Wavelength Tuning in Two-Section Distributed Bragg Reflector Laser by Selective Intermixing of InGaAsP-InGaAsP Quantum Well Structure*

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Abstract: The two-section tunable ridge waveguide distributed Bragg reflector (DBR) laser fabricated by the selective intermixing of an InGaAsP-InGaAsP quantum well structure is presented. The threshold current of the laser is 51mA. The tunable range of the laser is 4.6nm, and the side mode suppression ratio (SMSR) is 40dB.

Key words: tunable laser; DBR laser; quantum well intermixing; MOCVD

EEACC: 4320J; 4270; 4130

CLC number: TN248.4　　**Document code:** A　　**Article ID:** 0253-4177(2003)09-0903-04

1 Introduction

Interdiffusion of quantum-well structures has been widely investigated for its applications in integrated photonics recently. It is a powerful technique for integrating the regions of different band gap in the same epitaxial layer. Various quantum-well intermixing (QWI) techniques have been used for GaAs- and InP-base MQW structures, such as pulsed laser irradiation, ion implantation[1], and impurity free vacancy diffusion (IFVD)[2~4]. The QWI technology consists in using the SiO_2 dielectric film over the region of sample to enhance the amount of point defects created during rapid thermal annealing (RTA). A subsequent thermal annealing step induces QWI through the diffusion of the point defects across the structure. The degree of intermixing and therefore the bandgap energy shift obtained after annealing are related with the amount of point defects created during the process of RTA. However, the Si_xN_y thin film is in another conditions. The film could suppress the point defects created during the progress RTA, so the varieties of bandgap energy are little. The diffusion rates can be controlled by the experimental conditions. The spectrum is blue-shifted when Group Ⅴ atoms are intermixed. The spectrum is red-shifted when only Group Ⅲ atoms are intermixed. In the case of the blue-shifted spectrum, we can ignore the case in which only the Group Ⅲ atoms are intermixed.

Recently, we have used a SiO_2 dielectric film on an InGaAs cap layer to promote the intermixing of a strained InGaAsP/ InGaAsP MQW structures, and used Si_xN_y thin film to suppress the QWI during the process of RTA. The properties of the MQW structures before and after intermixing were investigated

* Project supported by State Key Development Program for Basic Research of China

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Received 20 February 2003, revised manuscript received 24 April 2003　

using photoluminescence (PL). Two-section tunable distributed Bragg reflector (DBR) laser was fabricated, and the characteristics of the *P-I* curve, wavelength tuning, and side mode suppression ratio (SMSR) were measured.

2 Experiment

The InGaAsP MQW structure contains six 7nm thick 1% compressive-strain InGaAsP ($\lambda = 1.6\mu m$) wells separated by 10nm thick -0.8% tensile-strain InGaAsP ($\lambda = 1.15\mu m$) barriers. The MQW structure was sandwiched with two undoped InGaAsP ($\lambda = 1.20\mu m$) optical confined layers (OCL), and the whole wafer was covered with the 0.5μm thick InP layer and 0.25μm thick InGaAs layer. The growth temperature was 650℃ and the growth rate for InGaAsP was lower than 1.0μm/h by using LP-MOVPE. The conduction band of the wafer is shown in Fig. 1.

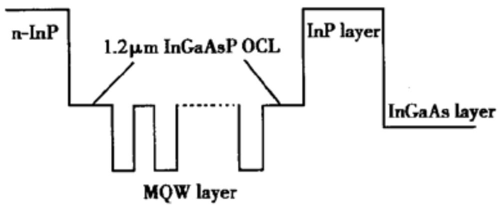

Fig. 1 Conduction band of the wafer

A 100nm Si_xN_y dielectric film was deposited on the InGaAs cap by electron cyclotron resonance (ECR), then we etched a graph on the Si_xN_y thin film as a mask, followed by a 150nm SiO_2 dielectric film deposited on the wafer by plasma-enhanced chemical vapor deposition (PECVD) to enhance the intermixing of the MQW. After deposition, we etched the SiO_2 thin film over the Si_xN_y film. The samples were heated for 80s at 750℃ in a N_2 environment. After the intermixing of MQW structure, the SiO_2 and Si_xN_y films, InP layer, and InGaAs layer were etched, a first-order distributed Bragg reflector grating was formed on the region covered with SiO_2 thin film during the process of RTA. At last, a etching stop layer, a p-InP ($N_d = 2\times10^{18}cm^{-3}$) cladding layer, and a p^+-InGaAs($N_d = 1\times10^{19}cm^{-3}$) contact layer were grown on the whole wafer. The ridge waveguide structure and the electrode process were successively performed by the standard technique. The structure of device is shown in Fig. 2.

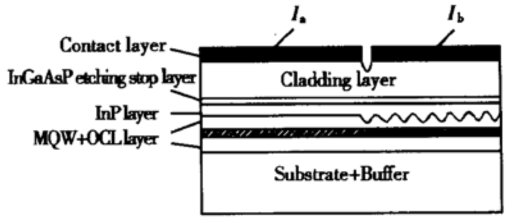

Fig. 2 Structure of two-section tunable laser fabricated by QWI

3 Results and discussion

Figure 3 shows the room-temperature PL spectra for the as-grown (dark line) and intermixed InGaAsP MQW structure after RTA covered with Si_xN_y dielectric film (dashed line), SiO_2 dielectric film (dotted line) and naked sample (dash-dotted line). The PL peak wavelength of the as-grown sample is 1.570μm.

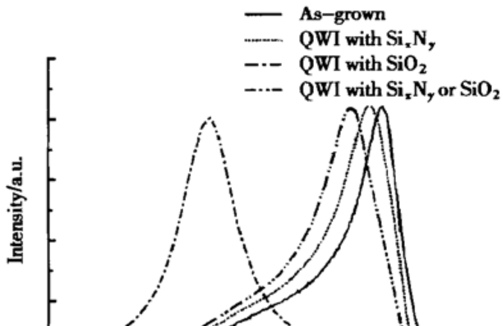

Fig. 3 Room-temperature PL spectra for the as-grown (dark line) and intermixed InGaAsP MQW structure after RTA covered with Si_xN_y dielectric film (dashed line), SiO_2 dielectric film (dotted line) and no covering (dash-dotted line)

After annealing for 80s at 750℃, the blue shift of the room-temperature PL peak wavelength for samples covered with Si_xN_y, SiO_2 and the naked sample are 5nm, 150nm, 12nm, respectively. This RTA process generates point defects at the sample surface, significantly enhancing the intermixing rate of Group III and V atoms between the interface of well/barry and thereby enabling large bandgap shift to be achieved in the InGaAsP-InGaAsP quantum well system. In this experiment, the blue shift of the excition transition energy is attributed to the interdiffusion of P into and As out of the InGaAsP quantum well. It can be seen from Fig. 3 that Si_xN_y, SiO_2 dielectric film are good for suppressing and enhancing QWI. This band-gap change is large enough for the fabrication of various photonic integrated devices which need waveguide regions or modulator.

Figure 4 displays the power-current (*P-I*) curves for a F-P laser and two DBR lasers with different length of DBR regions, which were all fabricated

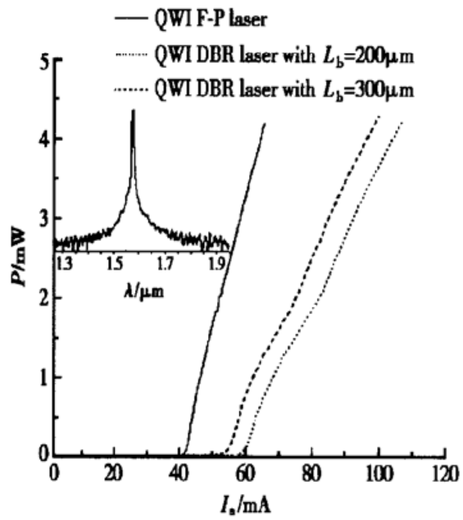

Fig. 4 Power-current curves for the intermixed samples with the same length of active region and different length of DBR region, and the F-P laser

by QWI. The three samples have the same length of active region (L_a = 300μm). And it is noticed that about 24% increase of threshold current was observed between the F-P laser (Solid line) and the DBR laser (dashed line). However, the slope efficiency shows very little change, which indicates that the material quality remains high after intermixing using this technique. The threshold current of the laser with the length of 200μm DBR (dotted line) shows about 6mA increase compared with that of the length of 300μm DBR (dashed line). The reason is that the coupling strength of 300μm DBR is stronger than that of 200μm DBR.

With the technique of QWI, the dependence of the emission wavelength on the current of DBR region is given in Fig. 5. The tuning range is about 4.6nm. The varieties of wavelength are caused by the injected electron-hole plasma effect when the current of DBR increases from 0 to 30mA. The mode jump interval is about 0.8nm. However, when the current in DBR region is more than 30mA, the further increase of the carrier density is very difficult because of Auger recombination, and the further decrease of the effective index with increased carrier density is usually overshadowed by increasing thermal index shift, which resultes in the wavelength red-shift.

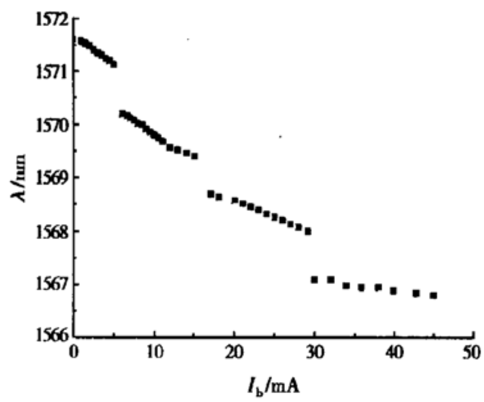

Fig. 5 Tuning characteristics of the tunable two-section DBR laser with different tuning current I_b at 80mA of active region current I_a

Figure 6 shows that the side mode suppression ratio (SMSR) is 40dB over the whole tuning range when the current of the active region is 80mA, except for the mode jump regions. This suggests that the high value of SMSR could be achieved by the technique of QWI, which is one of the most important characteristics of semiconductor laser.

4 Conclusion

In conclusion, we have applied one-step QWI process to the fabrication of two band-gap integrated

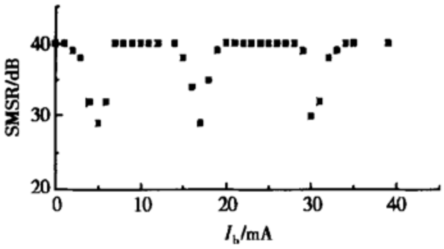

Fig. 6 SMSR curve of the DBR laser with Bragg grating current I_b

devices. A two-section wavelength tunable DBR laser has been fabricated, which indicates that the material quality remains high after intermixing. The 4.6nm tunable wavelength ranges with 40dB SMSR are realized.

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用选择混合 InGaAsP-InGaAsP 量子阱技术研制的两段波长可调谐分布布拉格反射激光器*

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摘要: 采用选择混合 InGaAsP-InGaAsP 量子阱技术, 研制出单脊波导结构的两段可调谐分布布拉格反射(DBR)激光器. 激光器的阈值电流为 51mA, 可调谐范围为 4.6nm, 边模抑制比(SMSR)为 40dB.

关键词: 可调谐激光器; DBR 激光器; QWI; 半导体激光器

EEACC: 4320J; 4270; 4130

中图分类号: TN248.4 **文献标识码**: A **文章编号**: 0253-4177(2003)09-0903-04

* 国家重点基础研究发展规划资助项目

陆 羽 博士研究生, 主要研究方向为采用 LP-MOCVD 生长 InGaAsP/InP 应变多量子阱材料和可调谐 DBR 单纵模半导体激光器光子集成电路等.

2003-02-20 收到, 2003-04-24 定稿

第24卷第9期 半 导 体 学 报 Vol. 24, No. 9
2003年9月 CHINESE JOURNAL OF SEMICONDUCTORS Sep., 2003

High Transconductance AlGaN/GaN HEMT Growth on Sapphire Substrates

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Abstract: The fabrication and characterization of AlGaN/GaN high electron mobility transistors (HEMT) grown on sapphire substrates by MBE are described. These 1.0μm gate-length devices exhibit a maximum drain current density as high as 1000mA/mm and a maximum transconductance of 198mS/mm. In sharp contrast to high current density HEMT fabricated on sapphire substrates, the extrinsic transconductance versus gate-to-source voltage profiles exhibit the broad plateaus over a large voltage swing. A unity gain cutoff frequency (f_T) of 18.7GHz and a maximum frequency of oscillation (f_{max}) of 19.1GHz are also obtained.

Key words: AlGaN/GaN; high electron mobility transistors; transconductance

PACC: 7340N

CLC number: TN325$^+$.3 **Document code:** A **Article ID:** 0253-4177(2003)09-0907-04

1 Introduction

AlGaN/GaN high electron mobility transistors (HEMT) are promising devices for high power, high temperature, and high frequency applications. This potential is due to the advantageous material properties. GaN itself possesses a wide band-gap of 3.4eV, a very high breakdown field (3MV/cm), and an extremely high peak velocity (3×10^7cm/s) and saturation velocity(1.5×10^7cm/s)[1]. In addition, AlGaN/GaN heterostructures with high conduction band offset and high piezoelectricity will result in high sheet carrier density in the $1.0\times10^{13}cm^{-2}$ range. Coupling this high sheet carrier density with the high breakdown field of GaN yields predictions of microwave power densities greater than 10W/mm at 10GHz.

In recent years, tremendous progress has been made in the material quality and device processing of GaN-based HEMTs, which has resulted in significant improvement in the DC and RF performances of these devices. MOCVD-grown 0.25μm gate-length AlGaN/GaN HEMT with drain current density as high as 1.4A/mm, transconductance of 400mS/mm, and an f_T of 85GHz and f_{max} of 151GHz has been demonstrated[2]. The best reported result of AlGaN/GaN HEMT in China was g_m of 157mS/mm, f_T of 12GHz with gate length of 0.25μm[3].

In this paper, we report MBE-grown AlGaN/GaN HEMT. A maximum extrinsic transconductance of 198mS/mm was obtained, which is the highest reported transconductance in China. These devices exhibited a maximum drain current density of 1000mA/mm, f_T and f_{max} of 18.7 and 19.1GHz, respectively. These results represent a significant improvement in the AlGaN/GaN-based HEMTs grown on sapphire substrates[4].

2 Device structure and fabrication

The schematic cross sectional structure of AlGaN/GaN HEMT is shown in Fig. 1. The het-

Received 17 March 2003, revised manuscript received 20 May 2003