



# PhD Thesis Defense **SERGIO LUCIO DE BONIS** 'Polaron Physics in Carbon Nanotube Electro-Mechanical Resonators'

SERGIO LUCIO DE BONIS

February 06, 2020

11:00

Seminar Room

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Thursday, February 6, 11:00. ICFO's Seminar Room

**SERGIO LUCIO DE BONIS**

Quantum NanoMechanics

ICFO-The Institute of Photonic Sciences

Carbon nanotube (CNT) mechanical resonators are unique systems because they combine remarkable mechanical properties with rich charge transport characteristics. Thanks to their intrinsically low-dimensional nature, their mass is extremely low. The mechanical resonance frequency reaches the GHz regime, can be widely tunable and they show quality factor as

high as several million. Nanotubes hold great promise for sensing applications. Nanotubes are an excellent system to study quantum electron transport, which range from Aharonov-Bohm interference to Coulomb blockade. These completely opposite regimes can be very efficiently coupled to the mechanics, since the two degrees of freedom, electrons and phonons, are embedded in the same system.

In the first section of this thesis we develop a detection scheme utilizing a RLC resonator together with a low-temperature HEMT amplifier.

This allows us to lower the current noise floor of the setup and carry out sensitive electrical noise measurements, demonstrating a displacement sensitivity of  $0.5 \text{ pm}/\text{Hz}^{(1/2)}$  and a force sensitivity of  $4.3 \text{ zN}/\text{Hz}^{(1/2)}$ . This surpasses what has been achieved with mechanical resonators to date and paves the way for the detection of individual nuclear spins. We also improve the device fabrication enhancing the capacitive coupling between mechanical vibrations and electrons flowing through the nanotube.

In the second part of this work, we study the electron-phonon coupling in CNT resonators in the Coulomb blockade regime and report on the long-sought-after demonstration of the ultra-strong coupling regime. Mechanical vibrations and electrons are so strongly coupled that it no longer makes sense to think of them as distinct entities, but rather as a quasi-particle: a polaron. First, we demonstrate that the polaronic nature of charge carriers modifies the quantum electron transport through the device. In previous electromechanical devices, the coupling was too weak to have any effect on the DC electrical conductance.

Second, we show high tunability of polaron states by electrostatic means. This is something not possible to do with polarons in other systems, such as bulk crystals. Notably, this interaction creates a highly nonlinear potential for the phonon mode which establishes nanotube resonator as a possible platform for the demonstration of mechanical qubits.

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**Thesis Advisor: Prof Dr Adrian Bachtold**



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