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Advances in nano-electromechanical systems

Foreword

Electro-mechanical systems played in the past and still play nowadays an important role in several technological devices. Even if we may not be aware of that, every day we make use of electrical motors, electro valves, detectors of force, acceleration, pressure, or gas. There exists a large variety of electro-mechanical devices. The minimal one is formed by a mechanical oscillator coupled to an electronic system used to both put into motion and detect it. Even such a simple system can have many applications. The oscillator can be used to detect force, acceleration, or mass variations. In order to perform such tasks it is necessary to detect its displacement as a function of time and to convert it to an electrical signal, which can then be processed by standard electronics. A common example is the accelerometer present in most car airbags, exploiting the small change in the capacitance of interdigitated fingers to detect the occurrence of a shock. As for purely electronic devices, miniaturization of electro-mechanical systems allows one to obtain lower consumption, higher operating speed, higher sensitivity, and all of that in a smaller space. The present lithographic technology allows producing resonators with transverse dimensions of the order of tens of nanometers, while using large molecules like suspended carbon nanotubes, resonators of micrometers length and sub-nanometer diameter have also been manufactured and operated. Nowadays, the field of Nano Electro Mechanical Systems (NEMS) is a steady growing component of the applied physics research.

Nano-electromechanical systems thus have important technological applications, but with extreme miniaturization the behavior of the devices does not necessarily simply scale down to the new dimensions. Actually, the interactions between the electrical and mechanical degrees of freedom have to be reconsidered at the nanometer scale. The low mass of the oscillator and its huge sensitivity to any external perturbation imply that the effect of the detector on the oscillator can no longer be neglected: even a single electron can affect the state of the oscillator. The detector and oscillator have to be regarded as parts of a complex interacting system, for which the interpretation of the measurement outcome could be a non-trivial task. Moreover, low oscillator masses naturally lead to high resonating frequencies, which now reach easily a few GHz. At milliKelvin temperatures quantum mechanical effects become non-negligible. Even more importantly, the detection of the tiny motion of nanometer scale oscillators has to face the ultimate quantum limit of displacement detection, which has been explored so far mainly for massive oscillators used for gravitational waves detection. The interest on NEMS of the fundamental research community grew thus rapidly in the last few years, particularly after the successful observation of a macroscopic mechanical oscillator in the ground state. One of the main goals of the community is now to investigate decoherence to further unveil the quantum to classical crossover. The improvement of the understanding of this field will also lead to the realization of a new class of quantum-limited ultrasensitive detectors with consequent fall-down in all branches of science.

The extremely reduced size of the oscillator naturally suggested from the beginning using quantum transport detection systems, like single-electron transistors (made of normal or superconducting metals) or quantum-point contacts. These methods are particularly effective for very small oscillators, like carbon nanotubes, where electronic transport takes place in the oscillator itself. For larger systems, between hundreds of nanometers and several microns, electromagnetic detection, with microwave or optical cavities, has proved to be very efficient. The NEMS field has thus become the ground of a fertile exchange between the quantum optics and quantum transport community. The present special issue presents recent advances in the field of Nano Electro Mechanical Systems with contributions in both electronic and electromagnetic detection methods.

In the first part three papers discuss, in three quite different contexts, electronic transport through suspended carbon nanotubes used as oscillators. The paper by P. Vincent et al. reviews two experiments performed on either singly clamped or doubly clamped carbon nanotubes. In the first one, field emission from the nanotube tip is used to detect its motion. In the second one, motion is detected exploiting the electrical non-linear response of the field effect transistor formed by the nanotube contacted between two metallic leads. In the second paper, by G. Rastelli et al., the quantum nature of the mechanical oscillations of a doubly clamped nanotube is explored theoretically. The paper considers the effect on the electronic transport of the magnetic and electrostatic force acting on the suspended nanotube when single electrons cross the junction. Finally the paper by R. Shekhter et al. reviews theoretical predictions for a suspended nanotube clamped between two superconducting leads. In this case the nanotube acts as a Josephson junction and different scenarios are

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investigated, showing both cooling and controlled pumping of energy in the mechanical mode of the nanotube, in the classical and quantum case.

The second group of papers considers a mechanical oscillator coupled to a microwave or optical cavity. Superconducting microwave resonators are extremely promising as detection devices for mechanical oscillators. The present technology allows embedding in the same chip superconducting quantum bits (quantum two-level systems), mechanical oscillators and microwave cavities. This opens the way to a wide range of experiments where the quantum two-level system is coupled to the mechanical oscillator. It is not by chance that it is in these systems that the first observation of a macroscopic oscillator in the ground state has been obtained by the groups of A.N. Cleland and J.M. Martinis. The next three papers give an overview of several phenomena observable when a mechanical oscillator is coupled to a microwave or optical cavity. Specifically, the paper by A.D. Armour and D.A. Rodriguez considers a linear oscillator whose position is coupled to the frequency of an electromagnetic cavity. The authors study the quantum regime of limit-cycle oscillations of the mechanical resonator, finding a reduction of the energy fluctuations. The next contribution by E. Buks investigates a similar system in presence of a mechanical non-linear (Kerr) term. The aim is to study its effect on the decoherence and, in particular, to inquire whether there exists a regime where decoherence is suppressed. Finally, the last contribution by N. Didier and R. Fazio reviews the physics of a microwave cavity coupled to a Qbit and a mechanical oscillator. It is shown how the two-level system can lead to a non-linear mechanical term and to the observation of a phonon-blockade effect.

The papers presented in this special issue allow having a view of recent advances in the field of Nano Electro Mechanical Systems. To conclude I would like to gratefully thank all the people that contributed to the publication of this special issue. It is thus a pleasure for me to thank the authors of the papers, the editors of the editorial board of the *Comptes Rendus Physique*, who supported the project, especially J. Villain for his help and supervision, and finally the Elsevier production staff for their efficiency and professionalism.

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