High power asymmetrical InAsSb/InAsSbP/AlAsSb double heterostructure lasers emitting at 3.4 μm

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Midinfrared lasers with an asymmetrical InPAsSb/InAsSb/AlAsSb double heterostructure are reported. Using the asymmetrical double heterostructure, p- and n-cladding layers are separately optimized; high energy-gap AlAsSb (\(E_g\sim1.5\) eV) for the p-type cladding layer to reduce the leakage current, and thus to increase \(T_o\), and low energy-gap InPAsSb (\(E_g\sim0.5\) eV) for the n-cladding layer to have low turn-on voltage. 100-μm-width broad-area lasers with 1000 μm cavity length exhibited peak output powers of 1.88 W in pulse and 350 mW in continuous wave modes per two facets at \(T=80\) K with \(T_o\) of 54 K and turn-on voltage of 0.36 V. Maximum peak output powers up to 6.7 W were obtained from a laser bar of total aperture of 400 μm width and cavity length of 1000 μm, with a differential efficiency of 34% and far-field beam divergence narrower than 40° at 80 K. © 1999 American Institute of Physics.

Midinfrared laser diodes emitting at 3–5 μm have a wide range of applications in high resolution gas spectroscopy, free space communications, low loss fiber optical communication, and military counter measure systems. For most applications, reliable high-power operation is critical as it determines sensitivity and spatial range of applications. III–V compound-based lasers are ideal candidates for high power operation1–4 as opposed to commercially available IV–VI compound-based lasers whose typical maximum output power is only 1 mW.

Previously, we demonstrated low-pressure metalorganic chemical vapor deposition (LPMOCVD)-grown InAsSb/InPAsSb lasers operating up to 1 and 3 W at 80 K with 100 and 300 μm total apertures, respectively.1,5 However, InPAsSb cladding layers have relatively small energy-gap difference from InAsSb active layer (\(\Delta E_g\sim0.1\) eV), and thus significant carrier leakage arises, as illustrated in Fig. 1(a). Our previous studies showed that the observed high temperature sensitivity of these lasers is attributed to the leakage current below 150 K.6–8

Another lattice-matching cladding layer material for InAsSb is AlGaAsSb alloys.2,9 However, these alloys have almost type-II band alignment with InAsSb unless with very high Al composition (>90%). The major disadvantage of AlGaAsSb with high Al composition is an extremely high conduction band offset \(\Delta E_c\) with InAsSb, amounting up to 1.2 eV, as shown in Fig. 1(b) which illustrates a band alignment of AlAsSb/InAsSb double heterostructure (DH) at strong current injection. Because of the large \(\Delta E_c\), the leakage of electrons is virtually completely suppressed. However, for the same reason, the high electron injection causes large charge accumulation and thus high voltage buildup between n-AlAsSb cladding layer and substrate (n-InAs or n-GaSb), as shown in Fig. 1(b).

Such a large voltage buildup causes at least two problems. First, as illustrated in Fig. 1(b), a large electron quasi-Fermi level discontinuity \(\Delta E_{Fc}\), arises between n-cladding layer and active layer. The hot carriers will rapidly relax with strong phonon emission, causing significant device heating. Identically, this high \(\Delta E_{Fc}\) means high turn-on voltage and a large electron quasi-Fermi level discontinuity \(\Delta E_{Fc}\), arises between n-cladding layer and active layer. The hot carriers will rapidly relax with strong phonon emission, causing significant device heating. Identically, this high \(\Delta E_{Fc}\) means high turn-on voltage and a...
reduced power conversion efficiency. A high turn-on voltage of 1.6 V was measured from AlAsSb/InAsSb DH lasers. This turn-on voltage is consistent with a simple estimation based on the schematic diagram in Fig. 1(b) which shows that $V_{on} \approx 1/e(\Delta E_{fc} + E_g(\text{InAsSb}))$, and $\Delta E_{fc} \approx \Delta E_c(\approx 1.2 \text{ eV})$ since the band bending is almost negligible near threshold, thus $V_{on} \approx 1.6 \text{ V}$. Second, the high electric field region formed because of the high charge accumulation [Fig. 1(b)] may also cause high rate of scattering, further increasing heating especially at high current injection.

Because of the absence of adequate lattice-matching cladding layer material for InAsSb with proper $\Delta E_c$ (i.e., not too small, and not too large), in this work, we consider an asymmetrical DH structure that uses advantages of both InPAsSb and AlAsSb materials. In this structure [Fig. 1(c)], InPAsSb is only used for $n$-cladding layer while AlAsSb is used for $p$-cladding layer so that both leakage current and voltage buildup are suppressed. Thus, we expect both low $V_{on}(\approx E_g \approx 0.4 \text{ eV})$ because of almost negligible $\Delta E_{fc}$ (within several $kT$ range), and higher $T_o$ at least below 150 K because of suppression leakage current.

The structure described in Fig. 1(c) was fabricated and tested. InAsSbP $n$-cladding and InAsSb active layers were grown on InAs substrate in an EMCORE LPMOCVD reactor. Lattice-matched AlAs$_{0.13}$Sb$_{0.87}$ $p$-cladding and $p^+$ InAs cap layers were then grown over the InAsSb active layer. The lasers consist of 100 $\mu$m wide stripes separated 200 $\mu$m from each other with cavity lengths between 400 and 1000 $\mu$m, without coating or passivation on the mirror facets.

Optical output power versus injection current ($P-I$) characteristics were measured in both continuous wave (cw) and pulsed (pulse width 6 $\mu$s, repetition rate 200 Hz) mode operation. A laser with a single stripe showed output power up to 1.88 W and 350 mW per two facets in pulse and cw modes at 80 K, respectively, as shown in Fig. 2. The laser emission spectrum centered at 3.4 $\mu$m total aperture in the inset of Fig. 2(a). As expected from the above argument, the turn-on voltage remained very small ($0.36 \text{ V}$) similar to the previous InAsSb/InPAsSb DH lasers. Characteristic temperature $T_o$ of 54 K was measured from the dependence of threshold current density on temperature as shown in Fig. 3. This is a clear improvement compared to the previous InAsSb/InPAsSb DH lasers which typically showed $T_o<40 \text{ K}$, and is, to the best of our knowledge, the highest reported $T_o$ for interband injection lasers operating in this wavelength range.

Figure 4 shows the $P-I$ curve for a laser bar consisting of four 100-$\mu$m-width stripes with 1000 $\mu$m cavity length measured at $T=80 \text{ K}$ in pulse mode. Maximum peak output power up to 6.7 W per two facets was obtained. The lasers showed a high overall differential efficiency of 34%. The emission wavelength shifted longer with the increase of injection current, indicating that the junction temperature is significantly higher than the ambient temperature at high current injection, presumably due to high Joule heating. Comparison with our previous experiments on the temperature dependence of emission wavelength shows that the junction temperature should be at least 70 K higher than the heat sink temperature (i.e., $T_o=150 \text{ K}$) at 6 W output even in pulse mode.
asymmetrical InPAsSb/InAsSb/AlAsSb double heterostructure. Using the asymmetrical double heterostructure, $p$- and $n$-cladding layers are separately optimized; high energy-gap AlAsSb ($E_g \approx 1.5$ eV) for the $p$-type cladding layer to reduce the leakage current, and thus to increase $T_o$, and low energy-gap InPAsSb ($E_g \approx 0.5$ eV) for the $n$-cladding layer so as to have low turn-on voltage. 100-$\mu$m-width broad-area lasers with 1000-\(\mu\)m cavity length exhibited peak output powers of 1.88 W in pulse and 350 mW in cw modes per two facets at $T=80$ K with $T_o$ of 54 K and turn-on voltage of 0.36 V. Maximum peak output power up to 6.7 W was obtained from a laser bar of total aperture of 400 $\mu$m.

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