

Towards mechanical quantum state control in carbon nanotubes

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Mechanical resonators offer a pathway to impactful applications ranging from ultraprecise sensing [1] to novel approaches in quantum information processing [2]. Accessing and controlling mechanical resonators at the quantum level requires long coherence times and a sensitive yet minimally invasive readout. In this context, carbon nanotubes (CNTs) provide an attractive platform as they combine exceptionally high mechanical quality factors of up to 5 million [3] with a large zero-point motion, which enhances their coupling to other systems. This makes it a promising platform to explore novel regimes such as the ultra-strong electromechanical coupling (USC) regime, where $g_{EM}/\omega_M > 0.1$ and nonlinearities in the mechanical states emerge for displacements at the level of the zero-point motion.

In this work, we explore a quantum hybrid system in which double quantum dots hosted in the CNT are coupled to the mechanical vibrations of the nanotube itself, and read out via a superconducting microwave resonator. We study the second flexural mode of the nanotube which lies in the GHz range allowing the observation of quantum effects due to its low thermal population. Our novel fully integrated architecture yields microwave resonators with frequencies around 5-8 GHz, minimally populated at millikelvin temperatures, while keeping sub-MHz internal loss rates; thus, overcoming the previous limitations of double-chip

assemblies [4]. The compact geometry is expected to provide new insights on the phenomena occurring in the USC regime, and provide a route toward controlled preparation and manipulation of quantum states with a predominantly mechanical character.

References

- [1] F. Ricci, et al. *Nano Letters* 19(10), (2019), 6711-671
- [2] Yu Yang, et al. *Science* 386, (2024), 783-788
- [3] Moser, J., Eichler, A., Güttinger, J., et al. *Nature Nanotech* 9, (2014)1007–1011
- [4] Von Horstig, et al. *Physical Review Applied*, 21(4) (2024), 044016

Figures

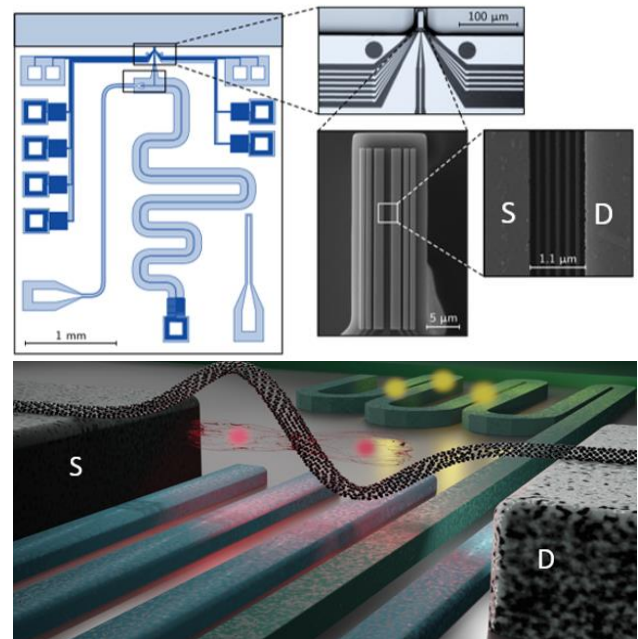


Figure 1 (Top) Full design of the integrated carbon nanotube device. The nanotube is suspended between the S-D electrodes over the five gates. (Bottom) Artistic representation of the hybrid system. The nanotube hosts the double quantum dot two level system (red), defined electrostatically by the five gate electrodes, which couples strongly to the second flexural mode. One of the gates is part of the resonator used for readout (yellow).