Interdiffusion effects on hole intersubband absorption in complex GaAs/AlGaAs quantum well structures

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Intersubband transitions within the conduction band in semiconductor quantum wells have been widely explored, which eventually led to their application in quantum well infrared photodetectors and quantum cascade lasers. There have been considerably fewer studies of hole intersubband transitions, which are more complicated than their electronic counterparts. They are very interesting, however, because of optical activity for both TM and TE light polarization, offering the possibility of both edge and surface-normal emission or absorption. Earlier studies have mostly focused on bound-continuum transitions in GaAs/AlGaAs and Si/SiGe systems for infrared detection. The interest in hole intersubband transitions has been recently renewed in view of their application for mid- and far-infrared emitters, including quantum cascade lasers. Considerable progress has been made in the design and realization of p-doped Si/SiGe quantum cascades, and luminescence has been obtained in the THz [1] and mid-infrared [2] range, although laser action has yet to be demonstrated.

The SiGe material system presents considerable growth challenges due to the lattice-mismatch induced strain. In contrast, the GaAs/AlGaAs system is virtually strain-free, and has a much better developed growth technology, which makes it attractive for realization of devices using hole intersubband transitions. Recent efforts have indeed resulted in growing rather complex p-doped multilayer GaAs/AlGaAs structures, showing well-resolved line-like spectra in absorption [3] and emission [4].

Quantum cascade lasers achieve population inversion using complicated carrier dymanics, i.e. scattering processes between the laser-active and a number of auxiliary states. A successful design and modelling of a cascade that will demonstrate gain critically depends on the accurate knowledge of the subband structure and the scattering rates derived from it, which in turn depend on both the actually grown structure profile and on the material parameters.

We have performed modelling of hole intersubband absorption of four quantum well structures embedded in superlattice-type barriers, described in [3], using the self-consistent 6×6 $\mathbf{k}\cdot\mathbf{p}$ model, which is very accurate within the energy range of interest, as comparison with empirical pseudopotential calculations [5] has indicated. The model accounts for full anisotropy and nonparabolicity of valence subbands and the optical transition matrix elements, as well as for the depolarization shift. A more complex structure than that of simple square wells, together with the fact that the system includes quasi-resonant states, delivers a larger sensitivity of the absorption spectra to various parameters, as illustrated in Fig. 1. However, this feature is in fact helpful in determination of the structural parameters by comparison of calculations with measurements.

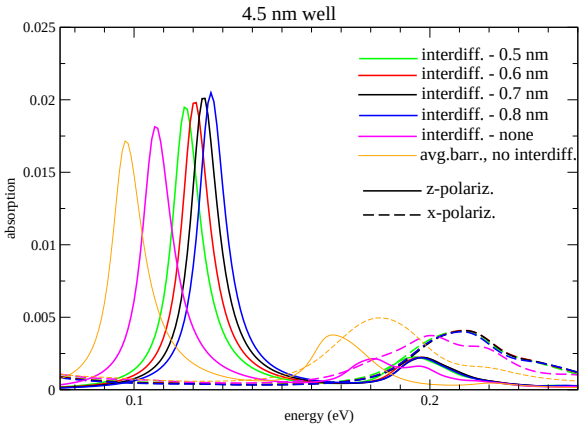

Fig. 1. The absorption profile evolution for the p-doped GaAs/AlGaAs superlattice-barrier quantum well structure described in [3] with variable degree of interdiffusion.

The measured absorption profiles were in the range of 100-300 meV, and included both HH-HH and HH-LH transitions. Good accuracy could be obtained with Luttinger γ parameters given in [6], while the older parameter sets performed less well. However, we find that a successful reproduction of measured transition peaks requires inclusion of layer interdiffusion, e.g. [7]. For the particular set of grown samples the interdiffusion length of 0.6-0.7 nm was deduced. Given that for high energy transitions the necessary well widths are rather small, and that the superlattice-barrier layers are also quite thin, the actual, interdiffused structure profile deviates substantially from the idealized, as illustrated in Fig. 2.

While the calculations within this model agree with the measured data to very good accuracy, the only case where discrepancies still exist are high-energy HH-LH transitions, for which the average-composition alloy barrier model per-

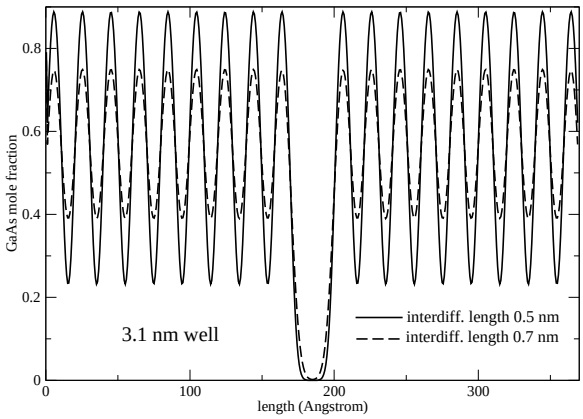

Fig. 2. The composition profiles of an initially rectangularly modulated all-binary GaAs-AlAs structure after interdiffusion.

forms better than the interdiffused superlattice-barrier model. Possible reasons for such behaviour will be discussed.

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