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Doctoral dissertation abstract

„Investigations of the dynamics of excitations in semiconductors and their low-dimensional structures in the near- and mid-infrared spectral range”

Semiconductor material systems, with a small fraction of bismuth and tin, such as Ga(Sb, Bi) or GeSn, emitting in the near and mid-infrared spectral range, have been the subject of intensive research in recent years due to their interesting physical properties. They could also find applications as an active region of light emitters and be an alternative or supplement to the currently used semiconductor technologies emitting in the above-mentioned spectral regions.

Despite the vast interest in this material system and many publications demonstrating their optical properties, the knowledge about the relaxation dynamics of optical excitations and its parameters in these materials is still minimal. The dissertation aims to fill this knowledge gap. For this purpose, optical excitation dynamics in Ga (Sb, Bi)/GaSb, (Ga, In) (Sb, Bi)/GaSb quantum wells and thin GeSn epilayers have been carried out using two complementary time-resolved spectroscopic techniques: time-resolved differential reflectivity and the time-resolved photoluminescence. These experiments are supported by experimental data from quasi-stationary experiments such as photoreflectance, photoluminescence, Raman spectroscopy, transmission electron microscopy, and high-resolution X-ray diffraction.

To carry out the research described in the dissertation, an experimental workshop was built to determine the dynamics of optical excitations in semiconductor materials and their low-dimensional structures with a characteristic bandgap energy of the system in the near- and mid-infrared spectral range of emitted photons. Additionally, the workshop was extended with a laser pulse diagnostics system that can work in near- and mid-infrared spectral ranges.

Investigations on Ga(Sb, Bi)/GaSb, (Ga, In)(Sb, Bi)/GaSb QWs allowed for the first time determination of the parameters of the dynamics of optical excitation relaxation processes in these types of structures. For both material systems, the intraband relaxation time to the quantum well ground state and the lifetime of optical excitations at the ground state of the well was determined. In the case of the Ga(Sb, Bi)/GaSb material system, the effect of nonradiative recombination on the lifetime of excitations in a quantum well was omitted due to the lack of a strong dispersion of an excitation lifetime and scaling of a lifetime with the width of the well. This postulate was negatively verified by the knowledge gained from research on the dynamics of optical excitations in (Ga, In) (Sb, Bi)/GaSb quantum wells. In this material system, a strong

dispersion dependence of excitation lifetimes was observed, which flattens with increasing bismuth fraction, suggesting an increasing role of nonradiative recombination centres with the increase of the Bi content.

Research performed on GeSn layers has shown that the emission from GeSn layers does not have to be related to the system's transition from the II-type to the I-type character with the increase of the Sn fraction. It has been shown that the observed emission is effective also from defects states located below the bandgap energy of GeSn. The research revealed for the first time that the dynamics of charge carriers in GeSn is complex. It has been demonstrated that intraband relaxation in GeSn is characterised by the existence of at least two relaxation channels: fast, related to the thermalisation of carriers to the bottom of the bands, and slow, which was related to the postulated carriers relaxation within the spatial fluctuation of the energy gap of the system. Moreover, it has been shown that the lifetime of charge carriers from emitting (defects) states is controlled by Shockley-Hall-Read recombination processes and possibly by surface recombination.