Experimental demonstration of directly modulated buried heterostructure DFB semiconductor laser based on reconstruction equivalent chirp technique

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Abstract: A directly modulated buried heterostructure distributed feedback (DFB) semiconductor laser based on the reconstruction equivalent chirp (REC) technique in the 1.3 μm wavelength domain is experimentally demonstrated. The packaged laser shows a good single longitudinal mode (SLM) property, with the side mode suppression ratio (SMSR) higher than 40 dB when the injection current is higher than 20 mA, as the threshold current is 10 mA. The direct modulation performance of the laser is also delightful, with the modulation bandwidth up to 10GHz at a low injection current (40mA), and the measured spurious free dynamic range (SFDR) up to 86 dB·Hz2/3.

Key words: directly modulated; buried heterostructure; DFB semiconductor laser; reconstruction equivalent chirp technique.

1. Introduction

Distributed feedback (DFB) semiconductor laser is one of the key components in the coherent optical communication system. DFB lasers with good single longitudinal mode (SLM) property and direct modulation performance are widely used to make the communication system much simpler [1-3]. The lasing wavelength and the SLM property of DFB lasers are mainly determined by the internal brag grating structure. However, in the traditional way, the fabrication of complex grating structures is accomplished with the electron beam lithography (EBL) method, which is known as complex and time consuming [4].

A method named reconstruction equivalent chirp (REC) technique has been used to fabricate the grating structures in DFB lasers [5-7]. According to the REC technique, complex grating structures, such like phase shifted gratings and apodized gratings, can be equivalent as a combination of uniform Bragg gratings and designed sampled gratings [8, 9]. Therefore, the fabrication of the grating structures based on REC technique can be realized by one step of holographic exposure to fabricate uniform grating structures, and another step of photolithographic to fabricate sampled gratings. However, due to the sampling structure, the effective index coupling coefficient of DFB lasers based on REC technique reduces to 1/π of which of conventional DFB lasers, causing the threshold current much higher and the
direct modulation performance worse [5]. As a consequence, a buried heterostructure (BH) waveguide is put in use to lower the threshold current and enhance the direct modulation performance [10, 11]. In this article, a 1310nm DFB laser with low threshold current of 10 mA is experimentally demonstrated. The side mode suppression ratio (SMSR) is higher than 40 dB at the injection current of 20 mA, which shows a good SLM property. The direct modulation characteristic has also been measured. The modulation bandwidth is 10GHz at a low injection current of 40 mA, and the spurious free dynamic range (SFDR) is 86 dB-Hz$^{2/3}$ at 10 GHz. The experiment results mean that the DFB lasers with BH structure based on REC technique are qualified for the fiber-communication system.

2. Principle and Design

According to the REC technique, a complex grating structure can be equivalent as a combination of a designed sampled grating and a seed uniform grating. If we set the Bragg wavelength of the +1\textsuperscript{st} order sub-grating as the working channel, the relationship between the lasing wavelength $\lambda$ and the sampling period $P$ can be expressed as,

$$\frac{1}{\lambda/2n} = \frac{1}{\Lambda_0} + \frac{1}{P}$$

Where $n$ is the effective index at lasing wavelength $\lambda$, and $\Lambda_0$ is the seed grating period. As a uniform grating, the $\Lambda_0$ is fixed, and then we can control the lasing wavelength by changing the sampling period. In order to achieve a good SLM property, we lead in a quarter-wave equivalent phase shift (EPS). As shown in Figure 1, the ESP $\theta$ can be achieved by bringing a shift $\Delta P$ in the sampling period at the center of the laser cavity. We can get a quarter-wave ESP by setting the $\Delta P$ equal to $P/2$, as the ESP $\theta$ is equal to $2\pi\Delta P/P$. The sampling period is usually in a precision of micrometer order, which means that the REC technique is much more conventional than the traditional ways.

![Figure 1](image.png)

**Figure 1** The schematic of the grating structure with equivalent $\pi$ phase-shift

The procedure to fabricate DFB laser with BH structure based on REC technique is almost the same with the traditional method [12, 13]. What is different appears when the grating structure is fabricated. According to the REC technique, after growing a multiple quantum-well (MQW) active structure by metal-organic vapor phase epitaxy (MOVPE), the uniform gratings, whose Bragg wavelength was about 1375 nm, were fabricated by holographic exposure. And then the sampled grating structures with the period of 4.15 $\mu$m were patterned by traditional photolithographic. And then a 3 $\mu$m wide ridge waveguide vertical to the grating lines was formed by wet etching to define the active regions. After this, a p-InP layer and an n-InP layer were grown around the ridge by MOCVD to form the current block layer. And then the p-InP cladding and InGaAs contact layers were regrown by MOCVD. In this article, two isolation ditches were etched along the ridge after the contact window was opened to reduce
the capacitance. High reflection film and Antireflection film were coated on the laser facets.

3. Experimental Results and Discussion

A buried heterostructure DFB semiconductor laser has been fabricated at the wavelength around 1310 nm. The characteristics of the laser has been measured experimentally. The P-I curve at the temperature of 25°C is shown in Figure 2. The threshold current is about 10 mA and the slope efficiency is about 0.4 W/A. The spectra of the laser has also been measured. As shown in Figure 3(a), the lasing wavelength is 1308.18 nm and the SMSR is 48.31 dB with the injection current of 40 mA. Figure 3(b) shows the measured SMSRs at different injection currents at 25°C. According to the measurement, the SMSR is higher than 40 dB when the injection current is higher than 20 mA, which shows a good SLM property.

![Figure 2 P-I curve measured at the temperature of 25°C](image)

![Figure 3](image)

The direct modulation performance of the laser is also researched in this article. The small signal frequency responses (SSFRs) at different injection currents at 25°C are shown in Figure 4. As we can see from the diagram, the 3 dB modulation bandwidth increases obviously as the injection current increases. The 3 dB bandwidth is larger than 10 GHz when the injection current is 40 mA.
Figure 4 The SSFRs measured at different injection currents at 25°C

The third-order intermodulation distortion (IMD3) is a significant property for the laser to estimate the direct modulation linearity. Two RF signals at 10 and 10.2 GHz are used to measure the IMD3 operating at 10 GHz with an injection current of 40 mA. The input power of the two RF signals is adjusted to be the same, varied from -6.12 to -0.63 dBm. The measurement is shown in Figure 5. According to the tested results, the noise floor with a 1 Hz bandwidth is reckoned to be -140 dBm/Hz. As shown in the diagram, the third-order intermodulation increases much faster than the fundamental signal. The tested SFDR is 86 dBHz$^{2/3}$, showing a good linearity.

Figure 5 The SFDR of the laser modulation at 10 GHz

4. Conclusion
In this article, a DFB semiconductor laser with BH structure based on REC technique has been reported. A low threshold current and high output power because of the BH structure has been obtained. Good SLM property has been achieved with the SMSR higher than 40 dB when the injection current is higher than 20 mA. The direct modulation performance has also been researched in this article. The modulation bandwidth is higher than 10 GHz when the injection current is 40 mA, and the SFDR is 86 dB-Hz$^{2/3}$ at an operating frequency of 10 GHz. The experiment results mean that the DFB lasers with BH structure based on REC technique is qualified for the fiber-communication system.

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