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

LIU Guo-li, WANG Wei, ZHU Hong-liang, ZHANG Jing-yuan, ZHOU Fan, WANG Xiao-jie and HU Xiao-hua

(*National Research Center for Optoelectronic Technology, Institute of Semiconductors, The Chinese Academy of Sciences, Beijing* 100083, *China*)

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
EEACC: 4320J; 4270; 4130
CLC number: TN248.4　　**Document code**: A　　**Article ID**: 0253-4177(2001)07-0832-05

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 "tapers" structures[1—7], 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 (SMSR)[8—12], especially strongly gain-coupled (GC) DFB laser[13—15]. There are also many reports about different coupling mechanism DFB/DBR lasers and their integrated devices in China[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

* Project Supported by National High Technology ("863") Program (Grant No. 863-307-11-1(15)) and National Natural Science Foundation of China (Grant No. 69896260).

LIU Guo-li　PhD student. His interest includes: strained InGaAsP/InP MQW selective area grown with LP-MOCVD, high speed electroabsorption modulated DFB laser, tunable single longitudinal mode semiconductor lasers, high speed lasers and electroabsorption modulators, photonic integrated circuits etc.

Received 28 December 2000, revised manuscript received 23 March 2001　

consists of double InGaAsP waveguide layers—a 180nm thick optical passive waveguide layer (λ= 1.2μm) at the bottom and an active waveguide layer for 1.55μm emission on the top. The active layer contains seven 6nm thick 0.7% compressed-strained wells (λ= 1.6μm) separated by 9nm thick lattice-matched barriers (λ= 1.2μm). The MQWs are sandwiched with undoped separate confinement heterostructure (SCH) layers (λ= 1.2μm). 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.

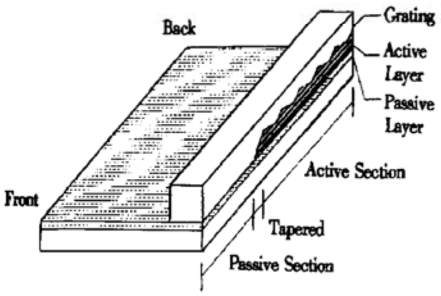

FIG. 1 Schematic Diagram of the Strongly GC-DFB+ SA-SSC

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.

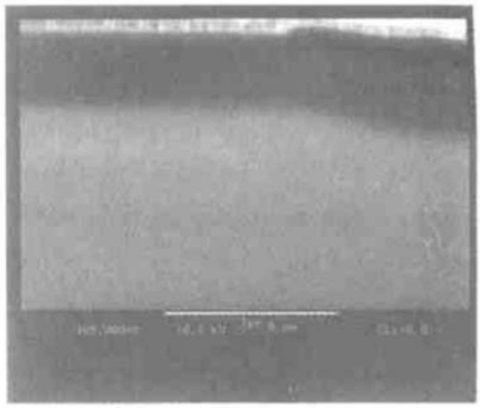

FIG. 2 SEM Picture of the Strongly GC-DFB+ SA-SSC

3 Results

Figure 3 shows the CW *L-I* characteristics of a 600μm long strongly GC-DFB + SA-SSC laser chip. The active and the passive section lengths are both 300μm. 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

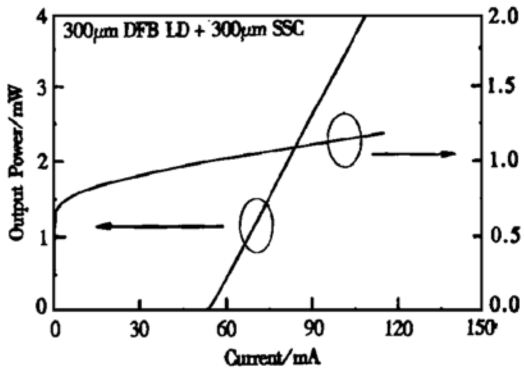

FIG. 3 Typical *L-I* Curve of the Strongly GC DFB LD+ SSC

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 ~ 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[14], 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.

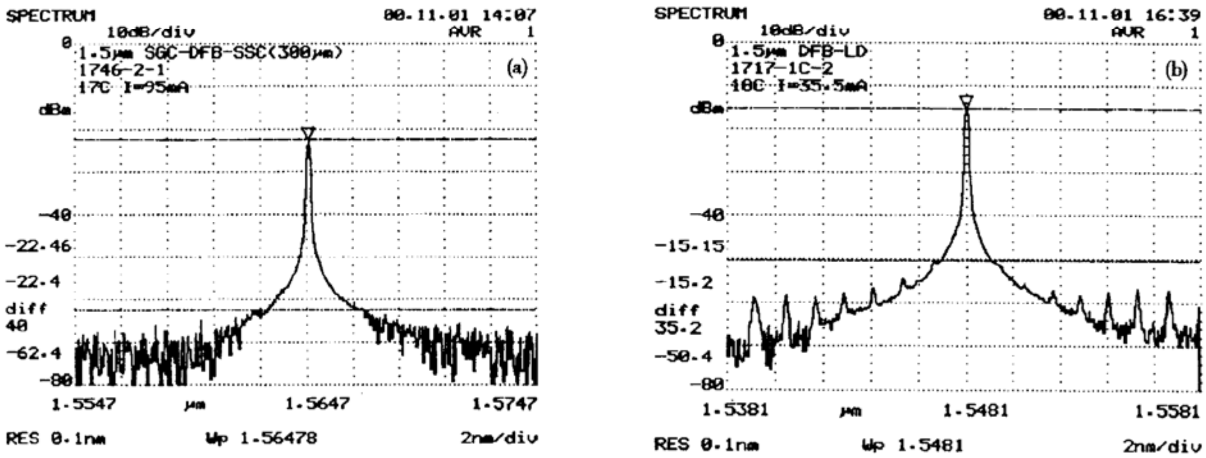

FIG. 4 Lasing Spectra of (a) the Strongly Gain-Coupled DFB and (b) the Index-Coupled DFB Lasers

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 300μm 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 circuler 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.

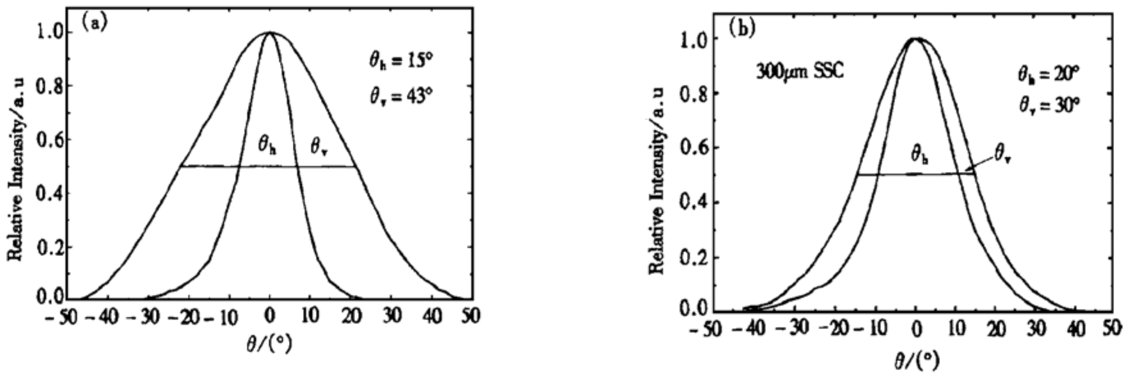

FIG. 5 Beam Divergence Angle in Horizontal (θ_h) and Vertical (θ_v) Directions of the Laser (a) Without SSC, (b) with 300μm SSC

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

[1] J. V. Collins, M. Dagenais and M. Itoh, Introduction to the Issue on Alignment Tolerant Structure for Ease of Optoelectronic Packaging, IEEE J. Selected Topics in Quantum Electron., 1997, **3**(6): 1306—1308.

[2] H. Kobayashi, M. Ekawa, N. Okazaki *et al.*, Tapered Thickness MQW Waveguide BH MQW Laser, IEEE Photon. Technol. Lett., 1994, **6**(9): 1080—1081.

[3] T. L. Koch, U. Koren, G. Elsenstein *et al.*, Tapered Waveguide InGaAs/InGaAsP Multiple-Quantum-Well Lasers, IEEE Photon. Technol. Lett., 1990, **2**(2): 88—90.

[4] R. B. Michael, U. Koren, B. I. Miller *et al.*, InP-Based Multiple Quantum Well Lasers with an Integrated Tapered Beam Expander Waveguide, IEEE Photon. Technol. Lett., 1994, **6**(12): 1412—1414.

[5] P. Doussiere, P. Garabedian, C. Graver *et al.*, Tapered Active Stripe for 1.5μm InGaAsP/InP Multiple Quantum Well Lasers with Reduced Beam Divergence, Appl. Phys. Lett., 1994, **64**(5): 539—541.

[6] H. Jeon, A. Mathur and M. Ziari, High Power Narrow Divergence DFB Laser Diode at 1.55μm, Electron. Lett., 1998, **34**(13): 1313—1315.

[7] T. Brenner, R. Hess and H. Melchior, Compact InGaAsP/InP Laser Diodes with Integrated Mode Expander for Efficient Coupling to Flat-Ended Singlemode Fibres, Electron. Lett., 1995, **31**(17): 1443—1445.

[8] J. Buss, Mode Selectivity in DFB Lasers with Cleaved Facets, Electron. Lett., 1985, **21**(5): 179—180.

[9] J. Kinoshita and K. Matsumoto, Yield Analysis of SLM DFB Lasers with an Axially-Flattened Internal Field, IEEE J. Quantum Electron., 1989, **25**(6): 1324—1332.

[10] Y. Luo, Y. Nakano, T. Tada *et al.*, Purely Gain-Coupled Distributed Feedback Lasers, Appl. Phys. Lett., 1990, **56**(17): 1620—1622.

[11] W. T. Tsang, F. S. Choa, M. C. Wu *et al.*, Semiconductor Distributed Feedback Lasers with Quantum Well or Superlattice Gratings for Index-or Gain-Coupled Optical Feedback, Appl. Phys. Lett., 1992, **60**(21): 2580—2582.

[12] Yidong Huang, Tetsuro Okuda, Kazuhiro Shiba *et al.*, High-Yield External Optical Feedback Resistant Partially Corrugated Waveguide Laser Diodes, IEEE J. Selected Topics in Quantum Electron., 1999, **5**(3): 435—441.

[13] A. Talneau, J. Charil and A. Ougazzaden, Very Low Threshold and High Power CW Operation in 1.55μm Gain-Coupled DFB Lasers with Periodically Etched Quantum Wells, Electron. Lett., 1997, **33**(22): 1881—1883.

[14] J. Hong, C. Blaauw, R. Moore *et al.*, Strongly Gain-Coupled (SGC) Coolerless (−40℃—+85℃) MQW DFB Lasers, IEEE J. Selected Topics in Quantum Electron., 1999, **5**(3): 442—448.

[15] D. M. Adams, C. Rolland, J. Yu *et al.*, Gain-Coupled DFB Integrated with a Mach-Zehnder Modulator for 10Gbits/s Transmission at 1.55c over NDSF, Proceedings of SPIE, 1997, **3038**: 45—54.

[16] ZHANG Jizhi, WANG Wei, ZHANG Jingyuan *et al.*, 1.27μm Partially Gain-Coupled MQW-DFB Lasers with Loss Gratings, Chinese Journal Semiconductors, 1996, **17**(3): 231—235 (in Chinese) [张济志, 王圩, 张静媛, 等, 1.27μm 吸收型部分增益耦合 MQW-DFB 激光器, 半导体学报, 1996, **17**(3): 231—235].

[17] CHEN Bo, WANG Wei, ZHANG Jingyuan *et al.*, 1.3μm InGaAsP/InP Strained MQW Complex-Coupled DFB Lasers, Chinese Journal Semiconductors, 1998, **19**(10): 793—797 (in Chinese) [陈博, 王圩, 张静媛, 等, 1.3μm InGaAsP/InP 应变多量子阱部分增益耦合 DFB 激光器, 半导体学报, 1998, **19**(10): 793—797].

[18] LUO Yi, WEN Guopeng, GAN Yunong *et al.*, 1.55μm InGaAsP/InP Strained MQW Gain-Coupled DFB Laser with an Improved Injection-Carrier Grating, Chinese Journal Semiconductors, 1999, **20**(4): 274—277 (in Chinese) [罗毅, 文国鹏, 甘雨农, 等, 含新型载流子注入光栅的 1.55μm InGaAsP/InP 应变多量子阱 DFB 激光器, 半导体学报, 1999, **20**(4): 274—277].

[19] LIU Guoli, ZHANG Jingyuan, WANG Xiaojie *et al.*, Tunable DBR Laser Fabricated by Selective Area Growth Technique, Chinese J. Lasers, 2000, **B9**(5): 395—399.

强增益耦合 DFB 激光器单片集成自对准模式变换器*

刘国利 王 圩 朱洪亮 张静媛 周 帆 汪孝杰 胡小华

(中国科学院半导体研究所 光电子国家工艺中心, 北京 100083)

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

EEACC: 4320J; 4270; 4130

中图分类号: TN248.4 **文献标识码**: A **文章编号**: 0253-4177(2001)07-0832-05

* 国家"八六三"高技术计划(No. 863-307-11-1(15))和国家自然科学基金资助项目(No. 69896260).

刘国利 博士研究生. 主要工作包括: 采用 LP-MOCVD 选择区域生长 InGaAsP/InP 应变多量子阱材料、高速电吸收调制 DFB 激光器、可调谐单纵模半导体激光器、高速激光器和电吸收调制器及光子集成器件等.

2000-12-28 收到, 2001-03-23 定稿