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Single Transverse Mode Operation of 1.55-μm Buried Heterostructure VCSELs

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1. Introduction

1.55-μm long-wavelength vertical-cavity surface-emitting lasers (LW-VCSELs) are promising light sources for optical networks. The most important performance criteria for VCSELs in optical networks are low threshold currnt, high-temperature operation, a stable transverse mode, and high optical power. High-temperature continuous-wave (CW) operation of 1.55-μm LW-VCSELs has been reported by using a tunnel junction [1], double-fused GaAs-based mirrors [2], and Sb-based mirrors [3]. However, none of them provides all of the essential properties simultaneously. In particular, it is dufficult to control the optical transverse mode in LW-VCSELs because the differential refractive index is very small [1,2] or extremely high [3]. Recently, we have achieved a low threshold current and a stable transverse mode in a buried heterostructure (BH) VCSEL by using thin-film wafer fusion, and this 5-μm VCSEL exhibits low threshold and a stable fundamental transverse mode up to the maximum optical output power [4]. However, this VCSEL with single-mode operation could not fulfill the operation temperature and optical power requirements. In this paper, we report the improvement of the optical power and high temperature operation for single mode operation of a 1.55-μm BH-VCSEL as a result of investigating the device size and gain offset effect. The emission area of the BH, which provides the single transverse mode operation, can be larger than those of oxidation and air-post structures.

2. Structure and Fabrication

A schematic cross-sectional view of our 1.55-μm VCSEL structure is shown in Fig. 1. The bottom mirror section consists of n-GaAs/AlAs and InP/InGaAsP DBRs. The top mirror consists of p-InP/InGaAsP including three intermediate step layers, and SiO2/TiO2 DBRs.

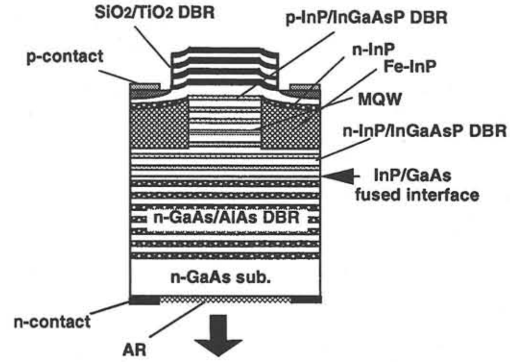

Fig. 1. Schematic cross-sectional view of BH VCSELs.

Fig.2 shows thin-film wafer fusion process. Both the InP-based and GaAs-based layers were grown by metal organic chemical vapor deposition (MOCVD). The active layers consist of 7 pairs of 1 %-compressibly strained InGaAsP MQWs, whose gain peak is 1528 nm. The resonant cavity wavelength of InP -based layers is observed 1542 nm. After the square mesa on the InP-based layers was formed by reactive ion etching, an Fe-doped InP layer as buried layer was grown. The epitaxial InP-based layer was stacked on a Si plate with wax for mechanical support. The InP substrate was selectively etched with chemical solutions. After the Si plate was detached by dissolving the wax at room temperature, the sample was put into an annealing furnace to form chemical bonds. The thin-film wafer fusion process was performed at 600 °C, which is lower

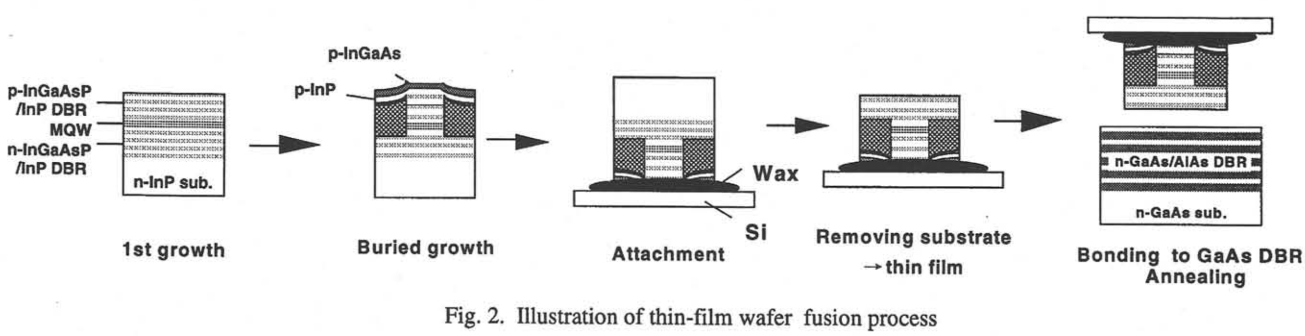

Fig. 2. Illustration of thin-film wafer fusion process

than the regrowth temperatures of buried layers. The device size fabricated ranged from 7 to 25 μm.

3. Results and Disscusion

Fig. 3 shows the optical output-current characteristics of 7 x 7 μm^2 LW-VCSELs at various temperature. The VCSELs exhibit a low threshold current of 0.69, threshold voltage of 1.5 V and maximum output powers of about 0.1 mW at 25 °C, respectively. Maximum CW operation temperature was 75 °C. At 25 °C, threshold current densities for various mesa size from 7 to 25 μm are about the same, 1.4-1.5 kA/cm^2. This indicates that in this BH VCSELs, leak current and optical diffraction loss are very small in this mesa size range. Because in the case of the air-post and lateral-oxidation type, threshold current density generally does not stay at the same value due to diffraction loss or /and carrier diffusion as emission area decreases [5]. Though differential quantum efficiency decreases with increasing temperature, threshold current is minimized around room temperature. This is attributed to the -14 nm gain offset.

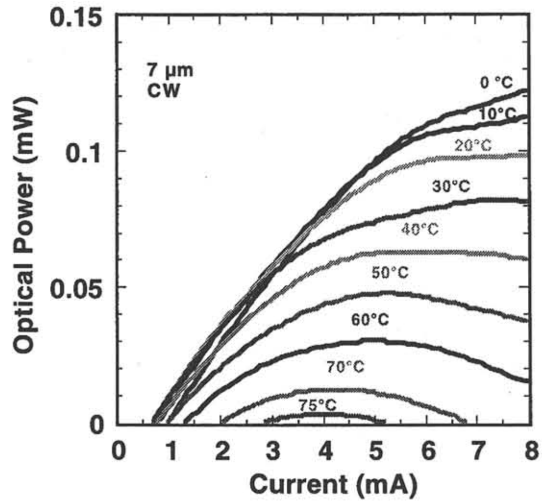

Fig. 3 Temperature dependence of L-I characteristics for 7-μm VCSEL under CW operation.

Fig. 4 shows optical spectra of 7-μm VCSELs at various current. For the 10-μm VCSEL, multiple spectrum peaks are observed even just above the threshold current. On the other hand, a single-lobe spectrum is observed for 7-μm VCSEL up to the maximum optical output power. The side mode suppression ratio is more than 40 dB and the linewidth is below 0.12 nm at the maximum optical output power. In far field patterns (FFPs), a symmetrical single lobe pattern is observed up to the maximum optical output power. The full width at half maximum of the FFP was measured to be 13 ° at 6 mA. This indicates that, for the 7-μm BH VCSEL, high-order modes are suppressed due to large diffraction loss and single transverse mode operation has been achieved at up to 0.1 mW maximum optical output power.

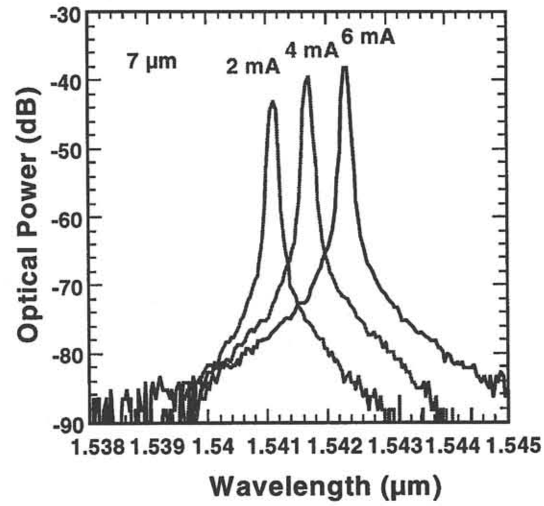

Fig. 4 Optical spectra under CW operation.

4. Summary

We have demonstrated the single transverse mode operation of 1.55-μm BH VCSELs on GaAs/AlAs DBR. The BH InP-based layers were successfully fabricated on a GaAs/AlAs DBR by thin-film wafer fusion. As a result, a 7-μm VCSEL exhibits low threshold current of 690 μA and voltage of 1.5 V and also exhibits in a single transverse mode up to 0.1-mW maximum optical output power under room-temperature CW operation. The maximum CW operating temperature is as high as 75 °C due to the -14-nm gain offset effect.

References

[1] M. Ortsiefer et al. *Electron. Lett.*, vol. 36, pp. 437-439, 2000

[2] A. Karim et al. IEEE *J. Select. Topics Quantum Electron.*, vol. 7. pp. 178-183, 2001.

[3] E. Hall et al. *Appl. Phys Lett.*, vol. 78. pp. 1337-1339, 2001

[4] Y. Ohiso et al. *IEEE Photon. Technol. Lett.*, vol. 13, pp.918-920 2001.

[5] O.-K. Kwon et al. *IEEE Photon. Technol. Lett.*, vol. 12, pp.1132-1134 2000.