Quantum Theory of Nanoelectromechanical Shuttling

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Abstract

In this thesis we study quantum phenomena in a nanoelectromechanical single-electron transistor (NEM-SET). NEM-SET is a single-electron transistor with a movable central island. The electron transport through the NEM-SET depends on the position of the island, which results in electromechanical coupling between the electron dynamics and the mechanical motion of the island.

In the first part of this thesis we consider the interplay between the classical motion of the island confined by a harmonic potential and coherent resonance tunneling of electrons through a single level in the island. It is shown that for bias voltages exceeding a certain critical value the equilibrium configuration of the mechanical subsystem becomes unstable. A new stable state is found which corresponds to the oscillations of the island with a constant limit cycle amplitude. The current-voltage characteristics in the new stable state are analyzed.

In the second part of the thesis the quantum dynamics of the vibrational degree of freedom is considered. The quantum master equation for the NEM-SET is derived. Using this equation it is shown that there are two regimes of NEM-SET operation: "quasiclassical" and "quantum". In the "quasiclassical" regime the dynamics of the mechanical degree of freedom and charge transfer through the system resemble ones obtained in the first part of the thesis. The "quantum" regime is characterized by the strong fluctuations of the current and amplitude of mechanical oscillations.

Finally, we study the NEM-SET with spin polarized leads. It is shown that in such a system the shuttle effects can be controlled via magnetic field. Different stable regimes of the spintronic NEM-SET operation are found and analyzed.

Keywords: Mesoscopic Physics, Self-Assembled Structures, Nano Electromechanical Systems, NEMS, Spintronics