Abstract of doctoral dissertation entitled: “Optical properties of semiconductor structure of group III-V diluted by bismuth”

The main goal of this dissertation was the investigation of optical properties of novel semiconductor alloys of group III-V diluted by bismuth, which can be applied in optoelectronics devices operating in the near and mid infrared spectral region. Due to the above mentioned aim the dissertation was focused mainly on these three issues: i) influence of bismuth on electronic band structure of host materials, ii) its impact on radiative and nonradiative recombination processes and iii) studies of temperature dependencies of optical transition in III-(V,Bi) semiconductor structure. In the case of this work semiconductor structures such as: GaSbBi, InPBi, InGaAsBi, InGaSbBi, AlGaSbBi and multi quamtum wells GaAsBi/GaAs were studied.

Influence of bismuth on band structure of host materials was investigated using experimental (photoreflectance and contactless electroreflectance) and theoretical (density functional theory DFT and ***kp*** model) methods. Results obtained using both approaches, it is experimental and theoretical, led to the same qualitative conclusions – increase of bismuth content lead to decrease of energy gap and increase of spin-orbit splitting. Furthermore, considering these phenomena quantitatively they depend on difference in electronegativity and ionic size between bismuth and atom which is replaced. It was concluded as well that both conduction and valence band are modified due to incorporation of bismuth atoms into host material. Additionally, band gap alignment in GaAsBi/GaAs quantum well was studied – it was concluded that value of valence band offset is ~55%.

Studies of temperature influence on optical properties of III-(V,Bi) semiconductor were conducted using PR experimental setup equipped with a helium closed cycle refrigerator. The temperature dependencies of E_0 (energy gap) and E_{SO} optical transitions and their broadening were obtained. In the case of gallium antimonide alloys diluted by bismuth the temperature induced reduction of band gap, in the range from 15K to 300K, is slightly smaller than in host material – it is ~70meV for GaSbBi and 82meV for GaSb. Moreover, the values of $\Gamma(0K)$, which is broadening of optical transition at 0K and it is mainly associated with alloy inhomogeneity, were analyzed. It was concluded, based on this consideration, that better quality compounds can be obtained by alloying GaBi with GaSb than alloying GaBi with GaAs – since Bi atoms are more similar to Sb atoms (in electronegativities and ionic sizes). On the other hand the broadening of optical transition of gallium arsenide alloys diluted by bismuth is one order of magnitude larger, which implies higher alloy inhomogeneities. Considering temperature induced reduction of energy gap of the above mentioned material the slight decrease of it was observed due to incorporation of bismuth atoms into host material.

For the studies of radiative and nonradiative recombination processes in III-(V,Bi) semiconductor alloys photoluminescence (PL) and time-resolved photoluminescence (TRPL) techniques were used. The PL and TRPL measurements were made at various temperature and excitation power for GaSbBi layers and GaAsBi/GaAs multi quantum wells. On the ground of the research, which was done, two emission channels were identified; i) dominant at low temperatures localized emission which has been attributed to the optical transition between the conduction band and native acceptor states, and ii) radiative recombination between the conduction band and valence band dominant at higher temperature for which acceptor states start to be occupied by thermally activated electrons from the valence band. This phenomena lead to thermal quenching of localized emission. Additionally, delocalized emission from GaSbBi layers start to be visible at temperatures above 50K, which allow to conclude that the scale of potential fluctuations in these samples is rather small in comparison to other dilute bismides (e.g., GaAsBi).