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Monolithic Integration of a Widely Tunable Laser with SOA Using Quantum-Well Intermixing*

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Abstract: This paper presents an SG-DBR with a monolithically integrated SOA fabricated using quantum-well intermixing (QWI) for the first time in mainland China. The wavelength tuning range covers 33nm and the output power reaches 10mW with an SOA current of 50mA. The device can work at available channels with SMSR over 35dB.

Key words: tunable laser; semiconductor-optical-amplifier; ion implantation; quantum-well intermixing
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1 Introduction

Widely tunable lasers are key components for wavelength division multiplexing (WDM) optical-fiber network systems. They can reduce cost in spacing, enable dynamic networking applications, and present opportunities for future monolithically integrated components in WDM systems[1~3]. The next generation of re-configurable optical networks requires tunable lasers to be light sources[4]. Re-configurable networks offer a higher degree of flexibility for capacity allocation. This is expected to be an important feature of optical networks, especially in urban spaces. Telecommunication imposes requirements on tunable laser tuning range, wavelength stability, output power, side-mode suppression ratio (SMSR), reliability, and so on.

Among the various widely tunable lasers, the sampled-grating distributed Bragg reflector (SG-DBR) laser is an ideal device because it can be monolithically integrated with other components in the WDM network architecture and be tuned over 40nm within a few microseconds[5]. For conventional SG-DBR lasers using a current injection tuning mechanism, the increasing tuning current results in an increase in internal absorption loss, which is roughly proportional to the increment in injection current. As a result, while working in some channels, the output light powers are quite weak even with high gain currents. The gain current can be increased to compensate the output power loss, but the gain section is located between the front mirror and the rear mirror, and the change in gain current can result in a corresponding change of lasing mode. The lasers integrated with SOA enable the output power to be controlled independently both by the gain current and the SOA current. So, an integrated SOA can make the device work at an individual channel with a reasonable output power.

In this paper, we present an SG-DBR laser with a monolithically integrated SOA. Using the ion implantation quantum-well intermixing method allows the mode overlap with the active quantum wells to be optimized[1]. The results show that the wavelength tuning range coverage reaches 33nm and that the device can work at available channels with an SMSR over 35dB. We also investigate the relation of the output power to SOA current, and the mode stability with changes in SOA currents.

2 Device design and fabrication

The schematic of the integrated device structure is shown in Fig. 1. The device is comprised of five sections: a semiconductor-optical-amplifier (300μm), a front mirror consisting of 6 periods of sampled grating (348μm), a gain section (380μm), a phase section (100μm), and a rear mirror of 10 periods of sampled grating (620μm). The total device length is 1748μm.

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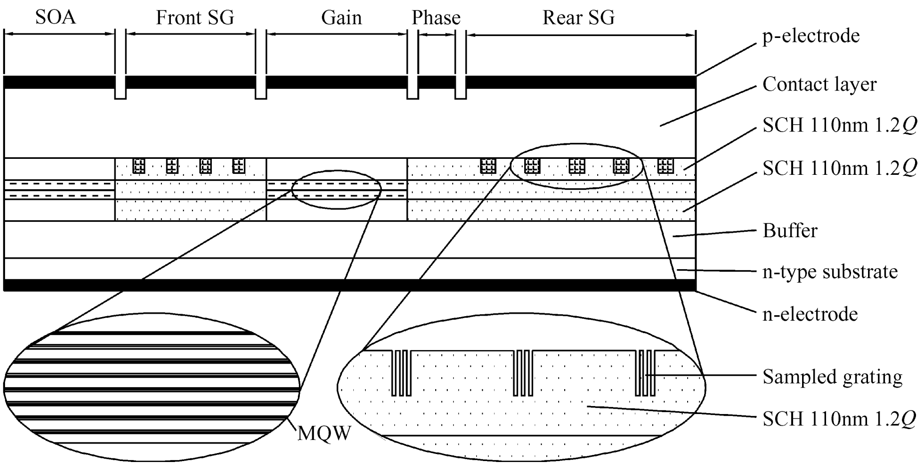

Fig. 1 Side view schematic of SG-DBR laser integrated with SOA

The integrated SOA is designed to make the laser work at reasonable light intensity.

The devices were epitaxially grown using a metal organic chemical vapor deposition (MOCVD) system with a horizontal reactor. The reactor pressure was an ultra-low-pressure of 22mbar, and the reactor temperature was 655℃. As shown in Fig. 1, the devices were grown on an n-type (100) oriented InP substrate. The epitaxial layer structure consists of six 5.5nm thick compressively strained InGaAsP multiple quantum wells, seven 9nm thick barriers sandwiched between separated confinement heterojunctions (SCH) with 1.2*Q* InGaAsP of 110nm, and then followed by an InP layer used for a grating mask, a 1.2*Q* stop etch layer, and a final InP buffer layer for P ion implantation.

The detailed QWI processes were as follows. First, a thermal silicon oxide layer was deposited on the chip. The SiO_2 layer served as a mask to prevent the ions from damaging the gain section and the SOA section. P^+ implantation and rapid thermal annealing (RTA) were carried out. As a result of the QWI process, the peak wavelength of the passive region implanted by P ions shifted from 1558 to 1447nm. The peak wavelength of gain region and SOA did not change significantly after QWI. The normalized room temperature photoluminescence (PL) spectra are shown in Fig. 2. The next process was etching the top buffer InP layer and 1.2*Q* stop layer using wet etching. The sampled gratings were defined holographically on the grating region of the upper SCH layer. Finally, the p-type cladding InP layer and p^+-InGaAs contact layers were regrown by a MOCVD system. A standard 2μm-wide ridge waveguide was formed by wet etching. The 20μm isolation trenches between individual sections were accomplished by etching p^+-InGaAs and He^+ implantation. In order to reduce lateral current leakage, a 400nm-thick thermal SiO_2 layer was deposited on the whole chip and the ridge contact window was opened by lithography. A Ti-Au metal layer was sputtered and a p-electrode was formed. Finally, the substrate was thinned and Au-Ge-Ni metal was evaporated on the backside. After alloying, the n-contact was formed and the sample chip was cleaved. The front and back facets were coated with antireflection (AR) film and high-reflection film, respectively. The device chips were soldered onto the carrier, die-attached to sub-mounts, and wire-bonded for continuous wave (CW) testing. They were driven by a four-channel current source. A part of the output power was coupled into a single-mode (SM) lensed fiber that connected to an optical spectrum analyzer or a power meter. The output power was measured by an integrating sphere. All measurements were performed at 25℃ using Peltier under the carrier.

3 Results

The characterization of tunable lasers is hard because of the complicated tuning mechanism. The lasing wavelength can be tuned via current injected into three different sections, including the front mirror

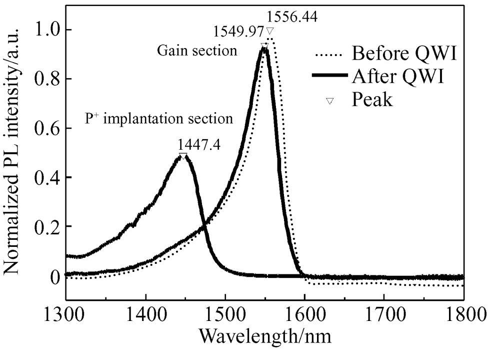

Fig. 2 Normalized room temperature PL spectra of the quantum-well sections and tuning sections implanted P^+

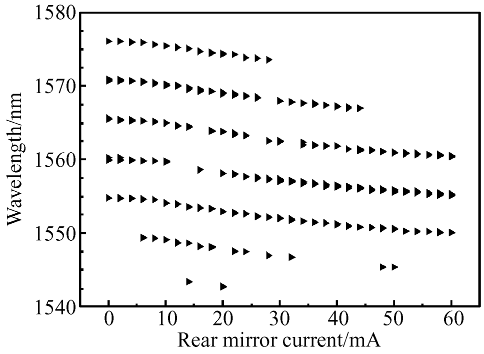

Fig. 3 Relationship between tuning wavelength and rear mirror current

section, rear mirror section, and phase section. The output power at different lasing wavelength can very greatly due to varied internal loss induced by tuning currents. The measurements were conducted in accordance with the following rules: the current injected into front mirror varied from 0 to 30mA with an interval of 1mA; the current injected into the rear mirror varied from 0 to 60mA with an interval of 1mA; the gain section and SOA section were injected at constant currents of 100 and 50mA, respectively. In order to simplify the measurement, the phase section was not injected with current. The results are shown in Fig. 3. The lasing wavelength can be tuned from 1543 to 1576nm, the tuning wavelength range covers 33nm, but not all channels are available.

In order to characterize the integrated SOA, we measured a set of *P-I* characteristic curves with different SOA currents, the current increased from 0 to 100mA in 10mA step. The relation between SOA currents and output powers are shown in Fig. 4. The output power increases as the current increases. When the SOA section current is 0mA, the SOA section serves as an absorber, and the output power is greatly absorbed. When the SOA current is over 60mA, the increase trend of output power is not sharp. The output power can reach 10mW with an SOA current of 50mA. It is recognized that the laser output power can be regulated by injecting current into the SOA.

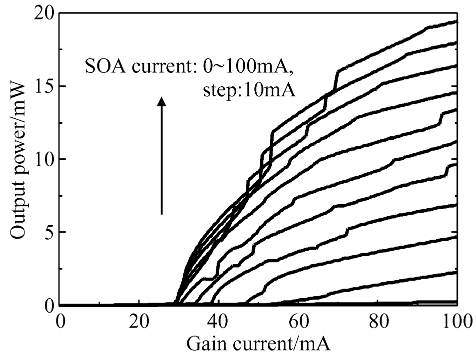

Fig. 4 *P-I* characteristic curves with SOA current from 0 to 100mA by the increment of 10mA

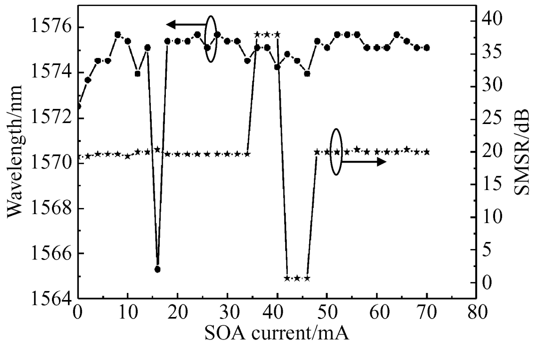

Fig. 5 Influence produced by SOA current on lasing wavelength and SMSR

The influence of SOA current on wavelength stability and side mode suppression ratio (SMSR) was studied. Figure 5 illustrates the relation between lasing wavelength, SMSR, and SOA current. The lasing wavelength remains basically stable, but varies at some tuning currents. This phenomenon is caused by edge reflection of cleaved facets[6]. At the same time, SMSR varies with the SOA currents, but the extent of the change is not obvious, and SMSR mostly reaches over 35dB. We conclude that, while operating at individual wavelengths, a reasonable output power and SMSR are available with proper SOA current.

4 Conclusion

We demonstrate the fabrication of a tunable laser integrated with SOA using the QWI method for the first time in China. A 33nm wavelength tuning range is achieved. The output power can reach 10mW with a SOA current of 50mA. The device can operate at an individual wavelength with a proper output power and SMSR over 35dB by injecting proper SOA current.

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量子阱混杂单片集成宽可调谐激光器与半导体光放大器*

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摘要： 采用量子阱方法集成半导体光放大器的取样光栅可调谐激光器，这在国内尚属首次．该器件波长调谐范围可达 33nm，在放大器注入 50mA 电流时，输出光功率可达 10mW，同时边模抑制比可达 35dB 以上．

关键词： 可调谐激光器；半导体光放大器；离子注入；量子阱混杂

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