Continuous-wave room temperature operated 3.0 μm type I GaSb-based lasers with quinternary AlInGaAsSb barriers

T. Hosoda,1 G. Belenky,1,a L. Shterengas,1 G. Kipshidze,1 and M. V. Kisin2
1Department of Electrical and Computer Engineering, SUNY, Stony Brook, New York 11794, USA
2Power Photonic Corporation, Stony Brook, New York 11790, USA

(Received 2 January 2008; accepted 8 February 2008; published online 4 March 2008)

Diode lasers emitting at 3.0 μm were designed and fabricated. Device active region contained two compressively strained InGaAsSb quantum wells incorporated in quinternary AlInGaAsSb barriers. Laser output power at room temperature was 130 mW in continuous wave regime and more than 1 W in pulse. © 2008 American Institute of Physics. [DOI: 10.1063/1.2890053]

Over the past several years, significant progress was achieved in development of high power type I GaSb-based quantum well (QW) lasers operating at room temperature within spectral region 2.3–2.8 μm. Devices with InGaAsSb strained QWs incorporated in AlGaAsSb barriers provide hundreds of milliwatt output power in cw regime.1 However, the performance of type I GaSb-based quantum well lasers at longer wavelength is not so impressive. Only 4 mW optical power in cw regime at room temperature with wavelength near 3 μm was shown in Ref. 8. Type I lasers based on AlInAsSb/InGaAsSb/GaSb heterostructure show emission at 3.26 μm in pulse mode at temperature up to 50 °C.9 Since the spectrum region 3.0–3.5 μm is attractive for a variety of gas sensing applications, different approaches had been used to design devices with these characteristics. Emission with wavelength close to 3 μm was registered in pulse mode up to 400 K from intersubband quantum cascade lasers based on InAs/AlSb heterostructure.10 Type II intersubband quantum cascade (QC) laser based on GaSb substrate demonstrates emission close to 3.3 μm and operates in cw regime up to 264 K.11

Earlier, we noted6 that improvement of the hole confinement is the decisive factor for development of GaSb-based laser diodes with enhanced performance. In this paper, we are reporting the characteristics of room temperature operating 3 μm type I GaSb-based lasers with improved carrier confinement. The devices output power at room temperature is 130 mW and in pulse is more than 1 W.

Laser heterostructures were grown using a Veeco GEN-930 solid source molecular beam epitaxy system on Te-doped GaSb substrates. The cladding layers were 2.5 and 1.5 μm wide Al0.2In0.8Ga0.4As0.07Sb0.93 doped with Te (n-side) and Be (p-side), respectively. Graded bandgap heavily doped transition layers were introduced between the substrate and n-cladding and between the p-cladding and p-cap to assist carrier injection. The nominally undoped Al0.2In0.8Ga0.4As0.02Sb0.98 waveguide layer with a total thickness of about 800 nm contained two 12 nm wide In0.33Ga0.67As0.23Sb0.77 QWs centered in the waveguide and spaced 40 nm apart. Thick waveguide and cladding layers were lattice matched to GaSb. The compressive strain in the QWs was about 1.8%. The wafer was processed into 100 μm wide oxide confined gain guided lasers. 2 mm long neutral-reflection [(NR) ~ 30%] and high-reflection [(HR) ~ 95%] coated lasers were In-soldered episide down onto Au-coated polished copper blocks and characterized.

Figure 1 shows the temperature dependence of cw light-current characteristics for 2 mm long NR/HR lasers. More than 130 mW cw output power was demonstrated at 290 K for the 2 mm long laser with threshold current about 0.6 A. In short pulse low duty cycle mode (200 ns/10 kHz), the 2 mm long devices show no thermal rollover and more than 1 W peak power level at 12 A at room temperature (Fig. 2). At 250 K, the device peak power is more than 1 W at 9 A of peak current. The inset in Fig. 2 plots the temperature dependences of the 2 mm long device threshold current and efficiency. Parameters T0 and T1 characterizing the exponential increase of the threshold current and decrease of the external efficiency with temperature are above 58 and 217 K, respectively.

The results presented above demonstrate that heterostructures with quinternary AlInGaAsSb waveguide and InGaAsSb QW layers (this approach was already used to de-

![Fig. 1. cw mode output power and spectral characteristics of 2 mm long NR/HR coated device with stripe width 100 μm.](image-url)
sign and fabricate lasers operated at room temperature in pulse mode\(^9\) are promising for fabrication of GaSb-based type I diode lasers with emission wavelength above 3 \(\mu\)m. Structures with quaternary AlGaAsSb waveguides/barriers have limitations which restrict their use for device development in this spectral range. The laser operation beyond 3 \(\mu\)m requires increasing the QW indium concentration above 50\% level. In order to keep the mechanical strain low, arsenic concentration in QW material must be increased. This results in strong degradation of the hole confinement in the active QWs.

Hole confinement in quaternary InGaAsSb/AlGaAsSb heterostructures can be restored by raising the aluminum concentration in the barrier (waveguide) layers. This leads to reduction of the waveguide refractive index, deteriorating the optical mode confinement, and to increase of the conduction band discontinuities at QW heterointerfaces. The presence of deep QWs for electrons can result in inhomogeneous QW populations in multi-QW laser diodes as well as create the situation of carrier heating during the intrawell electron relaxation. Under the condition of weak hole confinement, heating of the hole subsystem can be crucial for the ultimate laser operation.

Most of the above problems can be resolved by introducing indium into the waveguide composition. Indium noticeably decreases the direct energy gap of the barrier layers and, therefore, lowers the conduction band discontinuities in the active QWs. Moreover, the presence of indium in quaternary waveguide composition requires increased arsenic concentration in the waveguide (barrier) layers leading to improved hole confinement. Utilizing quaternary waveguides, we can decrease QWs strain and correspondingly increase the QWs width. Figure 4 illustrates the above considerations and defines the choice of the material compositions used in the design of the devices reported in this paper. For calculation of the band edge positions we use the data from review.\(^12\) Energy gaps were calculated using biquadratic interpolation algorithm.\(^13\) Valence band positions were obtained by linear interpolation. Figure 4 presents the calculated band edge positions at room temperature. It is readily seen that presence of indium in quinary alloy strongly decreases the energy positions of both conduction band and valence band as compared with quaternary Al\(_{0.7}\)GaAsSb composition (start points of solid curves marked with short arrows correspond to quaternary waveguide compositions without indium). Such a decrease favorably balances the confinement conditions for both electrons and holes. The vertical arrows indicate the direct energy gaps for quinary waveguide with 20\% aluminum and 20\% indium (left arrow) and 1.8\% strained quaternary QW composition with 54\% indium (right arrow). Figure 4 also shows the band edge positions for quaternary InGaAsSb alloy lattice matched to GaSb (dash-dotted lines) which would be the best choice in view of aluminum-free waveguide. Note, however, that quinary waveguide with no aluminum added provides insufficient confinement either for holes or for electrons at any composition and therefore should be avoided.

In conclusion, we proved that heterostructures with quinary AlInGaAsSb waveguide and InGaAsSb QW...
layers are promising for fabrication of room temperature operating GaSb-based type-I diode lasers with emission wavelength of 3 μm. Devices based on AlInGaAsSb/InGaAsSb/AlInGaAsSb/GaSb heterostructures demonstrate optical power 130 mW in cw regime and more than 1 W in pulse at room temperature.

Authors would like to thank Dr. D. Westerfeld of Power Photonic Corporation for fruitful discussions. This work was supported by the NYSTAR Contract No. C020000, AFOSR Grant No. FA9550-04-1-0372, and NSF Grant No. DMR071054.