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Long wavelength GaInNAsSb/GaNAsSb multiple quantum well lasers

W. Ha, V. Gambin, M. Wistey, S. Bank, H. Yuen, S. Kim and J.S. Harris, Jr.

The high demand for 1.3–1.55 μm lasers has led to the investigation of GaInNAsSb/GaNAsSb on GaAs. In-plane lasers operating out to 1.49 μm, with threshold current density of 930 A/cm^2 per quantum well and pulsed power up to 70 mW, are presented. In addition, photoluminescence out to 1.6 μm from GaInNAsSb quantum wells was observed.

Introduction: There is now a very high demand for low cost, 1.3–1.6 μm lasers to support the rapid expansion of optical metro area networks (MANs). The requirements for these lasers are broad operating temperature range (– 10–90°C), emission spectra over 1.3–1.6 μm, and moderate power (>10 mW). There is also a significant interest in higher power lasers as pumps for Raman amplifiers to greatly increase the available bandwidth. Much research has shown that GaInNAs, which is coherently lattice-matched to GaAs [1, 2], can provide the proper bandgap energy for operation in the 1.3–1.55 μm wavelength range. Laser diodes with GaInNAs quantum wells (QWs) have shown prospective characteristics, including low threshold current density, high temperature continuous-wave (CW) operation, and high T_o in the wavelength range of 1.1 to 1.3 μm [3, 4].

We previously reported lasers with emission out to 1.4 μm by incorporating nitrogen in the barriers [5]. While a high nitrogen concentration compensates for the lattice mismatch, device performance is dramatically degraded. To obtain emission past 1.4 μm, it is essential to incorporate more than 40% indium to the GaInNAs QWs. This, however, is not easily achieved in normal molecule beam epitaxial (MBE) growth owing to the lattice mismatch between GaAs and InAs. Much research has been done on antimony as a surfactant, which prevents 3-D growth and maintains 2-D growth [6]. Thus, we introduced antimony during the active layer growth and were able to incorporate up to 46% indium without either relaxation of the epitaxial film or 3-D growth. This GaInNAsSb QW results in a shift of the post-annealed photoluminescence (PL) to 1.6 μm. Our GaInNAsSb QW laser diodes have emission spectra out to 1.49 μm. The maximum pulsed output power at room temperature was 70 mW from both facets.

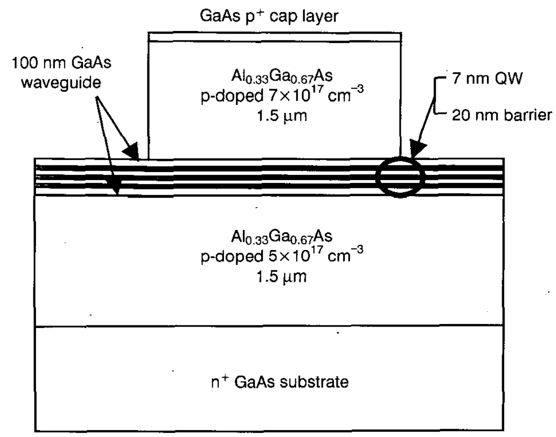

Fig. 1 *Schematic diagram of GaInNAsSb ridge waveguide laser*

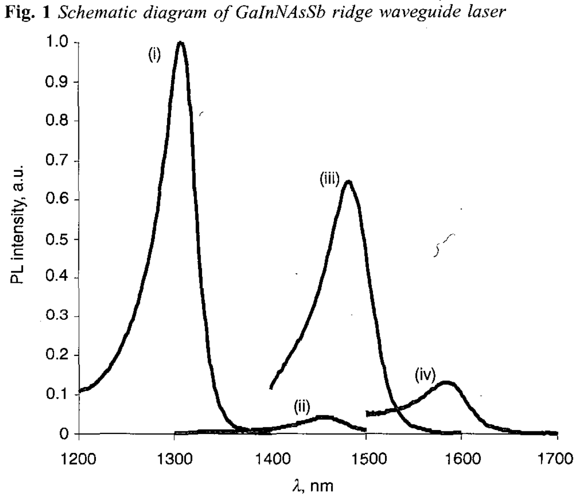

Fig. 2 *Photoluminescence of various normalised GaInNAsSb samples*
(i) highest 1.3 μm peak
(ii) 44% In and Sb flux of 4.6×10^{-8} Torr
(iii) 45% In and Sb flux of 7.2×10^{-8} Torr
(iv) 46% In and Sb flux of 1.7×10^{-7} Torr

Device growth and fabrication: Separate confinement heterojunction (SCH) multiple quantum well laser diode structures were grown on (100) n-GaAs substrate as shown schematically in Fig. 1. The active region consists of three 7 nm GaInNAsSb quantum wells separated by 20 nm GaNAsSb barriers. The active region is symmetrically embedded in a 120 nm-thick undoped GaAs waveguide. A 1.5 μm Si doped (5×10^{17} cm^{-3}) n-type $Al_{0.33}Ga_{0.67}As$ cladding layer was grown between the n-substrate and the active layer and a 1.5 μm Be doped (7×10^{17} cm^{-3}) p-type $Al_{0.33}Ga_{0.67}As$ cladding layer followed the active layer. A 50 nm p$^+$(1×10^{19} cm^{-3}) GaAs cap layer was grown for contacting. The MBE grown wafer was *ex-situ* annealed by rapid thermal annealing (RTA) to improve material quality [7].

Results: Fig. 2 shows the PL spectrum from GaInNAsSb QWs with GaNAsSb barriers. The standard luminescence at 1.3 μm is the highest PL intensity we have achieved with the GaInNAs/GaAs combination and is presented here for comparison purposes. Three samples with varying antimony fluxes and virtually identical indium composition (≤1%) were grown. GaInNAsSb quantum wells were grown at

200°C below regular GaAs growth temperature (400°C) to prevent phase segregation. The nitrogen concentration in quantum wells of these PL samples was 1.7% and that in barriers was 2%. We observed the comparable PL intensity to the reference PL sample at 1.48 μm and the PL peak out to 1.58 μm. The PL peak showed up out to 1.58 μm. With the 45% indium composition and an antimony flux of 7.2×10^{-8} Torr, which is the same growth conditions as Fig. 2 (iii), a ridge waveguide laser with three $Ga_{0.55}In_{0.45}N_{0.017}As_{0.933}Sb_{0.05}$ QWs and $GaN_{0.02}As_{0.93}Sb_{0.05}$ barriers was grown for fabrication. Fig. 3 shows the light output power against injection current, and the luminescence at 1.465 μm with a maximum power exceeding 70 mW from a 5 μm-wide stripe from both facets. The minimum threshold current density was 2.8 KA/cm^2 or 930 A/cm^2 per quantum well. To our knowledge, this is the lowest threshold current density for lasers with GaInNAs QWs beyond 1.4 μm on a GaAs substrate. With 1.4×10^{-7} Torr antimony flux and 46% indium composition, our laser device with $Ga_{0.54}In_{0.46}N_{0.017}As_{0.913}Sb_{0.07}/GaN_{0.02}As_{0.091}Sb_{0.07}$ shows laser emission at 1.49 μm at room temperature (Fig. 4). Device performance is degraded compared to the 1.46 μm laser and worse than expected from the PL results. The devices also have shorter wavelength emission than that of the PL samples grown under the same condition. This may be due to the unvalved antimony source used for these experiments, as the antimony flux may vary over the course of the growth. Lasers with emission at 1.55 μm and superior performance will be possible with further optimisation of the indium, nitrogen, and antimony mole fractions.

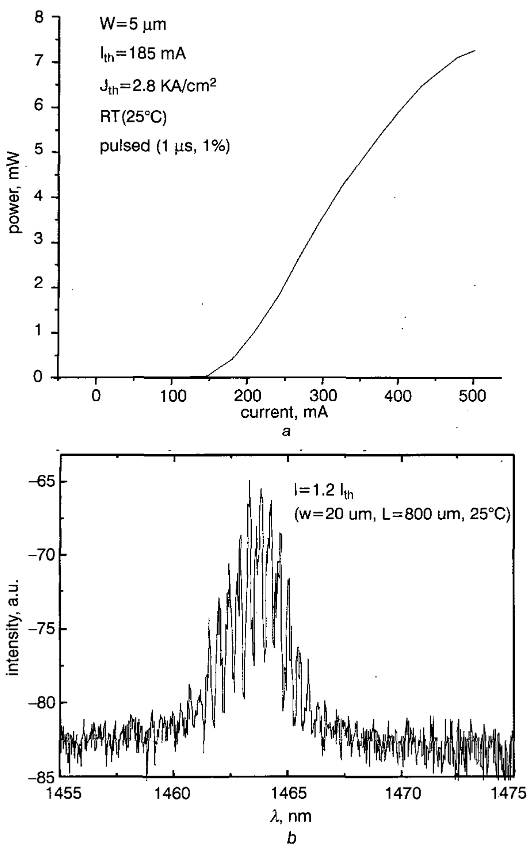

Fig. 3 *L-I curve and optical spectrum for GaInNAsSb/GaNAsSb ridge waveguide laser with peak emission at 1.465 μm*

a L-I
b Optical spectrum
Indium mole fraction 44% and antimony flux 6.86×10^{-8} Torr

Conclusion: We have demonstrated long wavelength laser emission and PL from GaInNAsSb multiple QWs with GaNAsSb barriers. The use of dilute nitrogen and antimony enabled incorporation of more indium (up to 46%) and red-shifted luminescence out to 1.584 μm. Record long wavelength emission from GaAs-based multiple quantum well lasers at 1.49 μm and record low 930 A/cm^2 per quantum well at 1.46 μm were observed.

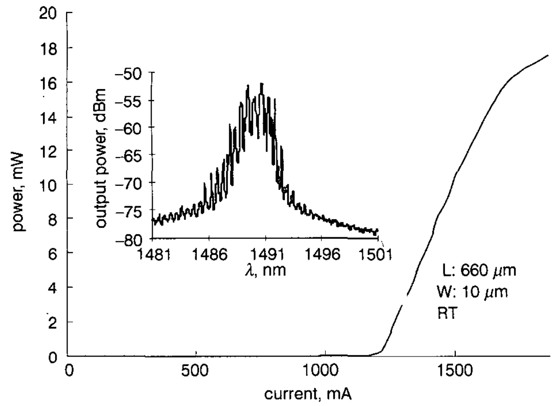

Fig. 4 *L-I curve and optical spectrum for GaInNAsSb/GaNAsSb ridge waveguide laser with peak emission at 1.49 μm*

Inset: optical spectrum
Indium mole fraction 46% and antimony flux 1.4×10^{-7} Torr

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Three-terminal dual-stage vertical-cavity surface-emitting laser

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A three-terminal dual-stage VCSEL, operating continuous-wave at room temperature has been fabricated. Independent biasing of the two active stages leads to an extended singlemode regime compared to conventional VCSELs. The parallel configuration reveals singlemode operation with a differential series resistance <35 Ω.

Introduction: The very successful research into conventional vertical-cavity surface-emitting lasers (VCSELs) at 850 nm wavelength has