Design and performance of a complex-coupled DFB laser with sampled grating*

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Abstract: A complex-coupled DFB laser with sampled grating has been designed and fabricated. The method uses the +1st order reflection of the sampled grating for laser single-mode operation. The typical threshold current of the sampled grating based DFB laser is 25 mA, and the optical output is about 10 mW at the injected current of 100 mA. The lasing wavelength of the device is 1.5385 μm, which is the +1st order wavelength of the sampled grating.

Key words: sampled grating; complex-coupled; +1st order wavelength；DFB
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1. Introduction

Distributed feedback (DFB) lasers are key components in modern optical communication systems which require highly stable laser sources with narrow linewidth and high output power. However, there exist two major limits in the conventional index-coupled DFB lasers: insufficient threshold gain difference between the main and side modes and a nonuniform axial photon distribution that causes the spatial hole burning[1,2]. Theoretically, pure gain-coupled lasers show a large threshold gain difference between the main and side modes[3], higher stability due to the standing wave effect[4,5] and less spatial hole burning[6]. However, it is difficult to fabricate pure gain gratings because gain variation causes carrier density variation, which in turn causes variation of the refraction index. Thus, lasers with both index and gain coupling coefficient are introduced and such complex-coupled lasers have been reported to exhibit excellent performance[7,8]. Even a small amount of gain coupling in complex-coupled DFB lasers can improve the threshold gain difference between the main and side modes significantly[3]. A sampled grating is a good tool for tailoring grating structures[9,10], and it is an effective way to change the coupling coefficient on a single wafer or even in the axial direction of a waveguide[9]. So it has been used in tunable distributed Bragg reflector (DBR) lasers[11,12], tunable DFB lasers[13,14], optical filters[15] and complex-coupled DFB lasers[9].

A complex-coupled DFB laser with a sampled grating has been designed and fabricated in this paper. The key concept of the design is to utilize the +1st order reflection of the sampled grating for single-mode operation. By using a sampled grating rather than a uniform grating, the laser wavelength can be changed by changing the superperiod of the sampled grating. Another key point is to use a conventional holographic exposure combined with the usual photolithography to form the sampled grating, which is easier and more cost-effective than the electron beam lithography method.

2. Device design and fabrication

The superperiod Z in complex-coupled DFB lasers can be calculated from

$$\lambda_0 = 2n_{\text{eff}}\Lambda, \quad (1)$$

$$Z = \frac{\lambda_0^2}{2n_{\text{eff}}(\lambda_{+1} - \lambda_0)}, \quad (2)$$

where λ_0 is the Bragg wavelength, λ_{+1} is the +1st order wavelength, n_{eff} is the effective index of the complex-coupled waveguide, and Λ is the grating period.

It is very important to suppress the lasing of the devices at the Bragg mode, so the active material gain curve of the waveguide used in the experiment should be taken into consideration as well to make the laser work at the +1st order mode. The Bragg mode is set at the edge of the gain curve, while the +1st order mode is set at the peak, as shown in Fig.1. Moreover, the complex-coupled structure can enlarge the threshold gain difference between the +1st order and Bragg modes, so the +1st order mode can be lasing first. The peak of the gain curve is at 1.54 μm, with a full width at half maximum (FWHM) of about 30 nm. So λ_0 and λ_{+1} are set at 1.52 and 1.54 μm, respectively. The effective index n_{eff} of the waveguide is 3.239. Λ and Z are therefore calculated from Eqs.(1) and (2) to be 234.6 nm and 17.83 μm, respectively. The total length of the device is 300 μm, and the duty cycle of the superstructure is designed to be 2/3. Figure 2 shows the calculated

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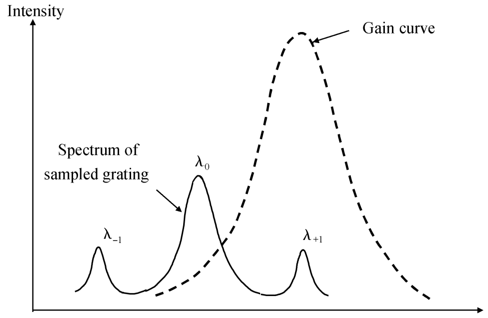

Fig.1. Schematic spectra of the gain curve and sampled grating.

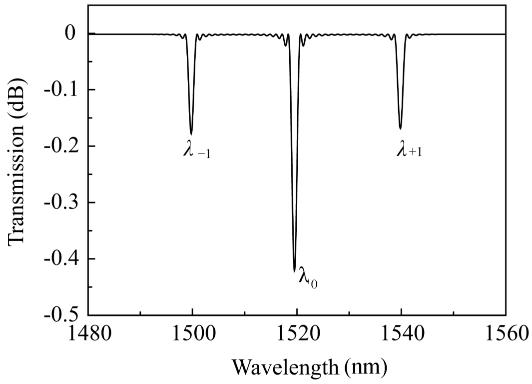

Fig.2. Calculated transmission spectrum of the designed sampled grating.

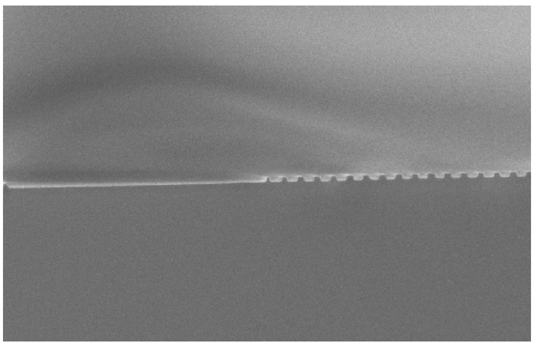

Fig.3. SEM photograph of the sampled grating.

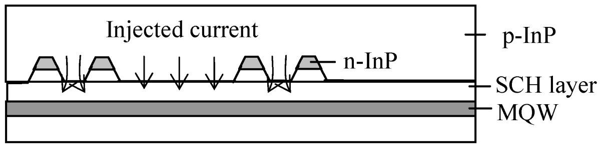

Fig.4. Schematic illustration of the sampled grating.

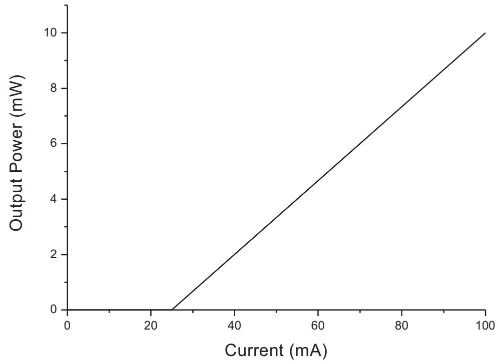

Fig.5. Typical *L–I* characteristics of the device at RT.

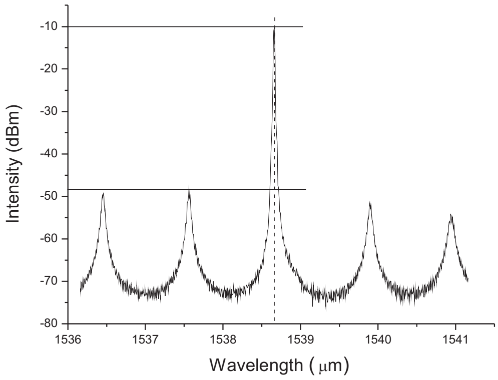

Fig.6. Measured emission spectrum of the device at RT.

transmission spectrum of the sampled grating using the transfer matrix simulation.

The device was fabricated by a conventional two-stage lower-pressure metal organic vapor phase epitaxial (MOVPE) growth. An InP buffer layer, a lower optical confinement layer (λ_{PL} = 1200 nm), an MQW active structure ($\lambda_{PL\text{-}MQW}$ = 1540 nm), an upper optical confinement layer (λ_{PL} = 1200 nm) and a 7 nm thick n-InP layer were successively grown on an n-InP (100) substrate in the first epitaxial growth. The MQW structure contains five undoped 8 nm thick 0.7% compressive strain InGaAsP quantum wells. The sampled grating was then fabricated on the upper SCH layer and the n-InP layer by a conventional holographic exposure combined with the usual photolithography. The scanning electron microscope (SEM) morphology of the sampled grating is shown in Fig.3. For the fabricated devices, the presence of the thin n-InP layer on top of the sampled grating modulates the injected current and induces a weak gain coupling to the DFB structure, shown in Fig.4. After the fabrication of the sampled grating, a p-InP cladding layer and a p^+-InGaAs contact layer were successively grown over the entire structure in the second epitaxial growth. Then a conventional ridge waveguide processing was performed. Ti–Au patterned p-contacts and AuGeNi n-contacts were formed on the p-side and the n-side of the device, respectively.

3. Device performance

Figure 5 shows the typical power–current characteristic of the device at room temperature (RT). The continuous wave threshold current of the device is 25 mA at RT. The output power is about 10 mW at the injected current of 100 mA, and the slope efficiency is about 0.13 W/A. Figure 6 shows the measured emission spectrum of the device at RT. The lasing wavelength is 1.5385 μm at the injected current of 30 mA, and a side mode suppression ratio (SMSR) up to 40 dB is achieved. The lasing wavelength coincides with the designed +1st order mode of the sampled grating, which demonstrates the effectiveness of the design. The dual-peak spectrum of the +1st order mode caused

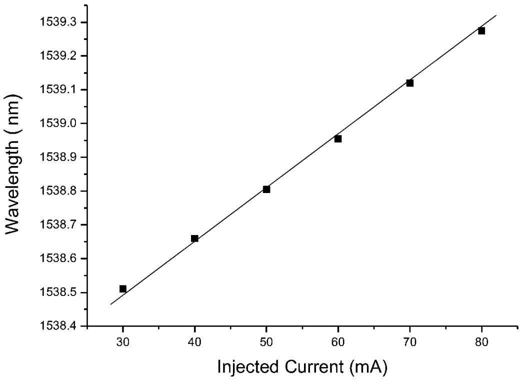

Fig.7. Current-dependent wavelength of the laser at RT.

by the hole-burning effect does not appear as the injected current increases. This reveals that the complex-coupled structure can restrain the hole-burning effect, which is one of the main limits in the index-coupled structure. The current-tuning rate of the emission mode is 0.0153 nm/mA, as shown in Fig.7, which is of the same order as those of conventional 1.3 and 1.5 μm lasers.

It should be noted that the lasing at 1.5136 μm has also been observed when the injected current is above 80 mA. The possible reason is that the threshold gain difference between +1st order and Bragg modes is not large enough, so the Bragg mode can also be lasing at higher injected current. The presence of the Bragg mode can be avoided by optimizing the design of the device. The lasing wavelengths of the +1st order mode and the Bragg mode are different to a certain extent from their designed values; this difference is introduced during the fabrication of the sampled grating.

The fabrication method can control the lasing wavelength among different stripes on a wafer by using an appropriate sampled grating structure. So the designed DFB laser with the sampled grating can be integrated into a DFB laser array. The DFB laser array using the sampled grating only needs a conventional holographic exposure combined with the usual photolithograph rather than expensive and time-consuming electron beam lithography.

4. Conclusion

A complex-coupled DFB laser with a sampled grating has been designed and fabricated. The sampled grating is formed by a conventional holographic exposure combined with the usual photolithograph. The +1st order reflection of the sampled grating is chosen to be the lasing wavelength, which is 1.5385 μm in the experiment. The typical threshold current of the device is 25 mA and the optical output is about 10 mW at the injected current of 100 mA.

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