Improvement of High Speed Performance for 10-Gb/s 850-nm VCSELs using InGaAsP/InGaP strain-compensated MQWs

Y. S. Chang, H.C. Kuo, F. I. Lai, Y. A. Chang, L. H. Laih and S. C. Wang*

Institute of Electro-Optical Engineering,
National Chiao Tung University, Hsinchu, Taiwan, R.O.C.

ABSTRACT

We present in this paper the MOCVD growth and characterization of high performance 850nm InGaAsP/InGaP strain-compensated MQWs vertical-cavity surface-emitting lasers (VCSELs). These VCSELs exhibit superior characteristics, with threshold currents ~0.4 mA, and slope efficiencies ~ 0.6 mW/mA. The threshold current change is less than 0.2 mA and the slope efficiency drops by less than ~30% when the substrate temperature is raised from room temperature to 85^{o}C. These VCSELs also demonstrate high speed modulation bandwidth up to 12.5Gbit/s from 25^{o}C to 85^{o}C.

KEYWORDS: MOCVD**,** InGaAsP, VCSELs, strain-compensated, high speed

1. INTRODUCTION

850 nm Vertical Cavity Surface Emitting Lasers (VCSEL) have become a standard technology for application in local area networks (LANs) from 1.25 Gb/s to 10Gb/s [1-4]. The main advantages of VCSELs are the low threshold current, low divergent angle, and circular beam, which lead to simpler packaging and low electrical power consumption. The surface emission from the VCSELs also makes easy the 2-dimensional array integration and allows wafer level testing, in turns leading to low fabrication cost. The use of an Al-free InGaAsP based active region is an attractive alternative to the conventional (Al)GaAs active region for IR VCSELs. Edge emitting diode lasers with Al-free active regions have demonstrated performance and reliability surpassing those of AlGaAs-active devices [5]. In addition, theoretical calculations have predicted a lower transparency current density, high differential gain and better temperature performance in VCSELs with strained InGaAsP active region as compared to devices with lattice-matched GaAs quantum-well active region [6]. These parameters are all very important in high

Vertical-Cavity Surface-Emitting Lasers VIII, edited by Chun Lei,
Kent D. Choquette, Sean P. Kilcoyne, Proceedings of SPIE Vol. 5364
(SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 doi: 10.1117/12.530055

speed and high temperature VCSEL design because the relaxation resonance frequency of the laser depends on the square root of the differential gain as well as on the difference between operation current and threshold current [4]. The use of tensile-strained barriers (InGaP) can provide strain compensation and reduce active region carrier leakage. Al-free materials are significantly less reactive to oxygen than AlGaAs, which makes them ideal for reliable manufacturing [5]. Proton implanted VCSELs using a $In_{0.18}Ga_{0.82}As_{0.8}P_{0.2}$ strained active-region have demonstrated good performance [7]. In this paper, we demonstrate the high speed and high temperature operation of 850nm oxide-confined VCSEL utilizing $In_{0.18}Ga_{0.82}As_{0.8}P_{0.2}/In_{0.4}Ga_{0.6}P$ strain-compensated MQWs (SC-MQWs).

2. EXPERIMENT

All structures were grown on Semi-insulating GaAs (100) substrates by low pressure metal organic chemical vapor deposition (MOCVD). The group-V precursors are the hydride sources AsH_3 and PH_3. The trimethyl alkyls of gallium (Ga), aluminum (Al) and indium (In) are the group-III precursors. The VCSEL structure as shown in Fig. 1 consists of an n-type 35-period-$Al_{0.15}Ga_{0.85}As/Al_{0.9}Ga_{0.1}As$ distributed Bragg reflector (DBR) which was grown at 750^{o}C. Then, a three-quantum-well active region $In_{0.18}Ga_{0.82}As_{0.8}P_{0.2}/In_{0.4}Ga_{0.6}P$ (8 nm/10 nm) and cladding layer (total 1λ thickness) were grown, followed by the growth of a 22-period $Al_{0.15}Ga_{0.85}As$ /$Al_{0.9}Ga_{0.1}As$ p-type mirror and a 1λ thickness of current spreading layer and thin GaAs contacting layer. The quantum well region growth temperature was set to 650^{o}C. Growth interruptions of 5s, 10s, or 15s were introduced before and after $In_{0.18}Ga_{0.82}As_{0.8}P_{0.2}$ QW growth. For the VCSEL structure, the gain peak position = 835 nm was determined by photoluminescence of an angle-etched sample while the FP-dip wavelength = 842 nm was determined by reflection measurement. The VCSELs were fabricated utilizing the high speed VCSEL processing to minimize capacitance while keeping reasonably low resistance [3]. The VCSEL has a 5 μm diameter emitting aperture defined by lateral oxidation and Ti/Pt/Au, AuGe/Ni/Au for p contact and n-metal, respectively.

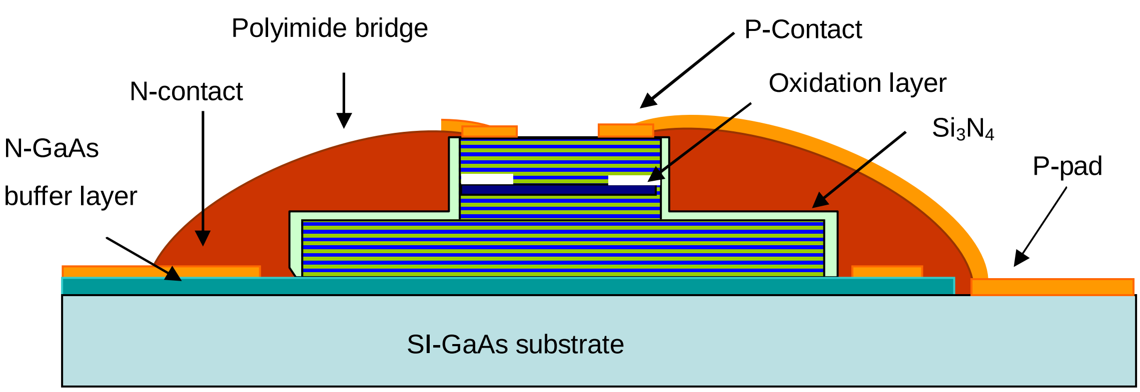

Figure 1. Schematic cross section of high speed VCSEL structure.

3. RESULTS AND DISCUSSION

Fig. 2 shows the typical SC-MQWs InGaAsP/InGaP VCSEL light output and voltage versus current (LIV) curves at room temperature and 85°C. These VCSELs exhibit kink-free current-light output performance with threshold currents ~0.4 mA, and slope efficiencies ~ 0.6 mW/mA. The threshold current change with temperature is less than 0.2 mA and the slope efficiency drops by less than ~30% when the substrate temperature is raised from room temperature to 85°C. This is superior to the properties of AlGaAs/GaAs VCSELs with similar size [4]. The resistance of our VCSELs is ~95 Ohm and capacitance is ~0.1 pF. As a result, the devices are limited by the parasitics to a frequency response of approximately 15 GHz.

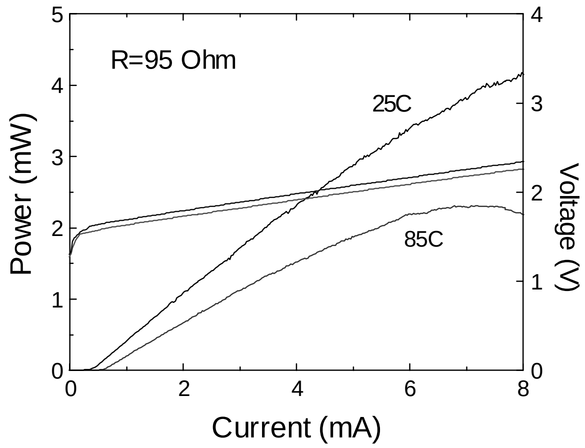

Fig. 2 SC-MQWs InGaAsP/InGaP VCSEL light output and voltage versus current (LIV) curves at room temperature and 85°C.

The small signal response of VCSELs as a function of bias current was measured using a calibrated vector network analyzer (Agilent 8720 ES) with on-wafer probing and 50 μm multimode optical fiber connected to a New Focus 25 GHz photodetector. Fig. 3 shows the smoothed small-signal modulation responses of a 5 μm VCSEL at

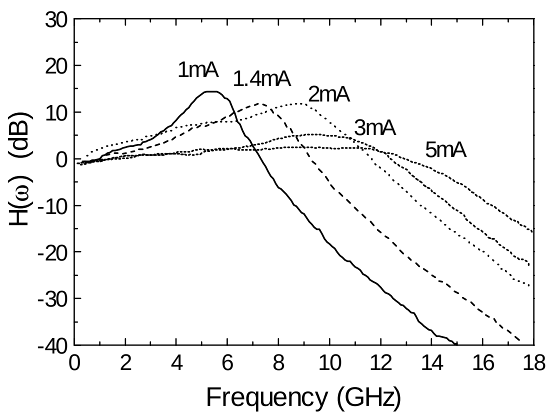

Fig. 3 Small-signal modulation responses of a 5 μm diameter VCSEL at different bias current levels.

different bias current levels. With only 3mA (5mA) of bias current, the maximum 3dB modulation frequency response is measured to be ~13 (14.5) GHz.

The modulation responses were fitted using an additional first-order parasitic term and standard modulation response obtained from single longitudinal mode rate equation:

$$H(f)=\frac{1}{1+(\frac{f}{f_0})^2}\cdot\frac{1}{(1-(\frac{f}{f_r})^2)^2+(\frac{\gamma}{2\pi f_r})^2(\frac{f}{f_r})^2}$$

where f_0 is parasitic pole frequency, f_r is resonant frequency, and γ is damping rate of the device.

As Fig.3 shown, the modulation bandwidth increased with increasing the bias current. With bias current of only only 3mA (5mA), the maximum 3dB modulation frequency response is measured ~13 (14.5) GHz. 14.5 GHz at 25°C. The resistance of our VCSELs is ~95 Ohm and capacitance is ~0.1 pF. As a result, the devices are limited by the parasitics to a frequency response of approximately 15 GHz. From the optimized fittings, we plotted resonant frequency as a function of the square root of the current above threshold in Fig. 4. The slope yields the modulation current efficiency of 11.6 GHz/(mA)$^{1/2}$.

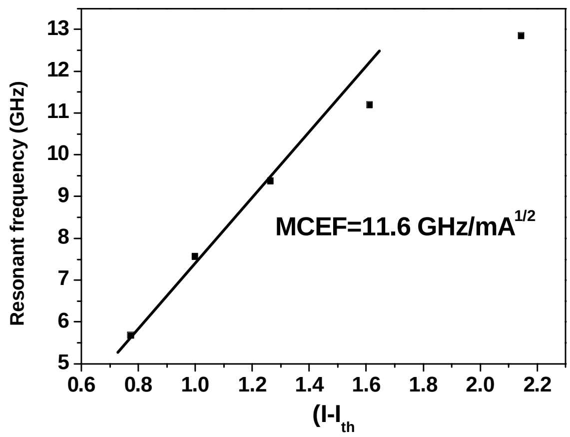

Fig. 4 Resonant frequency as a function of square root of current above threshold current

To measure the high-speed VCSEL under large signal modulation, microwave and light wave probes were used in conjunction with a 12.5-Gb/s pattern generator and a 12-GHz photoreceiver. The eye diagrams were taken for back-to-back (BTB) transmission on SC-MQWs InGaAsP/InGaP VCSEL. As shown in Fig. 5, the room temperature eye diagram of our VCSEL biased at 4 mA with data up to 12.5 Gb/s and 6dB extinction ratio has a clear open eye pattern indicating good performance of the VCSELs. The rise time Tr is 28 ps and fall time Tf is 41 ps with jitter(p-p)=20 ps.

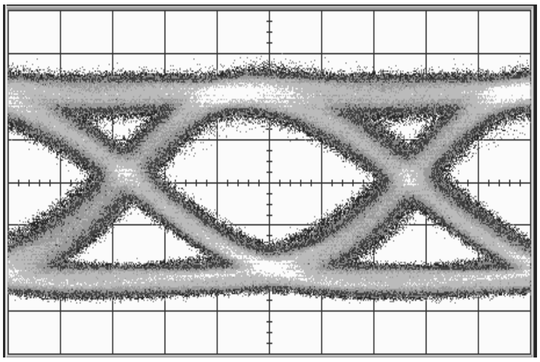

Fig. 5 Room temperature eye diagram of our VCSEL data up to 12.5 Gb/s and 6dB extinction ratio. The scale in the fig. is 15 ps/div

Finally, we have calculated the material gain of strained InGaAsP MQW and GaAs MQW using *LASTIP*.[8] Fig 6(a) shows the material gain as a function of emission wavelength while fig 6(b) shows the material gain as a function of carrier density. As shown in fig 6(a), the material gain of InGaAsP well is about 3 times higher than GaAs well and leads to a lower transparency carrier concentration shown in fig 6(b). This simulation results confirm again the benefit of strain-compensated InGaAsP/InGaP MQW and can give a guideline to the device design.

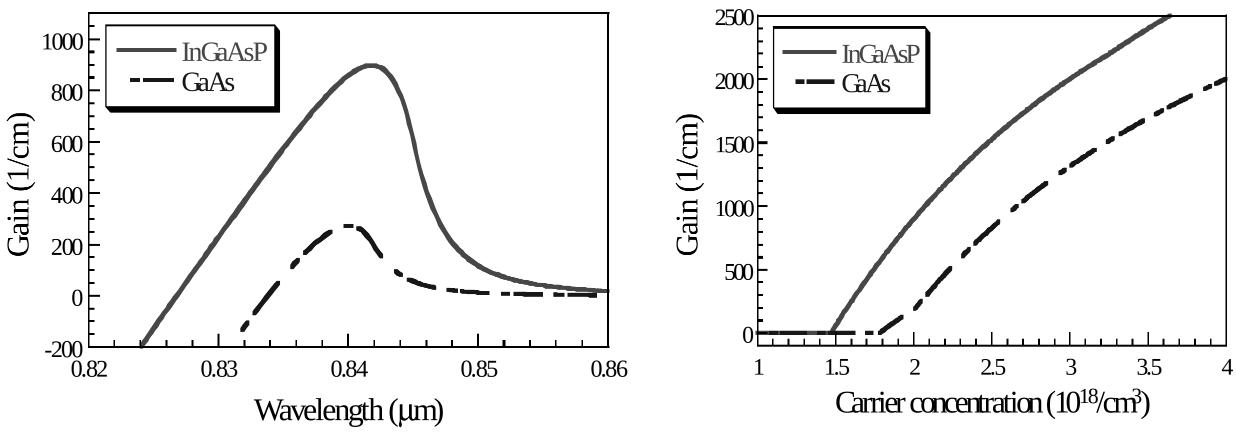

Fig 6(a) Comparison of gain spectra for InGaAsP/InGaP MQW and GaAs/AlGaAs MQW, well width =8 nm, Injection density= 2×10^{18} cm^{-2}.

Fig 6(b) Comparison of material gain under various carrier concentrations.

4. CONCLUSION

High performance SC-InGaAsP/InGaP MQW VCSELs were successfully grown by MOCVD. These VCSELs show very low threshold current, good temperature performance, and high modulation response of up to 12.5 Gb/s from 25^{o}C to 85^{o}C. All of these advantages- kink-free L-I, good temperature properties, high speed performance- make the novel VCSEL promising for optoelectronic and other commercial applications.

5. ACKNOWLEDGEMENT

The authors would like to thank Dr. C. P. Kuo of LuxNet Corportaion and Prof. Nelson Tansu of Leigh University for useful discussion and technical support. This work is supported by work was supports by the National Science Council, Republic of China, under contract NSC-90-2215 -E009-088 and by the Academic Excellence Program of the Ministry of Education of ROC under the contract NO. 88-FA06-AB.

REFERENCES

[1] J. A. Tatum, A. Clark, J. K. Guenter, R. A. Hawthorne, and R. H. Johnson, “Commercialization of Honeywell’s VCSEL technology,” *Vertical-Cavity Surface-Emitting Lasers IV*, K. D. Choquette and C. Lei, editors, Proceedings of the SPIE, **3946**, pp. 2-13, SPIE, Bellingham, WA, 2000.

[2] F. H. Peters and M. H. MacDougal, “High-Speed High-Temperature Operation of Vertical-Cavity Surface-Emitting Lasers” *IEEE Photon. Technol. Lett.*, **13**, No 7, p. 645–647, July 2001.

[3] F. H. Peters, D. J. Welch, V. Jayaraman, M. H. MacDougal, J. D. Tagle, T. A. Goodwin, J. E. Schramm, T. D. Lowes, S. P. Kilcoyne, K. R. Nary, J. S. Bergey, andW. Carpenter, “10 Gb/s VCSEL-based data links,” Photonics West, San Jose, CA, Tech. Rep. OE 3946–26, 2000.

[4] C.W. Wilmsen, H. Temkin, and L.A. Coldren, eds., *Vertical-Cavity Surface-Emitting Lasers: Design, Fabrication, Characterization, and Applications*, Cambridge University Press, 1999.

[5] L. J. Mawst, S. Rusli, A. Al-Muhanna, and J. K. Wade, “Short-wavelength (0.7 m< λ <0.78 m) high-power InGaAsP-active diode lasers,” *IEEE J. Select. Topics Quantum Electron.*, **5**, pp. 785–791, (1999).

[6] T. E. Sale, C. Amamo,Y. Ohiso, and T.Kurokawa, “Using strained lasers (AlGa) In As P system materials to improve the performance of 850 nm surface- and edge-emitting lasers,” *Appl. Phys. Lett.*, **71**, p. 1002–1004, (1997).

[7] N. Tansu, L.J Mawst, “Compressively-strained InGaAsP-active(λ=0.85μm) VCSELs” *IEEE Lasers and Electro-Optics Society 2000 Annual Meeting. LEOS 2000.* **2**, p. 724 -725 (2000).

[8] *www.crosslight.com*