Ultrafast Electronic Processes in Semiconductor Nanostructures

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We have made significant progress in our understanding of ultrafast electronic processes in semiconductor nanostructures by developing a detailed theory for electron-phonon many body interaction processes in GaAs quantum wires of 10-100 nanometers cross-sectional dimensions. Specifically, we have taken into account plasmon-plasmon and quasiparticle-phonon coupling effects in calculating femtosecond hot electron relaxation phenomena, showing that many-body coupling could lead to substantial enhancement in the energy loss rates of ultrafast electrons confined in semiconductor quantum wire nanostructures. We have also developed a quantitative theory, agreeing very well with experimental results, for electronic tunneling in GaAs-AlGaAs double quantum well structures taking Coulomb interaction induced many-body effects into account. We published 37 papers and produced 2 Ph.d.s under this project.
A. Statement of the Problem Studied

In our project, we have studied and finished the theoretical problems we originally proposed in our grant proposal. The specific problem we studied pertains to ultrafast (picosecond to femtosecond) electronic phenomena in low dimensional semiconductor nanostructures (e.g. quantum wells, quantum wires, quantum dots, multilayer superlattices, modulation doped heterojunction transistors). The theory we develop should apply to most compound semiconductor materials, but our specific numerical results are mostly for the GaAs-Al GaAs structures because of their technological relevance (and also because much experimental data are available for GaAs based nanostructures). We compare our theoretical results with the available experimental results, and find very good agreement. In summary, we accomplished all aspects of our originally proposed project.

B. Summary of the Most Important Results

1. Hot Carrier Relaxation in Nanostructures

We have developed a complete theory, taking full account of many-body effects, for hot electron relaxation in quantum wire structures. The theory includes plasmon-phonon and quasiparticle-phonon couplings as well as optical phonon bottleneck effect (the so-called “hot phonon” effect). We consider both Fröhlich coupling to LO-phonons and deformation potential coupling to acoustic phonons. The theory is in very good agreement with the available experimental results.

2. Hot Phonon Lifetime

We have studied in quantitative details the effect of hot phonon lifetime on hot electron relaxation rate in doped nanostructure materials.
(3). **Femtosecond Dynamics**

We have developed a detailed theory for electron-electron and electron-phonon interaction effects on carriers confined in quantum well and quantum wire structures at the femtosecond time scale.

(4). **Single Electron Tunneling**

We have developed a detailed theory for single electron tunneling in double quantum well structures, which takes into account electron-electron, electron-phonon, and electron-impurity interaction effects.

(5). **Optical Properties of Quantum Dots and Wires**

We have developed a theory for optical properties of semiconductor nanostructures by calculating the collective plasmon spectra and band gap renormalization.

(6). **Device Simulation**

We have done a device simulation calculation for modulation doped heterojunctions by taking into account the correlation among the remote dopant sites.
C. List of Publications


D. Personnel Supported by the Grant

(1). S. Das Sarma (PI)
(2). E. Hwang (Ph.D. awarded August 1996)
(3). L. Zheng (Post doc)
(4). R. Price (Post doc)
(5). P.I. Tamborenea (Ph.D. awarded August 1994)
(6). R.J. Radtke (Post doc)

Report of Inventions

None