ICFO

PhD THESIS DEFENSE: Integrated Charge Sensing and Electromechanics in Suspended Carbon Nanotube Quantum Devices

MARTA CAGETTI

March 17, 2026

15:00

Elements Room

In this thesis we present an ultrasensitive, fast and widely tunable charge detection architecture, suitable for the readout of both electronic states and mechanical motion. The platform is implemented in suspended carbon nanotube (CNT) devices. Our approach employs a radiofrequency (RF) readout scheme operating without impedance matching, thereby avoiding one of the main practical limitations of conventional reflectometry. The readout achieves charge sensitivities exceeding state of the art RF detection techniques, while relying on a comparatively simple measurement setup. The device is based on an integrated single nanotube platform, in which a system of gate defined quantum dots and a proximal quantum dot based charge sensor are hosted in the same suspended CNT and separated by a short metallic drain electrode. The drain is connected to an RLC resonator with a resonance frequency fRLC approximately 1.25 MHz and a bandwidth of 50 kHz, enabling RF readout of the charge sensor current at the circuit resonance. This geometry provides strong capacitive coupling while maintaining independent electrostatic control of the sensor operating point and of the target quantum dots. Using this platform, we achieve self charge sensitivities of order 10^-7 e/sqrt(Hz) and an exceptionally low single shot infidelity, 1 - F approximately 10^-15, for an integration time tau approximately 3.5 microseconds. Beyond the readout of electronic charge transitions in the target quantum dots, the same charge sensor provides highly sensitive access to the mechanical degrees of freedom of the suspended nanotube in the system region. Mechanical displacement is transduced into variations of the charge sensor quantum dot conductance, enabling measurements ranging from driven nonlinear dynamics to thermomechanical motion in the few phonon regime. Crucially, our platform allows operation in a regime where electromechanical backaction, which is typical of suspended carbon nanotubes hosting quantum dots, is strongly suppressed. This addresses one of the central challenges of CNT based nanomechanics: in single dot electromechanical architectures, achieving strong or ultrastrong coupling generally requires operation near charge degeneracy, where coupling to electronic reservoirs and stochastic tunneling lead to excessive dissipation, frequency noise and a pronounced reduction of the mechanical quality factor. Indeed, in previous experiments in the ultrastrong coupling regime, measurement backaction broadened the mechanical response to the point of obscuring access to the intrinsic mechanical properties. In contrast, in our devices we maintain high readout sensitivity without any observable degradation of the mechanical quality factor Q, enabling quantitative spectroscopy of the resonator while preserving its intrinsic mechanical properties. This capability to perform quantitative spectroscopy of a nanomechanical resonator coupled to a two level system in the few phonon regime constitutes a key requirement for advancing towards experiments in the quantum regime, where preserving intrinsic mechanical coherence is essential. The high degree of tunability of our platform enables precise control of charge occupation, tunnel couplings and electrostatic potentials, allowing systematic studies of electromechanical coupling from the single electron regime in a simple quantum dot to the double quantum dot configuration. We demonstrate ultrastrong electromechanical coupling, opening the door to future work on nonlinear nanomechanics, mechanical qubits, quantum delocalization and carbon nanotube based quantum simulation.

Tuesday March 17, 15:00 h. ICFO Elements Room
Thesis Director: Prof. Dr. Adrian Bachtold and Dr. Stefan Forstner
Hosted by: Academic Affairs