Towards a mechanical qubit in a double quantum dot in a carbon nanotube-based device

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Mechanical resonators are systems which present high quality factors and can easily couple to a wide range of forces. For this reason, they are excellent candidates for sensing and quantum information. While their qualities as sensors have been exploited for many years, it is only recently that their potential use as quantum bits (qubits) have been proposed.
To enable a mechanical qubit, the resonator may be coupled to an external force which induces anharmonicity in the energy dispersion curve of the harmonic oscillator. While they exist some theoretical proposals [1][2], inducing non-linearities on the energy spacing of a mechanical resonator has not yet been achieved experimentally.
In this context, the force exerted by single electron tunnelling on the mechanical vibration of quantum dots embedded in carbon nanotubes has been shown to induce such anharmonicity [2]. In practice this effect necessitates operation in the so-called strong coupling regime. In this regime, the mechanical motion of the carbon nanotube couples to the single electron tunnelling on the quantum dot leading to a ladder of charge-mechanical energy states.
In our work, we present data that evidences the ultra-strong coupling for the single quantum dot case and preliminary data for a double quantum dot system (DQD). In the latter, an electronic two-level system (eTLS), based on the delocalisation of an electron over the two quantum dots, can efficiently couple to the second flexural mode of the carbon nanotube. In the above mentioned ultra-strong coupling regime, the system presents an energy difference between its ground and first excited states significant enough to be used as a basis for a qubit.
The qubit decoherence of the charge-mechanical hybrid system is expected to display a sizeable improvement with respect to current state-of-the-art charge qubits [2].
In our project, we aim to show how to implement such a system experimentally including: our novel nanofabrication techniques for high quality DQDs and cavity read-out of the qubit states.

References

[1] F. Pistolesi, A. N. Cleland, and A. Bachtold. Proposal for a nanomechanical qubit. Phys. Rev. X 11, 031027, 2021.
[2] S. Rips and M. J. Hartmann. Quantum information processing with nanomechanical qubits.Physical Review Letters, 110, 3 2013.

Figures

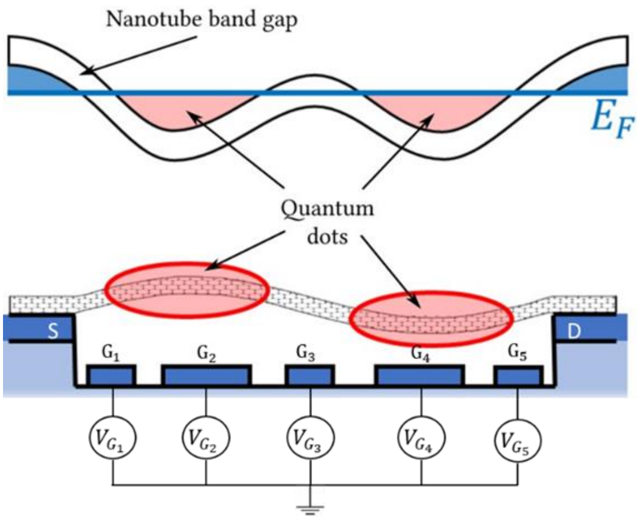

Figure 1: Scheme of a double quantum dot system defined on a suspended carbon nanotube over five gate electrodes.

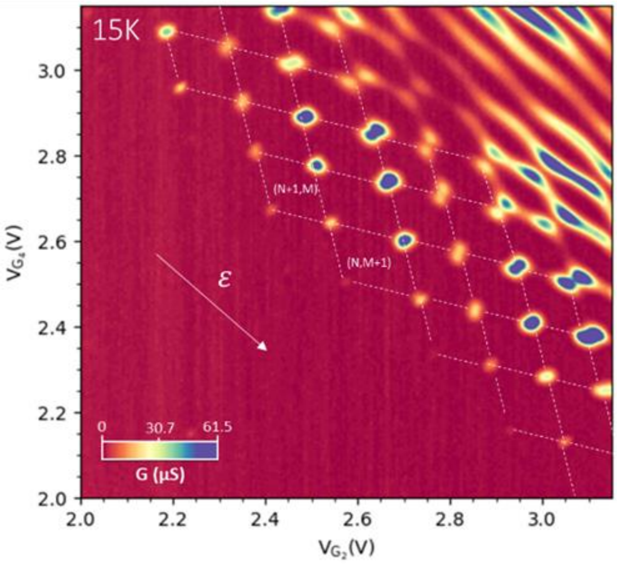

Figure 2: Double quantum dot charge stability diagram of one of our devices at 15K.