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Monolithic Integration of MQW DFB Laser and EA Modulator in 1.55μm Wavelength*

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Abstract The design and fabrication of 1.55μm wavelength Multiple Quantum Well (MQW) Distributed Feedback (DFB) laser integrated with electroabsorption modulator is reported. A static single longitudinal mode output power greater than 6mW in free space is obtained, with 0V bias to the 150μm length modulator and an extinction ratio of up to 11dB at 4V at 100mA operation current of 300μm length DFB laser. The modulator side and DFB laser side are coated with Antireflcetion (AR) and Highreflection (HR) coating respectively. The threshold current of DFB laser is about 16mA and the side mode suppression ratio is always greater than 35dB when the reverse bias voltage of the modulator is varied from 0V to 4V.

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1 Introduction

Multiple Quantum Well (MQW) Electroabsorption (EA) modulator integrated with Distributed Feedback (DFB) laser is full of promise for long-haul, broad-band optical fiber transmission system and optical networks. Firstly, using it as the transmitter of a system the signal transmission distance, which is bite error-free, is much longer than the one using DFB laser as transmitter, for the wavelength chirp of the former is smaller than that of

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direct modulation of DFB laser. At present, penalty-free 10Gb/s transmission over 100km of standard fiber at 1.55μm have been achieved with this external modulating light source[1]. Next, in comparison with $LiNbO_3$ Mach-Zehnder modulators, MQW InGaAsP/InP electroabsorption modulator offers long term stability, compactness, and less vulnerability to self-phase-modulation. In addition, the EA modulator integrated with DFB laser is a very attractive option because of the very low laser to modulator insertion loss and the reduction in packaging effort compared to external modulator. Finally, it is also used as ultra short optical pulse source with variable repetition rate when driving EA modulator by harmonic voltage and the time-bandwidth product of the optical pulse equals to 0.32 and it is very close to the 0.315 of the $sech^2$ pulse shape[2]. Its pulse width is maintained well over 6000km transmission in the recirculating loop experiment[3,4]. Therefore, it is an important light source for full optical network.

To match the band-gap between EA modulator and DFB laser, several kinds of techniques have been devised for this purpose, such as, respective epitaxy of DFB laser and EA modulator[5~8]; band-gap energy control selective area Metalorganic Chemical Vapor Deposition (MOCVD)[9]; vertical mode coupling[10], selective quantum-well area intermixing[11]; and identical active layer approaches[12,13]. In this letter, we report the Quantum Well (QW) structure, its characteristics, and the process of EA modulator integrated with DFB laser by respective epitaxy method.

2 Device Structures

The DFB laser active layer consists of six pairs of strained InGaAsP MQW with 0.8% compression strain, the well is of 7.0nm thick and the barrier is of 13nm thick InGaAsP with tensile strain for strain compensation. The absorption layer of the EA modulator consists of ten pairs of strained InGaAsP MQW with a photoluminescence wavelength of 1.49μm, the well is of 9nm thick InGaAsP with 0.5% compression strain, while the barrier is tensilly strained for stress compensation, and its thickness is 6nm. DFB laser length is 300μm and EA modulator length is 150μm, and the distance between them is 50μm. The advantage of respective epitaxy structure lies in that the QW strain amount, number, and well and barrier's thickness may be optimized independently for DFB laser and EA modulator.

3 Fabricating Process

The wafers for the integrated devices are grown by four-step Low Pressure (LP) MOCVD. First of all, first-order corrugation of period about 240nm is formed on the upper waveguide layer by using two beam holographic exposure, Reactive Ion Etching (RIE) and chemical etching. Then, p-InP cladding layer is grown by LP MOCVD at a growth temperature of 650℃. Next, MQW EA modulator is grown after removing the laser MQW layer at the EA modulator position. The fourth step is to form mesa by RIE and bury it with reverse p-n junction. RIE can create almost vertical walls and yield the etched pattern and dimension uniquely defined by that of the mask since it is insensitive to crystallographic orientation without wet etching problems such as etching dependence on material composition and crystallographic orientation and mask undercutting. The final step of epitaxy is to grow the p-InP up-cladding layer and the p^+-InGaAs ohmic contact layer.

4 Experimental Results

Figure 1 shows the light-current characteristics of the device. The typical value of threshold current is 16mA and the DFB laser and modulator lengths are 300μm and 150μm respectively. Both facets of the EA modulator and DFB laser are coated with AR and HR film respectively; the reflectivity of EA modulator facet is estimated to be less than 1%, and that of DFB laser facet is more than 90%. The isolation resistance between the DFB laser and EA modulator is greater than 10kΩ. The peak power is more than 10mW with laser-driven current of 150mA when the modulator is unbiased, the attenuation ratio is -12dB when the modulator is biased at -4V at the laser injection current of 100mA. The lasing wavelength is 1.55μm and the modulator have the photoluminescence wavelength of 1.49μm.

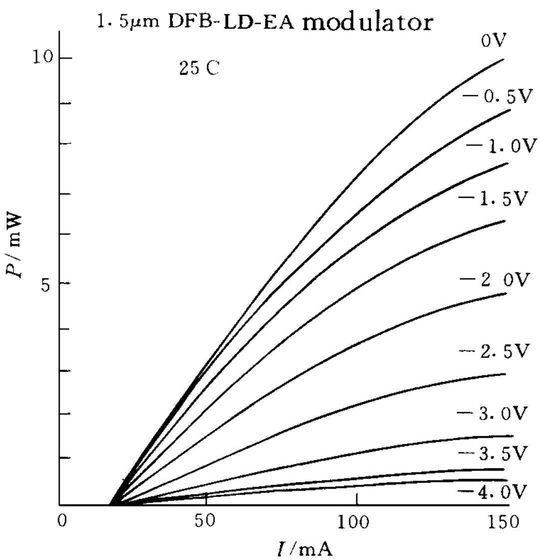

Fig. 1 L-I characteristics of a DFB laser integrated with EA modulator at different reverse bias

Figure 2 shows the attenuation characteristics of this monolithic integrated light source measured from the coupled into the tapered microlens fiber with different laser-driven currents. The residual light output at a higher voltage applied is very small and the extinction ratio is more than 20dB when the bias is changed from 0V to -4V. The extinction difference of fiber output and EA modulator's facet output at the same bias comes from separate confinement light.

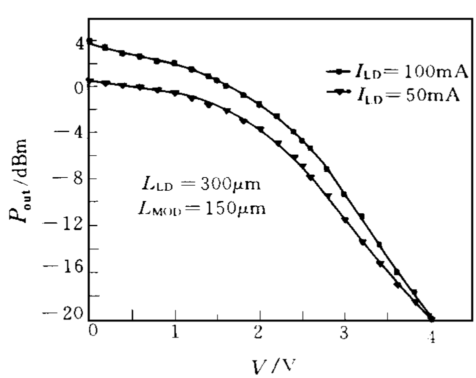

Fig. 2 Fiber output of a DFB laser integrated with EA modulator at different reverse bias

5 Summary

The waveguide structure and processing of EA modulator integrated with a DFB laser have been described. The output power of EA modulator's facet is greater than 10mW when the DFB laser is injected 150mA current with a 0V bias to the 150μm length modulator, and its extinction ratio of up to 12dB is achieved at 100mA operation current for 300μm length DFB laser with 4V bias to the modulator. The threshold current of the DFB laser is about 16mA and its side mode suppression ratio is always greater than 35dB when the reverse bias voltage of the modulator is varied from 0V to 4V and the resistance between the laser and modulator is more than 10kΩ.

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