High-power 2.3 µm laser arrays emitting 10 W CW at room temperature

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High-power 2.3 µm In(Al)GaAsSb/GaSb type-I double quantum-well diode laser arrays have been fabricated and characterised. Linear laser arrays with 19 100 µm-wide elements on a 1 cm-long bar generated 10 W in continuous-wave (CW) mode and 18.5 W in quasi-CW mode (30 µs/300 Hz) at a heatsink temperature of 18°C.

Introduction: It was recently shown that Auger recombination is not the fundamental limitation of the performance of type-I GaSb based semiconductor lasers operating up to 2.85 µm [1]. These devices operate at room temperature providing hundreds of milliwatts in the continuous-wave (CW) mode [1–4]. Diode laser arrays operating in the spectral range 2–3 µm are promising as compact and efficient light emitters for many applications, including infrared countermeasures. These devices can be used as low quantum-defect pumping sources for a new generation of optically pumped semiconductor lasers operating in band-II of the atmospheric transparency [5]. In this Letter we report on the design, fabrication and testing of 2.3 µm high power linear diode laser arrays comprising 19 emitters in a 1 cm-long laser bar. Such an array gives an output of 10 W CW and 18.5 W quasi-CW (qCW) (30 µs/300 Hz).

Device structure: The laser heterostructure was grown by solid-source molecular-beam epitaxy on *n*-GaSb substrates. Heavily doped, compositionally graded, 40 nm-thick regions between the cladding layers and the *n*-GaSb substrate and the p^+-GaSb cap layer improve electron and hole conduction. The *n*-region is Te-doped to 1×10^{18} cm^{-3} and the *p*-region is Be-doped to 2×10^{19} cm^{-3}. The cladding layers are 2 µm-thick $Al_{0.9}Ga_{0.1}As_{0.07}Sb_{0.93}$. The *n*-cladding layer is Te-doped to 3×10^{17} cm^{-3}, and the *p*-cladding layer is Be-doped to 1×10^{18} cm^{-3} over the first 0.2 µm and to 5×10^{18} cm^{-3} over the remaining 1.8 µm. This was done to reduce the internal optical loss caused by intervalance-band absorption in the *p*-cladding layer. The undoped SCH- and barrier-layer composition is $Al_{0.25}Ga_{0.75}As_{0.02}Sb_{0.98}$. The total width of the $Al_{0.25}Ga_{0.75}As_{0.02}Sb_{0.98}$ broadened-waveguide layer was about 800 nm. Two 200 nm-spaced 11.5 nm-wide $In_{0.41}Ga_{0.59}As_{0.14}Sb_{0.86}$ QWs provided optical gain. The wafer was processed into 1 mm-long, 1 cm-wide laser bars having a 20% fill-factor. Each single gain-guided element aperture was 100 µm. The facets were coated to reflect 3 and 95%. One bar was chipped into single laser emitters. Single lasers were indium-soldered epi-side down onto copper heatsinks and characterised.

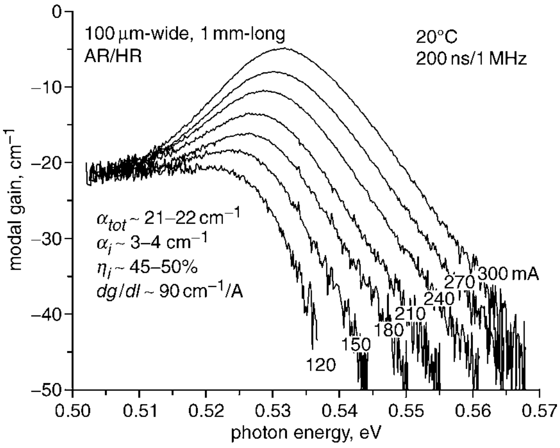

Fig. 1 *Current dependence of modal gain spectra of single 2.3 µm laser*

Results: Single lasers output 650 mW CW at 3.8 A. The output spectrum is centred near 2.36 µm; its full-width-at-half-maximum (FWHM) is about 14 nm at a current of 2 A. The FWHM of the transverse far-field pattern is about 63° and is current independent. The pulsed (200 ns, 1 MHz) laser external slope efficiency and threshold current were 0.21 W/A and 360 mA (180 A/cm^2 per QW) at 20°C. Parameters T_0 and T_1 characterising the exponential change of the pulsed threshold current and external efficiency with temperature in the range of 15–65°C were 95 and 183 K, respectively. To find the internal quantum efficiency, the internal optical losses were measured. We used the Hakki–Paoli method [6] supplemented by a spatial filtering technique to measure the optical gain and loss in gain-guided multimode lasers.

Fig. 1 shows the current dependence of the modal optical gain spectra measured at 20°C. The total optical loss (α_{tot}) is determined from the value of the modal gain in the long-wavelength part of the gain spectra, where the material gain is zero. For the mirror loss (α_m) of about 18 cm^{-1} for 1 mm-long coated devices, the internal optical loss (α_i) is 3–4 cm^{-1}. The calculated value of the laser internal quantum efficiency (η_i) is about 50%. The net modal differential gain is about 90 cm^{-1}/A. Accounting for the 50% internal efficiency, the QW material differential gain is 180 cm^{-1}/kA/cm^2. This QW material differential gain is about twice that of 1.3–1.5 µm InGaAsP devices [7, 8]. The higher differential gain of the 2.3 µm InGaAsSb QW material along with the higher T_0 and T_1 values indicate the great potential of this material system for high-power CW laser arrays operating over 2 µm.

A 1 cm-wide 1 mm-long AR/HR coated laser bar containing 19 100 µm-wide emitters separated by 500 µm was soldered into a micro-channel-cooled BeO heatsink [9]. Fig. 2 shows its light-current characteristics and wall-plug efficiency, as well as its spectrum (inset) at 30 A CW, all measured at 18°C. The maximum CW power of 10 W is reached at 70 A. The spectrum is centred near 2.36 µm with a FWHM of about 20 nm at 30 A CW. In the qCW mode (30 µs, 300 Hz, 0.9% duty cycle) the array output is over 18.5 W peak power at a peak current of 100 A. In the short-pulse, low-duty-cycle mode, the light current characteristic is linear up to nearly 20 W of peak power at 100 A of peak current without any cooling.

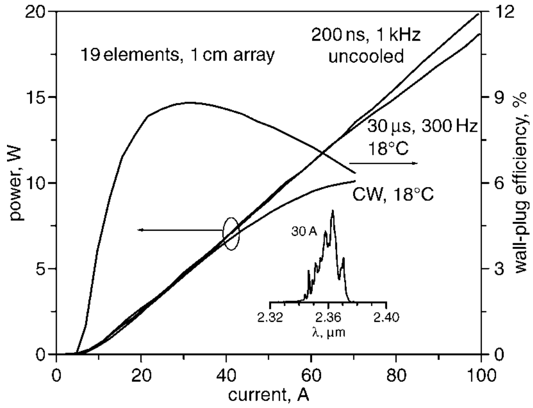

Fig. 2 *Power–current characteristics and wall-plug efficiency of a 19-element 2.3 µm laser linear array*

Conclusions: We have designed, fabricated and characterised 2.3 µm In(Al)GaAsSb/GaSb type-I double-QW diode laser linear arrays. At 18°C 1 cm-wide, 19-element linear arrays with 100 µm apertures and 1 mm-long cavities output 10 W continuous-wave (CW) and 18.5 W quasi-CW (30 µs/300 Hz). The array peak wall-plug efficiency is near 9%. Experimental results indicate that the differential gain of GaSb-based QW lasers is twice that of comparable InP ones and thus demonstrates their high potential for high-power CW room temperature laser arrays. These devices can be used directly as sources or as low-quantum-defect pumping sources for a new generation of optically pumped semiconductor lasers operating in band-II of atmospheric transparency.

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