Elastic and Inelastic Phenomena in Tunneling Processes Through Nanostructures

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In scanning tunneling experiments it is necessary to distinguish elastic and inelastic effects contributing to total tunneling current and spectra of tunneling conductivity. The most important effects caused by elastic tunneling through nanostructures are connected with changes of electron spectrum and nonequilibrium charges in the tunneling contact area. Moreover, Coulomb interaction of nonequilibrium electrons results in peculiarities of tunneling conductivity spectrum and formation of Coulomb singularities in current voltage characteristics for particular range of applied bias.

Enelastic tunneling spectroscopy deals with electron interaction with vibrational modes in tunneling processes through a single molecule, quantum dot or other nanostructure. At the present time there exist at least two types of experimental systems in which "single molecule" tunneling junctions are investigated. In these structures a single molecule is placed between the leads of the tunneling contact. The first type of experiments is scanning tunneling microscopy (STM) of molecules, adsorbed at various surfaces. In the second experimental setup one deals with molecules, deposited in the tunneling region of metal break-junctions. In both systems influence of electron-vibration interaction on transport properties of such structures was observed. In the presence of electron-vibration interaction inelastic contribution to the tunneling current appears, which provides a new tool - inelastic tunneling spectroscopy, method of diagnostics of molecule vibrational modes changes under adsorption etc. Tunneling current induces emission of vibrational quanta, which leads to effective "heating" of the phonon subsystem. The last effect may induce motion or desorption of adsorbed molecules thus allows single molecule manipulation on a surface. The aim of this report is to describe peculiarities, which appear in the tunneling characteristics due to the electron-vibration interaction and to find out under which conditions vibration "heating" is suppressed or enhanced.

The effective electron-vibration interaction for "singlemolecule" tunneling junctions consists of two different parts. The first part describes the effects of tunneling matrix elements modulation due to vibration of atoms. The second part corresponds to atom displacement to a new equilibrium position when electron is added to or removed from the molecule. The vibrational frequency is also modified with changing of electron number. Interference effects between the two parts of the electron-vibration interaction are very important. Intensity of vibration excitation strongly varies depending on constructive or destructive character of this interference.

For two electron levels the intensity of phonon generation can be tuned by changing the parameters of the tunneling junction (which influence the tunneling rates and the occupation numbers of electron states). For inverse population of two-level electron system strong phonon generation takes place which can lead to drastic changes of the properties of nanostructures. The problem of suppression of tunneling current induced phonon generation is very important for fabrication of semiconductor cascade lasers based on sequence of tunneling junctions. Using the obtained results one could analyze whether it is possible to achieve the threshold of optical generation before strong phonon generation , changing the parameters of the tunneling system.