Abstract

In recent years, there has been a significant increase in interest in mid-infrared radiation emitters, among which quantum cascade lasers (QCLs) play a key role. Due to the huge application requirements in various fields, the development of new advanced semiconductor heterostructures, fabrication and design optimisation of QCL lasers is a major research objective of many research groups worldwide.

The main objective of the dissertation was to develop the theoretical basis for a new waveguide design of cascade lasers and to fabricate QCL test structures based on InGaAs/AlInAs/InP heterostructures, in which confining layers characterised by a gradient concentration distribution of the active dopant were proposed. The realisation of the detailed research tasks was preceded by a review of the recent literature on the fundamentals of operation, fabrication technology and application areas of quantum cascade lasers. The results of the literature analysis, as well as preliminary results of modelling of such structures, were the motivation to define the aim of the PhD thesis and to propose a model of a new laser waveguide structure. Modelling of QCL structures for the 5 and 9 μm radiation emission range was carried out. Firstly, the influence of the thickness of the separating layer on parameters such as the modulus trapping coefficient Γ_E and the optical threshold gain g_{th} was modelled. In the next step, the influence of the thickness and doping level of the confining layers on the mentioned parameters Γ_E and g_{th} was verified. The final modelling step for the analysed wavelengths was the introduction of a novel gradient doping profile of the confining layers - linear and sinusoidal. The obtained results of simulation studies were the basis for proposing a new design of QCL lasers and its technological verification through fabrication and measurements of test structures in the Department of Microelectronics and Nanotechnology of Wrocław University of Technology in cooperation with the Łukasiewicz Reaserch Network - IMiF Research Network, VIGO company and a team of prof. Tomasz Czyszanowski from the Lodz University of Technology.

Prior to fabrication of the QCL laser test structures, a number of processes were carried out to optimise the growth parameters of the individual layers. The results of measurements of test structures of InGaAs and AlInAs ternary layers, InGaAs/AlInAs quantum wells and laser core based on InGaAs/AlInAs/InP heterostructure are described. In the final technological step, the effect of changing the thickness and doping profile of the confining layer on the laser operation was analysed. Preliminary studies of the fabricated test structures with the proposed waveguide layer changes are presented and the effect of the gradient doping distribution on their performance is determined.

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