Quantum Well Intermixing of InGaAsP QWs by Impurity Free Vacancy Diffusion Using SiO_2 Encapsulation

Zhang Jing, Lu Yu and Wang Wei

(Optoelectronic Research and Development Center, Institute of Semiconductors, The Chinese Academy of Sciences, Beijing 100083, China)

Abstract: Experiment on quantum well intermixing (QWI) of InGaAsP QWs by impurity free vacancy diffusion (IFVD) using SiO_2 encapsulation is reported. A maximum band gap wavelength blue-shift as large as 200nm is realized. Furthermore, an FP laser blue-shifted 21nm by QWI is fabricated with characteristics comparable with the as-grown one.

Key words: photonic integrated circuit; quantum well intermixing; IFVD; wavelength blue-shift
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1 Introduction

In order to fabricate monolithic photonic integrated circuits based on III-V component semiconductor such as InP and GaAs, sections with different band gap wavelengths need to be realized on the same epitaxy wafer. For example, four characteristic band gap wavelengths are typically required on the same wafer for the application at the C-band fiber-optic communication window: 1.55μm for gain section, 1.50μm for exciton absorption section, 1.45μm for tunable phase section, and below 1.40μm for passive waveguide section.

To fulfill such requirement, buttjoint method[1] can be used, but it must involve a serial of etching and regrowth process. Besides the cumbersome, the interface of different sections needs careful treatment to insure a high optical coupling efficiency. Selective area growth (SAG)[2] can also be used, but there is a transition area of gradual changed band gap wavelength between different sections, which typically extends several tens of microns.

Quantum well intermixing (QWI) has been proposed to overcome these difficulties. QWI involves a post-growth anneal process which induces interdiffusion of group III (e.g. Ga, In) and group V (e.g. As, P) composition species between wells and barriers. As a result of interdiffusion, the sharp potential interface between well and barrier is smoothed, the well composition (thus the band gap), the effective width of well and the height of the potential barrier height will also be changed. These will cause transition energies between confined states to be increased and band gap wavelength to be blue-shifted. In QWI, a high coupling efficiency of nearly 100% can be realized, and

Zhang Jing male, was born in 1975, PhD candidate. His research interest is in InP based photonic integrated circuits, especially by quantum well intermixing.

Lu Yu male, was born in 1974, PhD candidate. His research interest is in InP based photonic integrated circuits, especially distributed Bragg reflector (DBR) laser.

Wang Wei male, was born in 1937, professor, academician of the Chinese Academy of Sciences. His research interest is in InP based long wavelength semiconductor photonic devices.

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there is a sharp transition area of about 2~ 3μm between sections of different band gap wavelength[3].

There are several ways to realize QWI, for example, ion implantation induced disordering (IID)[4], photo-absorption induced disordering (PAID)[5], and impurity free vacancy diffusion (IFVD) induced disordering[6]. In this work, IFVD using SiO_2 encapsulation to generate diffusible vacancy during annealing has been investigated.

2 Experiment on QWI

It has been reported that if SiO_2 is deposited on Ga contained semiconductor layer (e.g. InGaAs), Ga atoms will diffuse into SiO_2 at an elevated temperature, leaving group Ⅲ vacancies in the InGaAs layer[7]. The vacancies then diffuse from the InGaAs layer to the substrate during annealing, resulting in interdiffusion of composition species between quantum well and barrier.

The quantum well structure used in our study was InGaAsP MQWs grown by low pressure MOCVD on (100) oriented n-InP substrate and consisted, from bottom to top, of a 1μm n-InP layer (Si doped: $1\times10^{18}cm^{-3}$), an undoped InGaAsP confinement layer (lattice matched, λ_g= 1.1μm), an active region made of five 6nm InGaAsP wells (strain= 0.9%, λ_g= 1.59μm) and four 10nm InGaAsP barriers (strain= −0.4%, λ_g= 1.18μm), an undoped InGaAsP confinement layer (lattice matched, λ_g = 1.1μm), a 0.4μm undoped InP layer, and a 0.2μm undoped InGaAs layer (lattice matched). The undoped InP was thick enough to prevent Si diffusion from SiO_2 into quantum wells during rapid annealing process. The whole structure is shown in Fig. 1. The as-grown MQWs have a PL peak wavelength of 1.538μm with a ±2nm non-uniformity at room temperature.

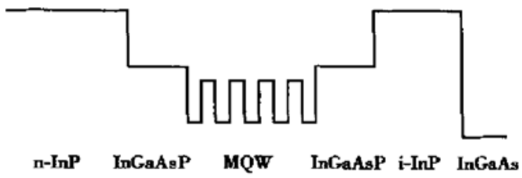

Fig. 1 Bandgap structure of the MQW structure for intermixing

First 150nm SiO_2 was deposited on the surface of the above structure by plasma-enhanced chemical vapor deposition (PECVD). The deposition was done at 300℃, with RF power of 50W, reactor pressure of 33.3Pa, and gas mass flow of SiH_4 (10sccm), N_2O (80sccm). Then the whole wafer was cleaved to small pieces of about 3mm × 3mm, and each of the small pieces was annealed in a rapid thermal annealing under N_2 gas flow. At last, PL measurement was carried out at room temperature to determine the band gap blue-shift. By varying the annealing temperature from 750℃ to 800℃ and the annealing time from 20s to 120s, we had a detailed investigation on the intermixing behavior for the multi-quantumwells structure mentioned above. The measurement results are shown as Figs. 2 and 3.

From Fig. 2 we can see that even after annealing of 40s at 775℃ (a wavelength blue-shift of 75nm), there is no significant reduction of PL intensity com-

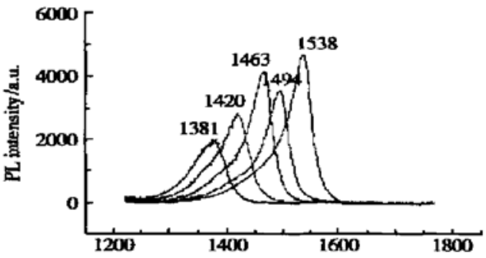

Fig. 2 PL spectra of pieces annealed at 775℃ for different time PL peak wavelength from right to left: as-grown, annealed for 20, 40, 80 and 120s

pared with the as-grown one, and the full width at half maximum (FWHM) of PL spectra (50nm) is almost the same. We can conclude that the optical property is well maintained after a modest quantum well intermixing process. The reduction of PL intensity and widening of PL FWHM for a further intermixing process (e.g. annealing longer than 80s at 775 ℃) can be explained due to the potential profile between wells and barriers smoothed enough so that quantum confinement is weaken. The maximum wavelength blue-shift of 200nm has been realized in our experiment of annealing at 800 ℃ for 120s. The wavelength blue-shift is large enough for fabricating photonic integrated circuits such as electroabsorption modulated laser (EML) and tunable DBR laser.

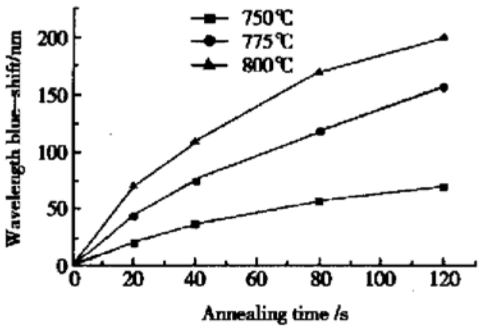

Fig. 3　PL peak wavelength blue-shift dependence on different annealing temperature and time

3　Blue-shifted FP laser fabricated by QWI

To further affirm that a modest QWI process does not deteriorate optical property of an as-grown quantum well, a blue-shifted FP laser was fabricated and compared with the as-grown one.

The quantum well structure was the same as the one used for QWI experiment. After SiO_2 was deposited using PECVD, the wafer was annealed at 750 ℃ for 20s, resulting a PL band gap blue-shift of 21nm. Then the SiO_2 layer, the upper undoped InGaAs and InP layer were removed using buffered HF, H_2SO_4+ H_2O_2+ H_2O and HCl+ H_2O respectively, and a p-InP cladding layer, a p-InGaAs contact layer were grown by LP-MOCVD. Stripes with the width of 2μm were patterned and etched along the [011] direction to form the reverse mesa ridge. After electrode fabrication, 300μm long FP lasers were cleaved and tested. In order to have a comparison, FP lasers using the as-grown quantum well structure were also fabricated. Figure 4 plots the output power versus driving current of the FP lasers using as-grown and blue-shifted quantum well respectively. And Figure 5 is their stimulated optical spectra.

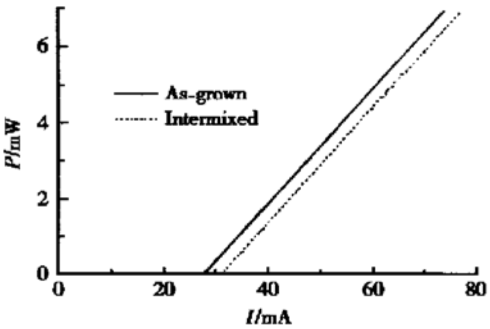

Fig. 4　*P-I* curves of FP laser fabricated by the as-grown and the intermixed (blue-shift of 21nm) MQWs

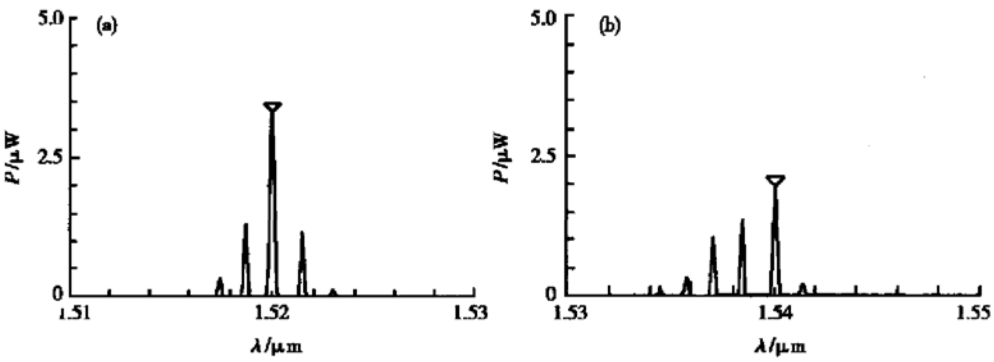

Fig. 5　Stimulated optical spectra of the intermixed laser (a) and the as-grown one (b)

The FP laser using the as-grown quantum well has a threshold current of 27mA, and the one using blue-shift quantum well has a threshold current of 30mA. The slight higher threshold can be explained due to a slight weaker quantum confinement. From Fig. 4, we can see that the differential quantum efficiencies of the two are almost the same, which confirms the well maintenance of quantum well optical property after QWI.

4 Conclusion

We report details of experiments on quntum well intermixing by IFVD using PECVD deposited SiO_2. A maximum wavelength blue-shift of 200nm has been realized. A blue-shifted laser has been fabricated with differential quantum efficiency about the same as the as-grown one. We conclude that optical property of quantum well is well maintained after a modest intermixing process. Thus quantum well intermixing using SiO_2/InGaAs interface to generate diffusible vacancy is a very promising way to fabricate photonic integrated circuits.

Further more, a DBR laser using QWI has been fabricated and will be reported elsewhere. Reliability test of the blue-shifted laser will be carried out.

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使用 SiO_2 介质膜实现 InGaAsP 量子阱混杂

张 靖 陆 羽 王 圩

(中国科学院半导体研究所 光电子研究发展中心, 北京 100083)

摘要: 报道了使用 SiO_2 介质膜导致的无杂质空位扩散实现 InGaAsP 多量子阱混杂的实验, 得到 200nm 的最大带隙波长蓝移. 另外, 采用量子阱混杂制作了蓝移的 FP 腔激光器, 其性能与未混杂的激光器相当.

关键词: 光子集成回路; 量子阱混杂; 无杂质空位扩散; 波长蓝移

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张 靖 男, 1975 年出生, 博士研究生, 主要从事 InP 基光子集成回路的研究.

陆 羽 男, 1974 年出生, 博士研究生, 主要从事 InP 基光子集成回路的研究.

王 圩 男, 1937 年出生, 中国科学院院士, 主要研究 InP 基长波长半导体光子器件.

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