Transport Through Wannier-Stark States in Biased Finite Superlattices

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In semiconductor superlattices, the strong coupling of the electronic eigenstates of adjacent wells leads to the formation of minibands which are separated by minigaps. In superlattices with a finite number N of periods, each single miniband is formed by N eigenstates which are delocalized over the whole superlattice length. Applying an external electric field perpendicular to the layer planes alters the quantum mechanical confinement between the neighboring wells and leads to a splitting and a localization of the states which are then given by the Wannier-Stark states. Due to this localization phenomena the transmission channels for resonant tunneling through the miniband of the superlattice are quenched, and as a consequence, electron transport through the miniband vanishes. Therefore investigations on Wannier-Stark states in semiconductor superlattices were mainly done using optical measurement techniques [1], [2].

Studying transport in biased finite superlattices requires to overcome the electric field induced decrease of resonant tunneling through the Wannier-Stark states. In this work this is achieved by the use of LO phonon scattering which can induce transitions between localized weakly overlapping states. For this purpose two different superlattices has been designed. The first superlattice consists of 5 periods of 3.5 nm $Al_{0.3}Ga_{0.7}As$ barriers and 3 nm GaAs wells, the second superlattice consists of 4 periods of 4 nm $Al_{0.3}Ga_{0.7}As$ barriers and 3.2 nm GaAs wells. The miniband width of the 5 period SL equals the optical phonon energy (36 meV) whereas the miniband width of the 4 period SL (23 meV) is well below the optical phonon energy. For this superlattice LO-phonon assisted transport through the miniband sets in at electric fields where the Wannier-Stark splitting tunes into the optical phonon energy.

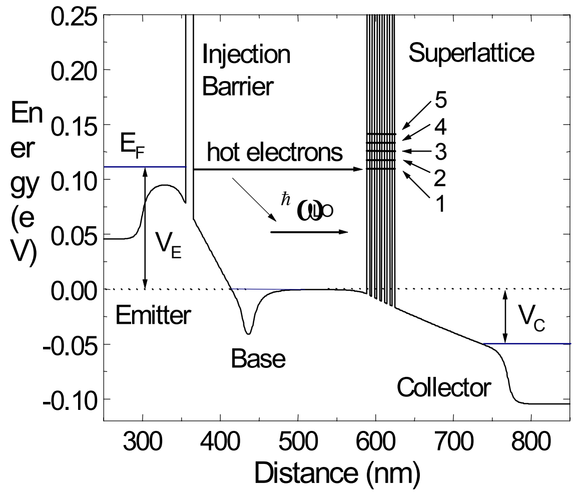
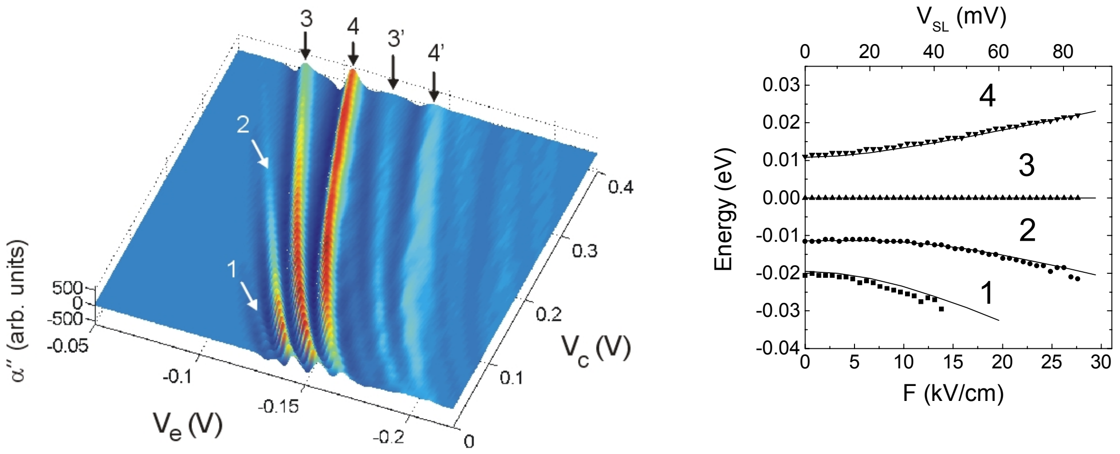


Fig. 1: Calculated conduction band diagram of a 3TD with positive bias applied to a 5 period superlattice.

A hot electron transistor [3], [4] is used to investigate electron transport through the first minibands of the superlattices. The band structure of the device is shown in Fig.1. The transmittance of the superlattice can be measured directly at given superlattice bias Vc by tuning the energy of the injected electron beam generated at the tunneling emitter barrier. The main characteristic thereby is the static transfer ratio $\alpha = I_c/I_e$ which directly reflects the probability of a hot electron to be transmitted through the superlattice. Due to the high resolution [4] of the spectrometer we are able to observe the energy splitting (Fig. 2) and the transmission behavior (Fig. 3) of the individual Wannier-Stark states separately in transport for both superlattices.



(a) (b)

Fig. 2: (a) Second derivatives of the transfer ratio vs. emitter bias at different collector biases for the 5 period superlattice; (b) Wannier-Stark states (symbols) of the 4 period superlattice compared to calculations (solid lines).

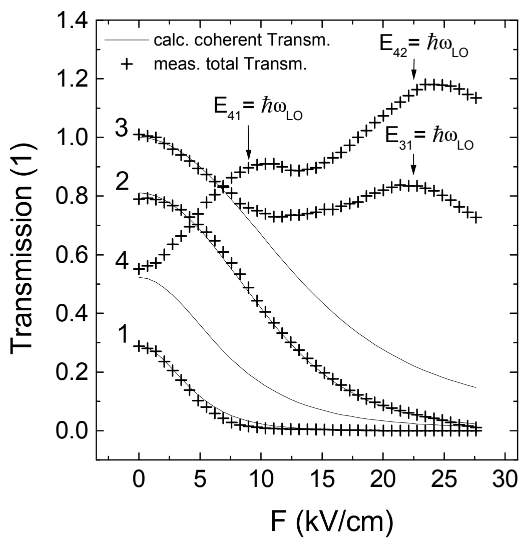


Fig. 3: Measured total transmission per states as a function of the electric field (crosses) compared to the calculated coherent transmissions of the individual Wannier-Stark states for the 4 period superlattice (solid lines).

The basic transport through Wannier-Stark states is identified to be coherent, the amplitudes of the quantum mechanical transmission are directly observed. Individual transport channels induced by LO-phonon scattering are observed when the Wannier-Stark states spacing tunes into the optical phonon energy as shown in Fig. 3.

References

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