

Monolithic Integration of Electro-Absorption Modulators and DFB Lasers by Modified Double Stack Active Layer Approach*

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Abstract: Monolithic electro-absorption modulated distributed-feedback (DFB) lasers are proposed and fabricated by using a modified double stack active layer. The 38mA threshold, 9dB extinction ratio (from 0.5V to 3.0V), and about 5mW output power at the 100mA operation current are achieved. Compared with other reported results (only 1.5mW at the same operation current) of the traditional stack active structure, the proposed structure improves the output power of devices.

Key words: multiple quantum wells; electro-absorption modulators; distributed-feedback lasers; monolithic integration

EEACC: 2520D; 2550B; 4320J

CLC number: TN248.4

Document code: A

Article ID: 0253-4177(2004)05-0481-05

1 Introduction

Electro-absorption modulators are getting more and more attractive in both digital and analog high-speed fiber-optic links because of its advantages over other optical modulators including directly modulated lasers and LiNbO₃ Mach-Zehnder external modulators. The multi-quantum wells (MQWs) design utilizing the quantum confined stark effect (QCSE) has a low driving voltage and high-speed performance^[1~3]. Especially, an electro-absorption modulated DFB laser (EML) is the

most practical device because the high coupling efficiency between the EAM and DFB-LD is achievable in the integrated structure. In addition, the compactness of the device results in lower packaging costs.

One of the important parameters having strong effect on the EML chip performance is the wavelength detuning ($\Delta\lambda$) between the absorption band edge wavelength (λ_{EAM}) of unbiased EAM and the lasing wavelength ($\lambda_{\text{LD-Bragg}}$) of DFB laser diode. Usually, λ_{EAM} is 40~60nm blue-shifted away from λ_{LD} . In order to obtain a desired $\Delta\lambda$, several monolithic integration techniques^[4] have been used

* Project supported by State Key Development Program for Basic Research of China (No. G20000683-1) and National Natural Science Foundation of China (No. 90101023)

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Received 19 November 2003, revised manuscript received 9 January 2004

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in studies reported previously, including selective area growth (SAG)^[5], butt-coupling^[6], quantum well intermixing (QWI)^[7], identical active layer (IAL)^[8], double stack active layer (DSAL)^[9], and twin-guide structure (TGS)^[10] as well. Among them, the DSAL scheme, at the same time, bears the advantages of independent optimization of the active structures of both the laser and the modulator, as for the butt-coupling technique, and processing simplicity, as for the IAL approach. However, EML chips fabricated by the traditional identical DSAL^[9] usually can emit very small power (about 1.5mW at 1.55 μ m wavelength at 100mA current) with zero bias voltage on EAMs owing to the absorption loss of laser active structure contained in the modulator section.

In order to increase the output power of the devices, we present a type of modified structure based on the DSAL for the first time. The key point is to reduce the absorption loss by removing the upper MQWs layer in the modulator region. Some original results demonstrated the modified DSAL approach had overcome the disadvantage of the traditional DSAL mentioned above.

2 Design and fabrication

The schematic diagram of EML devices using modified DSAL method is shown in Fig. 1. All material growth in this study were carried out by horizontal low-pressure metal organic chemical vapor deposition (LP-MOCVD) in AXTRON200 system. The double stack active structure including buffer n-InP, n-lower separate confining layer (SCL) (0.1 μ m-thick matched InGaAsP, λ_g = 1.2 μ m), lower MQWs, InP undoped space layer, upper MQWs, and 0.15 μ m-thick InP as a protecting layer, were grown on (100) n⁺-InP substrate in the first epitaxial step. The lower MQWs acting as absorption region of modulators consists of eight 10nm-thick InGaAsP wells (– 0.35% tensile strain, λ_g = 1.54 μ m) separated by seven 7nm-thick InGaAsP barriers (0.4% compressive stain, λ_g =

1.15 μ m). And the upper MQWs, as the gain area of laser, is composed of five 6.5nm-thick wells (compressive strain = 0.5%, λ_g = 1.62 μ m) and four 10nm thick barriers (tensile strain = 0.25% and λ_g = 1.2 μ m). The thin InP layer between lower and upper MQWs was utilized as an etch-stop layer in the next process step. After the first growth, the upper MQWs localized in the modulator section was etched off down to the InP etch-stop layer by using selective wet etching. Subsequently, a 100nm thick upper SCL layer with the same composition as lower SCL and a 150nm thick InP cap layer were grown on the whole wafer.

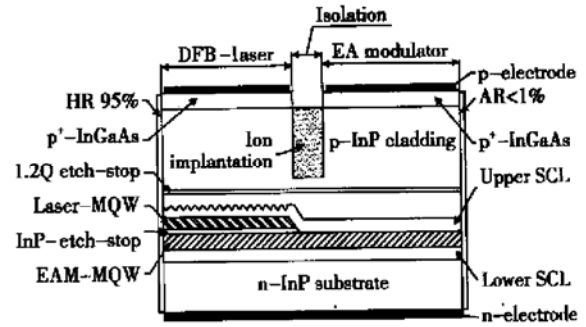


Fig. 1 Schematic view of the DMQS-EML

The first order Bragg grating with 241.4nm period and 70nm depth was formed selectively only in the laser section by convenient holographic lithography, dry-etching, and wet-etching. And then, a p-type InP cladding layer, p-type thin 1.2Q etch-stop layer, and p-type InGaAs contact layer were successively grown in the third growth process.

A simple ridge waveguide structure with 2 μ m width was realized in both the DFB laser and EA modulator section by using standard technology. Over 50k Ω isolation resistance between DFB laser and EA modulator can be achieved by etching the InGaAs contact layer in 50 μ m wide trench and using low energy He⁺ ion implantation. EML devices with 250 μ m long DFB laser sections and 170 μ m long EAM sections, high-reflection coated laser facets, and antireflection-coated EAM facets were mounted p-side up on Cu heat sinks for measurement.

3 Characteristics and discussion

In order to confirm the quality of stacked-active-layer structure, we measured the room temperature photoluminescence spectra at different process stages using micro-area photoluminescence (PL) meter. The results are illustrated in Fig. 2. Curve *a* is the PL spectrum after the first growth, from which we can see two peaks at the wavelength of $1.50\mu\text{m}$ (peak 2) and $1.57\mu\text{m}$ (peak 1) clearly, corresponding to the laser MQWs ($\lambda_{\text{EAM-PL}}$) and modulator MQWs ($\lambda_{\text{LD-PL}}$) structure, respectively. Curves *b* and *c* are the PL spectra in the modulator section and in the laser section, respectively, after upper separated confinement layer was grown. Obviously, the upper MQWs structure at the modulator section is removed off, while two peaks of two different types of MQWs structures can be clearly observed in the laser section.

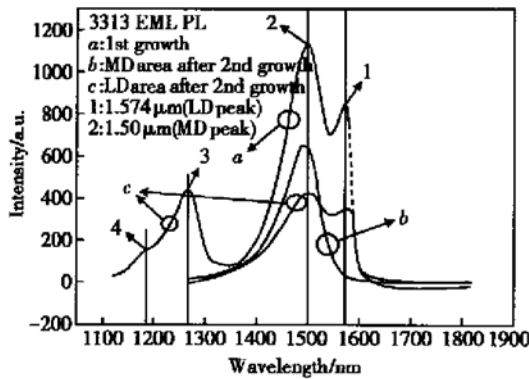


Fig. 2 PL spectra at different process stages

Figure 3 is the typical lasing spectrum of the EML chips with the modified stacked active layer structure at room temperature. The lasing peak wavelength ($\lambda_{\text{LD-Bragg}}$) is $1.583\mu\text{m}$, and side mode suppression ratio (SMSR) is about 40dB. According to the first order Bragg condition: $\lambda = 2\Lambda n_{\text{eff}}$, we can calculate the effective refractive index ($n_{\text{eff}} = 3.277$) of DFB laser section. Initial $\lambda_{\text{LD-Bragg}}$ we expected to obtain by supposing that $n_{\text{eff}} = 3.21$ prior to manufacturing the grating was $1.55\mu\text{m}$. As a re-

sult, the actual red-shifted amount of $\lambda_{\text{LD-Bragg}}$ with respect to $\lambda_{\text{LD-PL}}$ and $\lambda_{\text{EAM-PL}}$ are 8nm and 82nm, respectively. Such large detuning between $\lambda_{\text{LD-Bragg}}$ and $\lambda_{\text{EAM-PL}}$ results in small extinction ratio, which will be discussed later.

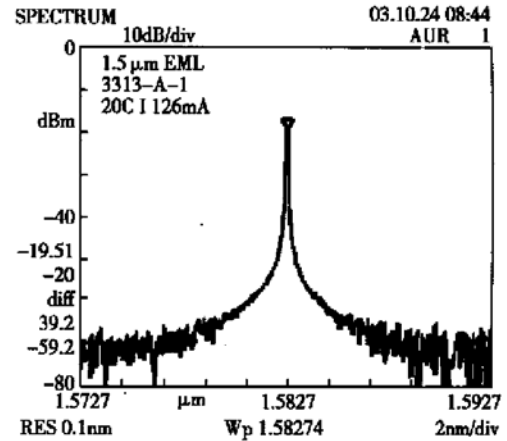


Fig. 3 Lasing spectrum of EML devices

The typical curves of output power at different applied voltage are illustrated in Fig. 4. The threshold current is about 38mA, and keeps constant when varying biased voltages applied to the

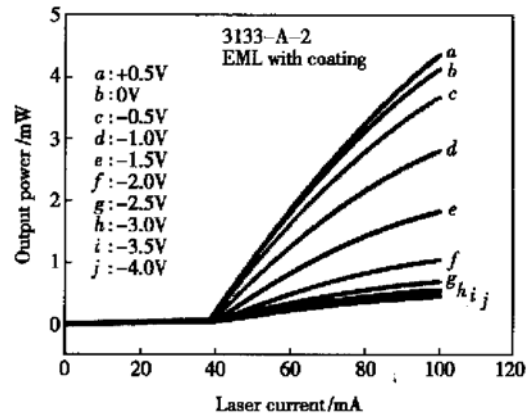


Fig. 4 $P-I$ characteristics curve at the different bias voltages applied to modulator section

modulator from positive 0.5V to negative 4V, which agrees with the high coupling efficiency of grating. The 5mW of output power from the EA modulator is realized at 100mA of driving current in the DFB laser section. Correspondingly, approximate 0.08mW/mA of slope efficiency is achieved. The typical curve of attenuation characteristics at

different bias of EA modulator is shown in Fig. 5. The static extinction ratio of this type EML device is about 9dB at the range of applied voltage from + 0.5V to - 3.0V. Stegmueller *et al.*^[9] reported in 2002 that the 1.55 μ m wavelength EML chips, of which both the laser and the modulator sections contained two MQWs structures, can output only 1.5mW power at 100mA operation current. The low output power was caused by the large absorption loss of the MQWs structure acting as laser active material in the modulator section. Therefore, our adopted structure has quite obvious effect of reducing the absorption loss to improve the output power of EML chips.

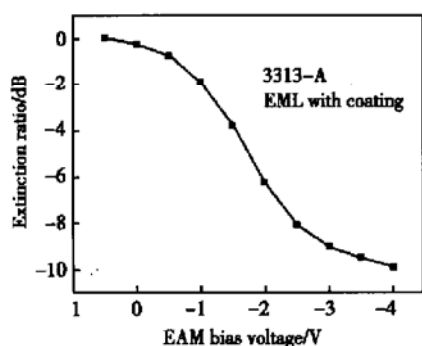


Fig. 5 Typical static extinction characteristics curve of EML chips

The high threshold current of this type of EML is attributed to two primary factors. First, the modulator MQWs layer underneath the laser MQWs layer largely reduces the optical confinement factor of laser MQWs area, captures a portion of electrons injected from n-type substrate, as well as absorbs a certain amount of photons generated in the laser active area. The second harmful influence on the threshold current is from the second epitaxial growth process, which creates a great number of defects and enhances nonradiation recombination and scattering loss. The smaller extinction ratio of EML chip may result from a rather large wavelength detuning between $\lambda_{LD-Bragg}$ and λ_{EAM-PL} . Such problems will be overcome in the near future.

4 Conclusion

In summary, monolithic electro-absorption modulated DFB lasers are proposed by a modified double stack active layer approach. Stacked two different types of multiple quantum well structures, serving as gain area of DFB laser diode and absorption area of modulator, respectively, are grown in a single growth. Furthermore, the upper MQWs layer in the modulator section is removed in order to reduce the material absorption loss. The original results demonstrated that our proposed structure has obvious advantages over the traditional stack active one. Some factors resulting in slight high threshold current and rather low extinction ratio were taken into account. And performance of the modified double stack active layer structure of EML will be improved in the future work.

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电吸收调制器和 DFB 激光器一种改进的双有源层堆积集成方法*

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摘要: 提出了一种改进型的双有源层堆积方法制作单片集成电吸收调制的 DFB 激光器, 报道了器件的制作过程和主要性能, 初步结果为: 阈值电流 38mA, 激光器在 100mA 下出光功率 4.5mW 左右, 调制器消光比约 9dB(从 +0.5V 到 -3.0V). 对比此前国外报道的具有常规双量子阱堆层结构的器件结果(出光功率仅 1.5mW), 我们制作的器件的出光功率有了明显的提高.

关键词: 多量子阱; 电吸收调制器; 分布反馈激光器; 单片集成

EEACC: 2520D; 2550B; 4320J

中图分类号: TN248.4

文献标识码: A

文章编号: 0253-4177(2004)05-0481-05

* 国家重点基础研究发展规划(批准号: G20000683-1)和国家自然科学基金(批准号: 90101023)资助项目

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2003-11-19 收到, 2004-01-09 定稿