1.53μm GaInNAsSb laser diodes grown on GaAs(100)

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1.53 m GaInNAsSb laser diodes grown on GaAs(100)

J.A. Gupta, P.J. Barrios, X. Zhang, G. Pakulski and X. Wu

GaInNAsSb/GaNAs double quantum well ridge waveguide laser diodes with room temperature lasing wavelength of 1532 nm are reported. The devices exhibit leakage-corrected threshold current densities as low as 969 A cm^{-2} per quantum well in pulsed mode, with characteristic temperatures as high as 90 K.

Introduction: In the past decade, GaInNAs vertical cavity and edge-emitting laser diodes have been used for 1.3 µm emission with promising results [1]. Although early efforts at wavelengths suitable for long-haul fibre transmission yielded devices with very high laser threshold currents [2, 3], the most recent devices have had more reasonable characteristics. These latest devices have used GaInNAs [4] or GaInNAsSb [5, 6] active regions, producing emission in the 1.5 µm range.

In this Letter we present results of GaInNAsSb/GaNAs double quantum well lasers with record lasing wavelength of 1532 nm. The structures were grown by molecular beam epitaxy (MBE) using a novel method of Ar gas dilution in a radio frequency (RF) plasma to control the active nitrogen flux for MBE growth. Narrow, single-lateral-mode ridge waveguide (RWG) devices were tested in pulsed mode and exhibit threshold currents as low as 115 mA ($w = 3$ µm) at room temperature (RT), while wider ($w = 10$ µm) devices exhibit high characteristic temperatures of 90 K. After accounting for lateral leakage current, the threshold current densities for sets of devices with cavity lengths of 1202 and 444 µm were found to be 1.94 and 2.66 kA cm^{-2}. These results provide clear confirmation of the promise of GaInNAsSb active regions for GaAs-based 1550 nm laser diodes.

Fabrication: The lasers were grown on an $n+$ GaAs substrate in a custom VG V90 MBE system. Fluxes were provided by group-III and dopant effusion cells with valved cracker cells for As_2 and Sb_2. Active nitrogen was provided by a VEECO RF plasma source using N_2/Ar dynamic gas switching, as described previously [7]. The active region, grown at 415°C, nominally consists of two 7 nm $Ga_{0.61}In_{0.39}N_{0.027}As_{0.962}Sb_{0.011}$ quantum wells with 20 nm $GaN_{0.044}As_{0.956}$ barriers, within a 371 nm GaAs waveguide. 1.5 µm $Al_{0.33}Ga_{0.67}As$:Be (1×10^{18} cm^{-3}) and 1.8 µm $Al_{0.33}Ga_{0.67}As$:Si (2×10^{18} cm^{-3}) cladding layers were grown at 600°C. After each 97 nm of n-cladding growth, a 3 nm GaAs:Si layer was grown to smooth the surface. The top 100 nm GaAs:Be contact layer was doped to 1×10^{19} cm^{-3}, while the bottom GaAs:Si buffer layer was doped to 2×10^{18} cm^{-3}. Before fabrication, the wafer was annealed at 700°C, for 300 s under flowing N_2 with GaAs proximity capping.

RWG lasers were fabricated using chemically-assisted ion beam etching with standard Ti-Pt-Au and Au-Ge-Ni p- and n-contact metallisations, respectively. The lasers were cleaved into bars with Fabry-Perot cavity lengths of 1202, 894 and 444 µm and mounted p-side up onto alumina carriers. Each bar contains devices with ridge widths from 2 to 10 µm. Measurements were made in pulsed mode with a 1% duty cycle and the output power was measured using a calibrated Ge detector. The emission spectra were measured using an optical spectrum analyser.

Results: Fig. 1 shows the light output with input current (L–I) curve for a narrow, 2 µm-wide RWG device with cavity length 1202 µm. The RT threshold current was found to be 157 mA with stimulated emission wavelength near 1532 nm at low current injection, as shown. Temperature-dependent measurements of this device yielded a characteristic temperature, T_0, of 66 K, while a 10 µm-wide device with the same cavity length exhibited $T_0 = 90$ K. The lowest threshold current measured in this study was 115 mA for a narrow RWG device measuring 3 by 444 µm, and the same device exhibited the highest external differential efficiency, η_D, of 35%.

The lateral leakage current in these devices was estimated using the method of [8]. Fig. 2 shows the dependence of threshold current on ridge width for the complete set of devices. For each cavity length, the leakage current was determined from the expression $I_{th} = J_{th}wL + I_{leak}$, via a linear regression of the data in Fig. 2 for widths longer than 4 µm. The narrowest devices (2 and 3 µm) were excluded because these dimensions are close to the estimated carrier diffusion length. Note that this analysis yields a single value of threshold current density for each cavity length, as well as the leakage current estimate.

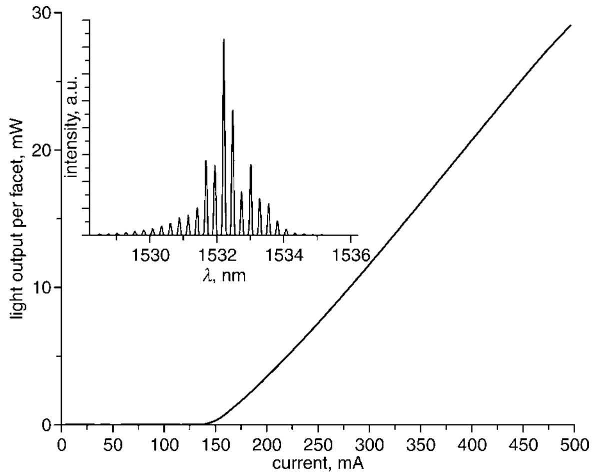

Fig. 1 *Light output per facet (L) against applied current (I) for laser diode (width 2 µm, length 1202 µm)*

Inset: Spectrum at 165 mA ($1.05 I_{th}$)

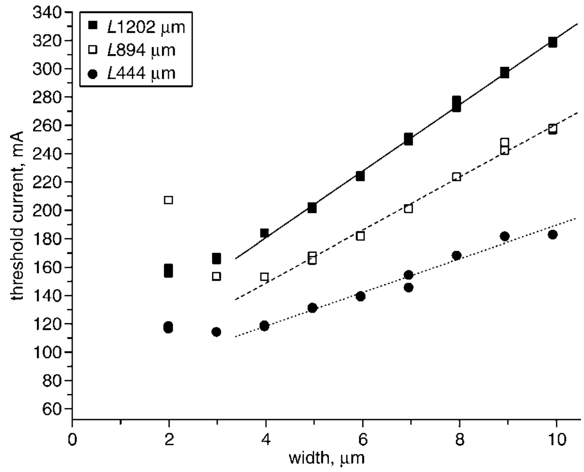

Fig. 2 *Threshold current (I) dependence on ridge width for several cavity lengths as indicated*

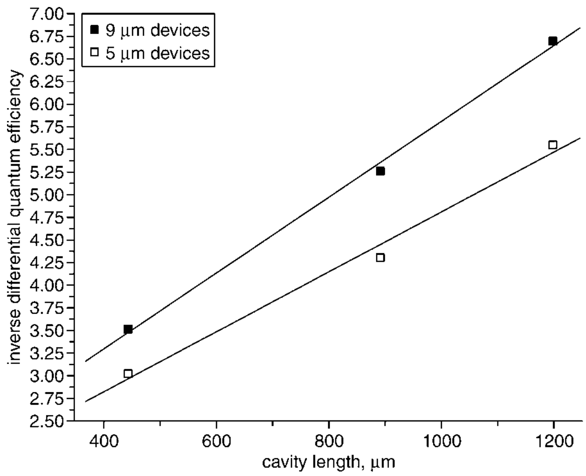

Fig. 3 *Inverse differential quantum efficiency dependence on cavity length for 5 and 9 µm ridge widths as indicated*

For device widths of 5 and 9 µm, the internal quantum efficiency, η_i, and internal loss, α_i, were determined from Fig. 3. For the 5 µm-wide devices we found $\eta_i = 0.66 \pm 0.13$ and $\alpha_i = 25 \pm 7$ cm^{-1}, while the 9 µm-wide devices had $\eta_i = 0.61 \pm 0.07$ and $\alpha_i = 29 \pm 5$ cm^{-1}.

In Fig. 4 we plot the relationship between threshold current density, J_{th}, and cavity length. The current density for infinite cavity length was found to be 806 A cm^{-2} per quantum well, and for devices of width 5 and 9 µm, the transparency current densities were $J_{tr} = 317$ A cm^{-2} and 282 A cm^{-2}, using the internal parameters determined earlier.

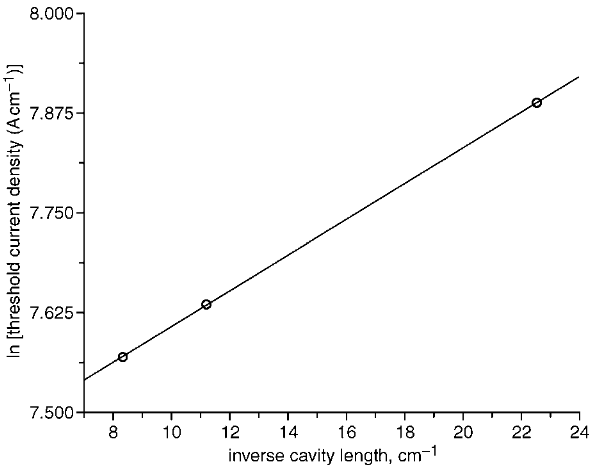

Fig. 4 *Threshold current density dependence on inverse cavity length*

Conclusion: We have demonstrated 1.53 µm emission from GaInNAsSb RWG laser diodes with relatively low threshold currents. To our knowledge, this is the longest lasing wavelength achieved for GaInNAs(Sb) lasers on GaAs substrates. Future work will focus on refinement of the laser design to improve the internal parameters and optimise the devices for 1.55 µm.

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