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A Novel Two-Section Co-Cavity Wavelength Tunable Semiconductor Laser

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Abstract　A novel wavelength tunable semiconductor laser based on DFB (Distributed Feedback) structure with two non-uniform sections and co-cavity is reported in this paper. The laser structure was grown by three-step MOCVD and subsequently processed into the PBH-LD (Planar Buried Heterostructure-Laser Diode) devices. The device was tuned in two ways. A discontinuous wavelength tuning range of 11.1nm and a continuous wavelength tuning range of 2.6nm was achieved in different tuning ways. Only one control current was used to have the wavelength tuned in both ways.

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1　Introduction

Wavelength tunable laser diodes are promising light sources for wavelength-division-multiplexing (WDM) networks, coherent communications and optical measurement applications. Much attention has been paid to it due to its wavelength tunability, which make the system applications more flexible. Recently, a series of complicated devices with large tuning range have been proposed, such as: the DBR (Distributed Bragg Reflector) laser with quasi-continuous wavelength tuning range of 17nm[1], the SG-DBR (Sampled-Grating-DBR) laser with quasi-continuous wavelength tuning range of 45nm[2] and the GCSR (Grating assisted Codirectional coupler with rear Sampled grating Reflector) laser with quasi-continuous wavelength tuning range of 40nm[3] *et al*. However, these kinds of devices

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usually contain compicated gratings and waveguide, which makes their fabrication difficult. At the same time, several electrodes are necessary to have the wavelength tuned, which is inconvenient to use.

Compared with these kinds of wavelength tunable lasers, DFB lasers have relatively small tuning ranges, but reveal essential advantages such as less complicated technological processing, lower price, narrower linewidth, and higher output power. Therefore, it is rather desirable to enlarge the tuning range of DFB lasers. The conventional two-section DFB laser has a wavelength tuning range of 2.4nm when the two sections are non-uniform injected[4]. Several methods have been proposed to enlarge the wavelength tuning range of DFB lasers. A DFB laser operated in the gain-lever mode has been reported to be tuned over 6.1nm at the wavelength of 1530nm[5].

In this paper a novel co-cavity two-section non-uniform DFB lasers was proposed and fabricated. Only one control current was used to have the wavelength tuned. The fabrication of this structure was the same as that of conventional PBH (Planar Buried Heterostructure) DFB lasers except that 1) two-time exposures must be used to make the gratings and 2) isolation groove must be made to have the two sections electrically isolated. Only one control current needs changing to have the wavelength tuned. This kind of device not only has the advantage of easy fabrication and simple usage but also shows an enlarged wavelength tuning range.

2 Device Design

The designed active layer and waveguide of the proposed non-uniform two-section DFB LD are shown in Fig.1. The front section is 2μm wide, 200μm long, without any grating in it, and the light output from its Anti-Reflection (AR) coating facet, while the back sectin is 3μm wide, 300μm long, with grating in it. The component and thickness of the active layer in both sections are uniform.

The key points of the structure are as followed: 1) The non-uniformity of the two sections should support an enlarged gain-lever effect, which conducts a large wavelength tuning range[6,7]. 2) The front section can be regarded as a mode expander, which may decrease the far field divergence, as a result, a higher coupling efficiency can be achieved[8].

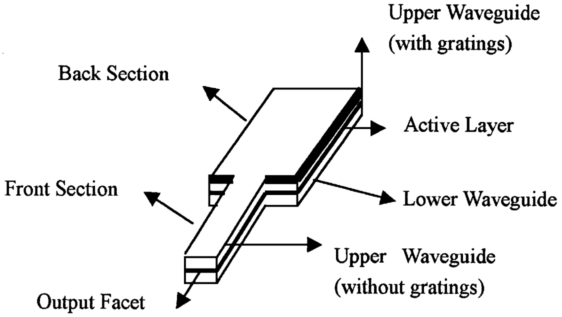

FIG.1 Schematic diagram of designed active layer and waveguide

3 Device structure and realization

The PBH structure of the non-uniform two-section co-cavity DFB laser is shown in Fig. 2. The structure was grown by three-step MOCVD epitaxy growths and subsequently processed into the PBH-LD device[9,10].

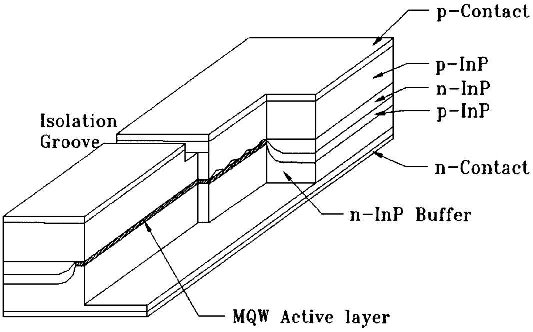

FIG. 2 Schematic diagram of non-uniform two-section co-cavity DFB laser

The active layer consists of six undoped 8nm wide InGaAsP quantum wells ($\lambda_g \sim 1.54\mu m$, 0.8% compressive strain) and 12.5nm wide InGaAsP barriers ($\lambda_g \sim 1.2\mu m$, -0.35% tensile strain), embedded in two lattice-matched InGaAsP waveguides. The upper waveguide consists of two lattice-matched InGaAsP layers ($\lambda_g \sim 1.2\mu m$, $1.1\mu m$), 145nm totally in thickness. The lower waveguide consists of two lattice-matched InGaAsP layers ($\lambda_g \sim 1.2\mu m$, $1.1\mu m$), 150nm thick in total.

In this structure, the grating was fabricated only in the upper waveguide in the "back section" by two-time exposures. The grating has a period of 240nm and a depth of 50nm. An isolation groove was made in the p-side contact to isolate the two sections electrically. The isolation groove is 50μm wide and around 0.4μm deep, which provides an isolation resistance of about 300Ω between the two sections. The "front section" is 200μm long and the "back section" 300μm. The facet of the "front section" was AR coated and acts as the output facet. The facet of the "back section" is High-Reflection (HR) coated.

4 Characteristics

In this paper, the current applied to the front section was called I_f and to the back section called I_b.

Fig. 3 and Fig. 4 are the wavelength as a function of current.

In Fig. 3, I_b kept at 80mA and I_f was changed to have the wavelength tuned. When I_f was changed from 30mA to 100mA, the change of wavelength was continuous. When I_f was changed over 100mA, the wavelength change was discontinuous. The hopping modes have narrow gaps, with the widest one no more than 1nm. When I_f was changed from 30mA to 270mA, the wavelength was tuned from 1.5047μm to 1.5518μm, with a discrete wavelength tuning range of 11.1nm.

In Fig. 4, I_f kept constant while I_b was changed in order to have the wavelength tuned. When I_f kept at 50mA and I_b was changed from 30mA to 230mA, the change of wavelength was continuous, with a tuning range of 2.6nm. When I_f kept at 90mA and I_b was changed

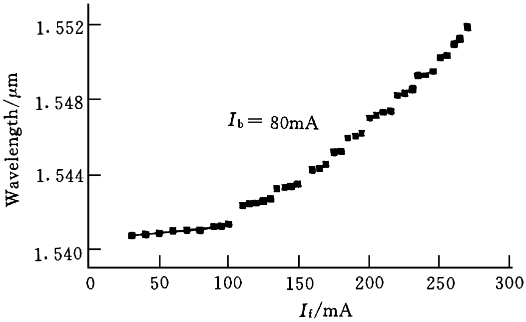

FIG. 3 Wavelength versus I_f, when I_b was biased at a certain current of 80mA

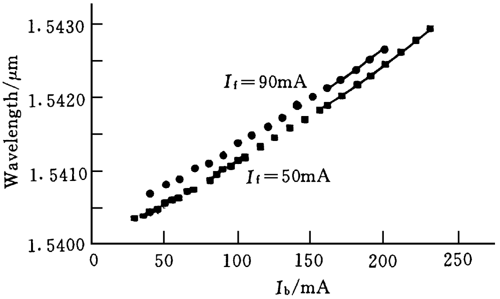

FIG. 4 Wavelength versus I_b, when I_f was biased at certain currents of 50mA and 90mA

from 40mA to 200mA, the change of wavelength was continuous too, with a tuning range of 2.04nm.

The Side Mode Suppression Ratio (SMSR) of all the modes in Fig. 3 and Fig. 4 were higher than 32dB.

The lasing mode of the two-section co-cavity semiconductor laser was fundamentally determined by the grating of the back section. In the DFB lasers, the longitudinal mode is determined by the grating, though it is only partially fabricated in the cavity. The device not only shows high SMSR but also keeps single mode lasing over a large current range (for example, when I_f kept 50mA and I_b was changed from 30mA to 230mA), which is in good agreement with this explanation.

5 Discussion

For both DFB and DBR semiconductor lasers, the lasing wavelength is determined by the period of the grating.

$$m\lambda = 2\Lambda n_{\mathrm{eff}} \tag{1}$$

Where m, an integer, is the diffraction order. For the first-order gratings, m equals to 1 and for the second-order gratings, m equals to 2. λ is the free-spaced Bragg wavelength. n_{eff} is the effective index or refraction and Λ is the period of the gratings. Λ is determined once the device is fabricated. Actually, wavelength can be changed only through the change the effective index.

There are several ways to have the effective index n_{eff} changed. The most widely used one is to change the injection current. When the injection current is changed, the carrier density in the active layer and the waveguide will be changed alongside. The variation of the carrier density will change the effective index n_{eff}, which can be expressed as:

$$\Delta n_{\mathrm{eff}} = - \frac{a_h\lambda_0}{4\pi} a\Gamma (N - N_t) \tag{2}$$

Here N_t is the transparent carrier density, $a_h\lambda_0 a\Gamma$ can be regarded as a constant for a certain wavelength. As can be seen from (2), the effective index n_{eff} decreases with the increase of the carrier density N. From (1), the decrease of the effective index n_{eff} will cause a blue shift of the lasing wavelength.

For DBR lasers, the wavelength will have a blue shift when the carrier density increases. This agrees well with experiment[1]. For DFB lasers, there is an active layer under or above the gratings. When the injection current increases, the gain of the active layer increases, which causes an increase in the output power. More carriers are changed into photons when the output power increaes. Then the carrier density is clamped at the threshold carrier density. In this way, the change of the carrier density, then the change of effective index and wavelength are not as remarkable in DFB lasers as those in DBR lasers, even under the same variation of injection current. That means tunable DBR lasers have larger wavelength tuning range than that of tunable DFB lasers[1,5].

Multi-section DFB lasers are always used to achieve wavelength tunability. In multi-section DFB lasers, the mechanism of the wavelength tuning is rather complex.

As can be seen from Fig. 3 and 4, the lasing wavelength has a red shift with the increase of injection current. The same kind of wavelength red shift in multi-section DFB lasers has been observed in other experiments[11,12]. It can be explained as followed:

5.1 Gain-lever Effect

Gain level effect can take effect in multi-section DFB laser under appropriate conditions. When multi-section DFB lasers operate in the gain-lever mode, a small change of carrier density in one section can cause a large change of carrier density in other sections, which is prohibited by the gain clamp in the conventional one-section DFB lasers. Gain-lever effect can be used to enlarge the wavelength tuning range[11,13]. The detailed explanatiion is as follows.

The gain in the whole cavity equals the loss when the laser lases. For the two-section co-cavity semiconductor lasers, the threshold gain is provided by the two sections, which can be expressed as:

$$g_{\mathrm{th}} = \frac{g_1 L_1 + g_2 L_2}{L_1 + L_2} \tag{3}$$

Where g_{th} is the threshold gain, g_1 and g_2 are gains of the two sections, respectively. L_1, L_2 are the respective effective lengths of the two sections[13]. We can assume section 1 to be the control section, and section 2 the gain section. When the injection current of section 1 increases, gain will increase accordingly, so that the photon density in this section will increase, so will the output power. At the same time, section 2, which is biased at a certain current, may has a decreased carrier density due to the increase of the photon density in the co-cavity of the device. The decrease of carrier density in section 2 causes a decrease of gain in this section. A new equilibrium was achieved when (3) is satisfied again. When section 1 is biased in such a situation in which gain changes lineraly with the change of carrier density, and section 2 is biased in another situation in which gain is saturated and changes little with the change of carrier density, a small change of carrier density in section 1 may cause an opposite large change of carrier density in section 2, until reaching an proportional and opposite gain change satisfying (3). When the injection current of the control section increases, the carrier density in the gain section might decrease greatly, which will cause an increase in the effective index, and then a red shift of lasing wavelength will take place. Generally speaking, the gain section is longer than the control section in order to get a larger gain lever effect. In our experiment, the back section can be regarded as the gain section and the front section as the control section. When the injection current of the back section kept constant while that of the front section changing, a large wavelength tuning range was achieved, which is in good agreement with this theory.

5.2 Effect of temperature

The lasing wavelength of DFB lasers will increase with the increase of the temperature. In our experiments, the current applied to the device was quite large. So a temperature increase due to the current injection was non-avoidable.

To estimate the thermal effect on the wavelength tuning, we measured the lasing wavelength when the currents of both the front section and the back section were changed simultaneously to 200mA in both the pulse operation and the CW operation. The wavelength difference was only 0.66nm between the pulse operation and the CW operation in this device. Compared with the 2.6nm continuous wavelength tuning range and the 11.1nm discrete wavelength tuning range, we can say that the thermal effect on the wavelength tuning was negligible.

As can be seen from Fig. 4, the wavelength changed almost linearly with the change of the current. When the current increased, the wavelength changed a little quicker. The increase of temperature may account for this.

In one word, the red shift of the wavelength can be explained by gain-lever effect with the increase of temperature playing an unimportant role.

6 Summary

A novel non-uniform two-section co-cavity wavelength tunable laser based on DFB structure was proposed and fabricated. It is easy to fabricate the device because of its simple structure. The fabrication of this structure was compatible with convertional DFB lasers. The devices were tuned in two different ways. A continuous wavelength tuning range of 2.6nm and a discrete wavelength tuning range of 11.1nm were achieved in different ways. Only one control current was used in both the two tuning ways.

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