Extended Abstracts of the 1992 International Conference on Solid State Devices and Materials, Tsukuba, 1992, pp. 243-245 **PC1-11**

High Efficiency InGaAs/InGaAsP Compressively Strained Multi-Quantum-Well Laser Diode

S. Ogita, H. Kobayashi, T. Higashi, O. Aoki, N. Okazaki, and H. Soda

Fujitsu Laboratories Ltd, Atsugi
10-1 Morinosato-Wakamiya, Atsugi, 242-01, Japan

The characteristics of the InGaAs/InGaAsP compressively strained multi-quantum well laser diodes with the thin wells was studied experimentally to realize the pumping laser diode for the optical fiber amplifier. The high external quantum efficiency and the comparatively low threshold current density were obtained when the thickness of well was reduced to less than 2 nm. The output power as high as 200 mW was also demonstrated in the coated sample with the optimized well-structure.

1. Introduction

The compressively strained multi-quantum well (MQW) structure is one of the most suitable structure for the high power pumping laser diode of the optical fiber amplifier[1]. To achieve the high power operation at a moderately low drive current, the internal loss should be reduced as low as possible. Generally, the internal loss is mainly determined by the loss in the active layer. So, in the MQW structure, the decrease of the number of wells is much effective for this purpose. However, the threshold carrier density drastically increased when the number of wells decreased because the differential gain of the MQW laser becomes saturate at a high injection level. The high threshold carrier density induces the increase of the loss in the active layer, and also accelerates the decrease of the slope efficiency at a high drive current caused by the heating of the active layer. The saturation of the differential gain strongly depends on the thickness of the wells. The thin well has the large density of state and so its differential gain dose not saturate at a high carrier density. Therefore, the reduction of the thickness of wells in the MQW structure is an effective method to achieve the high power operation.

In this paper, we studied the dependence of the external differential quantum efficiency on the thickness and the number of wells whose thickness of less than 2 nm. We also studied the temperature dependence of the lasing characteristics, and optimized the MQW structure based on the obtained results.

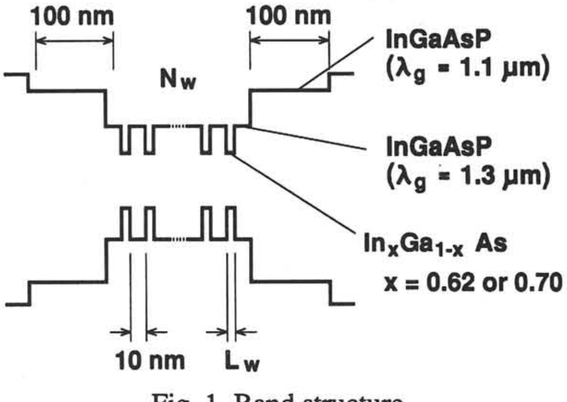

Fig. 1 Band structure

2. Structure

The band structure of our samples is shown in Fig. 1. The InGaAsP SCH layers were introduced besides the MQW layer for improving the optical confinement to the well layer. The thickness L_W of the well layer was changed from 0.9 nm (=3 monolayers) to 2.1 nm (=7 monolayers). For the content x of In in the $In_xGa_{1-x}P$ well layer, we tested two cases of 0.62 and 0.7. The lasing wavelength was 1.42-1.52 μm. After the growth of the MQW structure using MOVPE on the n-type InP substrate, the FBH structure was fabricated by the conventional LPE. The measured sample had the 600 μm-long-cavity and the as-cleaved facets.

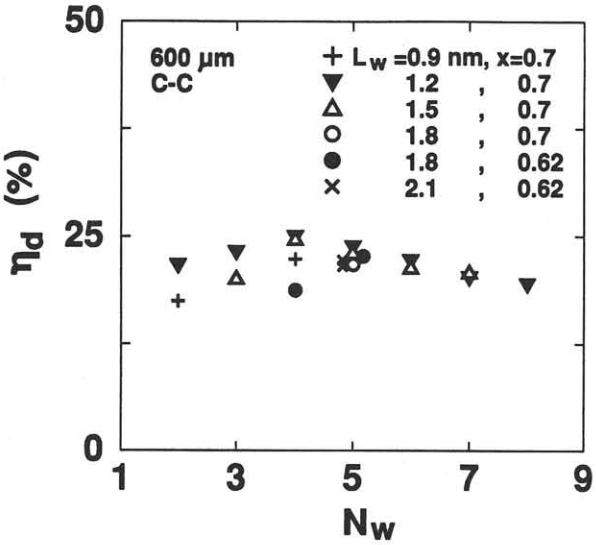

Fig. 2 The dependence of the external quantum efficiency η_d on the number N_w of the wells.

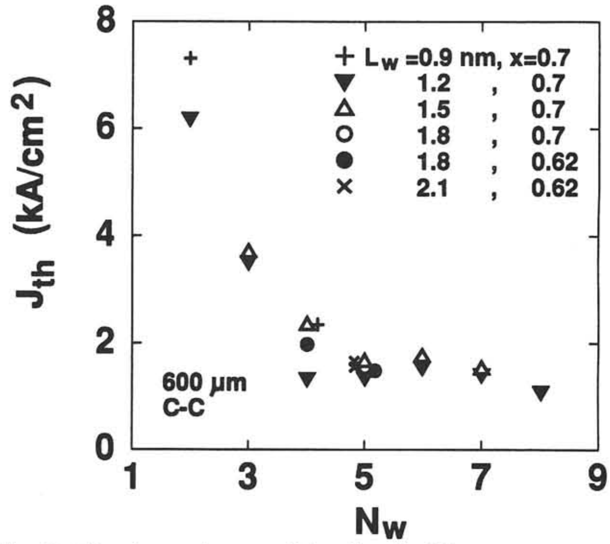

Fig. 3 The dependence of the threshold curremt demsity J_{th} on the number N_w of the wells.

3. Results and discussions

First, we studied the dependence of the external differential quantum efficiency η_d at a low drive current on the number N_w of wells by varying the L_w, as shown in Fig. 2. The the large η_d of 22%/facet (0.2 mW/mA/facet) was obtained even for the L_w = 0.9 nm.The η_d increases by reducing the N_w when $N_w \geq 5$. This is due to the reduction of internal loss. The maximum value of the η_d was 25%/facet (0.22 mW/mA/facet) for the 4 pair 1.2-nm-thick wells. When $N_w \leq 3$, the η_d decreases by reducing the N_w. Fig. 3 shows the measured threshold current density J_{th}. The J_{th} drastically increases when $N_w \leq 3$, which corresponds to the decrease of the η_d. Therefore, the decrease of η_d for $N_w \leq 3$ could be caused by the increase of the threshold carrier density, which induces the increase of the internal loss. For $N_w \geq 5$, the J_{th} takes almost constant value of 1.5 kA/cm^2. From these two figures, we confirmed that the MQW structure with the thin wells whose thickness of less than 2.1 nm are much effective one to achieve the high η_d. These two figures also showed that the η_d and J_{th} are almost independent of the L_w, especially when $N_w \geq 5$. This means the loss in the barrier layer could not be negligible for the very thin wells less than 2.1 nm. The difference of the lasing characteristics between x = 0.62 and x = 0.7 was not clear for $L_w \leq 2.1$ nm from our results.

Fig. 4 and Fig. 5 show the internal loss α_i and internal quantum efficiency η_i respectively. Fig 4 showed that the α_i decreases when the N_w decreases for $N_w \geq 4$, and drastically increases for the N_w = 3. Fig. 4 also showed that the α_i is almost independent of the L_w. These results support the above discussion about η_d. The η_i takes the large value of 75%, which is independent of both the L_w and the N_w, shown in

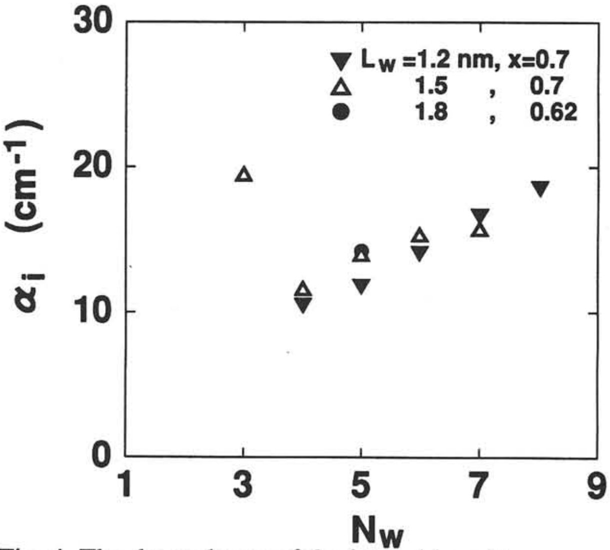

Fig. 4 The dependence of the intrnal loss α_i on the number N_w of the wells.

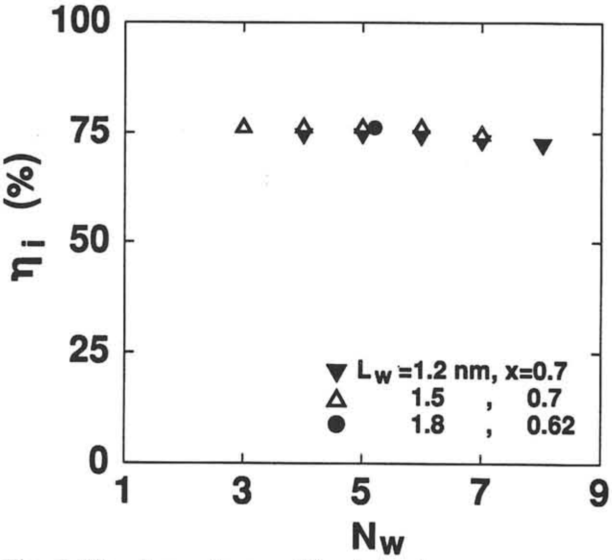

Fig. 5 The dependence of the intrnal quantum efficiency η_i on the number N_w of the wells.

Fig. 5. This means the carrier injection to the well layers is sufficiently large for the $L_W \leq 2.1$ nm.

Next, we estimated the increase of the threshold carrier density at a high drive current. Fig. 6 showed the characteristic temperature T_0 measured in the high temperature range from 60°C to 90°C. The horizontal axis is the calculated optical confinement factor to the wells using the simple slab-waveguide analysis. From this figure, the samples with the same optical confinement factor had almost the same T_0. This means the T_0 depends on only the volume of the well layers. Therefore, the reduction of the threshold carrier density in the well layers is indispensable to improve the high power characteristics. The T_0 as high as 45K, which is equal to the values for the bulk cases is obtained for the optical confinement factor of more than 1.4%. The number and the thickness of the wells should be selected to the optimum values which satisfies this criteria about the optical confinement.

Based on the above results, we fabricated the high power laser diode emitting at 1.48 μm. The example of the L-I characteristics for the MQW structure with $L_W = 1.8$ nm, $N_W = 5$, and $x = 0.62$ was shown in Fig. 7. The high slope efficiency of 0.43 mW/mA and the high power operation exceeding 200 mW were obtained. The drive current at the output power of 150 mW was moderately low value around 500 mA. These data are sufficient values to realize the pumping laser diode for the optical fiber amplifier. The characteristics of the laser diode module with the optical fiber pigtail using this devices was shown in Fig. 8. The high output power of 100 mW coupled to the optical fiber was achieved at the sufficiently low drive current of 550 mA.

4. Conclusion

We studied the dependence of the external differential efficiency and the characteristic temperature on the thickness and the number of wells in the compressively strained InGaAs/InGaAsP MQW laser for the designing the high power pumping laser diode. High external quantum efficiency of more than 20%/facet was obtained for the thin wells whose thickness of less than 2 nm without the increase of the threshold current density. We also demonstrated high power operation with a moderately low drive current using the MQW structure with the 5 pair 1.8-nm-thick wells.

Ref.

1) P. J. A. Thijs, Tech. Dig. Optical Fiber Conf., San Diego, USA, paper WB2 (1991) 67

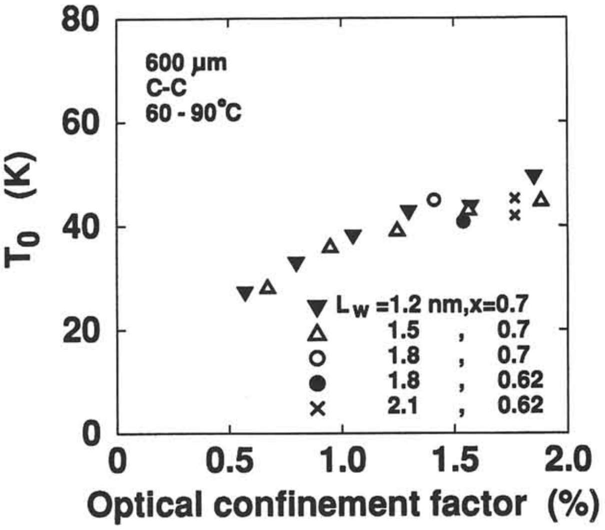

Fig. 6 The dependence of the T_0 measured in the high temperature range from 60°C to 90°C on the calculated optical confinement factor to the well layer

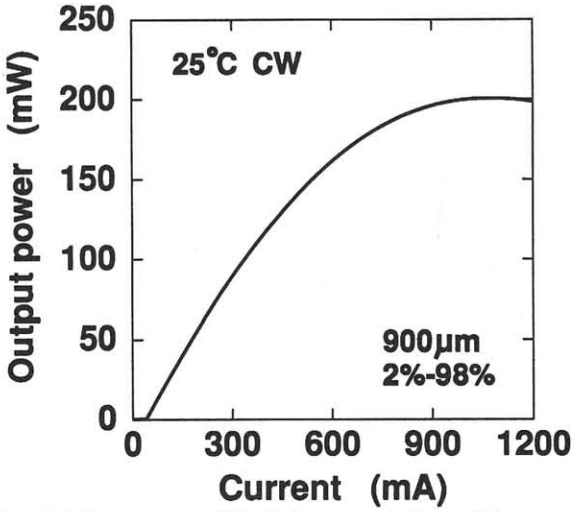

Fig. 7 The measured L-I characteristics of the coated samples with a 900-μm-long cavity

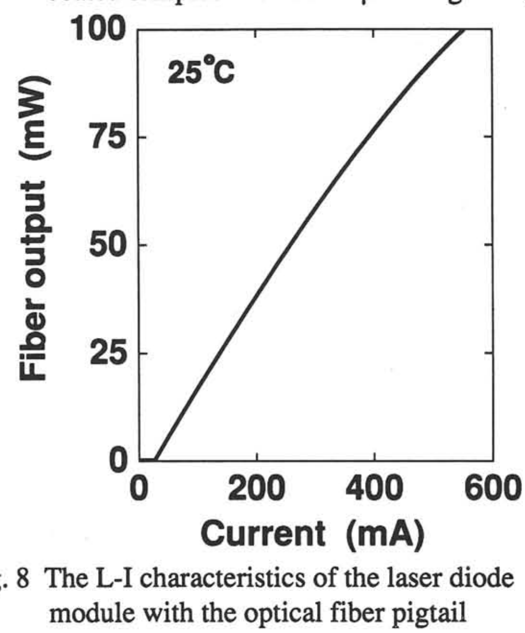

Fig. 8 The L-I characteristics of the laser diode module with the optical fiber pigtail