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A New Process for Improving Performance of VCSELs

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Abstract: A new process method is proposed to improve the light output power of GaAs vertical cavity surface-emitting lasers (VCSELs). The VCSELs with open-annulus-distributed holes have a light output power 1.34 times higher than those with ring trenches. The 14μm-aperture devices have a light output power higher than 10mW and have a maximum of 12.48mW at 29.6mA. In addition, open-annulus-distributed holes offer bridges for current injection, so the connecting Ti-Au metal between the ohmic contact and bonding pad does not have to cross the ring trench, and it therefore would not cause the connecting metal to be broken. These VCSELs also show high-temperature operation capabilities, and they have a maximum output power of 8mW even at an operation temperature of up to 60℃.

Key words: epitaxial growth; laser diode; quantum-well laser; semiconductor laser; vertical-cavity surface-emitting laser
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1 Introduction

Vertical-cavity surface-emitting lasers (VCSELs) have emerged as attractive light sources for various applications in optical communication, optical computing, optical interconnects, laser printing, and optical storage. The main advantages are their low-cost fabrication and packaging, low drive currents, low divergence circular beams, and the possibility of integrating VCSELs in 1D and 2D arrays for parallel links. Over the past few years, the excellent performance of oxide-confined VCSELs has been reported in the literature in terms of low threshold current[1,2], high output power[3], high wallplug efficiency[4], low operating voltages[5], a high intrinsic modulation bandwidth[6], and very high fabrication yields[7]. Here, we have fabricated and characterized the static properties of GaAs-AlGaAs VCSELs using open-annulus-distributed holes instead of a ring trench as the lateral oxidation windows (as shown in Fig. 1). Our results show that the process we propose can effectively increase the output power and enhance the high-temperature operation.

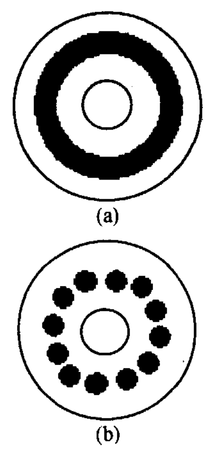

Fig. 1 Sketches of ring trench and open-annulus-distributed holes

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2 Device structure and fabrication

The epitaxial structures used in this study were grown by molecular beam epitaxy (MBE) on n-plus GaAs substrates. The bottom Bragg reflector consisted of 34 n-type Si-doped $Al_{0.9}Ga_{0.1}As$/GaAs pairs with quarter-wavelength-thick layers. The active region contains a GaAs-AlGaAs-based three-quantum-well in a one-wavelength cavity for 850nm emission. The top Bragg reflector consists of 24 p-type C-doped $Al_{0.9}Ga_{0.1}As$/GaAs pairs. A 35nm $Al_{0.98}Ga_{0.02}As$ layer used for the subsequent selective lateral oxidation was placed in the fourth quarter-wavelength layer above the active region. Test wafers with similar structure were repeatedly grown and characterized by photoreflectance and photoluminescence spectroscopy until the precise growth conditions and epitaxial structure were achieved. Chemically assisted reactive ion beam etching (using Cl_2/BCl_3) was used to etch open-annulus-distributed holes down to the active layer, using silicon nitride as the etch mask. After many 4μm-depth open-annulus-distributed holes were formed, the wafer was oxidized in the N_2/H_2O atmosphere for 50min at a temperature of 420 ℃. Then a thin 200nm silicon nitride passivation layer was coated on the wafer. Since the open-annulus-distributed holes offer bridges for current injection, the connecting metal between the ohmic contact and bonding pad does not have to cross the ring trench, and it therefore would not cause the connecting metal to be broken. The same oxidation process was simultaneously carried out on the bonding pad to prevent a leakage current. Afterwards, a Ti/Pt/Au ring contact deposited on the top of the 100μm-width mesa and a Ge/Ni/Au broad-area contact on the lapped GaAs substrate side. Rapid thermal annealing was carried out at 410 ℃ for 60s to reduce the contact resistance.

3 Device characteristics

Figures 2 and 3 show the dependence of voltage and light output power as a function of injected current. The VCSELs exhibit a threshold current of 1.6mA, threshold voltage of 1.8V. The 14μm-aperture devices have a light output power higher

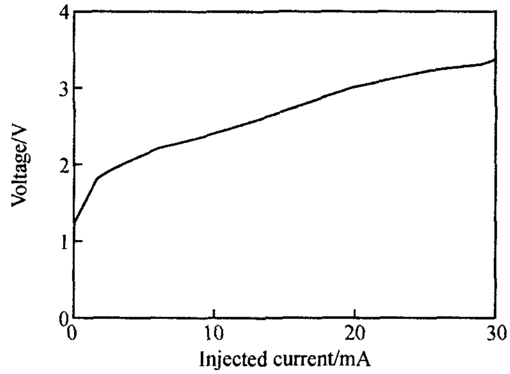

Fig. 2 Voltage as a function of injected current

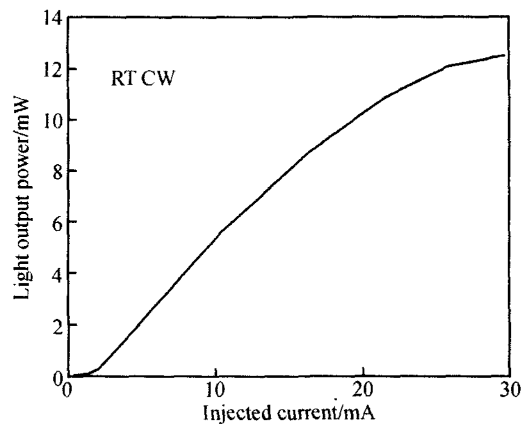

Fig. 3 *L*-*I* characteristics of VCSEL

than 10mW and have a maximum of 12.48mW at 29.6mA. Figure 4 shows the *L*-*I* characteristics for the VCSEL devices, some with open-annulus-distributed holes (group a) and the others with a ring trench (group b). All the VCSEL chips are taken from the same epi-wafer. The fact that the device with open-annulus-distributed holes does not need to be planarized with polyimide prior to the deposition of the metal benefits heat removal and improves the lasing performance effectively, especially the output power[8~10]. The devices in group a have a light output power 1.34 times higher than the group b devices. The optical absorption of the DBR stacks can be minimized due to their low resistance (superlattice structure[11]). The highly efficient de-

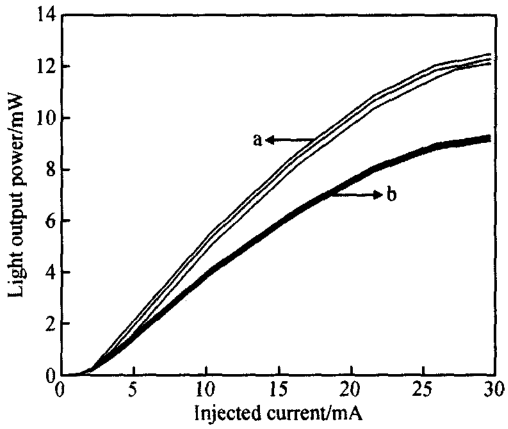

Fig. 4 L-I characteristics for VCSEL devices Some are with open-annulused-distributed holes (group a), others are with a ring trench (group b).

vices with low internal heating and effective external heat removal are well suited for operation over a wide temperature range. Figure 5 shows far field (FF) data for the VCSELs. There is no difference between the two device structures. Figure 6 shows the L-I characteristics of the open-annulus-distributed holes VCSELs in the temperature range from 20 to 80 ℃. The VCSELs have a maximum output power of 8mW even at an operation temperature of up to 60 ℃. Figure 7 shows the temperature dependence of the threshold current for the VCSELs. The threshold current increases from 1.6 to 2.6mA in the operation temperature range of 20 to 80 ℃. The threshold current is determined by the temperature dependent gain and the alignment of the gain maximum and the lasing mode.

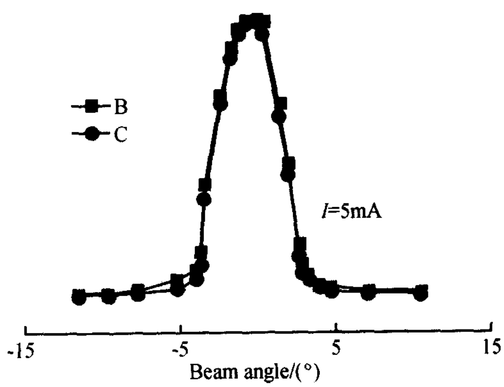

Fig. 5 Far field (FF) data for the VCSELs at 5mA B represents device with open-annulus-distributed holes and C with a ring trench.

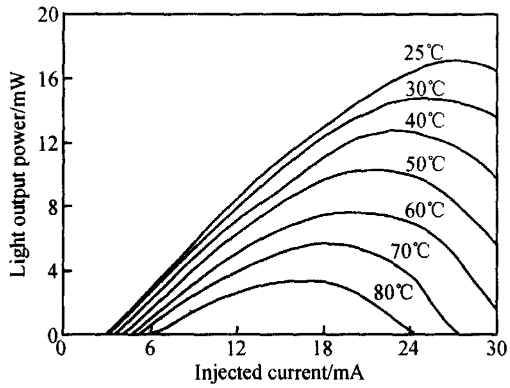

Fig. 6 L-I characteristics of the VCSELs with open-annulus-distributed holes at various temperatures

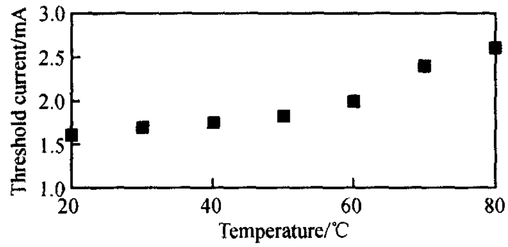

Fig. 7 Temperature dependence of threshold current for the VCSELs

4 Conclusion

We have fabricated oxide-confined VCSELs with open-annulus-distributed holes. Significant improvement in light output power is observed for devices with open-annulus-distributed holes. Results from comparison show that these VCSELs with open-annulus-distributed holes have better output characteristics than those with a trench. The VCSELs exhibit a threshold current of 1.6mA and a threshold voltage of 1.8V. The 14μm-aperture devices have a light output power higher than 10mW and have a maximum of 12.48mW at 29.6mA. Highly efficient devices with low internal heating and effective external heat removal are well suited for operation over a wide temperature range. The VCSELs have a maximum output power of 8mW even at an operation temperature of up to 60 ℃.

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一种提高垂直腔面发射激光器性能的新工艺

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摘要: 采用一种新的工艺方法提高了垂直腔面发射激光器的输出功率. 采用开环分布孔代替环形沟槽,使器件的输出功率提高了 0.34 倍. 14μm 孔径的器件输出功率超过 10mW,工作电流为 29.6mA 时,最大输出功率达到 12.48mW. 而且,这些开环分布孔为电注入提供了便捷的桥通道,很好地解决了电极易过沟断线问题. 器件表现了良好的高温工作特性,当温度高达 60 ℃时输出功率仍可达到 8mW.

关键词: 外延生长; 激光二极管; 量子阱激光器; 半导体激光器; 垂直腔面发射激光器

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