Two-color pump-probe spectroscopy of electron dynamics in doped superlattices

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With respect to their dynamics semiconductor superlattices (SL) have been much less investigated than other heterostructures like quantum wells. In Ref. [1] we have already reported on single-color pump-probe measurements on doped superlattices where we could observe the interminiband relaxation and subsequent cooling of the heated electron distribution in the lower miniband of a SL after excitation to the upper one. However, superlattices have a broad absorption range so that excitation at a special *k*-value in the mini-Brillouin zone influences the electron distribution over the entire zone. Therefore we have performed two-color pump-probe measurements on three doped superlattices to investigate the intraminiband dynamics.

We employed infrared pulses from the free-electron laser FELBE at the Forschungszentrum Dresden-Rossendorf as the pump beam and synchronized broadband THz pulses generated by optical rectification in GaSe as the probe beam. The three GaAs/AlGaAs superlattices had nearly the same doping concentration but different miniband widths of 10 meV, 22 meV and 45 meV, which is smaller or larger, respectively, than the optical phonon energy of 36 meV.

We have first analyzed the cooling behavior. At low temperature, electrons were excited to the upper miniband by the FEL pulse at the zone center of the superlattice mini-Brillouin zone and the interminiband transition was probed at the zone edge (see Fig.1). The excited electrons relax back to the ground miniband where they heat up the electronic distribution. A higher temperature leads to more absorption at the zone edge low energy transition, as can be seen in Fig.1. Therefore we found an induced absorption signal after excitation, which decays when the electronic distribution cools down (see Fig.2). In the superlattice structures with miniband widths below the optical phonon energy we measured cooling times of 40-50 ps for pump intensities higher than 20 MW/cm². For smaller pump intensities the time constants rose up to 200 ps. The sample with the miniband width of 45 meV showed a much shorter cooling time of 3.5 ps, nearly independent of the pump intensity. This can be explained by the new relaxation channel through polar optical phonons.

Additionally we performed room temperature measurements where the lower miniband is already occupied at the zone edge so that no induced absorption should be observed. In fact we measured a positive transmission change which decays in a few picoseconds in all samples. This can be attributed to a relaxation process in the lower miniband where the electrons at the zone edge relax to the miniband center, which is depleted of electrons by the pump pulse.

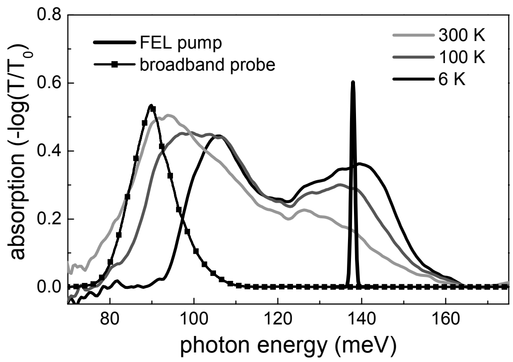

Fig. 1. Linear absorption spectra for the sample with a miniband width of 10 meV, shown for different temperatures. Also shown is the configuration of the two-color pump-probe experiments with the spectral positions of the FEL pump pulse and the broadband THz probe pulse, which is tuned to the Brillouin-zone edge.

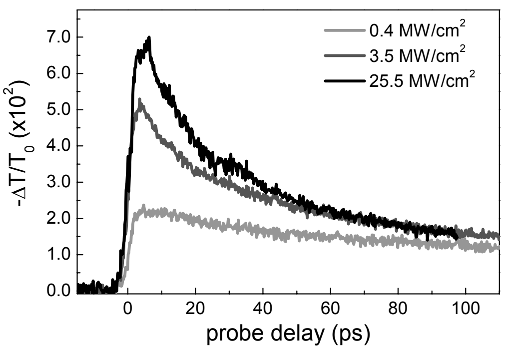

Fig. 2. Two-color pump-probe signals for the sample with a miniband width of 10 meV at a lattice temperature of 5 K, recorded for different pump intensities. For higher intensities the decay times are more or less constant (50 ps) whereas at the lowest intensity we find a decay over 200 ps. After 100 ps all curves merge, reflecting equal temperatures of the electron gas.

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REFERENCES

[1] D. Stehr, S. Winnerl, M. Helm, T. Dekorsy, T. Roch, and G. Strasser, Appl. Phys. Lett. **88**, 151108 (2006)