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10Gb/s EML Module Based on Identical Epitaxial Layer Scheme*

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Abstract: A 10Gb/s transmitter module containing an electroabsorption modulator monolithically integrated with a distributed feedback (DFB) semiconductor laser is fabricated using the identical epitaxial layer scheme. Gain-coupling mechanism is employed to improve the single mode yield of the DFB laser, while inductively coupled plasma dry etching technique is utilized to reduce the modulator capacitance. The integrated device exhibits a threshold current as low as 12mA and an extinction ratio over 15dB at -2V bias. The small signal modulation bandwidth is measured to be over 10GHz. The transmission experiment at 10Gb/s indicates a power penalty less than 1dB at a bit-error-rate of 10^{-12} after transmission through 35km single mode fiber.

Key words: DFB lasers; EA modulators; photonic integrated circuit; gain-coupling
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1　Introduction

Electroabsorption (EA) modulated distributed feedback (DFB) semiconductor lasers are key devices for high-speed fiber communication systems due to their low frequency chirp, high modulation efficiency, compact size, and high reliability[1~4]. With the development of wavelength division multiplexing (WDM) technology, the bit-rate of optical fiber communication systems keeps increasing, and 10Gb/s EA modulated lasers (EMLs) are now widely used in long-haul, trunk-line applications. It is important to develop technologies to fabricate EMLs for 10Gb/s applications at a low cost while maintaining the device performance.

One of the key issues in the design and fabrication of EMLs is to realize wavelength compatibility between the lasing wavelength of DFB laser and the excitonic absorption edge of the EA modulator. Various techniques have been proposed for this purpose, including butt-joint, selective area growth, selective etching, and multiple quantum well interdiffusion[1~4]. However, many of these techniques involve multiple-step epitaxy or suffer from poor reproducibility. In our study, we have adopted a very simple integration scheme known as the identical epitaxial layer (IEL) structure in which the laser section and modulator section use the same multiple-quantum-well (MQW) structure

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as the active layer and the absorption layer, respectively. By using this very simple device structure, it is possible to reduce the fabrication process complexity while maintaining high device performance[4,5].

To increase the modulation bandwidth of an EML, the EA modulator section is often processed into a high-mesa ridge waveguide structure to reduce the device capacitance. Careful control of the ridge width is crucial to the modulation speed of the device. In our work, a high-mesa ridge waveguide with ridge width less than 3μm is formed by inductively coupled plasma (ICP) dry etching technique. Dry etching provides not only good reproducibility and dimensional control, but also highly anisotropic etching profile, which is ideal for the fabrication of narrow high-mesa ridge waveguide with a vertical sidewall. Compared with reactive-ion-etching (RIE), ICP allows high-density plasma at a low bias, thus reducing the surface damage of etched material. This makes ICP dry etching technology very suitable for the fabrication of optoelectronic devices.

In this letter, we report a 10Gb/s transmitter module containing an EA modulator integrated with a DFB laser. The device structure, fabrication procedure, and device performance are presented.

2 Device fabrication

Figure 1 depicts the schematic of our IEL integrated device, which requires two-step metal-organic chemical-vapor-deposition (MOCVD) growth. During the first growth, n-InP buffer layer, lower guiding layer, MQW active layer, and upper guiding layer were grown on the n^+-InP substrate successively. The MQW structure consists of 5 pairs of 10nm thick 0.84% compressively strained InGaAsP well and 10nm thick lattice-matched InGaAsP barrier (λ_{PL} = 1.25μm), sandwiched between two 120nm thick InGaAsP guiding layers (λ_{PL} = 1.25μm). An additional n-InP carrier-blocking layer was grown on the top of the upper guiding layer for the implementation of carrier-induced gain-grating so as to utilize gain coupling to improve the device performance[6]. First-order grating was then formed in the DFB region by etching through the carrier-blocking layer and part of the upper guiding layer, while the n-InP layer above the modulator region was selectively removed simultaneously.

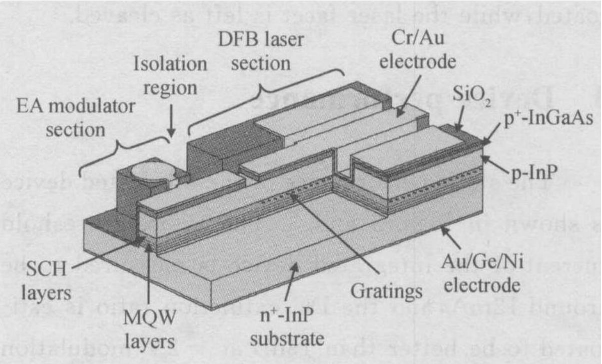

Fig. 1 Schematic of an IEL integrated light source

The detuning between the Bragg wavelength of the grating and the excitonic absorption peak of the modulator is crucial to device performance, such as output efficiency, extinction ratio, and transmission capability[5]. The optimal wavelength detuning is closely related to the MQW structure. According to the measured photocurrent data and the simulated transmission capacity of an IEL integrated light source, the optimal detuning value for our IEL devices is found to be around 40nm[7,8].

During the second growth, a p-InP cladding layer and a p^+-InGaAs contact layer were successively grown on the top of the wafer. After MOCVD regrowth, the wafer is processed into device chips. The laser section of our integrated device is processed into a standard ridge waveguide structure, in which reverse mesa has been adopted to improve electrode contact and thermal characteristics[9]. A 3μm wide high-mesa ridge waveguide structure is formed in the modulator section by ICP dry etching. To further reduce the device capacitance, a 2μm thick SiO_2 insulation layer is deposited by plasma-enhanced chemical-vapor-deposition (PECVD) beneath the bonding pad.

The lengths of the DFB laser section and the EA modulator section are 400 and 100μm, respectively, with a 40μm wide isolation region formed by removing the contact layer and the electrode in between. The typical isolation resistance is measured to be more than 15kΩ. To suppress the optical feedback due to the modulator output facet reflection, the modulator facet is anti-reflection (AR) coated, while the laser facet is left as cleaved.

3 Device performance

The static performance of the fabricated device is shown in Figs. 2 and 3. The typical threshold current of the integrated device is measured to be around 12mA, and the DC extinction ratio is estimated to be better than 16dB at -2V modulation bias. It is seen that IEL light sources with excellent device performance can be fabricated by optimizing the wavelength detuning. Meanwhile, as a result of the gain-coupling mechanism incorporated into the device, the integrated devices exhibit excellent single mode performance, and the typical side-mode-suppression-ratio is measured to be over 40dB.

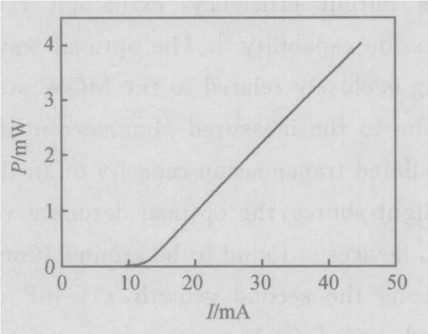

Fig. 2 P-I curve of the integrated light source

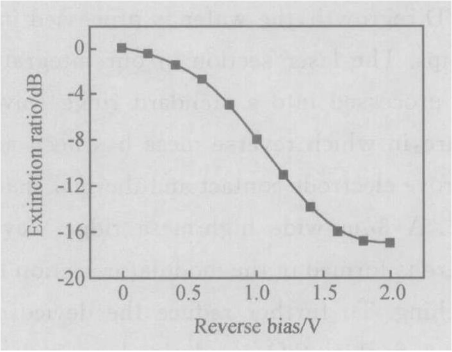

Fig. 3 Extinction ratio versus modulation bias The injection current into the DFB laser section is 30mA.

To measure the small signal modulation bandwidth, the integrated device chip was mounted onto an AlN submount, which contains a 50Ω thin-film resistor connected in parallel with the EA modulator for impedance matching. The microwave signal from an Agilent 8722 network analyzer was fed to the EA modulator section of the integrated device through a cascade ACP40 on-wafer probe. The modulated optical signal was converted into microwave signal by an Agilent 11982A lightwave converter and sent back into the network analyzer. The measured small signal response at a DC bias of -1V is shown in Fig. 4(a), which indicates a 3dB electrical bandwidth over 10GHz.

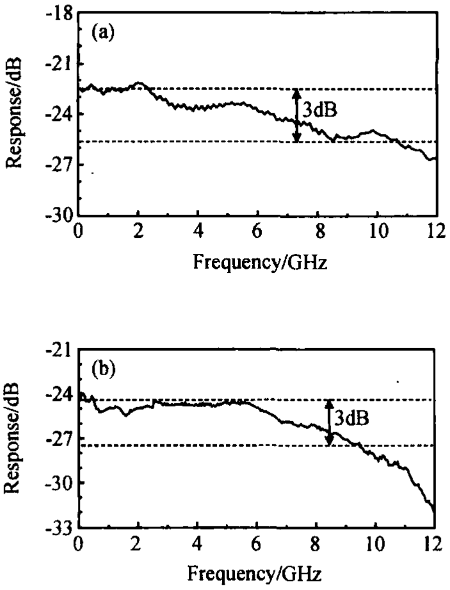

Fig. 4 Small signal frequency response of the EML before (a) and after (b) packaging The DC bias applied to the EA section is -1V.

The integrated device chip was then packaged into a compact module, which contains the EML chip on submount, an optical coupling lens system, an optical isolator, a monitor photodiode, and a temperature control unit. The module is attached with a single-mode fiber pigtail, and a K-connector is used for high-frequency modulation signal input. The optical power coupled from the pigtail is greater than 0.5mW at an injection level of 60mA. The small signal frequency response of the packaged module is shown in Fig. 4 (b). A 3dB electrical bandwidth over 9 GHz can be secured, which is sufficient for 10 Gb/ s operation.

Transmission experiment at 10 Gb/ s was carried out to test the large signal modulation performance of the transmitter module. A 10 Gb/ s pseudorandom nonreturn-to-zero (NRZ) signal from an Advantest D3186 pattern generator was applied to the integrated light source module. Figure 5 are the eye diagrams before and after transmission measured with a Tektronix CSA8000 communications signal analyzer. The bit-error-rate (BER) performance is summarized in Fig. 6. After transmission through 35km single-mode-fiber, the module exhibits a power penalty is less than 1dB at BER = 10^{-12}.

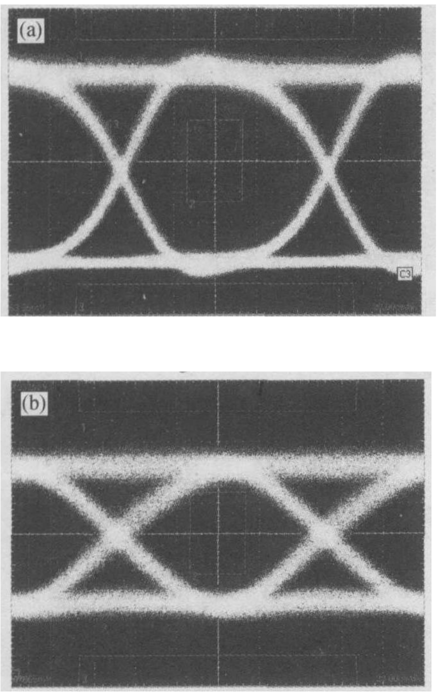

Fig. 5　Eye diagrams under 10 Gb/ s NRZ modulation
(a) Back-to-back; (b) After 35km transmission through single mode fiber　The modulation voltage swing and the DC bias are 2 and - 1V, respectively.

4　Conclusion

We have successfully developed a compact module containing an electroabsorption modulator monolithically integrated with a DFB laser for 10 Gb/ s optical transmission systems. By adopting the IEL integration scheme, the fabrication process of the integrated light source is greatly simplified. Excellent single-mode operation is realized by taking advantage of gain-coupling mechanism. To reduce the device capacitance, ICP dry etching technique has been used in device fabrication. The fabricated device shows good DC performance and a small signal modulation bandwidth over 10 GHz. Clear eye opening has been demonstrated under 10 Gb/ s NRZ modulation. After transmission through 35km single mode fiber, the power penalty is measured to be less than 1dB at BER = 10^{-12}. The module is believed to have great potential for future application in 10 Gb/ s optical fiber transmission systems because of its simplicity and cost effectiveness.

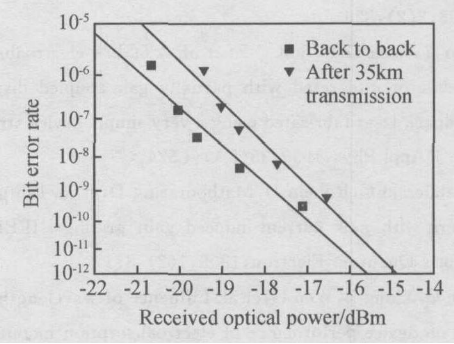

Fig. 6　Bit-error-rate performance of the EML module

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基于同一外延层结构的10Gb/s单片集成光发射模块*

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摘要: 利用同一外延层集成工艺方法制作了10Gb/s电吸收调制器/分布反馈(DFB)半导体激光器单片集成光发射模块.在器件中引入增益耦合机制以提高单模成品率,并采用感应耦合等离子体干法刻蚀技术以降低调制器电容.集成器件阈值电流为12mA,在-2V偏置时的消光比为15dB,器件的小信号调制带宽超过10GHz.在10Gb/s调制速率下经过35km单模光纤传输后,误码率为10^{-12}时的功率代价小于1dB.

关键词: 分布反馈激光器; 电吸收调制器; 光子集成回路; 增益耦合
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