1.3 µm GaAs/GaAsSb quantum well laser grown by solid source molecular beam epitaxy

P.-W. Liu, G.-H. Liao and H.-H. Lin

A highly strained GaAs/$GaAs_{0.64}Sb_{0.36}$ single quantum well laser has been grown on GaAs (100) substrate by using solid source molecular beam epitaxy. The uncoated broad-area laser demonstrates 1.292 µm pulsed operation with a low threshold current density of 300 A/cm^2. The spontaneous emission of the laser was also studied. The result reveals that the Auger recombination component dominates the threshold current at high temperature.

Introduction: 1.3 µm GaAs-based lasers are now of great interest because they have been recognised to be the key light sources for optical communications in the future. The most important advantage of 1.3 µm GaAs-based lasers is the capability to fabricate 1.3 µm vertical cavity surface emitting lasers (VCSELs) with the integration of the well-developed GaAs/AlAs distributed Bragg reflectors (DBRs) and AlAs oxidation techniques. One of the active media used for GaAs-based 1.3 µm lasers is the strained GaAs/GaAsSb quantum well (QW) [1–3] which exhibits a staggered type-II band alignment and possesses a potential of emitting photons with wavelength longer than that corresponding to the fundamental bandgap energy of each constituent. The strained GaAs/GaAsSb QW is a promising material for optical communication applications.

We have successfully used molecular beam epitaxy (MBE) to grow a GaAs/GaAsSb double quantum well laser and obtained 1280 nm emission with a low threshold current density of 210 A/cm^2 at room temperature [3]. To extend the lasing wavelength to 1.3 µm, we increased the Sb content in the GaAsSb quantum well and reduced the number of quantum wells to one. In this Letter, we demonstrate the results of the grown single quantum well (SQW) laser. The spontaneous emission of the grown laser was also studied and compared with the reported results of the InGaAsN device [4].

Experiments: The lasers were grown on n^+-GaAs (100) substrate by solid-source molecular beam epitaxy (SSMBE). The active region of the laser was grown at 500°C. It consists of one 7 nm-thick $GaAs_{0.64}Sb_{0.36}$ quantum well and two 80 nm-thick GaAs barriers and was sandwiched between two 0.1 µm-thick AlGaAs step graded layers. The Al composition is graded from 0.1 to 0.5, centre to upper (lower) at the top (bottom) waveguide layer. $Al_{0.6}Ga_{0.4}As$ layers with 1.5 µm thickness serve as the cladding layers of the laser. The AlGaAs layers and a 0.5 µm-thick buffer n^+-GaAs layer were grown at 580°C. Finally, 50 µm-wide broad-area lasers with different cavity lengths were fabricated using standard photolithography, wet-etching, and metallisation processes.

After processing and mirror cleavage, the lasers were tested under 2 µs pulsed current with a repetition rate of 500 Hz. The lasing spectrums were taken using a HP70951A spectrum analyser. On the measurement of the spontaneous emission (SE) of the laser, we used a fibre bundle positioned at a fixed distance from the lateral side of the cavity. The collected SE signal was detected by a Ge detector using a lock-in technique.

Results and discussion: Fig. 1 shows the room temperature photoluminescence (PL) spectrum of the GaAs/GaAsSb single quantum well laser with the top p-cladding layer removed. The peak position is at 1.3 µm, and the full width at half maximum (FWHM) is about 80 meV. The relatively broad FWHM is not unusual in GaAs/GaAsSb QWs [5–6], and can be attributed to the type-II inherent nature of the GaAs/GaAsSb QW and the Sb composition fluctuation in GaAsSb resulting from Sb segregation or phase separation [6–7].

Fig. 2 shows the L-I characteristic of the laser device under pulsed-mode operation. The threshold current density is about 300 A/cm^2. This is the lowest threshold current density reported for GaAs/GaAsSb quantum well lasers grown by MBE at 1.29–1.3 µm wavelength range. The inset in Fig. 2 shows the spectrum of a laser with a cavity length of 2.2 mm. The lasing wavelength is at 1.292 µm. We also measured the cavity length dependency of the threshold current density. The threshold current density for infinite cavity length is 217 A/cm^2 for the GaAs/GaAsSb SQW laser. The internal quantum efficiency is 44% and the internal loss is 5.4 cm^{-1}. The low quantum efficiency may be due to the high carrier density in the active medium.

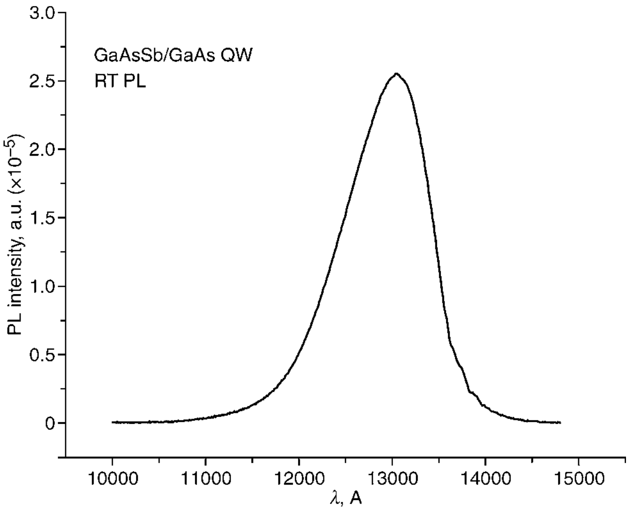

Fig. 1 *Room temperature PL spectrum of GaAs/GaAsSb SQW laser with top p-cladding layer removed*

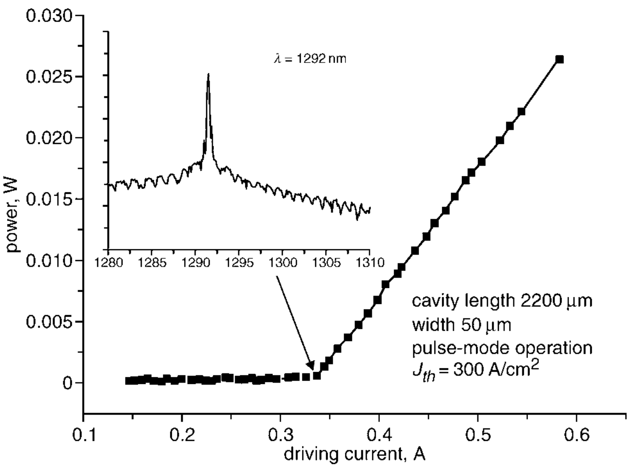

Fig. 2 *Light against current characteristic of 2.2 mm-long GaAs/GaAsSb SQW laser*

Inset: Lasing spectra of GaAs/GaAsSb SQW laser

Because of the low gain and low spontaneous recombination rate in type-II QWs, carriers pile up in QWs and the waveguide layer. These high-density carriers may enhance the internal loss and degrade the external quantum efficiency especially in lasers with short cavity. The temperature characteristics were measured from 25 to 85°C, and the characteristic temperature is 59 K. By measuring the spontaneous emission, we can obtain better insight into the recombination mechanism of the grown GaAs/GaAsSb SQW laser [4]. The integrated spontaneous emission rate L is proportional to n^2, where n is the carrier density. The current flowing through the device I will be $I \propto n^z$. The Z factor depicts the dominant current path in the laser [4]. Therefore, we have $I \propto (L^{1/2})^z$ [4]. By drawing a plot of $\ln(I)$ against $\ln(L^{1/2})$, the Z value can be derived.

Fig. 3 plots the close-to-threshold power factor Z_{th} against temperature for the SQW GaAs/GaAsSb laser (squares) and for comparison the Z_{th} values for a InGaAsN/GaAs laser [4] (triangles). It shows that the temperature behaviour of the Z_{th} value is close to that of the InGaAsN laser. The Z_{th} value is about 2.2 near 300 K and increases to $Z_{th} \sim 2.7$ at 353 K. This shows the significant increasing Auger current contribution at threshold as temperature increases. The high carrier density in type-II QWs as discussed above may account for the higher Auger recombination rate. More detailed measurements and analysis are now in progress.

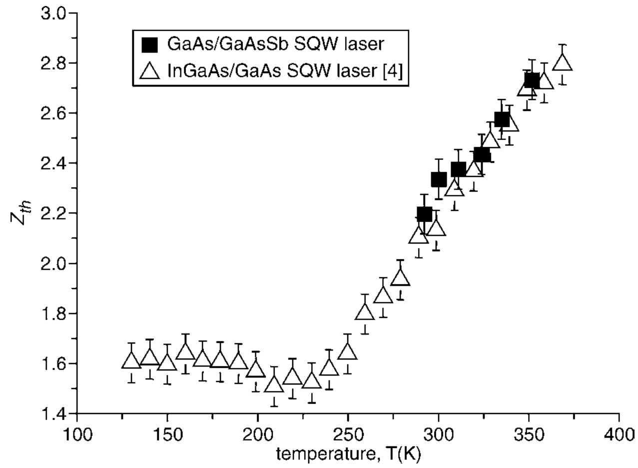

Fig. 3 *Power factor close to threshold Z_{th} against temperature for GaAs/GaAsSb SQW and InGaAsN/GaAs lasers*

Conclusion: We have successfully grown a GaAs/GaAsSb single quantum well laser using SSMBE. The laser exhibits a low threshold current density of 300 A/cm^2, and the lasing wavelength is at 1.292 μm. The internal quantum efficiency is 44% and the internal loss fitted is 5.4 cm^{-1}. The characteristic temperature is 59 K. The spontaneous emission of the laser was also measured. The higher carrier density in type-II QWs may result in a higher Auger recombination rate which dominates the threshold current as temperature increases.

Acknowledgment: This work was supported by the National Science Council of the Republic of China under contract number NSC 92-2215-E-002-024.

2 December 2003

Electronics Letters online no: 20040119
doi: 10.1049/el:20040119

P.-W. Liu, G.-H. Liao and H.-H. Lin (*Graduate Institute of Electronics Engineering and Department of Electrical Engineering, National Taiwan University, Room 419, No. 1, Section 4, Roosevelt Road, Taipei, Taiwan, Republic of China*)

References

1 Ryu, S.W., and Dapkus, P.D.: 'Low threshold current density GaAsSb quantum well lasers grown by metal organic chemical vapour deposition on GaAs substrates', *Electron. Lett.*, 2000, **36**, pp. 1387–1388

2 Yamada, M., Anan, T., Tokutome, K., Kamei, A., Nishi, K., and Sugou, S.: 'Low-threshold operation of 1.3 μm GaAsSb quantum-well lasers directly grown on GaAs substrates', *IEEE Photonics Technol. Lett.*, 2000, **12**, pp. 774–776

3 Liu, P.W., Lee, M.H., Lin, H.H., and Chen, J.R.: 'Low-threshold current GaAsSb/GaAs quantum well lasers grown by solid source molecular beam epitaxy', *Electron. Lett.*, 2002, **38**, pp. 1354–1355

4 Fehse, R., Tomic, S., Adams, A.R., Sweeny, S.J., O'Reilly, E.P., Andreev, A., and Riechert, H.: 'A quantitative study of radiative, Auger, and defect related recombination processes in 1.3-μm GaInNAs-based quantum well lasers', *IEEE Sel. Top. Quantum Electron.*, 2002, **8**, pp. 801–810

5 Teissier, R., Sicault, D., Hamand, J.C., Ungaro, G., Le Roux, G., and Largeau, L.: 'Temperature-dependent valence band offset and band-gap energies of pseudomorphic GaAsSb on GaAs', *J. Appl. Phys.*, 2001, **89**, pp. 5473–5477

6 Zuo, S.L., Hong, Y.G., Yu, E.T., and Klem, J.F.: 'Cross-sectional scanning tunneling microscopy of GaAsSb/GaAs quantum well structures', *J. Appl. Phys.*, 2002, **92**, pp. 3761–3770

7 Kaspi, R., and Evans, K.R.: 'Sb-surface segregation and the control of compositional abruptness at the GaAsSb/GaAs interface', *J. Cryst. Growth*, 1997, **175/176**, pp. 838–843