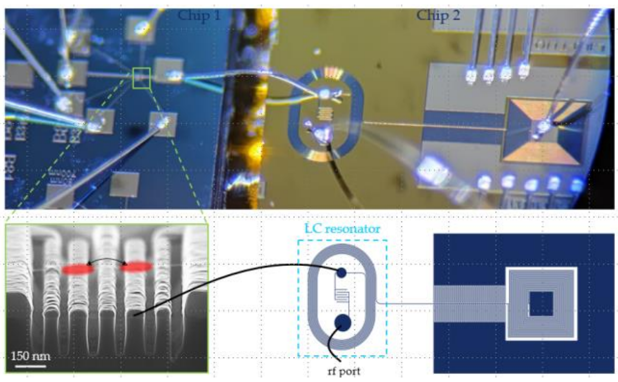

Figure 1: 2-Chip assembly optical picture of the superconducting spiral cavity (schematic bottom right), coupled with the nanotube device (bottom left SEM picture).