A Novel Three-Section Self-Pulsating DFB Laser with Hybrid Grating*

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Abstract: A 1.55μm InGaAsP-InP three-section DFB laser with hybrid grating is fabricated and self-pulsations (SP) with frequencies around 20GHz are observed. The mechanism of SP generation in this device is researched. Furthermore, the important role of the phase tuning section on the SP is investigated.

Key words: self-pulsation; DFB laser; QWI
PACC: 4230Q; 4255P
CLC number: TN365　　**Document code**: A　　**Article ID**: 0253-4177(2008)04-0682-04

1 Introduction

Self-pulsation (SP) DFB lasers are now widely researched for the next generation of millimeter-wave carriers over fiber and can also be used in a WDM configuration for wireless networks operating at 40GHz[1]. In addition, SP DFB lasers have many promising applications in future optical networks, especially for all-optical clock recovery[2,3], which is a key function in all-optical 3R regeneration.

SP DFB laser diodes with multiple DFB regions were fabricated for this purpose. Generally, such multisection DFB lasers are divided into two-section lasers[4,5] and three section lasers[6,7]. In the latter type, the introduction of a passive phase tuning section reduces the modal overlap leading to greater modal independency and, hence, a larger tuning range[8]. Different SP mechanisms have been proposed, including spatial hole burning (SHB)[9,10], dispersive self-Q-switching (DQS)[6], and beating type (BT) oscillation[5,9]. As is shown in earlier reports, the detuning of lasing wavelength between laser sections of a multi-section SP DFB laser plays an important role in the generation of SP[11]. Methods have been reported to realize static wavelength detuning, including varying the grating period[11], introducing a phase-shift into one DFB section[12], and varying the ridge widths[13].

In this paper, we fabricate three-section DFB devices with a combination of one DFB section with index-coupled grating and one with gain-coupled grating, and a phase tuning section between these two DFB sections. The variation of grating type in the two DFB sections and, hence, the variation in effective refractive index induces the detuning of the lasing wavelength in this new way. This method is relatively simple compared with the methods mentioned above. On the other hand, in order to retain high device reliability and integrity, the phase tuning section that is designed as a transparent passive waveguide is fabricated using quantum-well intermixing (QWI) instead of the traditional butt-joint growth procedure. As far as we know, this is the first report to use this method in SP lasers.

2 Device fabrication

The device is schematically shown in Fig.1. It consists of two 325nm long DFB sections and a 200nm

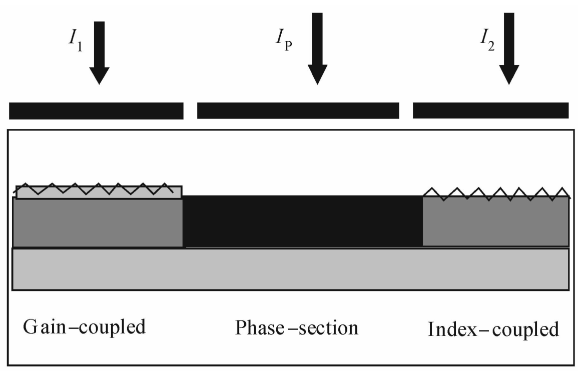

Fig.1　Schematic of device structure

* Project supported by the National Natural Science Foundation of China (Nos. 90401025, 60476009), the State Key Development Program for Basic Research of China (Nos. 2006CB604901, 2006CB604902) and the National High Technology Research and Development Program of China (No. 2006AA01Z256)

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Received 13 September 2007, revised manuscript received 5 November 2007

long phase tuning section between them, in which DFB section 1 is partially gain-coupled, and DFB section 2 is pure index-coupled, but both sections have the same grating parameters. For the phase tuning section, the traditional butt-joint growth procedure was adopted, that is, removing its active layer and the p-side waveguide[14], and then another epitaxy. In order to keep all the layers as grown and enhance the integrity of the device, we use the quantum-well intermixing method to realize the blue shift of the active layer in the phase tuning section, which behaves like a transparent waveguide. Phase tuning is possible via current injection into this section.

The DFB laser was fabricated on InP substrate. First, the n-InP buffer layer, lower separate confinement heterojunction (SCH) layer, 1.55μm multiple quantum well (MQW) active layer, upper SCH layer, and a complex layer for gain-coupled grating were grown by low pressure metal organic vapor phase epitaxy (MOVPE) at 655℃. Then, the active layer of the phase tuning section was treated by QWI to attain a wavelength blue shift. Detailed information is given in next section. Next, we removed part of the complex layer located in the phase tuning section and index-coupled section, and Bragg gratings with same parameters are fabricated in both DFB sections at one time by holographic exposure. After that, a stop etching layer, the InP cladding layer, and the InGaAs contact layer were grown in the second epitaxy step. Finally, the ridge etching, ion implantation, sputtering p-electrode (Ti/Au), and vaporizing n-electrode (Au/Ge/Ni) were completed. Trenched isolation regions separating each of the sections are all 50μm long, which contribute to the electrical separation by He^+ ion implementation. The two facets are left as cleaved.

3 Device performance

The as-grown MQWs had a PL peak wavelength of 1535nm at both the DFB sections and phase tuning section. Then P^+ ions were implanted into the surface of the phase tuning section with an ion energy of 150keV and dose of 5×10^{13} cm^{-3}. The whole wafer was then thermal annealed for 100s at 700℃ to induce the QWI process. As a result of QWI, a 130nm wavelength blue-shift occurred at the P^+ implanted phase tuning section. Meanwhile, only a 10nm blue shift occurred in the non-implanted DFB sections. The results are shown in Fig. 2. In this way, we fabricated a phase section that is transparent to the DFB modes.

Now we proceed to describe the experimental results. The three-section DFB laser was temperature stabilized at 25℃. The output of the laser was coupled

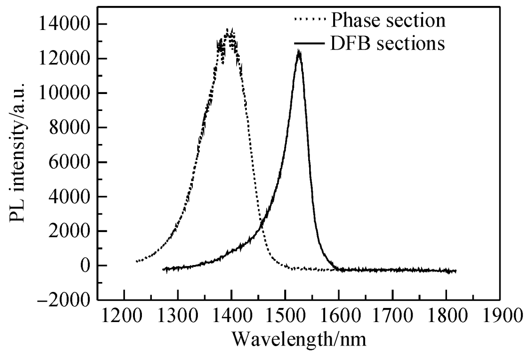

Fig.2 PL spectra of different sections after thermal anneal at 700℃ for 100s

into a single-mode fiber. An optical spectrum analyzer with a resolution of 0.01nm was used to monitor the optical spectrum of the laser; a photodetector followed by an RF spectrum analyzer was used for the monitoring of the RF spectrum. This system can operate in a frequency range up to 45GHz. When operated individually, the threshold current for each DFB section is around 25mA. When injected with a current of 90mA individually, section 2 has a two-mode emission, whose wavelengths are 1526.1nm and 1527.1nm, and section 1 has a single mode emission with a wavelength of 1526.6nm. This wavelength difference, which is attributed to the different grating type of both DFB sections, shows that the design of our device successfully attains the detuning of lasing modes.

When DFB section 1 operated at 90mA, and DFB section 2 operated at 65mA, we change the current in the phase tuning section to create self-pulsation. At critical phase currents, only slight variations of this parameter are sufficient to change the RF spectra drastically. This is shown in Fig. 3, in which the lower spectrum at 4mA corresponds to stable lasing and the trace represents the instrument's baseline. When decreasing the phase current I_p to 1.1mA, the onset of the self-pulsation of 16GHz can clearly be detected in the corresponding upper RF spectrum.

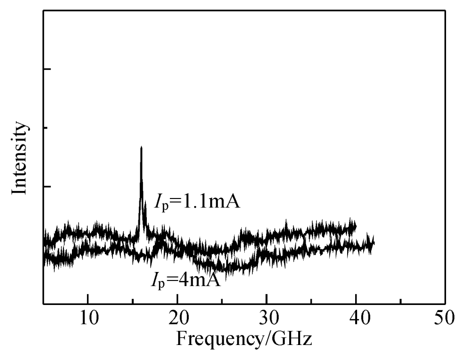

Fig.3 Switching OFF and ON the self-pulsation (16GHz) by the phase tuning current I_p

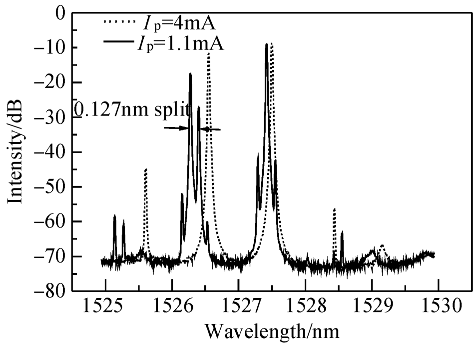

Fig. 4 Optical spectra of the DFB laser under the same operating condition as in Fig. 3

The corresponding optical spectra of these two cases are shown in Fig. 4. The figure indicates that a splitting of one emission mode, which is directly correlated to the RF frequency, is caused by the variation of the phase current. This example shows that by adjusting the phase conditions, the self-pulsation can be turned ON and OFF in our device.

For a better understanding of the results, Figure 4 displays the corresponding optical spectrum under a same injection condition as in Fig. 3. When I_p is 4mA, there are two isolated modes, and no SP appeared. When I_p is decreased to 1.1mA, the mode with shorter wavelength splits into two, and the mode spacing is 0.127nm, which equals an SP with frequency 15.87GHz. This result is very close to the one detected in Fig. 3. Thus, we attribute the SP observed to BT oscillation. The two beating modes, however, can not be regarded as the two modes from the two DFB sections, respectively. Instead, we think one is confined to one section, and the other mode is common to both sections. This common mode satisfies a main mode condition of one section and any order of the FP modes of the opposite section, including a main FP mode.

Experimentally, phase tuning is possible via the injection current into this section. With varied current, an appearance and disappearance of SP is observed, and the frequency of SP also changes. Figure 5 shows a typical example of the tuning of the phase current covering about 17mA. Within this range, the frequency varied in a range from 15 to 21GHz. Thus, the phase tuning is not only essential for switching on the SPs but also can be used to fine tune the frequency.

4 Conclusion

In summary, three-section DFB lasers with hybrid grating and a QWI induced blue shifted phase tuning section have been fabricated. This hybrid grating

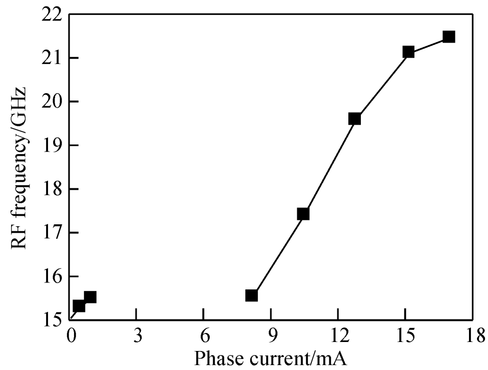

Fig. 5 Measured variation of the pulsation frequency with the phase tuning current

structure is proven to effectively give rise to emission wavelength detuning. This detuning, as well as the phase tuning section, is of great importance to the SP and influences it significantly. Consecutively, tunable SPs in the 20GHz range are demonstrated. As a result, this device is reliable and effective for tunable SP generation.

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混合光栅型的三段式自脉动 DFB 激光器*

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摘要： 制作了 1.55μm InGaAsP-InP 三段式混合光栅型 DFB 激光器. 观察到了 20GHz 左右的自脉动信号. 讨论了自脉动的产生机制，并且对调相区所起的作用进行了研究.

关键词： 自脉动；DFB 激光器；QWI
PACC： 4230Q；4255P
中图分类号： TN365　**文献标识码：** A　**文章编号：** 0253-4177(2008)04-0682-04

* 国家自然科学基金(批准号：90401025，60476009)，国家重点基础研究发展规划(批准号：2006CB604901，2006CB604902)和国家高技术研究发展计划(批准号：2006AA01Z256)资助项目

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2007-09-13 收到，2007-11-05 定稿