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Monolithic Integration of DFB Laser Diode and Electroabsorption Modulator by Selective Area Growth Technology*

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Abstract In this article, first we classified the controllability of energy gap in selective area growth (SAG) technology. The red-shift of wavelength from 1.51 to 1.58μm was realized when the SiO_2 mask stripe width varied from 0 to 30μm. The monolithic integration of a distributed feedback (DFB) laser diode with an electroabsorption modulator by SAG technology was demonstrated. InGaAsP multi-quantum well structure was employed as the active layer of laser and modulator, which was grown at the same time with grating in the laser region. The static attenuation of 5dB at -2.5V was achieved.

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1 Introduction

Electroabsorption (EA) modulator, which is based on quantum-confined-Stark effect (QCSE) in quantum well structure or Franz-Keldysh (FK) effect in bulk structure, is very promising for application in long haul high-speed (GHz) fiber communication system. It offers many advantages, such as low chirp characteristics, compact, and easy integration with other semiconductor devices. Monolithic integration of EA modulator with distributed feedback (DFB) laser diode should give potential benefits of lower cost, higher output power and ease of packaging. Many studies have been reported on integration of DFB laser diode and EA modulator[1~7]. Several integration technologies have been used in previous reported papers, that is, stacked layer technology[1], butt-joint technology[2,3], selective area growth (SAG) technology[4] and identical layer technology[5,6]. One major difficulty in fabrication of photonic integration devices has been to reproduce good optical waveguide cou-

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pling between the functional elements. In previous research of butt-joint waveguide we found it was not so easy to grow high coupling efficiency waveguide[3]. The SAG technology using metalorganic chemical vapor deposition (MOCVD) has attracted much attention recently because it offers an ideal waveguide coupling between DFB laser diode and EA modulator automatically, and also because it enables to simplify fabrication procedure. This technology is based on the SAG induced growth rate enhancement and composition changes[7] in the materials of quantum well layer. In the SAG technology, the energy gap of multi-quantum well (MQW) active layer can be adjusted easily by changing the mask dimension.

In this article, we investigate the controllability of the energy gap by SAG and employ the SAG technology to integrate DFB laser diode with EA modulator. To our knowledge, this is the first time to integrate DFB laser diode and EA modulator using SAG technology in China.

2 Experiments

First, 0.2μm thick SiO_2 film was deposited on (100) S-doped InP wafer by plasma-enhanced chemical vapor deposition method. Then SiO_2 masks pattern as illustrated in Fig. 1 were formed by standard photolithography followed by chemical etching in a buffered HF solution. The width of the growth region (W_g) between SiO_2 mask was 15μm, and the width of the mask region (W_m) changed from 0 to 30μm. Then InGaAsP MQW structure was grown on a patterned substrate by low-pressure MOCVD. To obtain the energy gap at different W_m and W_g, the center part of growth region was made into stripe Fabry-Perot (FP) laser diode and the energy gap can be determined by the lasing wavelength of the laser diode. While integrating the DFB laser diode and EA modulator, the grating was partially made on the DFB laser region by using holographic technology before growing MQW structure. The thicknesses of well and barrier were 0.6 and 0.9nm, respectively, in the unmasked region. All the epitaxy growth was done on AIXTRON-200 LP-MOCVD system. The growth temperature was 650℃. The growth rate for InGaAsP was lower than 1.0μm/h.

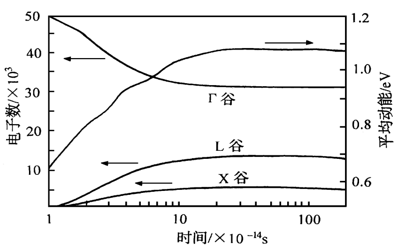

Fig. 1 Schematic diagram of mask pattern. W_g= 15μm, W_m changes from 0 (no mask) to 30μm

3 Results and discussion

3.1 Energy gap control

In this section, we discuss the controllability of energy gap by changing W_m of SiO_2 mask. The lasing wavelength of FP stripe laser diode under various W_m is shown in Fig. 2. Obviously, the lasing wavelength keeps basically linear relationship versus W_m at equal

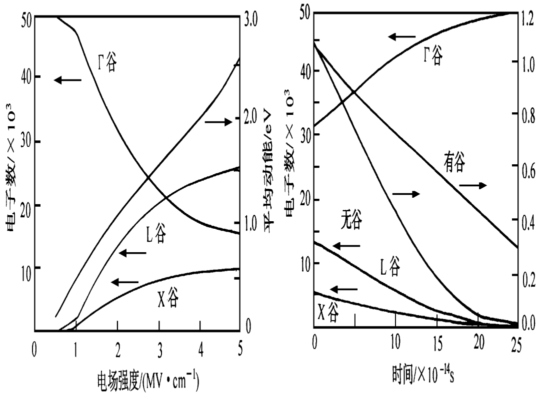

Fig. 2 Lasing wavelength of FP laser diode of different W_m, where $W_g = 15\mu m$

W_g. Larger W_m and smaller W_g lead to a larger red-shift. The wide range of controllable energy gap is attributed to the change in quantum energy level associated with different well thickness, which resulted from the growth rate enhancement and also with the difference in well layer compositions caused by diffusion supply of group Ⅲ atoms through the mask. It offers an easy method to obtain different energy gaps in different parts during simultaneous epitaxy, which has wide application in photonic device integration such as multi-wavelength laser array, spot size converter.

3.2 Monolithic integration of DFB laser diode and EA modulator

This section describes the device structure and static performance of an InGaAsP MQW EA modulator integrated with a DFB laser diode on the basis of previous section. The mask pattern employed here consists of a pair of 16μm SiO_2 stripes ($W_m = 16\mu m$) with 15μm separation ($W_g = 15\mu m$) in the laser region, while there is no SiO_2 mask in the modulator region. Partially grating with a period of 241nm was made by holography method followed by RIE dry etching. MQW of modulator consists of 6nm thick well and 9nm thick barrier; both were InGaAsP lattice matched to InP. After growing MQW structure, 2μm wide stripe was formed by standard photolithography and wet etching. The stripe was then buried with reverse p-n InP junction as current blocking layer. A 50μm wide electronic isolation groove was formed between DFB laser and EA modulator to eliminate the electric interference for EA modulator worked under reverse bias and high frequency. The isolation resistance of the etched groove is 5kΩ typically. Figure 3 shows the static attenuation ratio characteristics under different reverse bias voltages of the as-cleaved device. The attenuation ratio at reverse bias of 2.5V is -5dB. The high-frequency modulation characteristics are being measured and will be reported elsewhere.

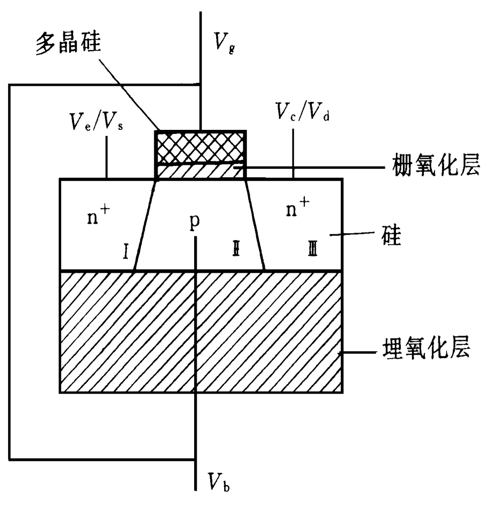

Fig. 3 Attenuation characteristics at various reverse voltages

4 Conclusion

We have demonstrated the energy gap controllability of InGaAsP MQW SAG technology by LP MOCVD. The wavelength can be changed from 1.51 to 1.58μm when W_m is changed from 0 to 30μm. SAG technology was successfully applied to the monolithic integration of EA modulator with DFB laser diode. The static attenuation ratio at reverse bias of -2.5V arrived at -5dB.

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