第 25 卷第 9 期 半 导 体 学 报 Vol. 25, No. 9
2004 年 9 月 CHINESE JOURNAL OF SEMICONDUCTORS Sep., 2004

High-Power and High-Efficiency 650nm-Band AlGaInP Visible Laser Diodes Fabricated by Ion Beam Etching*

Xu Yun[1], Cao Qing[1,2], Sun Yongwei[1], Ye Xiaojun[1], Hou Shihua[1], Guo Liang[1,2] and Chen Lianghui[1]

(1 *Institute of Semiconductors, The Chinese Academy of Sciences, Beijing* 100083, *China*)
(2 *E-O National Co., Ltd, Huizhou* 516023, *China*)

Abstract: High power and high-slope efficiency 650nm band real-refractive-index ridge waveguide AlGaInP laser diodes with compressive strained MQW active layer are formed by pure Ar ion beam etching process. Symmetric laser mesas with high perpendicularity, which are impossible to obtain by traditional wet etching method due to the use of a 15°-misoriented substrate, are obtained by this dry etching method. Laser diodes with 4μm wide, 600μm long and 10%/90% coat are fabricated. The typical threshold current of these devices is 46mA at room temperature, and a stable fundamental-mode operation over 40mW is obtained. Very high slope efficiency of 1.4W/A at 10mW and 1.1W/A at 40mW are realized.

Key words: AlGaInP visible lasers; Ar ion beam dry etching
PACC: 7340L; 4255P; 8160C
CLC number: TN248.4 **Document code**: A **Article ID**: 0253-4177(2004)09-1079-05

1 Introduction

A high-power (> 30mW continuous wave (CW)) and highly reliable laser diode lasing at a wavelength of 630~660nm has been demanded as a light source for recordable DVD systems such as DVD-RAM (random access memory), DVD-R (recordable) and so forth. Usually AlGaInP visible light laser diode oscillating in the 650nm wavelength is used for above purpose. Since the first room-temperature continuous-wave operation of AlGaInP laser diode was achieved in 1985[1], much effort has been devoted to improving the laser performance such as high power and high efficiency[2,3].

In recent years, misoriented substrates have been widely used in the fabrication of AlGaInP laser diodes in order to suppress the spontaneous ordering in group Ⅲ sublattices, consequently increasing the bandgap energy of GaInP and AlGaInP[4~6], and to increase the p-type doping level in the cladding layer[5,7]. However, the misoriented substrates usually result in an asymmetric mesa stripe when the traditional wet etching method is used in laser fabrication. Consequently, it is difficult to get high performance operation due to the degradation of the transverse mode stability, especially in high-power and high-temperature operation. Therefore dry etching method, with anisotropic etching characteristic, has been usually adopted for getting symmetrical and vertical mesa when us-

* Project supported by National High Technology Research and Development Program of China (No. 2002AA313050)

Xu Yun female, was born in 1974. PhD candidate. She is engaged in the research of quantum well intermixing technology and the fabrication of high power AlGaInP quantum well laser diodes.

Received 29 October 2003, revised manuscript received 11 May 2004

ing misoriented substrates[3,8].

In China, extra brightness AlGaInP LED was first realized in 1998[9] and the output parameters were greatly improved in 2002[10]. For the AlGaInP LD, it was first fabricated by our group in 1997 using traditional wet etching method and the RT CW output power was higher than 5mW and the slope efficiency was 0.15~0.7W/A, with a maximum output power of 22mW[11]. In this paper, we report the successful fabrication of 650nm-band AlGaInP laser diodes with real-refractive-index ridge waveguide structure, by using of the dry etching process. A maximum output power of about 43mW and high slope efficiencies of 1.4W/A at 10mW and 1.1W/A at 40mW are realized. This is the best result reported for AlGaInP laser diodes in China.

2 Experiment

Figure 1 shows the schematic structure of the compressive strained AlGaInP laser diodes with a ridge waveguide. The epitaxial growth of the laser was carried out by one-step MOCVD using a 15°-misoriented substrate: a Si-doped n-GaAs buffer layer, a 1.1μm-thick Si-doped n-$(Al_{0.9}Ga_{0.1})_{0.5}In_{0.5}P$ cladding layer, the undoped compressive

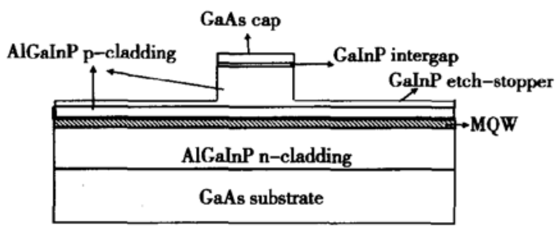

Fig. 1 Schematic structure of the compressive strained AlGaInP LD

strained MQW active layer, a 0.3μm-thick Zn-doped p-$(Al_{0.9}Ga_{0.1})_{0.5}In_{0.5}P$ cladding layer, a Zn-doped p-$Ga_{0.5}In_{0.5}P$ etching-stopper layer, a 0.95μm-thick Zn-doped p-$(Al_{0.9}Ga_{0.1})_{0.5}In_{0.5}P$ cladding layer, a 0.08μm-thick Zn-doped p-$Ga_{0.5}In_{0.5}P$ intergap layer, and a 0.5μm-thick Zn-doped p-GaAs cap layer.

For dry etching, LKJ-100 ion beam system was employed. In the whole dry etching process, only Ar plasma gas was involved as the working substance, and the poisonous chlorine-based dry etching, which usually used for III-V compounds[3,8], was avoided in this experiment for environment reason. The working pressure was about 2×10^{-2}Pa, and the Ar ion beam was extracted and accelerated to 300eV with a beam flux density of 0.3mA/cm^2 before it arrived to the epilayer. The average velocity of etching was about 17.3nm/min and the dry etching process was carried out at a temperature below 10℃. The etching mask was 3.2-μm-thick photoresist and the resist was photolithographically patterned prior to the dry etching.

A 4μm-wide ridge stripe was formed by the dry etching method described above. After dry etching, traditional wet etching method was combined to further etch the epilayer down to the etch-stopper layer and at the same time, remove the dry-etching damage to the layer surface made by the ion beam.

Ohmic contacts were formed with Ti/Pt/Au for the p side and AuGeNi/Au for the n side. The cavity length was 600μm, and the reflectivity of the front and rear facets was 10% and 90%, respectively. The laser chip was mounted on Si heat sink in a p side down configuration.

3 Results

Figure 2(a) shows the cross-sectional scanning electron microscope (SEM) image of dry-etched epilayer. For comparison, Figure 2(b) is the SEM image of the same layer etched by traditional wet-etched method, and the topmost layer is the p-electrode. The substrate in both cases was 15°-misoriented and the epitaxial layer structure was also the same. Both of the etch depth was about 1.3μm. It can be seen that the dry etching method can result in etched anisotropical profile with high perpendicularity on the two sides of the ridge. By contrast, the wet-etched mesa stripe is obviously asymmetric due to the misoriented substrate. In addition, a smooth and no roughness surface and sufficient uniformity for the whole epilayer were observed in the dry etching process (not shown in this Figure). Furthermore, another advantage of the dry etching method is its accurate controllability of etching depth because the etching rate can be examined when the energy and beam flux density are fixed.

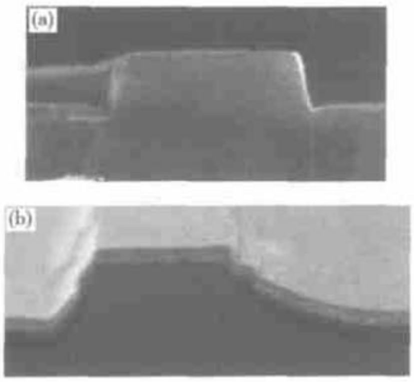

Fig. 2　SEM images of dry-etched (a) and traditional wet-etched epilayer (b) using the same substrate with the same etching depth

Figure 3 shows the CW light output power versus current (*P-I*) characteristics of the laser diodes at room temperature. The threshold current was 47mA, and the operating currents at 10mW/40mW were 55mA/82mA, respectively. Very high slope efficiency of 1.4W/A at 10mW was realized, and even at 40mW the slope efficiency can be reached to 1.1W/A, compared with the same batch of laser diodes fabricated by traditional wet etching method, for which the slope efficiency was 0.8W/A at 10mW and the maximum output power was 30mW.

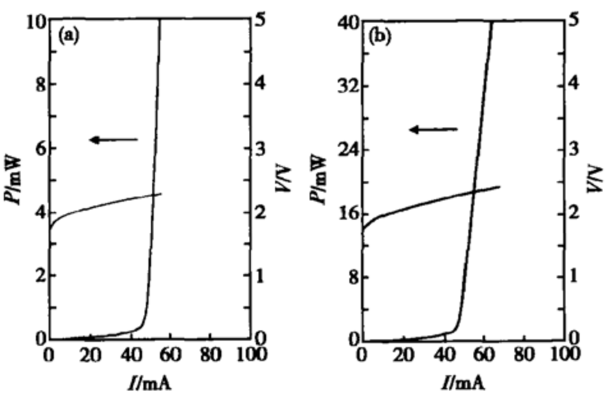

Fig. 3　Typical RT CW *P-I* characteristics　(a) 10mW; (b) 40mW

The far-field pattern at 40mW is shown in Fig. 4. There was no steering in the horizontal far field distribution up to 40mW, indicating truly single lateral mode operation. The full angles at half maximum power perpendicular ($\theta_{\perp}$) and parallel ($\theta_{\parallel}$) to the junction plane were 23° and 4.2°, respectively. The lasing wavelength of 40mW output CW operation at RT was 656.2nm as shown in Fig. 5.

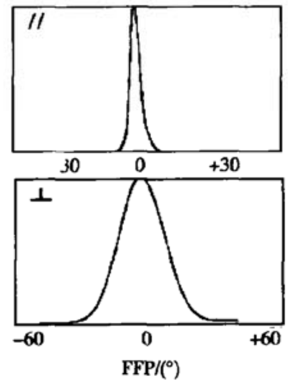

Fig. 4　Far-field pattern at 40mW

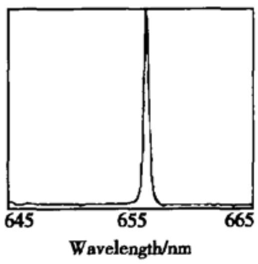

Fig. 5　Spectrum at 40mW

The highest output power of the fabricated laser diodes were about 43mW, higher than that of the laser diodes failed abruptly due to the COD (catastrophic optical damage). The aging test was carried out with a 10mW output at 70℃ and no obvious degradation of the LD was observed, indicative of the reliability and safety of the dry etching method in the AlGaInP LD formation.

4 Conclusion

In this paper, by using pure Ar ion beam dry-etching method, 4μm-wide, 600μm-long AlGaInP laser diodes lasing at 655nm with real refractive index ridge waveguide were fabricated. A smooth and no roughness surface, and etched anisotropical profile with high perpendicularity on two sides of the ridge can be obtained. As a result, the fabricated AlGaInP laser diodes have very high slope efficiency and stable mode operation as high as 40mW. The obtained slope efficiency is 1.4W/A at 10mW, and even at 40mW the slope efficiency can be reached to 1.1W/A, which is much higher than that of the laser diodes made by traditional wet etching method. The highest output power is about 43mW, higher than that of the laser diodes failed abruptly due to the COD (catastrophic optical damage).

Acknowledgements The authors would like to thank Hi-Tech Optoelectronics Company for providing the epitaxial layers, and the Beijing Institute of Advanced Ion Beam Technology for using their ion beam equipment.

References

[1] Kobayashi K, Kawata S, Gomyo A, et al. Room-temperature CW operation of AlGaInP double-heterostrucutre visible lasers. Electron Lett, 1985, 21: 93

[2] Shima A, Ono K, Yagi T, et al. Low-operating-current, high-power, 660nm laser diodes for DVD-RAM. Tech Dig Fifth Optoelectronics and Communications Conference (OECC), 2000: 534

[3] Isao K, Hideto A, Kiyotake T, et al. High-power 650-nm-band AlGaInP visible laser diodes fabricated by reactive ion beam etching using Cl_2/N_2 mixture. Jpn J Appl Phys, 1997, 36: 1892

[4] Tanaka T, Minagawa S, Kawano T, et al. Lasing wavelengths of Index-guided AlGaInP semiconductor lasers as functions of off-angle from (100) plane of GaAs substrate. Electron Lett, 1989, 25: 905

[5] Hamada H, Shono M, Honda S, et al. AlGaInP visible laser diodes grown on misoriented substrate. IEEE J Quantum Electron, 1991, QE-27: 1483

[6] Gomyo A, Suzuki T, Kobayashi K, et al. Effects of GaAs-substrate surface misorientation from (001) on band-gap energy in $Ga_{0.5}In_{0.5}P$. NEC Res Dev, 1994, 35: 134

[7] Minagawa S, Kondow M. Zinc-doping of (511) A layers of $(Al_{0.6}Ga_{0.4})_{0.5}In_{0.5}P$ grown by atmospheric metalorganic vapor phase epitaxy. Electron Lett, 1989, 25: 413

[8] Takashi Y, Yoshimasa S, Hitoshi H, et al. 650nm AlGaInP visible light laser diode with dry-etched mesa stripe. Jpn J Appl Phys, 1995, 34: 1273

[9] Wang Guohong, Ma Xiaoyu, Cao Qing, et al. High brightness orange AlGaInP LED fabricated by LP-MOCVD. Chinese Journal of Semiconductors, 1998, 19(9): 712(in Chinese) [王国宏, 马骁宇, 曹青, 等. LP-MOCVD 制备 AlGaInP 高亮度橙黄色发光二极管. 半导体学报, 1998, 19(9): 712]

[10] Wang Guohong, Shen Guangdi, Guo Xia, et al. Tunnel junction AlGaInP light emitting diode. Chinese Journal of Semiconductors, 2002, 23(6): 628

[11] Xiong Feike, Guo Liang, Ma Xiaoyu, et al. High performance GaInP-AlGaInP visible semiconductor laser diodes. Chinese Journal of Semiconductors, 1997, 18(6): 424(in Chinese) [熊飞克, 郭良, 马骁宇, 等. 高性能实用化 GaInP-AlGaInP 半导体量子阱可见光激光器. 半导体学报, 1997, 18(6): 424]

离子束刻蚀法制备大功率高效率 650nm AlGaInP 可见光激光器*

徐　云[1]　曹　青[1,2]　孙永伟[1]　叶晓军[1]　侯识华[1]　郭　良[1,2]　陈良惠[1]

(1 中国科学院半导体研究所, 北京　100083)
(2 惠州市中科光电有限公司, 惠州　516023)

摘要: 用纯 Ar 离子束刻蚀方法制备出大功率高效率 650nm 实折射率 AlGaInP 压应变量子阱激光器. 对偏角衬底, 干法刻蚀可得到湿法腐蚀不能得到的高垂直度和对称台面. 制备的激光器条宽腔长分别为 4μm 和 600μm, 前后端面镀膜条件为 10%/90%. 室温下阈值电流的典型值为 46mA, 输出功率为 40mW 时仍可保持基横模. 10mW, 40mW 时的斜率效率分别为 1.4W/A 和 1.1W/A.

关键词: AlGaInP 可见光激光器; Ar 离子束干法刻蚀
PACC: 7340L; 4255P; 8160C
中图分类号: TN248.4　　**文献标识码**: A　　**文章编号**: 0253-4177(2004)09-1079-05

* 国家高技术研究发展计划资助项目(批准号: 2002AA313050)

徐　云　女, 1974 年出生, 博士研究生, 从事量子阱混合技术及大功率 AlGaInP 量子阱激光器的研制.

2003-10-29 收到, 2004-05-11 定稿　