Intersubband relaxation dynamics in InGaAs/AlAsSb multiple quantum wells

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INTERSUBBAND transitions in semiconductor quantum wells (QW) are crucial for mid-infrared lasers, detectors, and modulators. New compound materials such as lattice matched InGaAs/AlAsSb and strain compensated InGaAs/AlAs, both grown on InP, feature large conduction band discontinuities (>1eV) and allow the extension of the available wavelength range into the near infrared. Such short wavelengths require narrow QWs (<3 nm) where the first excited state inside the QW may be raised above indirect (X or L) valleys within the Brillouin zone. Quantum cascade lasers involving subbands above the indirect minimum have recently been reported [1].

We have studied intersubband relaxation dynamics in $In_{0.53}Ga_{0.47}As/AlAs_{0.56}Sb_{0.44}$ multiple QWs with nominal (measured) thicknesses of 3.0 (2.9) and 4.5 (4.0) nm by femtosecond pump-probe experiments [2]. At early delay times, all samples show an exponential decay of the transient transmission with time constants of 0.8 to 1.5 ps, as shown in Fig. 1. At later delay times, the relaxation dynamics strongly depends on the QW thickness and doping. Bi-exponential decay is observed for 3 nm QWs, indicating several competing relaxation channels. Here electron transfer to X- and L-states in the barriers (Fig. 1b), which exists in the case of n-type modulation doping, or in the wells (Fig. 1c) is energetically possible. The data are analyzed in terms of an effective three-level model (inset of Fig. 1c), according to which the measured time constants can be expressed as $\tau_{slow} = \tau_{X1}$ and $\tau_{fast} = 1/(1/\tau_{21} + 1/\tau_{2X})$. Our results indicate that intervalley scattering in QWs occurs in the ps regime, much slower than in bulk semiconductors. This observation suggests that intersubband lasing involving states above indirect minima of the well material should be possible, as also confirmed by the results of [1].

REFERENCES

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Abstract received March 15, 2007. C. V.-B. T. acknowledges support from the Alexander-von-Humboldt Foundation.

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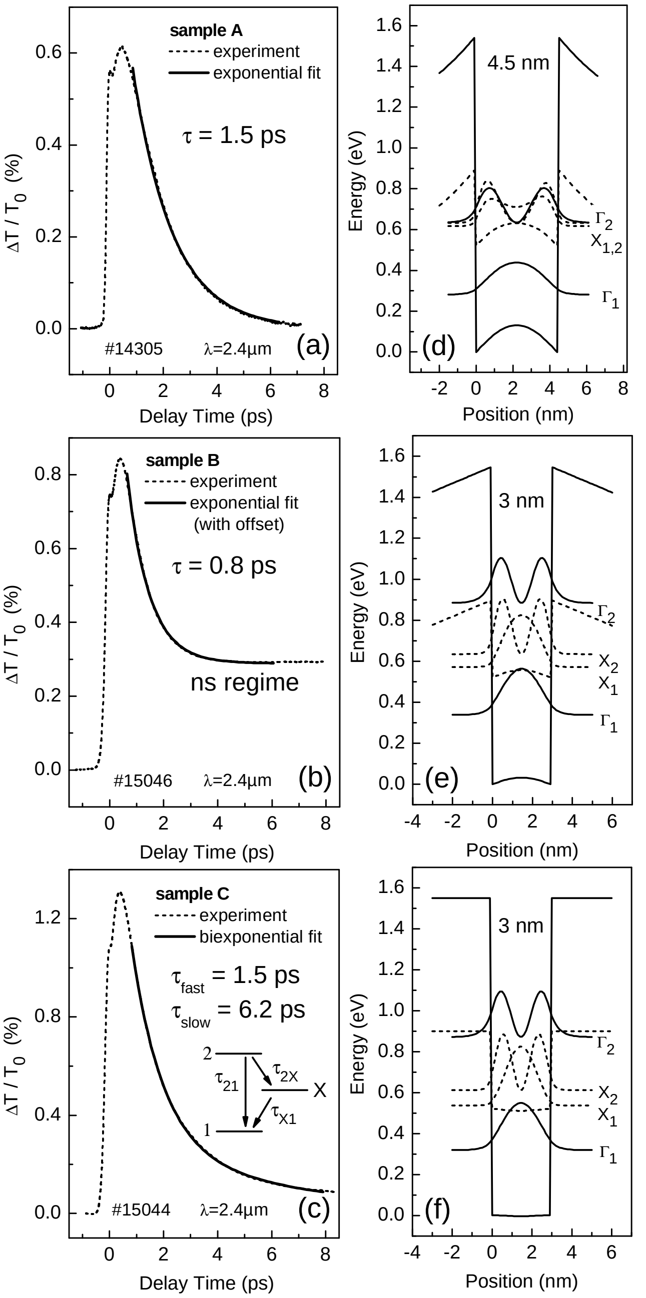

Fig. 1. Measured probe transmission of samples A (a), B (b), and C (c) vs. delay time together with numerical fits of the decay curve. Self-consistent conduction band edge profiles at the Γ- (solid lines) and X-point (dashed lines) for the same samples (d – f); probability densities of the subband states are also shown. The inset of (c) indicates a simplified three-level system used to analyze the data.