Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 1035-1037

Extremely Low Bias Current Operation of 1.3μm Strained-Layer MQW-DFB Laser for 97ch AM-FDM Transmission

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We have investigated strain effects on relaxation oscillation frequency (f_r) and efficiency for 1.3μm InGaAsP/InGaAsP strained-layer (SL) multiquantum well (MQW) lasers from the view point of the bandgap of InGaAsP barrier layer and the number of quantum wells (N_w). Enhanced f_r and efficiency were realized due to large strain effects in SL-MQW lasers with wide bandgap barrier layers (λ_g=1.05μm) and large N_w of 10. As a result, 97ch AM-FDM transmission has been successfully demonstrated at extremely low bias current (I_b=28mA) in 1.3μm SL-MQW distributed-feedback lasers.

Introduction

Low distortion and low noise 1.3μm distributed-feedback (DFB) lasers are widely used in Sub-Carrier Multiplexed (SCM) optical transmission systems, such as 40ch AM-FDM scheme for CATV. Previously, we have demonstrated 80ch AM-FDM transmission using a multiquantum well (MQW) DFB laser [1]. For further increase in channel number, which expands the modulation frequency range, the laser diode must be operated under higher bias current in order to obtain higher relaxation oscillation frequency (f_r) [2]. However, high bias current operation causes increase in the distortion in laser diodes due to leakage current and induces distortion in the electrical amplifier. Furthermore increased chirp due to large modulation current generates additional distortion and noise due to multiple reflections in the fiber transmission line which has many reflection points [3]. Therefore, reduction of the bias current while maintaining high f_r and output power is necessary for the laser diode. Introducing compressively strained quantum wells into the laser active layer has been theoretically predicted to enhance f_r [4] and the efficiency [5], however, the effects of strain have yet to be clearly demonstrated in devices.

We have investigated strain effects on f_r and efficiency for 1.3μm InGaAsP/InGaAsP strained-layer (SL) MQW lasers from the view point of the bandgap of barrier layers and the number of quantum wells (N_w), and realized high f_r and high output power under low bias current by the large strain effects due to employment of wide bandgap InGaAsP (bandgap wavelength λ_g=1.05μm) barrier layers and large N_w of 10. By using the SL-MQW-DFB laser, AM-FDM transmission with the largest recorded channel number (97ch) at extremely low bias current (I_b=28mA) was successfully demonstrated .

Device structure

Figure 1 shows the schematic band diagram for the MQW active layers. The multilayer growth of lasers was carried out by metal organic vapor phase epitaxy on n-InP substrate. The MQW active layer is composed of 6nm thick unstrained or compressively strained InGaAsP (Δa/a=0% or 0.7%) well layers with

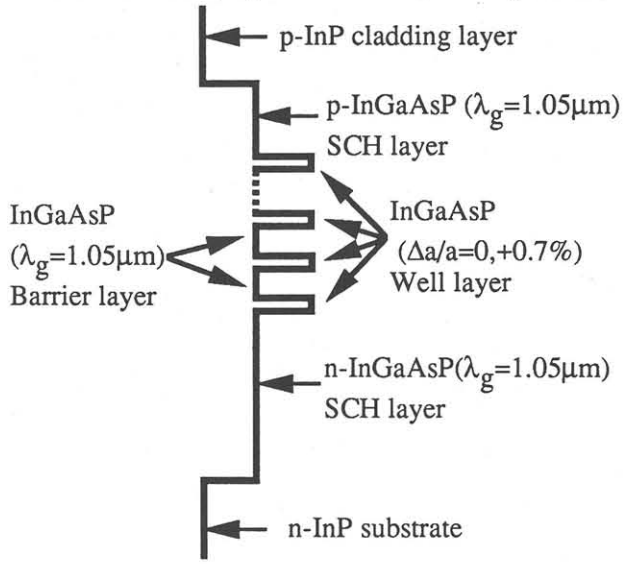

Fig.1 Schematic band diagram of MQW active layers.

10nm thick InGaAsP (λ_g=1.05μm) barrier layers. We changed the composition of InGaAsP well layers to obtain lasing at about 1.3μm for both unstrained MQW and SL-MQW lasers. The amount of the compressive strain was estimated by measuring X-ray diffraction. The number of quantum wells (N_w) are 5, 7 and 10. For comparison we also fabricated unstrained and strained MQW with narrower bandgap InGaAsP(λ_g=1.16μm) barrier layers. The MQW active layers are sandwiched by 150nm thick n-InGaAsP and 30nm thick p-InGaAsP separate confinement layers which have the same bandgap wavelength as that of barrier layers. The active region is buried to form a planar buried heterostructure by liquid phase epitaxy. The active region width and the cavity length are 1.2μm and 300μm, respectively. Both fabry-perot (FP) lasers with as-cleaved facets and DFB lasers with AR/HR (5%/80%) coated facets were fabricated for the investigation.

Experimental results

Figure 2 shows the N_w dependence of the threshold current (I_{th}) and the external differential quantum efficiency (η_d) under RT-CW operation for unstrained MQW-FP lasers and SL-MQW-FP lasers. The bandgap wavelength of barrier layers (λ_g^b) is 1.05μm. In all N_w, smaller I_{th} value and higher η_d value were confirmed in SL-MQW lasers than those of unstrained MQW lasers. Both small I_{th} of less than 10mA and high η_d of 60% are achieved in SL-MQW lasers with 10 wells. These improved performances in SL-MQW lasers are thought to be due to the reduction of threshold carrier density and the suppression of nonradiative recombination by strain effects [5].

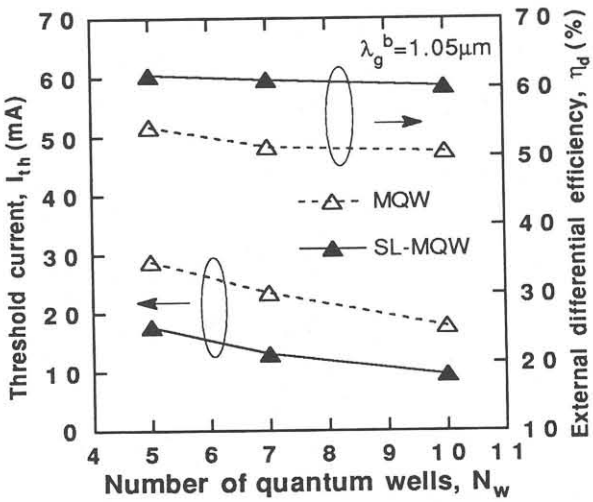

Fig. 2 N_w dependence of the threshold current and the external differential quantum efficiency for unstrained MQW lasers and SL-MQW lasers.

The dependence of f_r on the square root of the injection current above threshold ($\sqrt{I_b-I_{th}}$) for the unstrained MQW-FP laser and the SL-MQW-FP laser with 10 wells (λ_g^b=1.05μm) is shown in Fig. 3. The f_r values were determined by the peak frequency in the relative intensity noise spectra to avoid the influence of RC rolloff. From the figure, it is clear that the f_r values of the SL-MQW laser were increased by a factor of about 1.3 at the same $\sqrt{I_b-I_{th}}$ as compared with the unstrained MQW laser. This enhancement in f_r is thought to be mainly due to increase in differential gain [4].

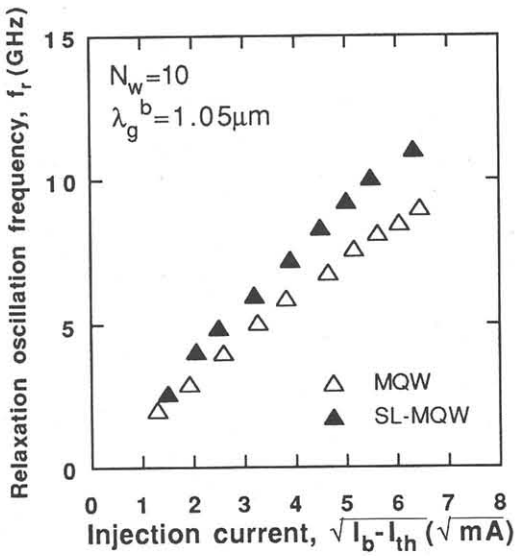

Fig. 3 The dependence of f_r on the square root of the injection current above threshold for the unstrained MQW laser and the SL-MQW laser with 10 wells (λ_g^b=1.05μm).

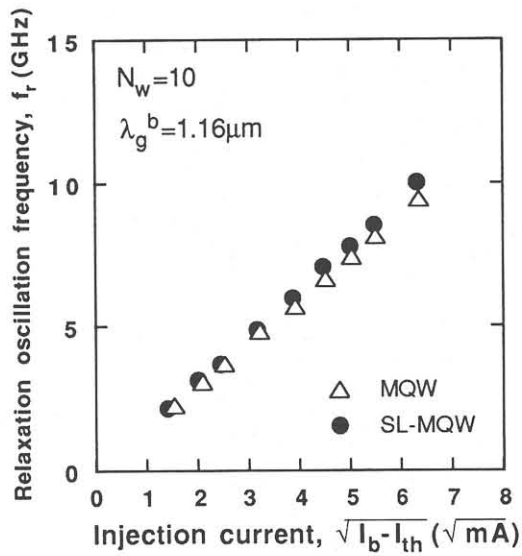

Fig. 4 The dependence of f_r on the square root of the injection current above threshold for the unstrained MQW laser and the SL-MQW laser with 10 wells (λ_g^b=1.16μm).

On the other hand, Figure 4 shows the dependence of f_r on $\sqrt{I_b-I_{th}}$ for the unstrained MQW-FP laser and the SL-MQW-FP laser with 10 wells (λ_g^b=1.16μm). Only small enhancement in f_r for SL-MQW lasers was obtained. Small strain effect on f_r was also confirmed in the samples with less than 10 wells. Taking account of the results in Fig. 3 and Fig. 4, it is considered that employment of the wide bandgap InGaAsP (λ_g=1.05μm) barrier layer is effective to obtain high f_r because carrier overflow from the well layer, which reduces the differential gain, is suppressed.

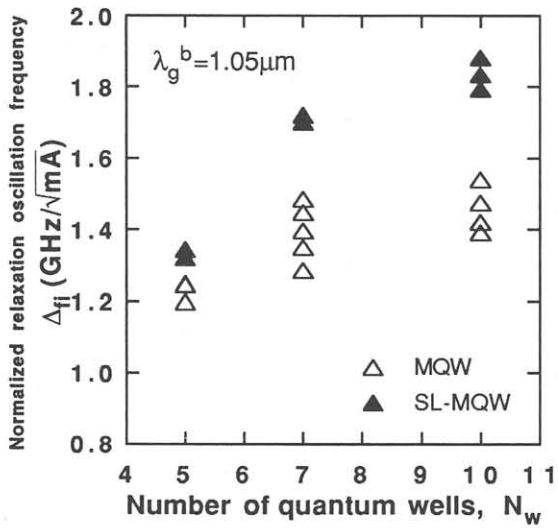

Fig. 5 The dependence of normalized f_r by $\sqrt{I_b-I_{th}}$ (Δ_{fi}) on N_w for unstrained MQW lasers and SL-MQW lasers (λ_g^b=1.05μm).

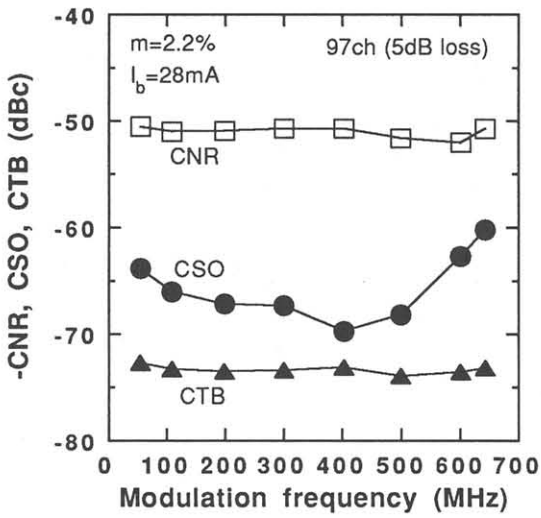

Fig. 6 97ch (5dB loss) AM-FDM transmission characteristics at a modulation depth of 2.2%/channel.

Figure 5 shows the dependence of normalized f_r by $\sqrt{I_b-I_{th}}$ ($\Delta_{fi}\equiv f_r/\sqrt{I_b-I_{th}}$) on N_w for unstrained MQW-FP lasers and SL-MQW-FP lasers (λ_g^b=1.05μm). The highest Δ_{fi} values were obtained in SL-MQW lasers with 10 wells. Increase in Δ_{fi} value was observed for SL-MQW lasers with more than 7 wells. This result indicates that a relatively large number of quantum wells is necessary to obtain high f_r.

Using SL-MQW-DFB lasers with 10 wells (λ_g^b=1.05μm), which were mounted in the packages with optical isolator, transmission characteristics were evaluated. Figure 6 shows 97ch AM-FDM transmission characteristics with loss budget of 5dB at a modulation depth of 2.2%/channel. The values of Carrier to Noise Ratio (CNR), Composite Second Order distortion (CSO) and Composite Triple Beat (CTB) are obtained : CNR>50dB, CSO<-60dBc and CTB<-73dBc in all channels. It is noted that bias current was only 28mA (=I_{th}+16.7mA). The CSO value at highest channel frequency (=643MHz) is mainly limited by f_r at the bias current. This represents an improvement of about 3dB for CSO and CTB as compared with that of unstrained MQW-DFB lasers under the same injection level (I_b-I_{th}) and the same CNR value. High f_r value of 8GHz (Δ_{fi}=2.0GHz/√mA) and high output power of 7.1dBm at a low bias current has enabled these excellent characteristics.

Conclusion

In conclusion, we have confirmed that wide bandgap InGaAsP (λ_g=1.05μm) barrier layer and large number of quantum wells (N_w=10) are effective to obtain high f_r and high efficiency for 1.3μm SL-MQW lasers. By using the SL-MQW-DFB laser with enhanced f_r and efficiency, 97ch AM-FDM transmission has been successfully demonstrated, for the first time, at extremely low bias current (I_b=28mA).

References

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