Strongly Gain-Coupled DFB Laser Monolithically Integrated with a Self-Alignment Spot-Size Converter

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Abstract: A new type strongly gain-coupled (GC) DFB laser and a new type self-alignment spot-size converter (SA-SSC) are proposed and successfully fabricated. The strongly GC-DFB laser is monolithically integrated with the SA-SSC with three-step epitaxies. A high single mode yield and large side mode suppression ratio is obtained from the strongly GC-DFB laser. A near circle far field pattern is obtained by using the SA-SSC.

Key words: strongly gain-coupled DFB laser; spot-size-converter; monolithic integration
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1 Introduction

The highly asymmetric elliptical beam profile from conventional semiconductor laser diodes is mainly responsible for the large coupling loss when the diode is coupled into a single mode fiber (SMF). Various techniques and structures have been developed for increasing the coupling efficiency, especially the proposed vertical, lateral and combined "papery" structures, which are crucial for realizing low loss optical mode conversion inside a laser cavity. But, the fabrication process is relatively complicated.

For high-speed optical fiber transmission, a single longitudinal mode light source is needed. Various coupled grating structures have been proposed for achieving single longitudinal mode high yield, narrow linewidth and side mode large suppression ratio (SMR)\textsuperscript{10-12}, especially strongly gain-coupled (GC) DFB laser\textsuperscript{13-15}. There are also many reports about different coupling mechanism DFB/DBR lasers and their integrated devices in China\textsuperscript{16-19}, however, most of them are weakly coupled ones. In this paper, we propose and demonstrate a strongly GC-DFB laser integrated with a self-alignment spot-size converter (SA-SSC) for the first time.

2 Design and Fabrication

The schematic diagram of the strongly GC-DFB monolithically integrated with SA-SSC is shown in Fig. 1. The laser waveguide structure

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consists of double InGaAsP waveguide layers—a 180nm thick optical passive waveguide layer ($\lambda=1.2\mu m$) at the bottom and an active waveguide layer for $1.55\mu m$ emission on the top. The active layer contains seven 6nm thick 0.7% compressively strained wells ($\lambda=1.6\mu m$) separated by 9nm thick lattice-matched barriers ($\lambda=1.2\mu m$). The MQWs are sandwiched with undoped separate confinement heterostructure (SCH) layers ($\lambda=1.2\mu m$). The first order Bragg grating with a 242nm period and 70nm depth is formed on the top SCH layer by convenient holographic lithography, dry-etching and wet-chemical etching. Due to the 40nm thick top SCH layer, at least 2 wells are partly etched off to form the period gain corrugation, which is in accord with the strong index corrugation.

A thin spacing layer is then grown on the top of the corrugation. And then, the spacing layer and the relevant active layer are partially removed off by using the selective etching to form a vertical taper on the mask-free section of the wafer. After removing the mask off, an etching-stop layer, a p-InP cladding layer and a p'-InGaAs contact layer are then successively grown on the surface of the wafer. All the material is grown with low-pressure MOCVD. The normal ridge waveguide and electrodes are formed by standard techniques. Figure 2 is the scanning electron micrograph (SEM) picture of this device. The strongly gain-coupled grating, the taper and the bottom passive waveguide can be seen clearly in Fig. 2.

**FIG. 2** SEM Picture of the Strongly GC-DFB+ SA-SSC

**3 Results**

Figure 3 shows the CW $L$-$I$ characteristics of a $600\mu m$ long strongly GC-DFB+ SA-SSC laser chip. The active and the passive section lengths are both $300\mu m$. The threshold current is $52mA$, and larger than that of the normal lasers due to small optical confinement factor of the active layer, low carrier injection efficiency and large internal loss caused by the thick active layer. And an optimized SCH waveguide layer, optimized active layers and the optimized regrowth procedure will be helpful for reducing the threshold current. With different length SA-SSC, the integrated devices have no obvious different threshold currents nor different slope efficiencies, which means that the insertion loss of the bottom waveguide is very small and has
little affection on the device characteristics.

The lasing spectrum of the strongly GC-DFB laser is shown in Fig. 4 (a) and the lasing spectrum of the normally index-coupled (IC) DFB laser is shown in Fig. 4 (b) for comparison. It can be seen clearly from Fig. 4 that the side mode is strongly suppressed in strongly GC-DFB laser due to the introduced gain-coupled mechanism and the \( \sim 3.5 \) in-phase index-coupled strength (product of the coupling constant and the cavity length). The gain couple constant is dependent on the number of the etched quantum wells (QW's) and in our case, the gain corrugation is formed by the etched two QW's in the total seven QW's, therefore, the gain couple constant is larger than that of the injection current grating. The stop-band, appeared in the normally IC-DFB laser amplified spontaneous emission (ASE) spectrum, can't be observed from the strongly GC-DFB laser ASE spectrum. The strongly GC-DFB is also quite different from the loss-coupled or anti-phase gain-coupled DFB laser and shows good characteristics\(^{[4]}\), such as a narrower linewidth and a higher single mode yield than the index-coupled DFB laser, therefore, it is more suitable for applications in the integrated light source. In our experiments, the strongly GC-DFB laser with cleaved facets has a high single mode yield, but a similar single mode yield for the normally IC-DFB laser can only be obtained with an asymmetrical coating.

![Lasing Spectra of (a) the Strongly Gain-Coupled DFB and (b) the Index-Coupled DFB Lasers](image)

The beam divergence angles (BDA) at FWHM of the strongly GC-DFB laser without any SA-SSC, shown in Fig. 5(a), were 15° and 43° respectively in the directions in parallel with and perpendicular to the junction plane. By using the bottom SCH layer as the passive SSC, the light emitted from the laser region can be easily coupled into the bottom passive SSC without any complex or special shape structures\(^{[1-7]}\) and the fabrication procedure is just one-step selective wet-chemical etching. The light distribution perpendicular to the junction plane is transformed then and so does the BDA. With a 300\( \mu \)m long passive waveguide, only one mode appears in the far field and the BDA at FWHM, as shown in Fig. 5(b), is reduced to 20°×30°. And a further narrow and circular BDA will be obtained with a thinner bottom waveguide. In our case, the coupling efficiency between the laser and the SSC is about 85% from calculation. For such a near circle beam profile, the coupling loss between the laser and the SMF can be reduced. Therefore, this type mode transfer is useful in packaging the optoelectronic device with the SMF.
4 Conclusion

A strongly gain-coupled DFB laser accompanied with large index-coupling strength is successfully fabricated with periodically etched quantum wells. A high single mode yield and a large side mode suppression ratio is obtained from this strongly GC-DFB laser. And a self-alignment mode transfer is successfully demonstrated while integrated with a strongly GC-DFB laser. The far field profile of this laser is changed from an asymmetric elliptical pattern to a near circle.

References


强增益耦合 DFB 激光器单片集成自对准模式变换器

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摘要：提出并成功制作出一种新型的强增益耦合 DFB 激光器与自对准模式变换器单片集成器件。采用三次外延实现上述器件。采用强增益耦合 DFB 激光器，获得了高单模成品率和大边模抑制比器件；采用自对准模式变换器，得到了近圆形的远场图样。

关键词：强增益耦合 DFB 激光器；模式变换器；单片集成

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