Room-temperature GaSb-based quinternary type-I quantum-well lasers for the wavelength range from 3.3 to 3.6 µm

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Introduction:

Long wavelength lasers with emission in the mid-infrared wavelength range above 3 µm are attractive light sources for trace-gas sensing systems with tunable diode laser absorption spectroscopy (TDLAS) [1]. Most important industrial gases show strong absorption lines in the spectral range between 2 and 4 µm, which can be theoretically covered by type-I GaSb-based devices. In order to achieve longer wavelengths, one has to increase indium content in the quaternary GaInAsSb quantum well material. Unfortunately, this brings the alloy deeper in the miscibility gap [2] and makes the growth more complicated. Additional complexity arises from the fact that in order to achieve a type-I band alignment in the quantum wells and to maintain at the same time a homogeneous filling, one has to use quinternary AlGaInAsSb barriers and waveguide layers for lasers with emission wavelengths longer than 3 µm. The latter makes the growth even more challenging and up to now only few groups worldwide have reported room-temperature operation of 3.3 µm lasers [3-4] and only recently lasing at 3.4 µm has been reported [5]. In this work, room-temperature operation of type-I GaSb-based lasers with quinternary AlGaInAsSb heterostructures emitting at 3.3 and 3.4 µm (fig. 1) is presented, and, for the first time, the extension of the room-temperature lasing wavelength up to 3.6 µm has been achieved (fig. 1), which is the longest room-temperature wavelength reported worldwide up to now for type-I GaSb-based diodes.

Device growth and fabrication:

Solid-source MBE grown laser structures consist of quarternary $Al_{0.9}Ga_{0.1}As_{0.08}Sb_{0.92}$ cladding layers, *n*- and *p*-doped with Te and Be, respectively. For the waveguide and barrier layers undoped quinternary AlGaInAsSb has been grown with the following compositions: $Al_{0.3}Ga_{0.3}In_{0.4}As_{0.4}Sb_{0.6}$ was used for 3.3 - 3.4 µm lasers and $Al_{0.3}Ga_{0.2}In_{0.5}As_{0.48}Sb_{0.52}$ for 3.6 µm lasers. Active regions were composed of compressively strained 10 nm thick GaInAsSb multiple quantum wells. For the lasers emitting at 3.3 and 3.4 µm three $Ga_{0.43}In_{0.57}As_{0.29}Sb_{0.71}$ and $Ga_{0.38}In_{0.62}As_{0.36}Sb_{0.64}$ QWs were used, respectively. For 3.6 µm laser, five $Ga_{0.3}In_{0.7}As_{0.48}Sb_{0.52}$ QWs were used in order to increase gain and optical confinement. Epitaxial structures after the growth have been processed into metal-clad ridge-waveguide broad area laser structures with ridges ranging in width from 15 to 220 µm. Finally, lasers with different resonator lengths were cleaved and mounted episide-up on copper heatsinks. Mirror facets were left as cleaved.

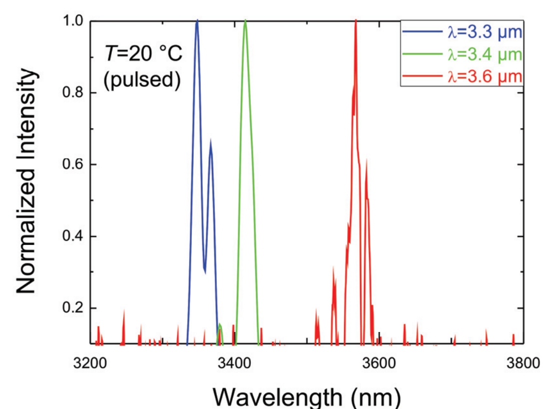

Fig. 1 – The measured spectra of the three fabricated edge emitters at 20°C and under pulsed operation are shown.

Device results and discussion:

All fabricated devices exhibit lasing under pulsed operation at room-temperature and above with relatively low-threshold current densities (see Fig. 2). The 3.3 and 3.4 µm lasers have extrapolated threshold current densities of 110 and 135 A/cm^2 per quantum well, at infinite resonator length (Fig. 2), whereas 3.6 µm laser has an extrapolated threshold current as high as 172 A/cm^2 per quantum well. Increasing threshold current density with increasing wavelength is expected, because non-radiative loss mechanisms, such as Auger-recombination and also free-carrier absorption, increase dramatically and higher carrier densities are required to obtain sufficient gain. Nevertheless, 3.3 and 3.4 µm lasers also exhibit continuous-wave operation near room-temperature (11°C), even though no heat removal optimization like episide-down mounting has been done. Further extension of operation temperature

should be possible by applying such advanced mounting techniques or by increasing the facet reflectivity to reduce the mirror losses. The measured T_0 values confirm this estimation: the lasers emitting at 3.3 and 3.4 µm achieve a T_0 of around 30 K up to 40°C, which is an impressive magnitude for this wavelength. Even the 3.6 µm laser achieves this value till around 15°C; at higher temperatures the T_0 decrease to ~10 K, which can be attributed to the small hole confinement of only around 40 meV. Hence, we expect improved temperature stability by increasing this offset

Conclusion:

The extension of room-temperature emission wavelength up to 3.6 µm for GaSb-based type-I edge emitting lasers with advanced quinternary AlGaInAsSb heterostructures has been realized for the first time and the performance has been compared to 3.3 – 3.4 µm lasers, which operate in pulsed operation at room-temperature and in continuous-wave (cw) up to 11°C. Increase in threshold current density with increasing wavelength is observed and is attributed to increasing non-radiative losses. Extension of cw-operation temperature should be possible by improving the heat removal from the device.

Acknowledgements

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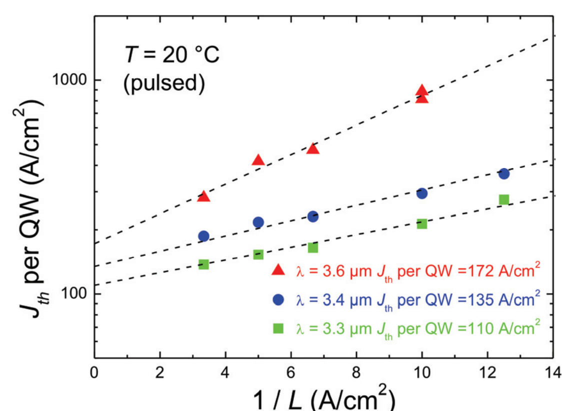

Fig. 2 – The measured threshold current density of each laser devices divided by the applied number of QWs is plotted against the inverse length (mirror losses).The threshold density per QW at infinity length (no mirror losses), which is shown in the legend, has been deduced from the fits (dotted line).