Long wavelength MOCVD grown InGaAsN–GaAsN quantum well lasers emitting at 1.378–1.41 µm

J.-Y. Yeh, N. Tansu and L.J. Mawst

Low threshold InGaAsN QW lasers with lasing wavelength at 1.378 and 1.41 µm were demonstrated by metal organic chemical vapour deposition (MOCVD). The threshold current densities are 563 and 1930 A/cm^2 for the 1.378 and 1.41 µm emitting lasers, respectively. The significant improvement of device performance is believed due to utilisation of high temperature annealing and introduction of GaAsN barriers to suppress the resulting wavelength blue shift. A comparable characteristic temperature coefficient of the external differential quantum efficiency, T_1, is observed for the InGaAsN–GaAsN QW laser compared to similar InGaAsN/GaAs structures.

Introduction: Novel materials such as InGaAsN represent one of the strongest candidates for GaAs-based long wavelength lasers at 1.3 µm for telecommunication application. In an effort to further explore the possibility of the InGaAsN active regions for wavelength extension, researchers have successfully realised lasers with emission wavelengths beyond 1.4 µm [1, 2]. Furthermore, using molecular beam epitaxy (MBE) growth, the addition of antimony into the InGaAsN has been utilised to achieve GaInNAsSb quantum well (QW) lasers around 1.3 µm [3]. For lasers emitting beyond 1.4 µm, GaInNAsSb QW lasers with low threshold current density of 1.1 kA/cm^2 and lasing wavelengths of 1.49 µm have been demonstrated, showing a promising future for the dilute nitride and antimonide material system [4]. However, these works all employed MBE growth techniques [1–4] and the performance of InGaAsN lasers grown by MOCVD has been limited to 1.38 µm with threshold current density of 2.2 kA/cm^2 [5].

To achieve MOCVD-grown InGaAsN QW lasers beyond 1.4 µm with good performance, we have conducted a systematic study on the growth parameters of [N]/V ratio, barrier layers and QW annealing temperature. In this Letter, we report record low threshold current density values for $\lambda = 1.378$ and 1.41 µm InGaAsN lasers by carefully choosing the QW growth condition, barrier material and annealing temperature. The threshold current densities are 563 and 1930 A/cm^2 for the 1.378 and 1.41 µm emitting lasers, respectively.

Growth and fabrication: Employing GaAsN as barriers, the effect of quantum size is reduced and consequently, wavelength extension can be achieved [6–8]. Moreover, by utilising GaAsN barriers, the wavelength blue shift resulting from high temperature thermal annealing could be effectively suppressed in contrast to using conventional GaAs barrier. For instance, we observed blue shifts of 58 and 31 meV for the 700°C annealed InGaAsN QW with GaAs and $GaAs_{0.985}N_{0.015}$ barriers, respectively. This is consistent with the results of MBE-grown InGaAsN–GaAsN structures, for which nitrogen out-diffusion was suggested to explain this behaviour [7]. For the 1.378 µm emitting InGaAsN lasers, a gas phase [N]/V ratio of 0.991, 3.5 nm $GaAs_{0.985}N_{0.015}$ barriers, and an annealing temperature of 680°C were utilised. Increasing the gas phase [N]/V ratio to 0.994, 3.5 nm $GaAs_{0.985}N_{0.015}$ barriers, and 700°C annealing resulted in the 1.41 µm emitting lasers, which represents the longest emission wavelength reported for MOCVD-grown devices. Based on room temperature photoluminescence (PL) studies of InGaAsN–GaAs QWs without thermal annealing, [N]/V ratios of 0.991 and 0.994 result in peak emission wavelengths of 1.38 and 1.45 µm, respectively. Utilising GaAsN barriers generates an extra wavelength red shift of about 20 nm. Thermal annealing at 680 and 700°C leads to an enhancement of optical quality by four to five times characterised by PL experiments, compared with a 640°C annealed QW. However, a higher temperature annealing leads to a blue shift penalty of 16 and 31 meV; nevertheless, the improved material quality is crucial to achieve low threshold InGaAsN lasers beyond 1.4 µm.

Both 1.378 and 1.41 µm lasers were grown by low pressure MOCVD on an *n*-type [100]-oriented GaAs substrate with trimethylgallium, trimethylaluminum, trimethylindium as group III sources and AsH_3, PH_3, U-dimethylhydrazine as group V sources. The structure consists of a single 6 nm InGaAsN QW grown at a temperature of 530°C with growth rate of 1.28 µm/h. The separate confinement heterostructure (SCH) is 300 nm undoped GaAs and cladding layers are 1.1 µm $Al_{0.75}Ga_{0.25}As$. The thermal annealing process was performed during the growth of *p*-type cladding layer for the duration of 27 min. The improvement in PL intensity from high temperature thermal annealing is found to be especially important for the InGaAsN–GaAsN QW. By contrast, InGaAsN–GaAs QW structures are not as sensitive to annealing conditions.

Broad area lasers with stripe widths of 100 µm were fabricated and alloys of Ti/Pt/Au and Ge/Ni/Au for *p*- and *n*-type contact layers were deposited by e-beam evaporator and rapidly annealed at 365°C for 30 s. The light power against current (*L–I*) measurement against temperature was performed under pulsed conditions with a 1% duty cycle.

Results and discussion: Fig. 1 shows the *L–I* curve and lasing spectrum of the 800 µm-long 1.378 µm-emitting InGaAsN QW lasers at 20°C. The room-temperature threshold current densities are only 563 and 661 A/cm^2 for the devices with 1 mm and 800 µm cavity, respectively. This optimised GaAsN barrier structure demonstrates a threshold current lower by almost a factor of two, from 1010 to 563 A/cm^2, compared with the previously reported 1380 nm InGaAsN–GaAs lasers, which required a higher nitrogen content [9]. This significant reduction in threshold current density is believed due to the improved QW crystal quality resulting from higher temperature annealing. In addition, a high slope efficiency of 140–155 mW/A, corresponding to an external differential quantum efficiency in the range 31–35%, was obtained. Fig. 2 shows the device threshold current density and slope efficiency against temperature from 10 to 60°C. The characteristic temperatures T_0 of 60–68K and T_1 of 40–70K were measured for device cavity ranging from 600 mm to 1 mm, indicating comparable temperature sensitivity compared to 1380 nm-emitting GaAs barrier devices with higher nitrogen content ($T_0 = 73$K, $T_1 = 82$ K (10–40°C) and 36 K (40–60°C) for 750-µm long devices) [9].

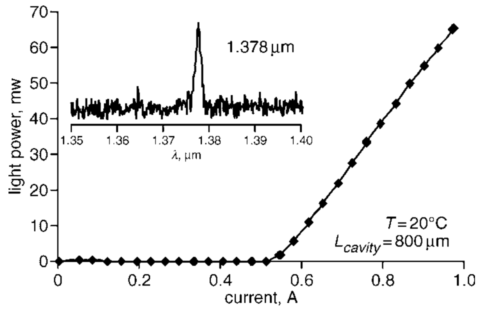

Fig. 1 *Measured L–I characteristics of 1.378 µm InGaAsN–GaAsN QW lasers*

Inset: Lasing spectrum

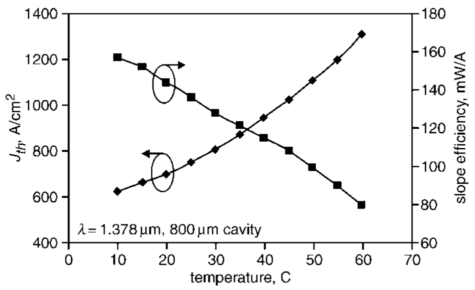

Fig. 2 *Temperature dependence of threshold current density and slope efficiency (two facets) of 1.378 µm InGaAsN QW lasers*

T_0 and T_1 are 64 and 71K for 800 µm-long devices within temperature range 20–60°C, respectively

1.41 µm-emitting InGaAsN lasers were achieved using a larger [N]/V ratio, GaAsN barriers, and higher annealing temperature. The *L–I* curve and lasing spectrum for 600 µm-long devices at 20°C are shown in Fig. 3. A higher threshold current density of 1930 A/cm^2 and lower slope efficiency of 82 mW/A were observed. Nevertheless, to the best of our knowledge, the 1.378 and 1.41 µm-emitting InGaAsN lasers reported here represent the lowest threshold current density with the longest lasing wavelengths achieved by MOCVD growth technique.

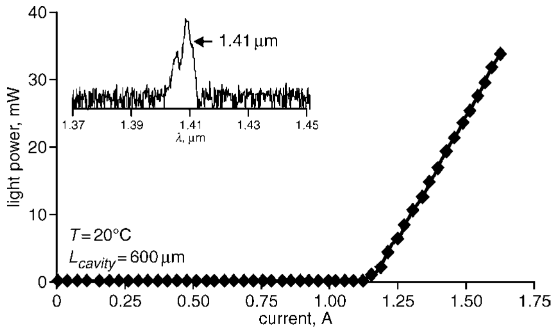

Fig. 3 *Measured L–I characteristic of 1.41 μm InGaAsN–GaAsN QW lasers*

Inset: Lasing spectrum

Conclusion: Low threshold InGaAsN QW lasers with lasing wavelength at 1.378 and 1.41 μm were demonstrated by MOCVD. The threshold current densities are 563 and 1930 A/cm^2 for the 1.378 and 1.41 μm emitting lasers, respectively. The significant improvement of device performance is believed due to utilisation of high temperature annealing and introduction of GaAsN barriers to suppress the resulting wavelength blue shift during annealing. Further studies are required to fully characterise the role of the GaAsN barrier material on the device temperature sensitivity.

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