1 Introduction

There is an increasing number of applications, such as trace gas spectroscopy, medical diagnostics, laser surgery and material processing, which require compact and robust laser sources emitting in the 2-3 μm wavelength range. Because of the strong absorption lines of a variety of relevant technical gases in this wavelength range [1], high resolution spectroscopic gas detection for industrial process monitoring or environmental control can be realized using such diode lasers. Continuous wave (CW) output powers at room temperature of a few tens of mW are required for these applications, together with a good spectral purity. Furthermore, LIDAR-measurements and optical free-space telecommunications can be achieved through the 2-2.5 μm atmospheric window. Because of the distinct absorption spectra of human tissue [2], medical diagnostic, such as noninvasive optical blood glucose monitoring [3] and laser surgery [2] are other promising applications. For the latter, output powers exceeding 1 W are required. Given the wide range of applications of lasers in material processing, not all can be dealt with using state-of-the-art GaAs-based high-power diode lasers, emitting around 1 μm. For example the welding of transparent plastic demands high power lasers at 2 μm, an application which is currently addressed by Ho-YAG solid state laser systems [4]. High-power diode lasers emitting at around 2 μm, with their potential lower cost and compactness can replace those systems. Finally, optical pumping of solid state lasers systems [5,6] is another application of high power 2 μm diode lasers.

The III-V compound semiconductor material system (AlGaIn)(AsSb) constitutes an ideal basis for the realization of diode lasers in this wavelength regime. GaInAsSb, either lattice matched to GaSb or deliberately strained, can be used for the active layer with a direct band gap between 1.7 μm and well above 3 μm. For the barrier and cladding layers, AlGaAsSb is well suited because of its larger band gap energy and lower refractive index than GaInAsSb.

Starting with the first III-V mid-IR laser in 1963, based on InAs homojunctions and a low-temperature emission at 3.1 μm [7], double-heterostructure (DH) lasers were developed with GaInAsSb active region and AlGaAsSb barriers, grown on GaSb-substrates. These lasers showed excellent performance at room temperature in the 2.0 to 2.5 μm range [8,9]. For the 3-4 μm range, DH-lasers employing InAsSb / AlGaAsSb layer sequences on GaSb or InAsSb / InAsPSb layers on InAs-substrates were fabricated with a maximum operating temperature of around 170 K in pulsed operation [10-12]. In 1992, the concept of strained quantum-well (QW) lasers was for the first time implemented in GaSb-based lasers [13] yielding significant improvements in laser output power and maximum operating temperature [14]. Nowadays GaInAsSb/AlGaAsSb Type-I QW lasers can be operated at room
temperature up to wavelength of 3.04 µm [15]. Above 3 µm, Type-II laser concepts, such as the W-Laser [16] seem to have a better performance than Type-I QW-lasers with an InAsSb active layer, mostly because the potential suppression of the CHHS-Auger recombination in these Type-II laser structures [17]. In this chapter, we will focus on GaInAsSb / AlGaAsSb Type-I diode lasers grown on GaSb-substrates.

2 III-Sb-based Material System

2.1 AlGaAsSb

The quaternary semiconductors Al$_x$Ga$_{1-x}$As$_y$Sb$_{1-y}$ are the ideal materials for barrier-, waveguide- and cladding layers of III-Sb based Type-I diode lasers. Because of the large width of the latter layers, they are almost exclusively grown lattice matched to the GaSb-substrate, which is achieved by adding a small amount of As to the AlGaSb to form Al$_x$Ga$_{1-x}$As$_y$Sb$_{1-y}$ with $y = 0.08 x$ [18]. The direct band gap for AlGaAsSb at 300 K, lattice matched to GaSb, is given by $E_g(\Gamma) = 2.297 x + 0.727 (1-x) - 0.48 x (1-x) eV$ [18].

The ternary alloy Al$_x$Ga$_{1-x}$Sb has the specific property of changing the character of the fundamental band gap twice upon increasing Al-content: from direct, with the $\Gamma$-conduction band minimum being lowest in energy, to indirect, with the L-point minima being lowest in energy for Al-contents above 25 % and to the X-point minima being lowest for an Al-content beyond approx. 45 % [18-20]. For AlGaAsSb lattice matched to GaSb, a similar behavior is expected as only a small amount of As is added, although some calculations suggest a direct to indirect crossover at an Al-concentration of only 14 % [18].

2.2 Strained GaInAsSb Layers

For the active layers, Ga$_{1-x}$In$_x$As$_y$Sb$_{1-y}$ is used which has a direct bandgap for all alloy composition and is lattice matched to GaSb if the condition $y = 0.913 x$ is satisfied [18,21]. Using a quaternary material for the active layer adds an additional degree of freedom for the design of QWs compared to a ternary material (such as the well known GaInAs): by changing the composition, two of the three relevant parameters bandgap $E_g$, strain $\varepsilon_{zz}$, and band offsets $\Delta E$ can be adjusted individually within certain limitations. To illustrate this property of the GaInAsSb material system, Figure 1 shows the band-edge profile for Ga$_{1-x}$In$_x$As$_y$Sb$_{1-y}$ grown on GaSb as a function of the In-content $x$ for three cases with different As-contents $y$ and thus different strain $\varepsilon_{zz}$. Starting with GaSb on the left side of each plot, the bandgap is decreased with increasing In-content, in all cases. Also shown are the band edges of AlGaAsSb lattice matched to GaSb, a similar behavior is expected as only a small amount of As is added, although some calculations suggest a direct to indirect crossover at an Al-concentration of only 14 % [18].