High-Power 2.3-μm GaSb-Based Linear Laser Array

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Abstract—**High-power 2.3-μm In(Al)GaAsSb–GaSb type-I double quantum-well diode laser arrays were fabricated and characterized. 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. Array power conversion efficiency peaked at 30 A and was about 9%. Device internal efficiency was about 50%. Individual laser differential gain with respect to current was about twice as high as in InP-based laser heterostructures, demonstrating the potential of GaSb-based material system for high-power CW room-temperature laser diode arrays.**

Index Terms—**Optical pumping, power lasers, quantum-well lasers, semiconductor laser arrays, semiconductor lasers.**

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 continuous-wave (CW) mode [2]–[10]. 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 [11].

High-power CW laser arrays based on InP material system were fabricated with the longest wavelengths of 1.9 μm (11 W per 1 cm bar) [12] and 2 μm (8.5 W per 1 cm bar) [13]. Further increase of the operating wavelength within InP-based material system leads to dramatic laser performance degradation. The longest reported operating wavelength of the diode laser arrays was 2.05 μm achieved with In(Al)GaAsSb–GaSb material system [14] though the array was not designed to work in high-power CW regime.

In this letter, we report on the design, fabrication, and testing of 2.3-μm high-power linear diode laser arrays comprisng 19 emitters in a 1-cm-long laser bar. The array output 10-W CW and 18.5-W quasi-CW (qCW) (30 μs/300 Hz). The laser heterostructure was grown by solid source molecular-beam epitaxy on n-GaSb substrates. An approximately 800-nm-thick $Al_{0.25}Ga_{0.75}As_{0.02}Sb_{0.98}$ broadened-waveguide layer that includes the two QWs was sandwiched between two 2-μm-thick $Al_{0.9}Ga_{0.1}As_{0.07}Sb_{0.93}$ cladding layers. Details of the lasers' heterostructure design can be found in [4]–[6]. 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 defined as a window in a dielectric. To simplify the processing procedure, no etching was performed to facilitate lateral current confinement. 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 characterized.

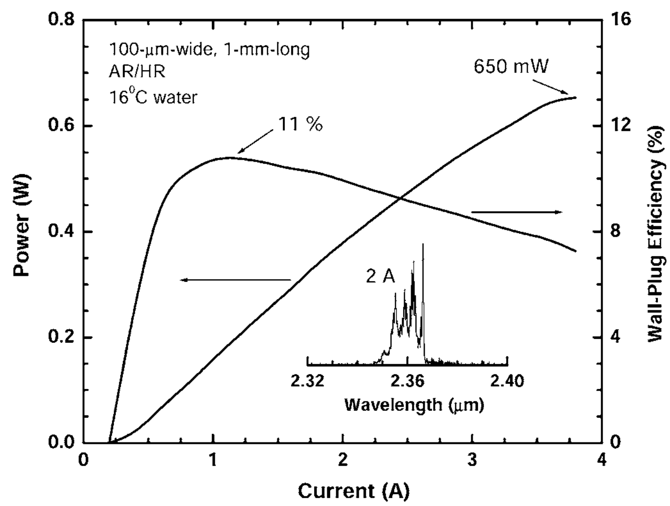

Fig. 1. Power-current characteristics, wall-plug efficiency, and spectrum of a single 2.3-μm laser.

Fig. 1 shows CW light–current characteristics and wall-plug efficiency (ratio of optical output power to total electrical input power) for a single 2.3-μm laser, taken at a heatsink temperature of 16 °C. Single lasers output 650-mW CW at 3.8 A. The output spectrum (insert in Fig. 1) is centered near 2.36 μm; its full-width at half-maximum (FWHM) is about 14 nm at a current 2-A CW. The FWHM of the transverse far-field pattern is about 63° and is current independent. The pulsed (200 ns, 1 MHz) laser external quantum 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 characterizing the exponential change of the pulsed threshold current and external quantum efficiency with temperature in the range of 15 °C–65 °C were 95 K and 183 K, respectively. To find the internal quantum efficiency, the internal optical losses were measured. We used Hakki–Paoli method [15] supplemented by a spatial filtering technique to measure the optical gain and loss in gain guided multimode lasers.

Fig. 2 shows the current dependence of the modal optical gain spectra measured at 20 °C. The total optical loss $(\alpha_{\rm tot})$ 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

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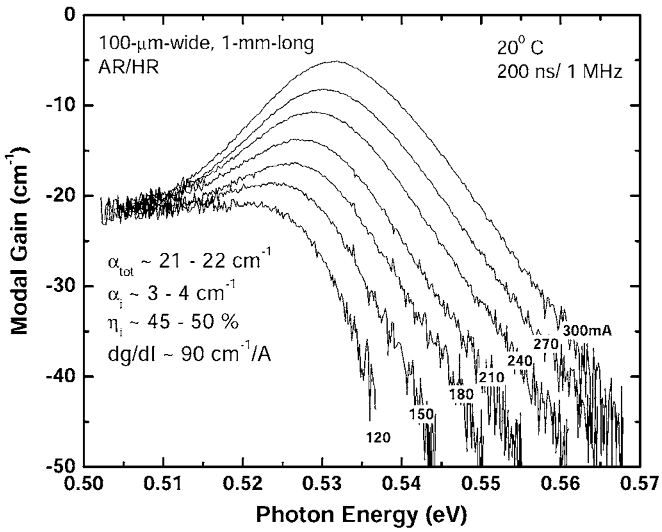

Fig. 2. Current dependence of the modal gain spectra of a single 2.3-μm laser.

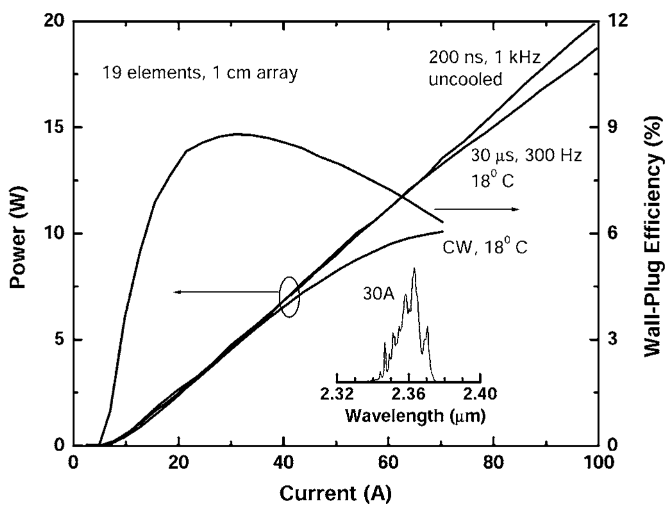

Fig. 3. Power-current characteristics and wall-plug efficiency of a 19-element 2.3-μm laser linear array.

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, where 90 cm^{-1}/kA/cm^2 was calculated for a 1.3-μm 9-QW capped mesa buried heterostructure laser [16], and about 100 cm^{-1}/kA/cm^2 was calculated for a 1.5-μm 3-QW gain guided device [17]. The higher differential gain of the 2.3-μm In(Al)GaAsSb lasers partially stems from high compressive strain over 1.5% in QWs and along with the higher T_0 and T_1 values indicates the great potential of this material system for high-power CW laser arrays operating over 2 μm.

A 1-cm-wide 1-mm-long antireflection/high-reflection coated laser bar containing 19 100-μm-wide emitters separated by 500 μm was soldered into a microchannel-cooled Be–O heatsink. Fig. 3 shows its light–current characteristics and wall-plug efficiency, as well as its spectrum (insert) at 30 A CW, all measured at 18 °C. The maximum CW power of 10 W is reached at 70 A. The spectrum is centered 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 over 18.5-W peak power at a peak current of 100 A. In the short-pulse, low-duty-cycle mode, the light–current characteristics is linear up to nearly 20 W of peak power at 100 A of peak current without any cooling.

Array heating causes the saturation of the CW and qCW light–current characteristics. The thermal resistance of the array is about 0.5 K/W and was determined from the emission spectrum red shift with power dissipation. This thermal resistance leads to active region overheating of about 25 °C at an output power of 5-W CW and about 75 °C at 10 W. The somewhat excessive heating at high currents is related to the wall-plug efficiency (<9% maximum). The array CW output power could be increased substantially if the wall-plug efficiency is improved.

The relatively low laser power conversion efficiency is attributed to 1) 50% internal efficiency—about 50% of the injection current after threshold is parasitic, and 2) excess voltage drop across the laser heterostructure—the voltage at threshold is about 1 V and it rises up to over 2 V at 3 A for a single laser, while laser energy quantum is only 0.54 eV.

The internal efficiency is reduced by lateral current spreading and nonradiative Shockley–Reed–Hall recombination in the waveguide layer. Lateral current spreading is substantial in the current laser design since no steps were taken to confine carriers laterally at the time of wafer processing. Lateral current spreading can be expected in the 2-μm p-cladding and ~800-nm waveguide layers as well as from lateral diffusion in the QWs. We performed measurements of the current dependence of the true spontaneous emission (TSE) from the side of the single lasers before and after threshold [18]. After threshold, the TSE continues to increase with current though at a slower rate than before threshold. Since TSE is expected to pin in the gain region after the threshold, it is lateral current spreading that is responsible for the observed increase of TSE with current after threshold. We estimated the lateral current spreading of about 20%–25% following the approach presented by Smowton and Blood [18]. After taking the lateral current spreading effect into account, we obtain a value of about 70% for the injection efficiency. It was demonstrated that GaSb-based lasers with wavelengths longer than 2 μm suffer from poor hole confinement [1]. No direct heterobarrier hole leakage was observed in these structures [19]. Hole escape from the QWs into the $Al_{0.25}Ga_{0.75}As_{0.02}Sb_{0.98}$ waveguide layers and their subsequent nonradiative recombination reduces laser injection efficiency.

The parasitic barriers for carrier transport from cladding to waveguide layer makes a large contribution to the excessive voltage drop and series resistance [20]. Careful adjustment of the cladding/waveguide material composition and doping profile can reduce the excessive voltage drop across the laser heterostructure.

Once the laser power conversion efficiency is improved, the optimum laser bar fill-factor will be higher than the current 20%, thus increasing the maximum power from a single bar.

Summarizing, we designed, fabricated and characterized 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 CW and 18.5-W qCW (30 μs/300 Hz). The output spectrum is centered near 2.36 μm with spectral width of about 20 nm. 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 a low quantum-defect pumping sources for a new generation of the optically pumped semiconductor lasers operating in band-II of atmospheric transparency.

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