Voltage Tunability of Intersubband Lifetimes in SiGe Quantum Well Structures

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Time resolved experiments on biased quantum well structures provide insight into the dependence of intersubband dynamics on the externally applied electric field. The outcome of such experiments is central for understanding the physics of optoelectronic devices like quantum cascade lasers. We report on a direct determination of quantum well intersubband relaxation times for spatially direct and diagonal transitions and the resulting continuous voltage tunability of intersubband relaxation times. The results were obtained by picosecond resolved pump-pump photocurrent experiments on biased SiGe valence band quantum well structures using a free electron laser. By varying the applied voltage, the intersubband hole relaxation times for quantum well structures are increased by a factor of two.

Introduction

Driven by the strong need for Si-based optoelectronic devices for a wide range of applications considerable endeavors have been made to develop a laser in this material system. Silicon is an indirect semiconductor and therefore cannot be used for direct optical transitions over the bandgap. However, the concept of infrared emitters based on quantum cascade heterostructures, which is very successfully applied to III-V material systems, constitutes a promising approach towards a SiGe infrared laser. But while emission of infrared radiation of various wavelengths has been demonstrated for p-type SiGe quantum cascade structures [1] [2], lasing has yet to be achieved. One of the key issues for the achievement of lasing is the build up of population inversion, which is essentially dependent on the excited state's lifetime. As valence band structure calculations for SiGe heterostructures are of high complexity, it is crucial to acquire the key intersubband relaxation times experimentally. In previous works we reported the first direct determination of ultrashort HH2-HH1 relaxation times (550 fs) by pump-pump photocurrent experiments [3] and compared transmission pump-probe experiments with pump-probe PC measurements by determining SiGe LH1-HH1 relaxation times in the ps regime, pointing out the advantage of latter [4].

Experimental

The samples where grown pseudomorphically on a $Si_{0.8}Ge_{0.2}$ [100] pseudosubstrate. One period of the sample structure constitutes of a deep central QW separated symmetrically by Si barriers from two shallow side wells. The central $Si_{0.67}Ge_{0.33}$ QW has a width of 40 Å and is separated by 10 Å thick barriers from 100 Å wide side wells. 100 Å wide barriers separate the $Si_{0.67}Ge_{0.33}$ side wells from the 300 Å wide $Si_{0.8}Ge_{0.2}$ spacers between the active regions. The central wells and adjacent Si barriers were Boron doped with a concentration of 10^{18} cm^{-3}. The sample consists of 15 periods of the described structures sandwiched between $Si_{0.8}Ge_{0.2}$ contact layers of doping concentration of $4x10^{18}$ cm^{-3}. For vertical PC measurements the samples were processed into mesas of 400 x 400 μm^2 and contacted by Al:Si metallization.

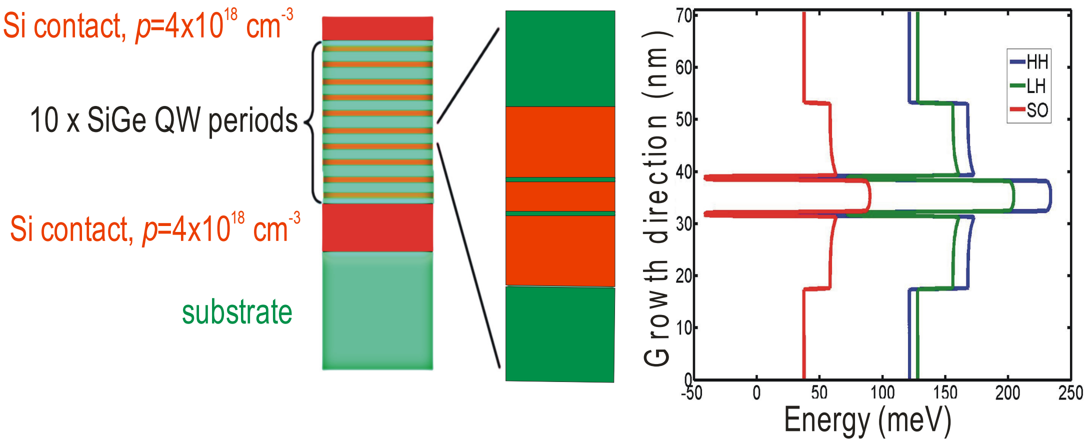

Fig. 1: Sketch of the molecular beam epitaxially grown structure on $Si_{0.8}Ge_{0.2}$ [100] pseudosubstrate. Also shown are the valence band edges as resulting from the growth profile.

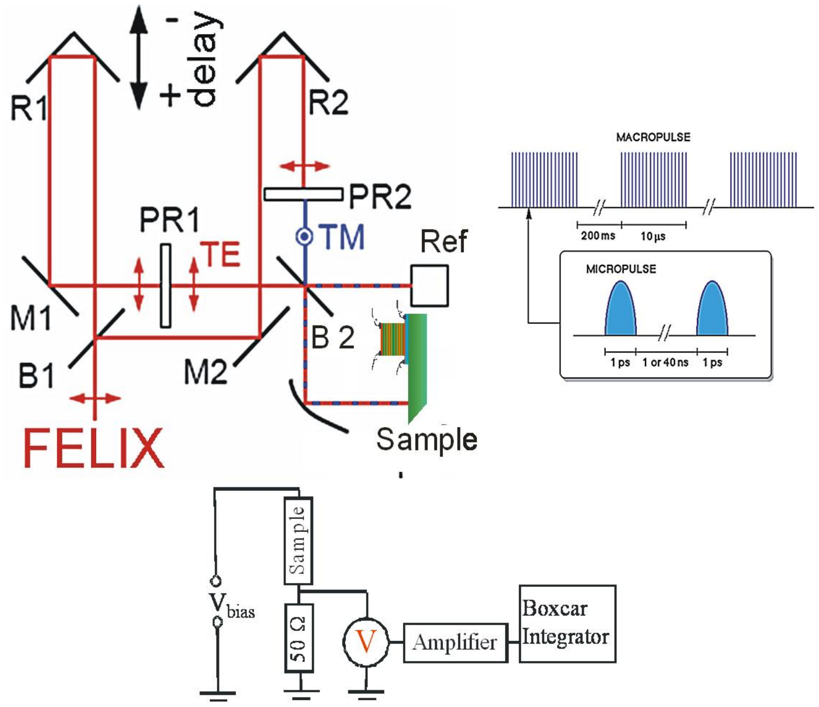

Fig. 2: Pump-pump measurement setup.

In order to determine the LH1-HH1 relaxation time PC pump-pump experiments were performed. The FEL beam was tuned to the respective HH1-LH1 resonance energy of the sample (29.5 meV). It enters the optical setup in TE polarization and is split by a beam splitter (Fig. 2). The polarization of beam 1 is turned by 90°. Beam 2 remains in purely TE polarization and is reflected by a movable mirror allowing to adjust the delay between TE and TM+TE pulse on a femtosecond scale. Before being coupled into the sample waveguide, the beams are made collinear again using a second beam splitter. The integral PC through the variably biased sample originating from the delayed TE and TM+TE micropulses is measured as a function of the delay.

Results

The results of the pump-pump measurements after subtracting backgrounds are presented in Fig. 3 for a series of voltages applied to the sample contacts. The curves show an asymmetry with respect to the sign of the delay, which is due to the polarization dependence of the transition involved. They further exhibit a systematic dependence of the PC decay behavior on the applied bias. The PC signal decays significantly slower with increasing voltage. The reason for the relaxation time tuning can be found in the sample's band structure.

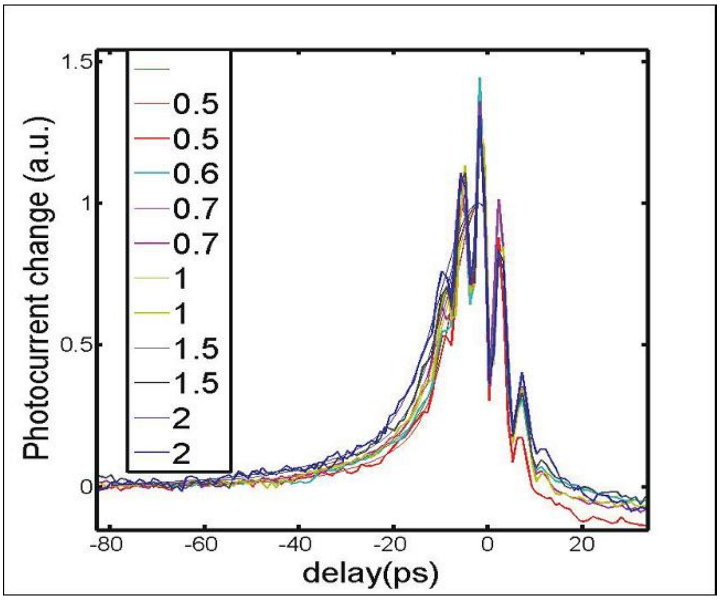

Fig. 3: Change in the decay of the additional photocurrent with the applied bias. The relaxation time increases by a factor of two when changing the bias between 0.5 and 2 V.

As the applied bias is increased, the investigated optical transition changes from a spatially direct into a spatially indirect transition, decreasing wavefunction overlap of the transition's ground and excited states and thus increasing the relaxation time.

Conclusion

In conclusion, we report a directly observed bias-tuning of intersubband relaxation times in QW structures. By continuously changing a spatially direct into an indirect transition, we were able to increase the monitored intersubband relaxation time by a factor of two.

References

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