Electric field induced [MATH]-X transition in GaAs-AlAs coupled quantum well structures
M. Hagn, A. Zrenner, G. Böhm, G. Weimann

To cite this version:

HAL Id: jpa-00251629
https://hal.science/jpa-00251629
Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Electric field induced Γ-X transition in GaAs-AlAs coupled quantum well structures

M. HAGN, A. ZRENNER, G. BÖHM and G. WEIMANN

Walter Schottky Institut, Technische Universität München, Am Coulombwall, 85748 Garching, Germany

Abstract: Phonon replicas are investigated at the electric field induced Γ-X transition in GaAs/AlAs coupled quantum well structures by photoluminescence spectroscopy. In the real- and k-space indirect regime the observed replicas are assigned to AlAs LO, TO and LA zone-edge phonons. At the indirect-direct transition those phonons disappear and a new replica emerges, which is assigned as a GaAs-LO phonon at the Γ-point. The observed phonon replicas are shown to be a local probe for the distribution of the ground state electronic wave function in the GaAs/AlAs coupled quantum well structure.

The absorption and recombination spectrum of a semiconductor material reflects directly the nature of the elementary band gap. Both direct and indirect gap semiconductors play important roles in optical device applications. Since the introduction of III-V quantum well (QW) structures the research activities in this field concentrated mainly on the excitonic properties of those structures and on QW lasers. For both topics direct gap systems such as GaAs/AlGaAs are favourable. Only in the field of GaAs/AlAs short period superlattices (SPSL) the indirect gap material AlAs attracted appreciable interest. As a function of the individual layer width the gap of a GaAs/AlAs SPSL can be tuned from direct to indirect. Close to the critical layer thickness of the direct-indirect crossover the application of additional electric field or hydrostatic pressure was show to result in the direct-indirect crossover (Γ-X transition in the GaAs/AlAs system) as well. Recently a new GaAs/AlAs coupled QW (CQW) structure was introduced, which can be regarded as one period of a SPSL. In the present paper the electric field induced Γ-X transition is studied in such a GaAs/AlAs CQW structure by means of photoluminescence (PL) spectroscopy.

Fig. 1 (a) Layer sequence of the electric field tunable GaAs/AlAs CQW structure. (b) Band diagram of the active part of the structure for negative VB. The real- and k-space indirect transition E_0^X → HH_0 is indicated.
The investigated CQW structures are configured as electric field tunable hetero-type n⁺-i-n⁺ photo diodes. The overall layer sequence and the band diagram of the active GaAs/AlAs CQW's in the center of the i-region are shown in Fig. 1. The CQW's are embedded between two i-Al₀.₄₆Ga₀.₅₄As cladding layers. Electric tunability is obtained via the n⁺-GaAs layers on both sides of the intrinsic region. The top n⁺-GaAs layer is thin enough (950Å) to allow for optical access to the active layers from the surface. The structures have been grown by molecular beam epitaxy (MBE). The GaAs QW width has been chosen 30Å. For this width the confinement energy of the lowest electron subband E₀Γ (=170meV) compensates just about the offset between the GaAs Γ-conduction band (CB) and the AlAs X-CB. Since the confinement energies for X-point subbands in the AlAs layer E₀X are generally small (m*ₓ=1.1mₑ), those two subbands are energetically almost degenerate. Starting with this alignment the Γ-X transition can be easily obtained by application of an external electric field. As indicated in Fig. 1, three different samples with an AlAs layer width of 30, 40 and 50Å have been grown. Compared to a SPSL the present structure is asymmetric. As a consequence, the real- and k-space indirect transition from the X-point subband E₀X in the AlAs layer is red-shifted for negative bias voltage V_B and blue-shifted for positive V_B. In a SPSL there would be always a red-shift since there is an AlAs layer on either side of a given GaAs layer. In recent work on GaAs/AlAs CQW's the electric field induced Γ-X transition was clearly observed. The emission energies of the direct and indirect recombination as a function of V_B could be described quantitatively.

In this contribution we analyse phonon assisted recombination channels to find information about the spatial location of the electronic ground state as a function of V_B. At the anticrossing this ground state undergoes a transition from the GaAs to the AlAs layer.

In the real- and k-space indirect regime the recombination spectrum consists of an intense zero-phonon line and three phonon satellites. To identify the observed phonon replicas the observed emission lines are plotted relative to the energetic position of the zero phonon line for different V_B in Fig. 2. The energy loss with respect to the zero phonon line is found to be 26.5, 35.5 and 48.5meV. Almost similar numbers have been found previously in SPSL's. In contrast to the previous work on SPSL's we assign part of those...
Fig. 3 Relevant channels of energy relaxation after optical excitation to $E_0^\Gamma$. The energetic position of $E_0^X$ can be tuned by $V_B$ with respect to $E_0^\Gamma$.

Based on those arguments we can regard the phonon replicas as a local probe for the real-space position of the ground state electronic wave function in the GaAs/AlAs CQW. To further proof this interpretation we have analysed the evolution of the phonon replicas as a function of $V_B$ in the regime of the $\Gamma$-X transition. Results for the GaAs/AlAs 30Å/30Å structure are shown in Fig. 4. In the indirect regime ($-1V<V_B<0V$) the previously described AlAs-like replicas are observed. In the direct regime ($0.1V<V_B<1V$) those modes are absent. Instead a new mode appears which is interpreted as a $\Gamma$-point GaAs LO replica, in agreement with earlier work on SPSL’s$^4$. Right at the anticrossing at $V_B=0.1V$ a cross-over between those two regimes is evident. This cross-over is mediated by the voltage-induced transfer of the ground state electron wave function from the AlAs to the GaAs QW.
The critical $V_B$ for this transfer cannot be determined reliably by PL or PL-excitation spectroscopy because of the inherent changes in exciton lifetime and line shape or absorption. The spectroscopy of the phonon replicas however allows further insights into the properties of the electronic ground state in this CQW system. The phonon replicas provide thereby a local probe of the phonon spectrum in the QW of interest, namely in the QW in which the electronic ground state is localised. This work was financially supported by the BMFT Photonics project.