Low-threshold CW GaInNAsSb/GaAs laser at 1.49 µm

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Low-threshold room temperature continuous wave 1.49 µm GaInNAsSb lasers are presented. Room temperature threshold current density of 1.1 kA/cm^2 was observed with a high external quantum efficiency of 40% and maximum output power of 30 mW from both facets.

Introduction: Since the initial discovery by Kondow and co-workers of anomalous bandgap bowing in the nitride–arsenide alloys, much work has focused on demonstration of high-performance 1.3 µm range lasers [1–3]. Recent results from several groups have shown extremely low threshold edge-emitting lasers and high-performance VCSELs in the 1.3 µm range [3, 4]. While there has been considerable effort on growth of higher indium and nitrogen content alloys to decrease further the bandgap for 1.55 µm devices [5–7], state-of-the-art edge-emitting lasers show rapidly increasing threshold with wavelength. Results for GaInNAs(Sb) lasers between 1.2 and 1.5 µm are summarised in Fig. 1 [8]. Between 1.2 and 1.3 µm, threshold current density increases with wavelength ~2.2 A/cm^2 per nm. By comparison, the increase between 1.4 and 1.5 µm has been, hitherto, approximately 11.6 A/cm^2 per nm.

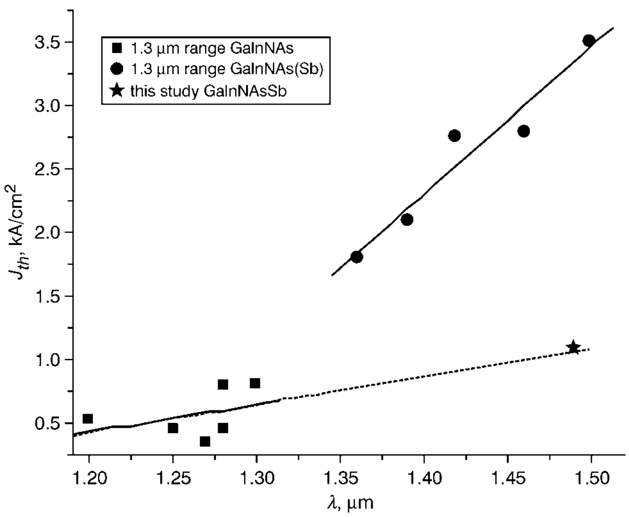

Fig. 1 *Recent trends in GaInNAs(Sb) lasers*

■ 1.3 µm range lasers with linear fit (solid line)
● previous 1.5 µm range lasers with linear fit (solid line)
★ represents this datum
Extrapolation of the 1.3 µm range fit (dashed line) to 1.5 µm fits well with the results of this study
Adapted from [8]

For the first time, a continuous wave (CW) 1.5 µm range GaInNAs(Sb) laser with threshold current density comparable to 1.3 µm range GaInNAs lasers is presented. Single quantum well (QW) photoluminescence (PL) samples had a room temperature (RT) PL peak at 1.42 µm and a linewidth of 29.7 meV. This is the narrowest PL linewidth reported for such QW structures, an indication of the much improved growth conditions of these lasers. RT threshold current densities of 1.1 kA/cm^2 (CW) and 910 A/cm^2 (pulsed) were observed for a 20 × 760 µm ridge waveguide device. The device lased at 1.49 µm and showed record high CW output powers up to 30 mW (both facets) with external efficiency of 0.34 W/A (40% external quantum efficiency) and a characteristic temperature of ~62K (pulsed). Devices were tested epi-side up, at RT, and without facet coatings. The CW threshold current density is in keeping with the trend of 1.3 µm range devices (Fig. 1), indicating that material degradation with increased nitrogen incorporation and longer wavelength is not as severe as once thought. Additionally, these devices represent a substantial improvement over those previously reported.

Fabrication: The lasers were grown on a (100) *n*-type GaAs substrate by solid source molecular beam epitaxy (MBE) with nitrogen supplied with a modified SVTA plasma cell and antimony by an unvalved cracker. Dopants were supplied by solid silicon and CBr_4 sources. The active layer was a single 70 Å GaInNAsSb QW surrounded by 200 Å thick GaNAs barriers. GaNAs barriers were chosen over GaNAsSb because of superior low-temperature growth morphology, strain compensation and likely improved electron confinement [9]. This layer was embedded in the centre of a one wavelength undoped GaAs waveguide surrounded by $Al_{0.3}Ga_{0.7}As$ cladding, as shown in Fig. 2. The structure was capped with a highly doped GaAs contact layer.

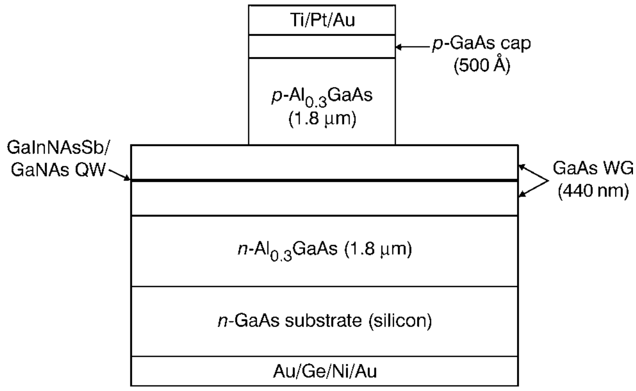

Fig. 2 *Device structure of lasers in this study*

Device fabrication consisted of lift-off metallisation (Ti/Pt/Au) followed by a self-aligned dry etch through the top $Al_{0.3}Ga_{0.7}As$ cladding layer. The wafers were thinned to ~120 µm to allow the cleavage of high-quality mirrors and backside metal was evaporated (Au/Ge/Ni/Au). This was followed by a one minute contact sinter at 410°C. Device bars ranging in length from 400–800 µm were manually cleaved.

Results: Fig. 3 shows the CW RT light output with input current (*L–I*) for a device measuring 20 × 760 µm. The device lased at 1.490 µm (Fig. 3 inset) with a CW threshold of 1.1 kA/cm^2. The CW slope efficiency was 0.34 W/A, corresponding to a 40% external quantum efficiency. To the best of our knowledge, these are the best threshold current density and efficiency data ever reported for a dilute-nitride laser in this wavelength range [6, 7]. Additionally, devices showed maximum CW output powers of ~30 mW before thermal rollover and pulsed output powers (5 µs pulse and 1% duty cycle) as high as 300 mW.

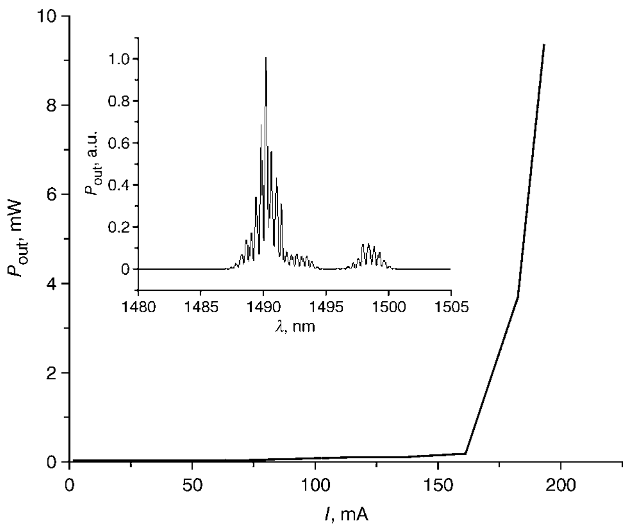

Fig. 3 *L–I for 20 × 760 µm device*
Inset: Spectrum

The device structure was chosen to minimise thermal heating around the active layer to allow CW operation. A difference of ~200 A/cm^2 between pulsed and CW threshold current density indicates some heating, although other devices showed significantly less difference. The turn-on voltage was ~0.9 V, which compares favourably to the bandgap energy of 0.83 eV. Additionally, the diode ideality factor was computed to be ~1.3. These data indicate an excellent balance between device heating issues and free carrier absorption.

While the threshold current density is over three times lower for other reported devices at comparable wavelengths (Fig. 1), these devices are more temperature sensitive. The characteristic temperature (T_o) under pulsed conditions was 62K as measured from 25 to 60°C. This is likely due to reduced electron confinement in GaInNAsSb/GaNAs structures as compared to GaInNAs/GaAs [6].

Conclusions: We have demonstrated a 1.5 µm range GaInNAs(Sb) laser with a record low threshold current density of 1.1 kA/cm^2 and a record high external efficiency of 0.34 W/A. This is the first device in this wavelength range that conforms to the threshold current/wavelength trend observed for GaInNAs lasers ~1.3 µm. Extrapolation (Fig. 1) predicts a threshold current density of 1085 A/cm^2 at 1.5 µm, which matches quite well with the devices presented here. Future work will focus on achieving higher T_o and further reducing threshold current densities.

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