Temperature dependent near-field emission profiles of oxide-confined vertical cavity surface emitting lasers

T.C. Lu, W.J. Shieu, Y.H. Chang, L.H. Laih and S.C. Wang*
Institute of Electro-Optical Engineering, National Chiao Tung University,
1001 Ta Hsueh Rd., Hsinchu, Taiwan, R.O.C.

ABSTRACT

The near-field emission profiles of oxide confined GaAs vertical cavity surface emitting lasers (VCSELs) with 20μm aperture have been investigated at different operating temperature and different driving current. The subthreshold emission profile provided the information of carrier distributions. At 20°C, a uniform plateau profile was observed at subthreshold emission, which then transferred to a fundamental mode at just above the threshold current. At higher driving current, the fundamental mode evolved into higher order modes due to the spatial hole burning effect. However, at 90°C the subthreshold emission was no longer a uniform plateau profile but showed some locally high gain regions off the aperture center. The subsequent lasing mode profiles showed high order mode in coincidence with these locally high gain regions at 90°C. The higher order mode profiles remained nearly unchanged under different temperature conditions when driving at constant current above the threshold. These locally high gain regions probably caused by the non-uniformity of the open aperture and the current crowding effect. In addition to the spatial hole burning and thermal lensing effect, these locally high gain regions appeared at elevated operation temperature also affected the higher order mode transitions of oxide-confined VCSELs.

Keywords: near-field, oxide-confined, VCSELs, spatial hole burning

1. INTRODUCTION

Vertical cavity surface emitting lasers are revolutionizing the semiconductor laser industry. The surface emitting lasers offer several advantages over edge emitting semiconductor lasers, including low threshold current, low divergence circular beam, the possibility of one- and two-dimensional array formation[1], and inexpensive wafer-scale fabrication[2]. Recently, oxide-confined VCSELs have shown superior optical and electrical properties than the implanted VCSELs due to the precise control of the oxidized aperture size and position[3]. However, the transverse mode evolution is still a fascinating subject both in oxide-confined and implanted VCSELs. For implanted VCSELs, the absence of the index guide in the transverse direction makes the mode patterns complicated due to various factors such as carrier distribution and thermal lensing effect. The inherent index guide in oxide-confined VCSELs results in more stable mode patterns but the higher order mode distribution needs to be further studied. The near-filed images below threshold have been reported for oxide-confined VCSELs[4, 5], but the temperature dependent relations have not been investigated. In this paper, we report the thermal characteristics of oxide-confined VCSELs by analyzing the near field profile both in subthreshold and above threshold operations.

2. EXPERIMENTAL

A selectively oxide-confined VCSEL with a 20 μm circular aperture was investigated. The designed emission wavelength was around 850nm. The device was grown by metal-organic chemical vapor deposition (MOCVD) system. The structure consists of an n-type bottom distributed Bragg reflector (DBR) of 30.5 pairs of $Al_{0.12}Ga_{0.88}As/AlAs$ and a

*Correspondence: Phone: 886-3-5712121ext56320; Fax: 886-3-5716631; E-mail: scwang@mail.nctu.edu.tw

p-type top DBR of 20.5 pairs of $Al_{0.12}Ga_{0.88}As/Al_{0.9}Ga_{0.1}As$. The λ-cavity consists of three quantum wells imbedding in top and bottom grading $Al_xGa_{1-x}As$ (x=0.3 → 0.6) confinement layers and two $Al_{0.6}Ga_{0.4}As$ cladding layers. The AlAs oxide layer is placed at the first pair of the top DBR above the active region. The experimental setup in the probe station is shown in Fig.1. The L-I profiler was used to measure the current-light output characteristics. The optical spectrum analyzer was used to measure the spectrum of the emission beam. The oxide-confined VCSELs have been investigated by using a 100X objective lens with long working distance and a cooled charged-coupled device (CCD) camera. The temperature was controlled with the TE cooler. The near-field profile of the VCSELs operating at various current and temperature was observed from the monitor.

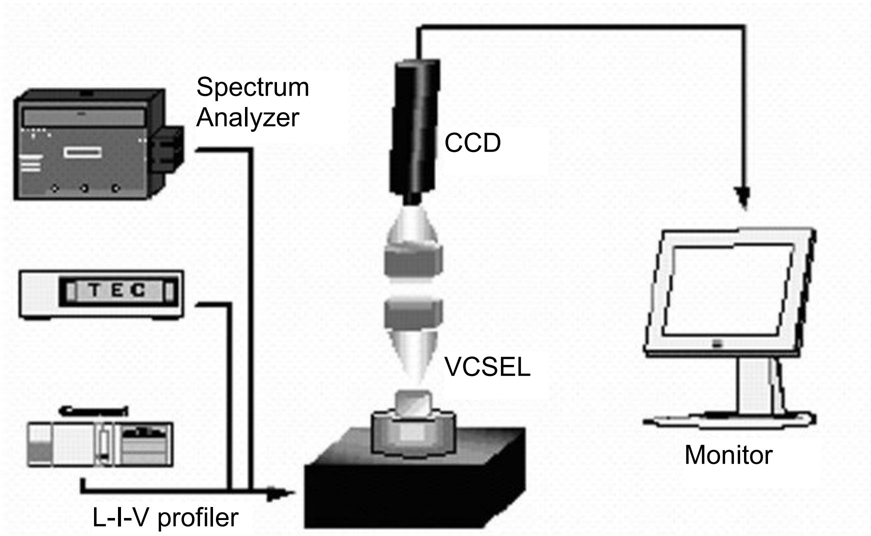


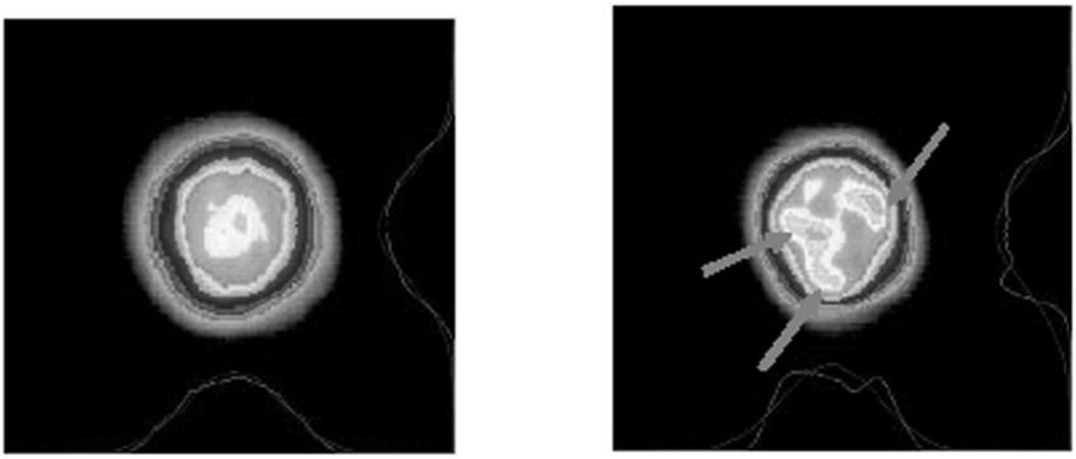
Fig. 1 Experimental setup

3. RESULTS AND DISCUSSION

The wavelength of the emission beam of the VCSELs is 847nm. The light output power versus current characteristics of the VCSELs have been measured at 20°C and 90°C to verify the threshold current. At 20°C and 90°C, the threshold current was 3mA and 5.5mA, respectively. The increase of the threshold current at high temperature is mostly due to the larger gain offset The near field emission pattern with current injection of 2.9mA at 20°C is shown in Fig. 2(a) and with 4.5 mA current injection at 90°C is shown in Fig. 2(b). In Fig. 2(a), a uniform plateau emission profile suggests the uniform distribution of injection carriers in the oxide-confined VCSELs. As the temperature increased to 90°C, the local high gain regions appear at the outer ring of the aperture as indicated with arrows in Fig. 2(b).

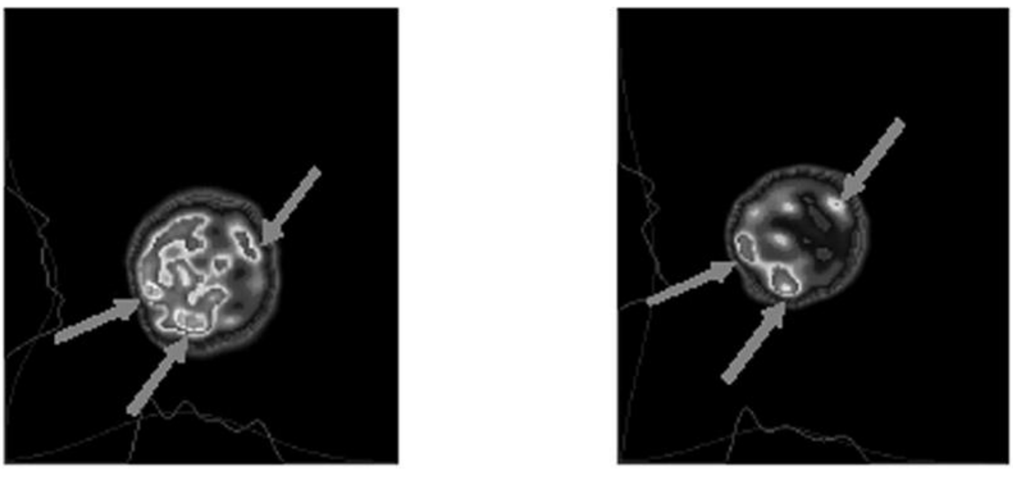
Fig. 3 shows the near-field patterns at 6 mA at operating temperature of 20°C and 90°C. To insure the stimulated emission of the VCSELs, the driven current was chosen to be above threshold current at 20°C and at 90°C. From Fig. 3, the areas of high emission intensity do not vary with increasing temperature. In addition, these high intensity areas locate closely at the local high gain regions appeared at subthreshold and high temperature condition. The emitting intensity at high operating temperature became weaker than lower temperature. This is due to the offset between the resonance cavity mode and the gain peak at higher temperature. Fig. 4 shows the spectrum of the lasing modes when the driven current was 6mA at 20°C and 90°C. The lasing modes also show no variation with increasing temperature but only have the slight red shift due to the movement of the cavity mode at high temperature.

As far as the oxide-confined VCSELs are concerned, the transverse mode distribution should not change easily for the superior structure design of the oxide aperture supplying the strong index confinement. As a consequence, the high emitting intensity regions indicated with arrows do not change as the temperature increases. At 20°C, an uniform plateau profile was observed at subthreshold emission, which then transferred to a fundamental mode at just above the threshold current. At higher driving current, the fundamental mode evolved into higher order modes due to the spatial hole burning effect. However, at 90°C, the driven current of 6mA is just above the threshold, the transverse direction should only show the fundamental mode or first of few higher order modes. But the non-uniform current injection to some regions force the VCSELs to emit complicated higher order transverse mode. When the driven current was lowered to below the threshold, some high intensity regions of the spontaneous emission profile coincidentally located at the lasing mode positions. We believe that in addition to the spatial hole burning effect and current crowding effect, the higher order mode evolution of oxide-confined VCSELs could be influenced by these local regions with high gain and low resistance. The formation of these regions needs to be further studied.



(a) (b)

Fig. 2 The near field patterns of spontaneous emission when driven current was under threshold at (a) 20°C and (b) 90°C. The arrows indicate the local high intensity region.



(a) (b)

Fig. 3 The near field patterns of stimulated emission when driven current was 6 mA at (a) 20°C and (b) 90°C. The high intensity regions indicated with arrows do not change with increased temperature but the weaker intensity at 90°C was due to the mismatch of the resonance cavity mode and gain peak.

4. CONCLUSION

In summary, we have investigated the near field patterns of oxide-confined VCSELs for spontaneous and stimulated emission at different operation temperatures. At 20°C, a uniform plateau profile was observed at subthreshold emission, which then transferred to a fundamental mode at just above the threshold current. At higher driving current, the fundamental mode evolved into higher order modes due to the spatial hole burning effect. However, at 90°C the subthreshold emission was no longer a uniform plateau profile but showed some locally high gain regions off the aperture center. The subsequent lasing mode profiles showed high order mode in coincidence with these locally high gain regions at 90°C. The higher order mode profiles remained nearly unchanged under different temperature conditions when driving at constant current above the threshold. These locally high gain regions probably caused by the non-uniformity of the open aperture and the current crowding effect. In addition to the spatial hole burning and thermal lensing effect, these locally high gain regions appeared at elevated operation temperature also affected the higher order mode transitions of oxide confined VCSELs.

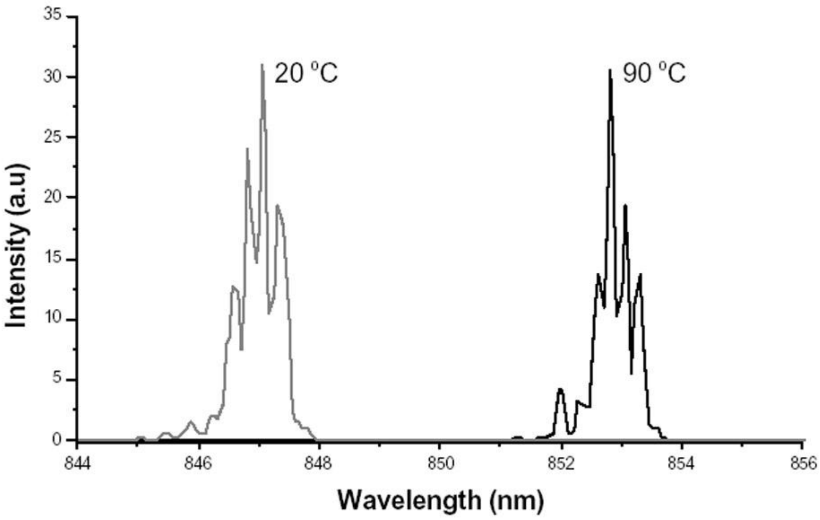


Fig. 4 The spectrum of oxide-confined VCSELs when driven current was 6 mA at 20°C and 90°C with the spectral resolution of 0.1nm.

5. ACKNOWLEDGMENT

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REFERENCES

1. K. J. Ebeling, U. Fiedler, R. Michalzik, G. Reiner and B. Weigl, Int. J. Electron. Commun. Vol. 50, pp. 316-326, 1996
2. W.W. Chow, K.D. Choquette, M.H Crowford, K.L. Lear, and G.R. Hadley, IEEE J. Quantum Electron. Vol. 33, NO. 10, pp. 1810-1824, October 1997
3. K. D. Choquette, K.L. Lear, R. P. Schneider, and K. M. Geib, Appl. Phys. Lett. Vol. 66, NO. 25, pp. 3413-3415, 1995.
4. C. Degen, I. Fischer and W. Elsaber, Optics Express, Vol. 5, NO. 3, pp. 38-47, 1999
5. J. Kim, J. T. Boyd, Howard E. Jackson, and K. D. Choquette, Appl. Phys. Lett., Vol. 76, NO. 5, pp. 526-528, 2000