A 1.3μm Low-Threshold Edge-Emitting Laser with AlInAs-Oxide Confinement Layers*

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Abstract: A 1.3μm low-threshold edge-emitting AlGaInAs multiple-quantum-well (MQW) laser with AlInAs-oxide confinement layers is fabricated. The Al-contained waveguide layers upper and low the active layers are oxidized as current-confined layers using wet-oxidation technique. This structure provides excellent current and optical confinement, resulting in 12.9mA of a low continuous wave threshold current and 0.47W/A of a high slope efficiency of per facet at room temperature for a 5-μm-wide current aperture. Compared with the ridge waveguide laser with the same-width ridge, the threshold current of the AlInAs-oxide confinement laser has decreased by 31.7% and the slope efficiency has increased a little. Both low threshold and high slope efficiency indicate that lateral current confinement can be realized by oxidizing AlInAs waveguide layers. The full width of half maximum angles of the Al-InAs-oxide confinement laser are 21.6° for the horizontal and 36.1° for the vertical, which demonstrate the ability of the AlInAs oxide in preventing the optical field from spreading laterally.

Key words: AlInAs-oxide confinement; RWG; edge emitting; laser

EEACC: 4320J

CLC number: TN248.4 **Document code:** A **Article ID:** 0253-4177(2004)06-0620-06

1 Introduction

The long-wavelength semiconductor lasers emitting at 1.3μm are very attractive for access networks and optical interconnects. They are required to meet several demands including super-performance, long-term reliability, low cost, and so on. Especially, the temperature characteristic of GaInAsP semiconductor lasers is poor due to the Auger recombination current and the thermal leakage current[1]. As for active layers, there are some materials investigated for an emission wavelength at 1.3μm, and some of them are reported on super performance[2~4]. As a promising one among them, AlGaInAs strained MQW lasers are developed. AlGaInAs MQW lasers have a large ΔE_c of conduction band offset, which can efficiently suppress the carriers' thermal leakage. So low threshold current, high efficiency, and high characteristic temperature can be obtained.

On the other hand, conventionally there are mainly two types of structures used in edge-emitting lasers to prevent the lateral current from spreading, that is the ridge

* Project supported by National Natural Science Foundation of China (No. 90101023)

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Received 27 October 2003, revised manuscript received 16 January 2004

waveguide (RWG) structure and the buried heterostructure (BH). The RWG lasers' processes are simple but their threshold currents are high due to the poor lateral current confinement. The BH lasers are widely used as the long-wavelength optical sources to meet the requirement of stable transverse mode beam, low threshold current, and so on. However, the fabrication process of the BH lasers is very complicated because one or more regrowth steps and precise control of the active width as narrow as approximately 1.5μm are needed. Except for that, there is a serious oxidation problem for the Al-contained active layers when they were etched to be a reverse mesa before the buried process.

Recently, there has been great interest in applying a buried layer of native oxide to optoelectronic devices because of the native oxide's insulation and low refractive index. The native-oxide of Al-contained III-V alloys provides both electronic and optical confinement making it possible to fabricate low threshold, high efficiency lasers. In addition, it simplifies the process of the laser fabrication. For vertical-cavity surface-emitting lasers (VCSELs), the native-oxide of AlAs has been employed in DBR structures[5], or in current constriction[6~8]. For edge-emitting lasers, as for GaAs-based devices, the native-oxide of AlAs has been utilized to fabricate stripe-geometry lasers[9] and index-guided lasers[10]. With InP-based long-wavelength edge-emitting lasers, structures with an inner AlAs or AlInAs oxide layer as current confinement have been reported[11,12]. In the edge-emitting lasers, the Al-contained layers are inserted into the upper cladding layer or the lower cladding layer or both, located away from the active layers for preventing the degradation of the active region.

In this paper, we report a 1.3μm low-threshold edge-emitting AlGaInAs MQW laser with Al-InAs-oxide confinement layers. It is different from the structures reported before; we made the Al-InAs waveguide layers oxidized for the current and optical confinement directly. This work is very challenging and seems to be very attractive because of its simpler structure. The AlInAs-oxide confinement laser had obtained 12.9mA of a low continuous wave (CW) threshold current, 0.47W/A of a high slope efficiency per facet, 21.6° of a horizontal far-field FWHM angle, and 36.1° of a vertical far-field FWHM angle at room temperature for a 5-μm-wide current aperture. Compared with the RWG laser, the AlInAs-oxide confinement laser had much lower threshold current, increased slope efficiency, and a relative large horizontal far-field FWHM angle. All these characteristics demonstrated that the AlInAs-oxide can provide excellent lateral current confinement and optical field confinement.

2 Device design and fabrication

Figure 1 shows a schematic diagram of the AlInAs-oxide confinement laser. All the hetero-structure layers were grown by low-pressure metalorganic vapor phase epitaxy on an InP substrate. The active region included six AlGaInAs quantum-well layers and was sandwiched by a pair of 100-nm-thick $In_{0.47}Al_{0.53}As$ waveguide layers. A pair of 1.5-μm-thick InP cladding layers was located on and below the active region. A 50-nm-thick $Ga_{0.1}In_{0.85}As_{0.05}P$ etch-stop layer was inserted in the p-InP cladding layer and 100nm away from the active region to facilitate the RWG structure fabrication. A 50-nm-thick p^+-$Ga_{0.18}In_{0.71}As_{0.11}P$ barrier reduction layer was grown at the top of the upper p-InP cladding layer followed by a 100nm $In_{0.53}Ga_{0.47}As$ cap layer.

After growth, a layer of 150nm SiO_2 was deposited on the crystal surface. The SiO_2 layer was then patterned into 20-μm-wide stripes using standard photolithographic techniques. These SiO_2 stripes served as etching mask for wet-chemical etching to define the mesa by etching away the InGaAs cap layer, the GaInAsP barrier reduction layer, the 1.5-μm-thick p-InP cladding layer, the GaInAsP etch-st op layer, the active region and part of the n-InP cladding

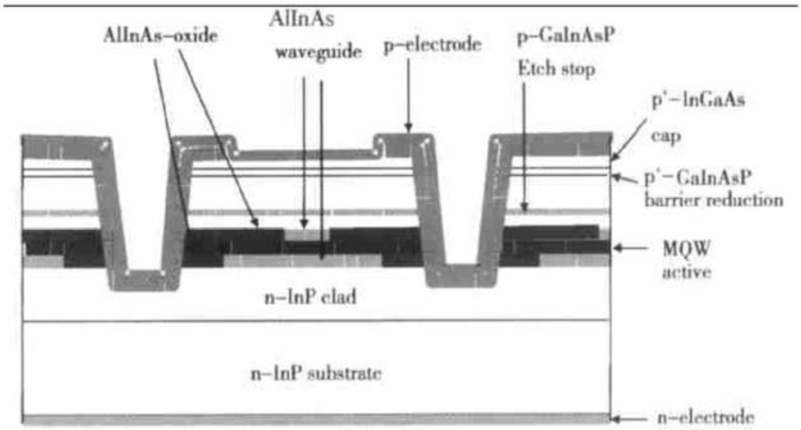

Fig. 1 Schematic diagram of the AlInAs-oxide confinement laser

layer. Then the edges of the upper and lower 100-nm-thick $Al_{0.53}In_{0.47}As$ waveguide layers were exposed. The wafer was then immediately placed in an oxidation furnace at 520℃ supplied with pure nitrogen flow bubbled through water at 90℃. The oxidation rate was around 0.06~0.09μm/min. After about 90min, the nitrogen carrying saturated H_2O vapor was stopped, and the wafer was annealed in dry N_2 for about 30min. The oxidized wafers were covered with 350nm SiO_2 film, and the contact window was opened by CF_4 dry etching. The wafers were lapped and polished for about 100μm of thickness. The samples were then metallized with Ti/Pt/Au for p contact and Au/Ge/Ni for n contact and then alloyed. Finally, the lasers were cleaved, sawed, and mounted on the In-coated copper heat sinks (p side up) for device characterization.

For comparison, a RWG laser with the same wafer and same wide ridge as that of the AlInAs-oxide confinement laser's current apertureis was fabricted. But there was a difference from the Al-InAs-oxide confinement laser like that, the ridge mesa of RWG was etched down to GaInAsP etched stop layer only.

3 Results and discussion

Figures 2 and 3 show separately the typical spectra of the AlInAs-oxide confinement laser and the RWG laser. It can be seen that no evidential shift of emission wavelength is introduced due to the oxidizing of the AlInAs waveguide layer. Both of two types of lasers obtained 1.3μm emission wavelength, and their emission intensities were of no evidential difference too. There is no evidence

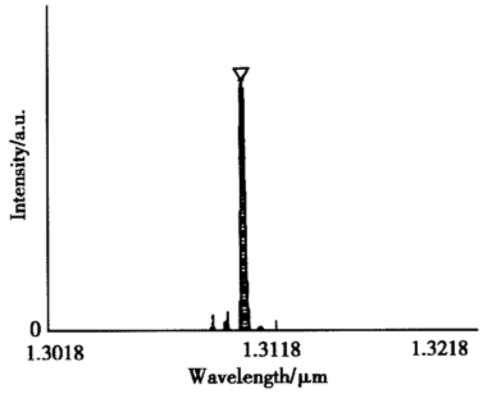

Fig. 2 Lasing optical spectrum from RWG laser at 38mA driving current

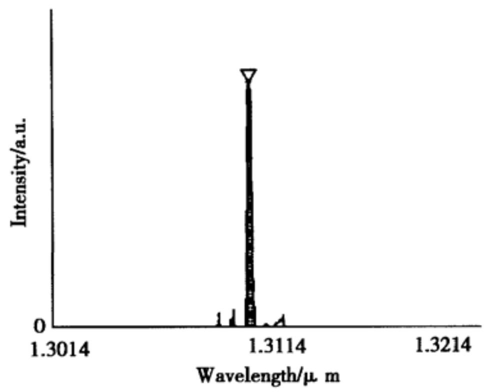

Fig. 3 Lasing optical spectrum from AlInAs-oxide confinement laser at 38mA driving current

that can indicate any influence of oxidizing the Al-InAs waveguide layers for the microstructure of the quantum wells in the active layers. But this issue needs to be further discussed by investigating other facts.

The typical light output power versus current (P-I) characteristics of 300-μm-long AlInAs-oxide confinement lasers and 300-μm-long ridge wave-guide lasers under CW operation are shown in Fig. 4. The AlInAs-oxide confinement laser diode has 12.9mA of a threshold current and 0.47W/A of a slope efficiency per facet, while the RWG laser diode has 18.9mA of a threshold current and 0.45W/A of a slope efficiency per facet. The threshold current of the AlInAs-oxide confinement laser diode is decreased by 31.7% and the slope efficiency is increased a little compare with those of the RWG laser diode. These data show that the AlInAs-oxide in the AlInAs-oxide confinement laser had indeed provided a good confinement for the lateral current expanding in the active region. Lower threshold current and higher slope efficiency of the AlInAs-oxide confinement laser diode would be obtained if high-reflection (HR) facet coatings were used.

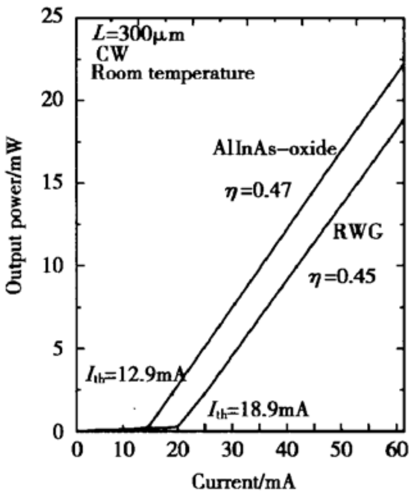

Fig. 4　Room temperature CW light output power versus injection current (L-I) characteristics of the AlInAs-oxide laser and the RWG laser

Figures 5 and 6 show the far-field patterns of the RWG laser and the AlInAs-oxide confinement laser. All diodes were measured under 40mA direct current (DC) driving current at room temperature. The FWHM angles of the AlInAs-oxide confinement laser are 21.6° for horizontal and 36.1° for vertical. And the FWHM angles of the

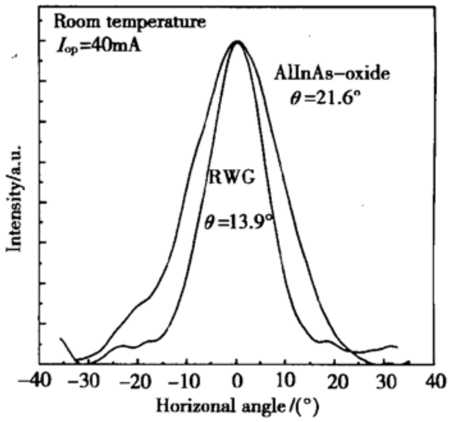

Fig. 5　Far field patterns of AlInAs-oxide laser and RWG laser in horizonal direction

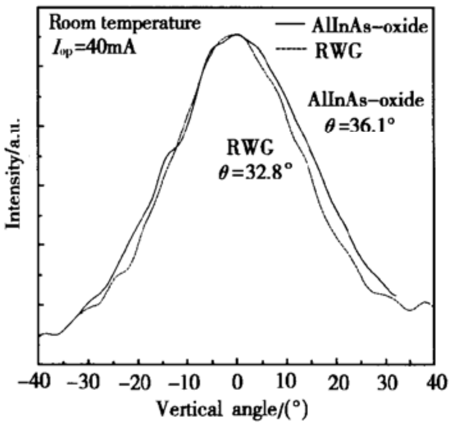

Fig. 6　Far field patterns of AlInAs-oxide laser and RWG laser in vertical direction

RWG laser are 13.9° for horizontal and 32.8° for vertical. The larger difference of the parallel far field to the junction plane of them demonstrates that there is a different lateral optical field confinement between the AlInAs-oxide structure and the RWG structure. The refractive index of AlInAs is about 3.23, while the one of AlInAs-oxide is about 2.51 for 1310nm light wave[13]. And the difference between the refractive index of the oxidized AlInAs waveguide and that of the unoxidized AlInAs waveguide poses the different effective refractive index in the active region. So, a lateral effective index step is formed in the active region. Together with the large lateral index step in the waveguide, the AlInAs-oxide confinement structure provides a stronger confinement for the lateral optical field than the RWG structure. Therefore, the AlInAs-oxide confinement laser has a larger far-field FWHM angle in horizontal direction. On the other hand, there is no any change in the active layers and the waveguide layers vertical to the junction plane for both structure, so the vertical far-field FWHM angle of the AlInAs-oxide confinement laser is not evidently different from that of the RWG laser.

4 Conclusion

A 1.3μm low-threshold edge-emitting AlGaInAs MQW laser with AlInAs-oxide confinement layers has been fabricated. The Al-contained up and low waveguide layers have been oxidized as current-confined layers to confine the lateral current and the lateral optical field. The threshold current of the AlInAs-oxide confinement laser has been decreased by 31.7% compared with the RWG laser and the slope efficiency has been increased a little. The FWHM angles of the AlInAs-oxide confinement laser are 21.6° for the horizontal and 36.1° for vertical. The low threshold current, high slope efficiency, and large horizontal far-field FWHM angle indicate that the lateral current and optical confinement could be realized by oxidizing AlInAs waveguide layers. Supper performance would be obtained with the structure and the fabrication processes would be optimized.

Acknowledgement The authors would like to thank Qiu Weibin, Hu Xiaohua, Kan Qiang, Zhang Jing, Zhang Ruiying, Li Baoxia, Xu Yao etc. for their valuable discussions, Tian Huiliang, Shu Huiyun, Wang Baojun, Bian Jing, An Xin, Cai Shiwei etc. for their enthusiastic support.

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AlInAs 氧化物限制 1.3μm 低阈值边发射激光器*

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摘要: 研究制作了一种利用 AlInAs 氧化物作为限制的 1.3μm 边发射 AlGaInAs 多量子阱激光器. 有源层上方和下方的 AlInAs 波导层被氧化作为电流限制层. 这种结构提供了良好的侧向电流限制和光场限制. 当电流通道为 5μm 宽时, 获得了 12.9mA 的阈值电流和 0.47W/A 的斜率效率. 与具有相同宽度的脊条的脊波导结构的激光器相比, 这种 AlInAs 氧化物限制的激光器的阈值电流降低了 31.7%, 斜率效率稍微有所提高. 低阈值和高效率的特性表明, 氧化 AlInAs 波导层能够提供良好的侧向电流限制. 这种 AlInAs 氧化物限制的激光器垂直方向的远场半高全宽角为 36.1°, 而水平方向的是 21.6°, 表明 AlInAs 氧化物对侧向光场也有很强的限制能力.

关键词: AlInAs 氧化物限制; 脊波导; 边发射; 激光器

EEACC: 4320J

中图分类号: TN248.4 **文献标识码**: A **文章编号**: 0253-4177(2004)06-0620-06

* 国家自然科学基金资助项目(批准号: 90101023)

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2003-10-27 收到, 2004-01-16 定稿