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Novel Structure of 1.3 μm Strained-Layer MQW Complex-Coupled DFB Lasers

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abstract

We have proposed a novel structure of 1.3 μm strained-layer multi-quantum well complex-coupled distributed feedback lasers having an InAsP loss grating. In the proposed lasers, the InAsP loss grating and the strained-layer MQW active layer can be fabricated through an only one-step metalorganic vapor phase epitaxy process. Furthermore, the fabricated laser shows low threshold current (16.8 mA) and high efficiency (0.45 mW/mA) characteristics with high side-mode suppression ratio.

1. Introduction

Distributed feedback (DFB) lasers incorporating gain-coupled mechanism, such as gain-coupled (GC) and complex-coupled (CC), have been investigated recently as the light sources in optical communication systems. Theoretical analysis and experimental results have shown their favorable characteristics,[1-4] such as higher single-mode yield, higher side-mode suppression ratio (SMSR) and lower sensitivity to optical feedback as compared to index-coupled DFB lasers. There are two ways to implement the gain coupling mechanism into semiconductor lasers. One is to make a periodicity in the gain of the active layer itself, for example, by a growth of the active layer on the corrugated layer [5] and a periodic etching of the active layer.[6] The other is by placing a loss grating to obtain a periodic change in net gain.[1,7-9] The former type does not require excessive loss, however, needs careful treatment in the formation of the corrugated active layer in order to ensure the long reliability of the lasers. On the other hand, the latter type has an advantage that the gain-coupling coefficient can be controlled through the absorption coefficient of the loss grating. Therefore, this type allows flexibility of design of the active structure. However, it is afraid that excess loss occurs the degradation in the laser characteristics, such as threshold current and efficiency, and induces self-pulsation due to the saturable absorption. In order to avoid this problem, it has been reported that a relatively small duty factor (the ratio of the loss region to the grating pitch) is required for the loss grating.[10] In previous reports, two-step crystal growth has been required to fabricate the loss grating,[1,7-9] such as the growth of the loss layer, periodic etching and the regrowth. In this process, it is difficult to control the small duty factor of the loss grating.

In this work, we propose a novel structure of 1.3 μm strained-layer (SL) multi-quantum well (MQW) CC-DFB lasers having an InAsP loss grating. The InAsP loss grating and the strained-layer MQW active layer can be grown by only one-step MOVPE process. Furthermore, the small duty factor is easily realized because the InAsP is selectively formed in the groove of the corrugation. The fabricated laser shows low threshold current, high efficiency and high SMSR.

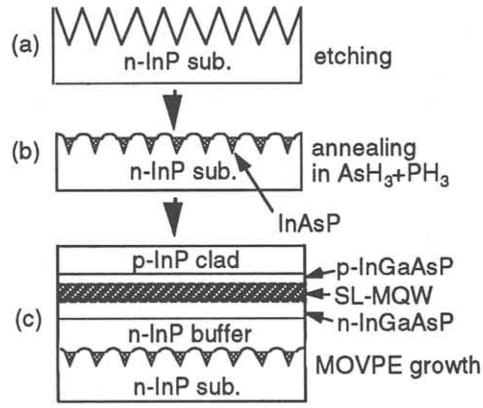

Fig. 1 Fabrication process.

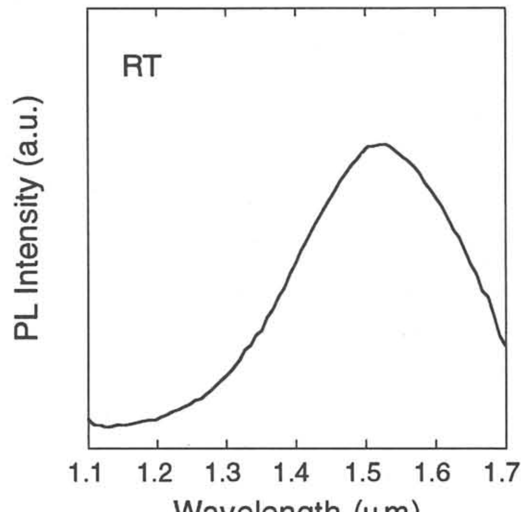

Fig. 2 PL spectrum from the corrugated substrate that has been covered by n-InP layer after annealing in the mixed atmosphere of AsH_3 and PH_3.

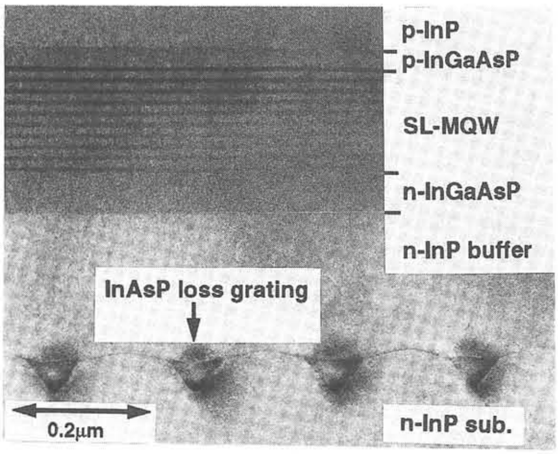

Fig. 3 TEM photograph of cross-sectional image of the fabricated structure.

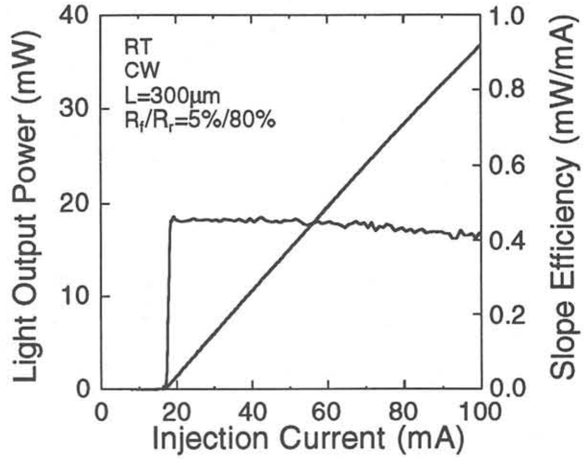

Fig. 4 L-I characteristics for the AR/HR (5%/80%) coated laser under CW operation at room temperature.

2. Fabrication

Figure 1 shows the fabrication process of the proposed 1.3 μm SL-MQW-CC-DFB lasers. At first, the first order grating has been fabricated on an n-InP substrate using conventional holographic technique as shown in Fig. 1 (a). In the next step, an InAsP grating has been selectively formed in the groove of the corrugation, by annealing the substrate with corrugation in the mixed atmosphere of arsine (AsH_3) and phosphine (PH_3) as shown in Fig. 1 (b).

Figure 2 shows the photoluminescence (PL) spectrum from the corrugated substrate that has been covered by n-InP layer after annealing in the above condition. Clear emission that has the peak at about 1.5 μm is shown in the PL spectrum. Because only emission from InP was observed from the plane substrate that has been covered by n-InP layer after annealing in the same condition, the emission in Fig. 2 is confirmed to be from the InAsP grating. We have also confirmed that the PL peak from the InAsP grating can be controlled by changing the ratio of AsH_3 and PH_3 . In this work, the InAsP grating with PL peak wavelength of 1.4 μm has been employed as the loss grating for a 1.3 μm lasing emission.

After the annealing process, the multi-layer including active layer has been grown on the substrate by MOVPE without taking out the substrate from the growth chamber as shown in Fig. 1 (c). The active layer is composed of 6 nm-thick compressively strained InGaAsP ($\Delta a/a = 0.6$ %) well layers and 10 nm-thick InGaAsP ($\lambda g = 1.05$ μm) barrier layers. The number of quantum wells (N_w) is 10. The amount of the strain was measured by double crystal X-ray diffraction. The MQW active layers are sandwiched between 50nm thick n-InGaAsP and 30nm thick p-InGaAsP separate confinement layers that have the same bandgap wavelength as that of the barrier layer. The active region is buried to form a planar buried heterostructure by liquid phase epitaxy. The active region width and the cavity length are 1.2 μm and 300 μm, respectively.

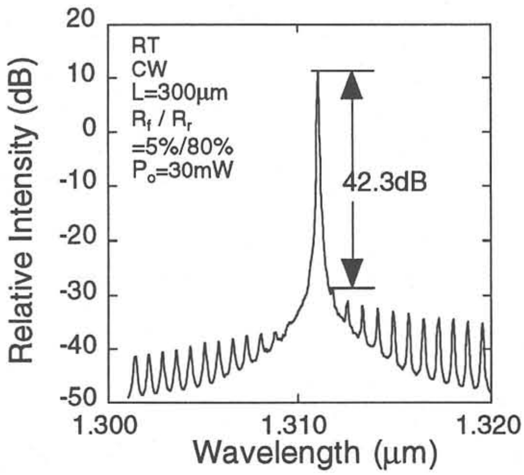

Fig. 5 CW spectrum at 30 mW for the AR/HR coated laser.

Figure 3 shows the transmission electron microscope (TEM) photograph of cross-sectional image of the fabricated structure. The InAsP loss grating is successfully formed on the n-InP substrate. From this picture, the duty factor is found to be about 0.2, which is favorable for decreasing extra loss while keeping sufficient gain-coupling coefficient.[10)]

3. Characteristics

The typical as-cleaved laser has shown a threshold current of 16.4 mA and a slope efficiency of 0.25 mW/mA under CW operation at room temperature. These values are almost the same with those of the conventional index-coupled DFB lasers. Furthermore, relatively high SMSR of more than 35dB has been realized even without facet coating. We have not observed the output level jump at threshold due to the saturable absorption. The lasing spectra exhibited asymmetric distributions with the shorter wavelength side having higher intensities. This result is consistent with theoretical prediction [11] because in this structure the gain periodicity is out-of-phase with that of the index. Figure 4 shows the typical light-injection current (L-I) characteristics for the AR/HR (5%/80%) coated laser under CW operation at room temperature. Low threshold current of 16.8 mA and high slope efficiency of 0.45 mW/mA are demonstrated. This efficiency is the highest value, as far as we know, in the long wavelength CC-DFB lasers. Figure 5 shows the CW spectrum at 30 mW for the AR/HR coated laser. High SMSR of 42.3 dB is realized. Furthermore, the L-I curve has good linearity. This high performance is thought to be resulted from the suitably controlled duty factor. These results indicate that the proposed structure is effective to obtain CC-DFB lasers with high performance.

4. Conclusions

We have proposed a novel structure of 1.3 μm SL-MQW-CC-DFB lasers having an InAsP loss grating, which can be fabricated through a simple process. In this structure, the proper duty factor can be realized easily. Furthermore, the fabricated laser shows low threshold current (16.8 mA) and high efficiency (0.45 mW/mA) characteristics with high SMSR.

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