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An Integratable Distributed Bragg Reflector Laser by Low-Energy Ion Implantation Induced Quantum Well Intermixing*

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Abstract: An integratable distributed Bragg reflector laser is fabricated by low-energy ion implantation induced quantum well intermixing. A 4.6nm quasi-continuous wavelength tuning range is achieved by controlling phase current and grating current simultaneously, and side mode suppression ratio maintains over 30dB throughout the tuning range except a few mode jump points.

Key words: photonic integrated circuit; distributed Bragg reflector laser; quantum well intermixing; wavelength tuning

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1 Introduction

Wavelength tunable single mode laser diodes are thought to be indispensable key components in the next generation of WDM optical communication system. They can be widely used in transmitters to ease inventory management, and at wavelength routing nodes to help realizing wavelength convert function. Monolithical integrated tunable lasers made on InP are promising in the near future. Besides their compact structure, they can be tuned fast by current injection. Furthermore, they have potential to be integrated monolithically with other InP based photonic devices such as electro-absorption modulators and wavelength converters[1,2]. The most developed tunable lasers based on InP are distributed Bragger reflector(DBR) lasers.

To achieve quasi-continuous wavelength tuning, DBR lasers should comprise one gain section, one phase tuning section, and one or more grating sections. Usually two materials with different band-gaps are required by the DBR lasers, a narrower band-gap material for the gain section while a wider for the phase tuning section and the grating sections to reduce absorption loss. Quantum well intermixing(QWI) is a way very promising to integrate different band-gap materials on the same wafer for its simplicity. Various approaches to achieve QWI have been discussed before, such as photo-absorption induced intermixing (PAID)[3], intermixing by impurity free vacancy diffusion (IFVD)[4], impurity induced disorder(IID)[5], and ion implantation induce disordering[6]. We used low-energy ion implantation to realize QWI in this work, and successfully fabricated an integratable DBR laser.

2 Structure of integratable DBR laser and process of fabrication

The schematic view of the integratable DBR is

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shown in Fig. 1. It consists of a gain section, a phase section, and two grating sections with different lengths. The longer grating has a higher power reflectivity to maintain a high SMSR while the shorter has a lower power reflectivity to form the resonant cavity and act as light output mirror. The two grating sections are connected by wire and driven by the same tuning current. When being used in photonic integrated circuits (PICs), the integratable DBR laser can achieve high output optical power and high SMSR simultaneously.

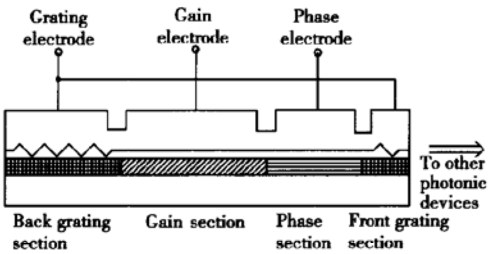

Fig. 1 Schematic view of the integratable DBR laser

The device was grown by LP-MOVPE in an Aixtron 200 reactor. The epitaxial structure used in this work consists of seven compressively strained (1%) InGaAsP wells sandwiched between 110nm 1.2Q optical confined layers, followed by 300nm un-doped InP implant buffer layer. Then, the gain section of the DBR laser was masked and QWI process was carried out. The QWI process involved a 100keV P^+ ion implantation with a dose for $5\times 10^{14}cm^{-3}$ and a rapid thermal annealing for 4min at 700℃. The depth of implantation is estimated to be about 100nm, which is much less than the thickness of the un-doped InP buffer layer. During the rapid thermal annealing, the whole wafer was covered by a PECVD grown SiO_2 layer to prevent surface from degradation.

After QWI process, the SiO_2 layer and the InP buffer layer were removed by wet etching. Then, a first-order Bragg grating was defined holographically on the grating section, and followed by the over-growth of p-InP cladding layer and p^+-InGaAs contact layer. The longer grating has a length of 150μm while the shorter has only 50μm. The power reflectivity of the grating is determined by the following equation: $R=\tanh^2(\kappa L)$, where κ is the grating coupling coefficient and L is the grating length. The grating coupling coefficient is estimated to be about $100cm^{-1}$, so the power reflectivities are about 0.8 and 0.2 for the longer grating and the shorter grating, respectively.

Then, ridge waveguide structure and electrode process were successively performed by standard technique. He^+ ion implantation was used electrically to isolate different sections, and the isolation resistance was measured to be over 100kΩ. Finally, the front facet of the DBR laser was coated anti-reflectively.

3 Measurement results and discussion

Figure 2 shows room-temperature PL spectra of the gain section (protected region) and grating section (implanted region) after RTA process. The PL peak wavelength of the as-grown sample is 1.575μm. After annealing for 4min at 700℃, the blue-shift of the peak wavelength is about 4nm for the gain section and 73nm for the phase/grating section, respectively.

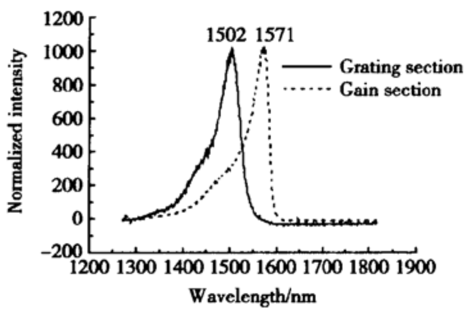

Fig. 2 PL spectra of different sections after RTA

After P^+ ion implantation, lots of group-V interstitial point defects were generated in the undoped InP buffer layer of grating section and phase section. And they were activated during the subsequent RTA process. The diffusion of the point defects will cause the composition intermixing between the well and the barrier, and group-V intermixing is much significant than group-III intermixing[7]. So is the PL wavelength blue-shifts. The small wavelength blue-shift in the gain section is due to self-intermixing behavior at an elevatory RTA temperature.

We have reported using SiO_2 encapsulation layer to promote QWI before[8,9], where a typic RTA temperature of over 750℃ was needed. Because our epitaxial structure was grown at 650℃, we believe that a lower RTA temperature will be better for the protection of the un-intermixed MQW region.

Figure 3 is the I-P relationship of the DBR laser. The threshold current is 27mA and the output optical power is about 9mW at 100mA driving current. The slope efficiency is estimatetd to be 0.12mW/mA. By further optimizing the power reflectivities of both gratings, more optical power can be extracted.

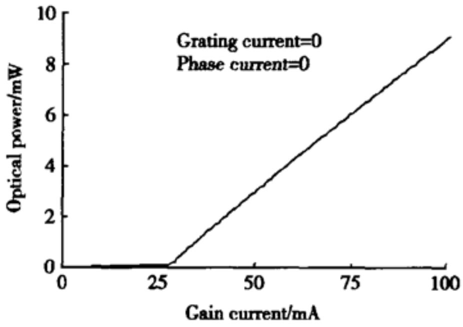

Fig. 3 I-P relationship of the integrated DBR laser

Figure 4 shows wavelength tuning by changing grating current, and Figure 5 is corresponding SMSR variation. When the grating current increases from 0 to 40mA, accumulated carrier decreases the effective index of the grating section through plasma effect and results in wavelength tuning. But when the grating current is over 40mA, further increase of the carrier density is difficult due to Auger recombination, thus wavelength remains unchanged. The wavelength changes discontinuously when the longitudinal lasing mode jumps from one to another. There are 7 longitudinal modes in total throughout the tuning range, and mode space is about 0.6nm. The SMSR is greater than 30dB throughout the tuning range except a few mode jump points, which means the grating reflectivity is large enough to maintain a high SMSR for practical use.

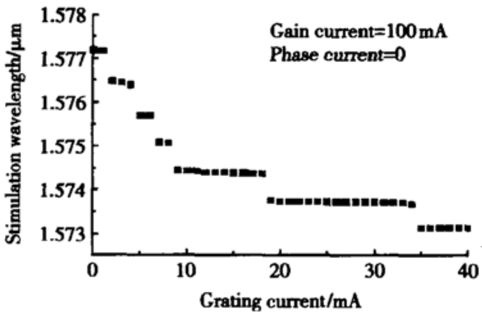

Fig. 4 Wavelength tuning with grating current

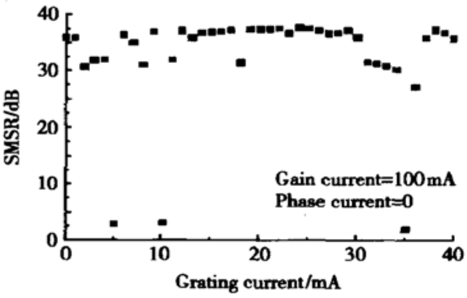

Fig. 5 SMSR with grating current

Figure 6 displays wavelength tuning by changing phase current. About 0.6nm continuous wavelength tuning is achieved, which is the same as mode space of the longitudinal modes. Thus, when grating current and phase current are changed simultaneously, quasi-continuous wavelength tuning can be achieved, and the total tuning range is measured as 4.6nm.

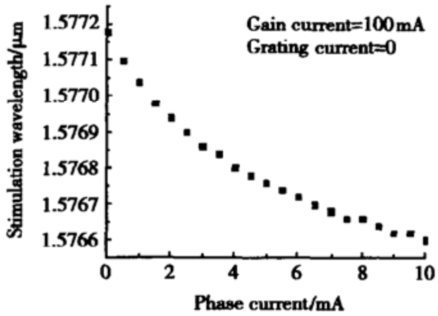

Fig. 6 Wavelength tuning with phase current

4 Conclusion

We applied low-energy ion implantation to realize QWI and successively fabricated an integratable DBR laser. A 4.6nm quasi-continuous wavelength tuning range is achieved with SMSR greater than 30dB. This kind of DBR laser has potential to be used in the photonic integrated circuits.

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使用低能离子注入导致的量子阱混杂方法制作可集成的分布式 Bragg 反射激光器*

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摘要: 采用量子阱混杂的方法制作了可集成的分布式 Bragg 反射激光器. 通过同时控制相位区和光栅区的注入电流, 该激光器的波长可以准连续地调谐 4.6nm. 在整个调谐范围内, 除了少数几个模式跳变点以外, 激光器的单模特性保持良好, 边模抑制比均达到了 30dB 以上.

关键词: 光子集成回路; 分布式 Bragg 反射激光器; 量子阱混杂; 波长调谐

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张　靖　博士研究生, 主要研究方向为使用量子阱混杂技术制作 InP 基光子集成器件.

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