Electronic Control of Flexural Nanowire Vibrations

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Akademisk avhandling som för avläggande av filosofie doktorsexamen vid Göteborgs universitet försvaras vid offentlig disputation den 9:e juni 2011, klockan 10.00 i Kollektorn, Institutionen för mikroteknologi och nanovetenskap (Chalmers), Kemivägen 9, Göteborg. Uppsatsen presenteras på engelska.

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Condensed Matter Theory
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ISBN: 978-91-633-5863-0

ABSTRACT

"Nanoelectromechanical systems" (NEMS) are nanometer-sized mechanical structures coupled to electronic devices of comparable size. The coupling between mechanical and electronic degrees of freedom, combined with their mesoscopic size, provide these systems with some unique properties that make them interesting from both the fundamental and technological point of view.

In this thesis, we present theoretical work about a specific kind of NEMS, that is a suspended doubly clamped carbon nanotube that is in tunneling contact with the supporting leads and the DC voltage-biased tip of a scanning tunneling microscope (STM).

The analysis presented here indicates that, in the classical regime, under the conditions of weak dissipation or sufficiently strong electromechanical coupling, the equilibrium configuration of the suspended nanotube becomes unstable and the system evolves towards a state of self-sustained periodic oscillations that is reminescent of the single-electron "shuttle" regime in Coulomb blockade nanostructures. Furthermore, combining the conditions for the onset of the electromechanical instability with the local character of the charge injection provided by the STM, it seems possible to generate a selective excitation of the bending vibrational modes of the nanotube.

Instead of pumping energy into the suspended nanotube, the electromechanical coupling can be also exploited to remove energy from it. Even though the tunneling electrons represent a strongly nonequilibrium environment interacting with the mechanical subsystem, the analysis presented in this thesis shows that the dynamics of the nanotube in the regime of weak coupling is formally equivalent to that one of a quantum harmonic oscillator coupled to an equilibrium thermal bath characterized by an effective temperature that can be much lower than the environmental (i.e. thermodynamic) temperature.

This nonequilibrium cooling effect studied here has an intrinsic quantum mechanical nature, since it is based on the (bias voltage controlled-) destructive interference between the probability amplitudes associated to those inelastic tunneling processes characterized by the emission of quantized vibrational excitations. When the transport of charge is thermally activated, this mechanism provides a simple procedure to drive the oscillating nanotube to nearly its quantum ground state.

Keywords: NEMS, carbon nanotubes, Coulomb blockade, shuttle instability, ground-state cooling, nonequilibrium thermodynamics.