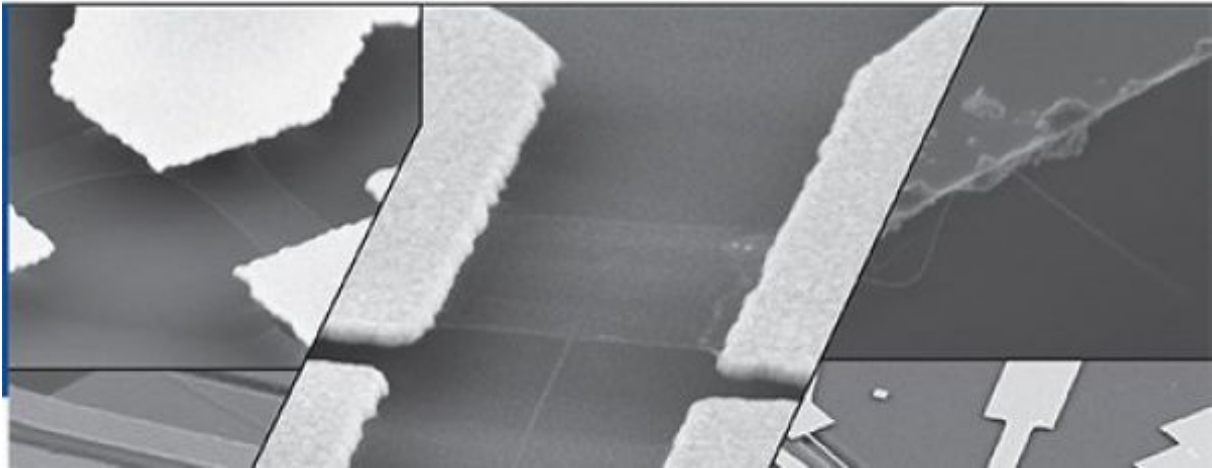


IOANNIS TSIOUTSIOS

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## PhD Thesis Defense IOANNIS TSIOUTSIOS 'Mechanical Resonators Based on Graphene and Carbon Nanotubes'

IOANNIS TSIOUTSIOS

July 26, 2016

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Tuesday, July 26, 16:00. ICFO Blue Lecture Room

**IOANNIS TSIOUTSIOS**

Quantum NanoMechanics

ICFO-The Institute of Photonic Sciences

Mechanical resonators based on graphene and carbon nanotubes have recently attracted considerable attention, due to the great wealth of remarkable properties that they exhibit. Their intrinsically low-dimensional nature qualify them as ideal systems to study mechanics at the nano-scale. Their mass is so low that they are extremely sensitive to external forces and

attached mass, which holds promise for sensing applications. In addition, these systems can vibrate at the GHz regime while their resonant frequencies can be widely tunable. Moreover, they exhibit strong mechanical nonlinearities and among their intriguing properties is the efficient coupling of their mechanical vibrations to electrons in the Coulomb blockade and Quantum Hall regimes.

However, working with these devices requires high level of control over the nanofabrication technologies as well as efficient readout and control of their motion. In this Ph.D thesis we address these requirements by fabricating and investigating various nanomechanical resonators based on graphene and carbon nanotubes, while exploring different techniques for the transduction of their motion.

We firstly study coupled mechanical resonators based on graphene and carbon nanotubes. We succeed to push the limits of modern nanofabrication techniques by realizing complex fully suspended structures that consist of two graphene membranes coupled by a multi-wall carbon nanotube. We employ electrical mixing transduction techniques to extensively characterize the complex vibrational dynamics of these systems at cryogenic temperature. Interestingly, we observe nonlinear coupling between the eigenmodes of the structures, highlighting the crucial role of nonlinearities in such nano-scale systems.

We then investigate the noise dynamics of singly-clamped carbon nanotube resonators, at room temperature, with very high sensitivity, by coupling their motion to the focused electron beam of a scanning electron microscope. This transduction scheme enables us to detect their motion in real-time and present a detailed analysis of the two-dimensional noise trajectories both in space and time. We show that these tiny objects behave as Brownian particles evolving in a two-dimensional harmonic potential. Moreover, we demonstrate phase-coherent measurements by implementing a phase-locked loop that allows us to track their resonant frequency in real-time, paving the way for high performance sensing applications.

Finally, we present the first steps towards studying suspended singly-walled doubly-clamped carbon nanotube resonators as hybrid nano-optomechanical systems, where the optical degrees of freedom are embedded inside the nanotube's structure. We develop a low temperature micro-photoluminescence setup to investigate the coupling between the mechanical vibrational modes and the localized zero-dimension excitons of the nanotubes. Additionally, we develop a chemical vapor deposition growth process for up to 10  $\mu$ m long narrow diameter, suspended nanotubes.

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**Thesis Director: Prof Dr Adrian Bachtold**

