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980nm Oxide-Confined Vertical Cavity Surface Emitting Laser*

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Abstract: Top-emitting oxide-confined intra-cavity contact structure 980nm VCSEL is fabricated by low-pressure metal organic chemical-vapor deposition (LP-MOCVD). Self-aligning etching process and selective oxidation are applied for current confinement. Output light power of 10.1mW and slope efficiency of 0.462mW/mA are obtained under room temperature, pulse operation, and injection current of 28mA. The maximum light power is 13.1mW under pulse operation. Output light power of 7.1mW, lasing wavelength of 974nm, and FWHM of 0.6nm are obtained under CW condition. The study of oxide-aperture influence on threshold current and differential resistance shows that lower threshold current can be obtained with a smaller oxide-aperture diameter.

Key words: VCSEL; oxide-aperture; self-aligning process

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1 Introduction

Vertical-cavity surface-emitting laser (VCSEL) is becoming a key device for optical interconnects, computing, and parallel processing for optical communication[1] due to the great potential advantages over edge-emitting laser (EEL), such as the possibility of large two-dimensional (2D) laser arrays, circular beam with low divergence, efficient coupling into optical fibers, single mode operation, and less expensive manufacturing. For last a few years, the oxide-confined VCSEL realizes low threshold[2,3] and high efficiency operation[4,5] owing to its unique confinement scheme, both of the electrical current and optical field. However, there are still issues of control of oxidation rate. Many factors, such as the $Al_xGa_{1-x}As$ layer thickness, composition, N_2 and temperature distribution of the oxidation furnace, etc., can significantly affect the oxidation rate of the oxide layer. And the final aperture size of the device seems to be the intrinsic property of the oxide-confined VCSEL. Moreover, low threshold current requires smaller oxide-aperture. On the other hand, when the aperture size is shorter than 3μm, the carrier diffusion out of the active layer and the scattering loss at the edge of dielectric aperture become non-negligible[6,7]. This will lead to a raised resistance and degradation of temperature characteristics.

In this paper, we report characteristics of top-emitting oxide-confined 980nm using intra-cavity contact structure VCSEL with three $In_{0.2}Ga_{0.8}As$/GaAs quantum wells. The influence of oxide-aper-

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ture size on threshold current and differential resistance is studied.

2 Device structure and process

VCSEL epi-structure used in this work was grown by low-pressure EMCORE D125 metal organic chemical-vapor deposition (MOCVD) on (100) n-type GaAs substrate misoriented 2° toward the {11⟩ A. The source materials used were trimethylaluminium (TMAl), trimethylgallium (TMGa), trimethylindium (TMIn), and arsine (AsH_3). Dopants for n-type and p-type materials were obtained from silane (SiH_4), disilane (Si_2H_6), and carbon tetrachloride (CCl_4), respectively. The alkyl and doping precursors were mixed in an injection block and carried by high-purity H_2 gas to the vertical growth reactor. The growth temperature, V/III ratio, and growth rate were 680~ 720℃, 100 ~ 200, and 2~ 4μm/h, respectively. The reflectance wavelengths of top and bottom DBR mirrors, the cavity resonance wavelength and the laser gain spectrum must all be aligned to a specific wavelength regime for optimum VCSEL performance by accurate controll of the thickness and composition of numerous layers.

Figure 1 shows a schematic cross-sectional view of the investigated top-emitting oxide-confined VCSEL structure. It began with 26 pairs of $Al_{0.9}Ga_{0.1}As$/GaAs bottom DBR following GaAs buffer layers. The active region consists of 3 pairs of 8nm-$In_{0.2}Ga_{0.8}As$/10nm-GaAs quantum well surrounded by AlGaAs space layer to form a 1-λ optical cavity. Three QWs were designed to be placed at standing wave peak. An 81nm thick $Al_{0.98}Ga_{0.02}As$ layer for oxidation confinement was introduced above the active cavity. Next λ/4 thick p^+ GaAs was used as Ohmic contact layer. Finally 22 pairs of undoped $Al_{0.9}Ga_{0.1}As$/ GaAs were used as top DBR.

The main processes of VCSEL devices were as following. First, epitaxial wafer was etched to form two coaxial cylindrical mesas and simultaneously

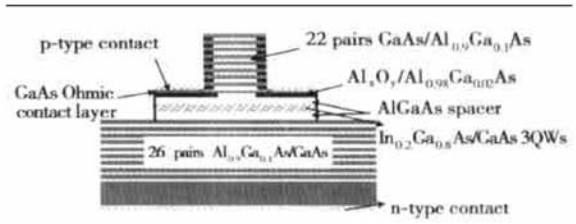

Fig. 1　Schematic cross section of oxide-confined VCSEL

exposed $Al_{0.98}Ga_{0.02}As$ layer by photolithographic techniques in combination with chemical wet etching and drying etching. Then, wet oxidation of $Al_{0.98}Ga_{0.02}As$ layer was performed in 432℃ oxide furnace with 95℃ H_2O bubbled through N_2. After that a thin SiO_2 passivation layer was coated on the wafer. Finally Ti/Au and AuGeNi were used for p-type and n-type contacts, respectively. We utilized three axes self-aligning process to ensure the concentricity of output light aperture, ring current implant aperture and $Al_{0.98}Ga_{0.02}As$ oxide-aperture in device fabricating.

3 Experimental results and analysis

Figure 2 shows typical reflectivity spectra of the VCSEL. The solid curve represents measured results and the dash-dotted curve represents calcu-

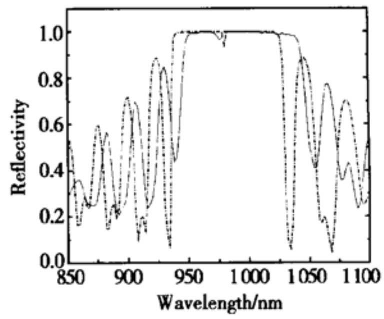

Fig. 2　Typical reflective spectra of VCSEL　Solid curve and dash dotted curve show measured and calculated result, respectively.

lated results. As can be seen from the reflectivity spectrum that a wide passband about 100nm with reflectivity of nearly 1 was obtained. The center of passband is 1000nm, which is accordant to the thickness variation of epi-layers grown by MOCVD. We found that the practical cavity resonant wavelength (976nm) has a 0.4% deviation from the design value.

Figure 3 shows the relation of oxidation length versus oxidation time at different temperature[8]. The oxidation rate shows great sensitivity to oxidation temperature. It increases with oxidation temperature. For each temperature, lateral oxidation length increases linearly with oxidation time, which indicates easy control of oxidation process. Selection of $Al_{0.98}Ga_{0.02}As$ layer not AlAs is just because it is reported that $Al_{0.98}Ga_{0.02}As$ has better mechanical stability during thermal process[9].

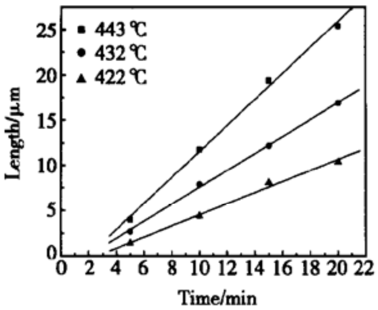

Fig. 3 $Al_{0.98}Ga_{0.02}As$ oxidation curve at different temperature

Light output power and operation voltage of VCSELs were measured using LD2002C5 laser test system. Figures 4 and 5 show the measured results.

Figure 4(a) shows a measured *P-I-V* curve under room temperature pulse operation, which pulse width is 30μs and pulse repeat rate is 100Hz. Specifications are as follows. The output light power is about 10.1mW at 28mA with threshold current of 2.5mA, threshold voltage of about 1.76V, and slope efficiency of about 0.462mW/mA. Figure 4(b) shows a slightly raised threshold current of 3.2mA measured under room temperature CW operation. This is presumed to be the result of the increased temperature in active region caused by the higher heating productivity than pulse operation. The inset shows its spectrum with a lasing wavelength of 974nm and a FWHM of 0.6nm at 20mA. The maximum power is about 7.1mW at 25mA. Compared with the former shown results, Figure 4(c) shows an obviously decreased threshold-current obtained by reducing the oxide-aperture diameter from 20μm to 8μm. This is presumably ascribed to better lateral confinement of carriers and optical fields. Whereas, the differential resistance increased drastically, up to 270.18Ω, while it is 102.22Ω for the oxide aperture of 20μm. The increased resistance will destroy the thermal property and reliability of VCSEL apparently. Consequently, it is critical to achieve a low differential resistance in the VCSEL device.

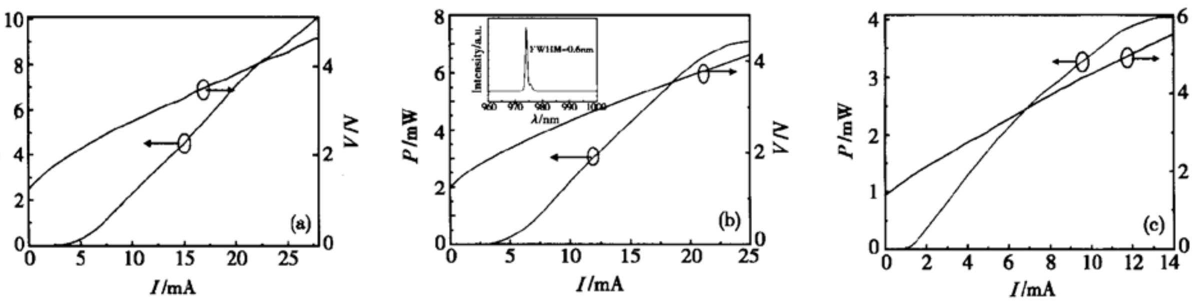

Fig.4 (a) *P-I-V* pulse operation; (b) *P-I-V* CW operation; (c) *P-I-V* CW operation

Figure 5 shows the dependence of output light power as a function of inject current for the oxide aperture diameter of 20μm. The maximum output light power is 13.1mW at 40mA under room temperature pulse operation, which pulse width is 30μs and pulse repeat rate is 100Hz.

4 Conclusion

We have presented the fabrication and experimental results of top emitting oxide-confined 980nm VCSEL. The VCSELs fabrication shows

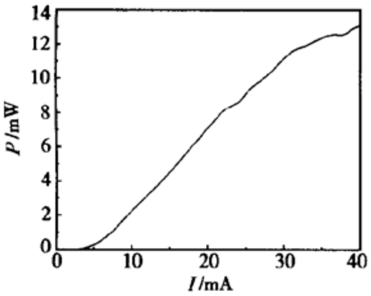

Fig. 5　P-I pulse operation

comparatively high slope efficiency, low threshold current, and high output power. Moreover, the relation of dependence of differential resistance and threshold current on oxide-aperture size is analyzed in detail.

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980nm 氧化物限制的垂直腔面发射激光器*

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摘要: 采用低压金属有机化合物气相外延(LP-MOCVD), 制备了顶端发射氧化物限制、内腔接触结构 980nm 的垂直腔面发射激光器. 应用了选择氧化和自对准工艺来实现电流限制. 在 28mA 脉冲电流驱动下, 器件的输出功率为 10.1mW, 斜率效率为 0.462mW/mA. 脉冲工作下, 最高输出功率为 13.1mW. 室温连续工作下, 输出功率为 7.1mW, 发射波长为 974nm, 光谱半宽为 0.6nm. 研究了氧化孔径对阈值电流和微分电阻的影响, 结果表明较小的氧化孔径可以获得低的阈值电流.

关键词: 垂直腔面发射激光器; 氧化孔径; 自对准工艺

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