Intersubband relaxation dynamics in InGaAs/AlAsSb multiple quantum wells

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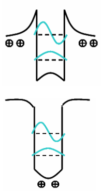
Abstract We report on a femtosecond pump-probe study of intersubband relaxation dynamics in narrow InGaAs/AlAsSb quantum wells. Intervalley scattering manifests itself by biexponential behavior with relaxation times of a few ps. Pumping slightly below resonance induces a transient probe absorption, which can be interpreted in terms of electron heating within the first subband.

Introduction

- Lattice matched InGaAs/AlAsSb grown on InP exhibits a large conduction band discontinuity (>1eV) and allows intersubband transition wavelengths in the near infrared.
- Such short wavelengths require narrow quantum wells (QWs) of <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].

Samples

- 50-period InGaAs/AlAsSb MQWs
- n-type, 3x10^{12} cm^{-2} per QW

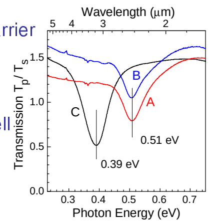


- doped in the barrier

Sample
A 4 nm QW
B 3 nm QW

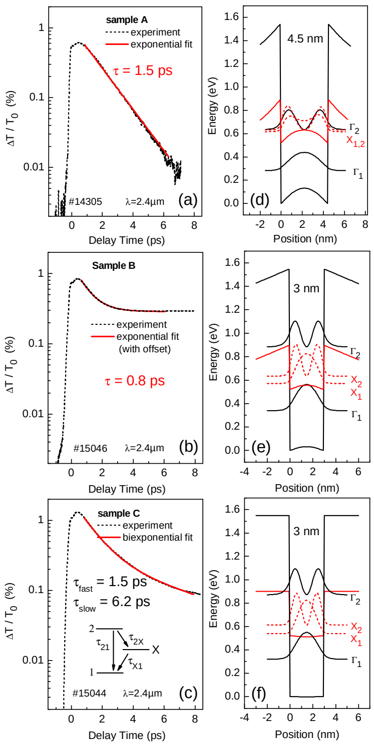
- doped in the well

Sample
C 3 nm QW
grown by MBE



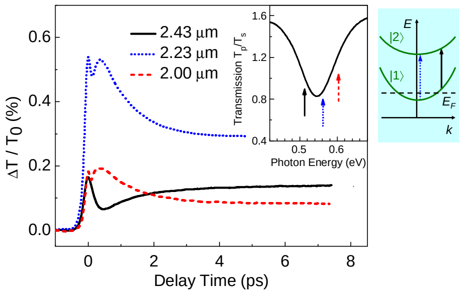
Intersubband relaxation

- Femtosecond pump-probe measurements indicate an exponential decay of the transient transmission at early delay times for samples A (a), B (b), and C (c), with time constants of 0.8 to 1.5 ps.
- At larger delay, the relaxation dynamics strongly depends on the QW thickness and doping. While single-exponential decay was observed in 4nm QWs, a second exponential component was present in 3 nm QWs, indicating several competing relaxation channels. Here electron transfer to X- and L-states in the barriers (b), which exists in the case of n-type modulation doping, or in the wells (c) is energetically possible.
- According to an effective three-level model (inset of (c)), measured time constants are expressed as $\tau_{slow} = \tau_{X1}$ and $\tau_{fast} = 1/(1/\tau_{21} + 1/\tau_{2X})$. Our interpretation is consistent with the respective conduction band edge profiles and occupation probabilities at the Γ- (black lines) and X-point (red lines) (d – f). These results indicate that intervalley scattering in QWs can occur in the ps regime, i.e., much slower than in bulk semiconductors [2].
- The latter result is further confirmed by the recent observation of intersubband lasing involving states above indirect minima of the well material [1].



Intrasubband cooling

- In the case of sample A, pumping below resonance (2.43µm) results in a reversal of the probe signal, i.e., an absorptive contribution which competes with the usual bleaching.
- Explanation: Nonparabolicity leads to different in-plane dispersion (different effective masses) of the individual subbands, which causes inhomogeneous broadening. Therefore, electrons with high k-values are predominantly excited on the low-energy side of the resonance. After intersubband excitation, electrons undergo electron-electron scattering. The electron temperature in the lowest subband increases, leading to enhanced absorption, i.e., reduced bleaching. This hot-electron distribution subsequently decays within a few ps (intrasubband cooling).
- This interpretation is further supported by the observation that it occurs most strongly in the narrowest QWs.
- An additional, extremely slow component (>> 100 ps) is caused by the return of electrons from the potential minimum in the barriers that is present in these modulation-doped structures [2],.



Conclusion

- Femtosecond pump probe measurements on narrow InGaAs/AlAsSb QWs provide evidence for intervalley scattering, which is however surprisingly ineffective.
- This explains why quantum cascade lasers still work at wavelengths as short as 3 µm.
- Observation of induced absorption yields signatures of intrasubband heating due to the nonparabolic band structure of narrow QWs.

[1] D. G. Revin *et al*., Appl. Phys. Lett. **90**, 021108 (2007).
[2] C. V.-B. Tribuzy *et al*., Appl. Phys. Lett. **89**, 171104 (2006).

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