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GaInAsP/InP Surface Emitting Laser with Two Active Layers

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As one step of realizing a multi-layer surface emitting (SE) injection laser, we have demonstrated a GaInAsP/InP laser structure with two active layers which are connected by a highly doped reverse biased tunnel junction. First we present the threshold current density for multi-layered structure and show how it is effective to reduce the threshold. Second, a prototype device with GaInAsP/InP (λ=1.22 μm) has been fabricated. Threshold current was 145 mA at 77 K and single longitudinal mode operation was achieved.

1. Introduction

A surface emitting (SE) injection laser has many advantages such as, i) it is easy to fabricate a short cavity and then single mode operation is expected because of its large mode spacing, ii) a two-dimensional laser array could be monolithically fabricated, iii) the SE laser and other devices can be integrated monolithically on the same substrate, iv) the laser test could be made in a wafer, and v) a narrow beam is achievable. Recently we demonstrated a GaInAsP/InP SE laser with short cavity length which operated up to 140 K under pulsed condition[1] and a GaAs/GaAlAs SE laser which operated at room temperature under pulsed condition.[2] However, the threshold current density is rather high compared to the conventional laser diode, since the gain region is smaller. Therefore, to increase the operation temperature and to reduce the threshold current density of SE laser, it would be necessary to increase the gain region or the mirror reflectivity. A structure with multi-active layers as shown in Fig. 1 would be very effective for this purpose and expected current injection schemes are considered to be transverse junction[3] and tunnel junction.[4],[5] In this study we demonstrate a new GaInAsP/InP SE laser structure with two active layers which are connected by a reverse biased tunnel junction as the first step of multi-layered SE laser.

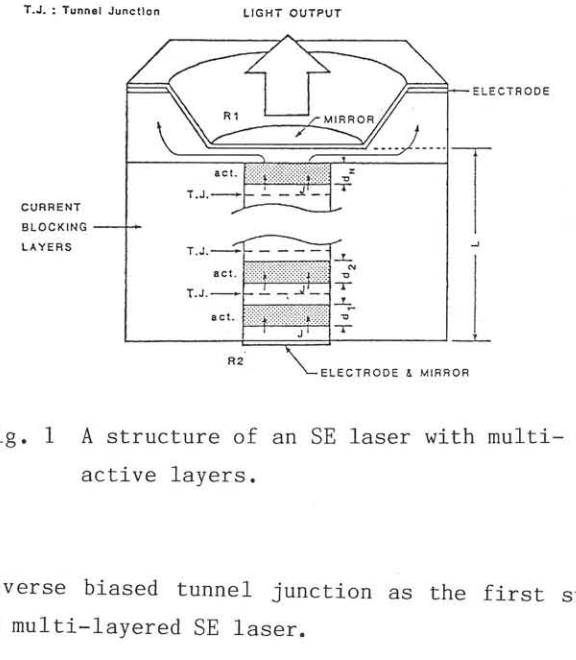

Fig. 1 A structure of an SE laser with multi-active layers.

2. Threshold of SE laser with multi-active-layers

The threshold current density J_{th0} of the SE laser with a single active layer is expressed by the following equation.

$$J_{th0} = \frac{d_0 e B_{eff}}{A_0^2}\left\{ \alpha_{in} + \alpha_{ac} + (L-d)\frac{\alpha_{ex}}{d} + \frac{1}{d}\ln\frac{1}{R}\right\}^2 \qquad (1)$$

where

L is the length of the cavity,

d_0 is the the active layer thickness,

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α_{ac} is the loss factor of the active layer,
α_{ex} is the loss factor of the cladding layer,
R is the average reflectivity ($=\sqrt{R_1R_2}$),
B_{eff} is effective recombination coefficient and
A_0 and α_{in} are the parameters expressing the peak gain g_p as

$$g_p = A_0 n - \alpha_{in} \tag{2}$$

For the SE laser with N active layers where each layer is separated by a highly doped p^+n^+ tunnel junction with a low reverse breakdown voltage, the same current is re-injected into each active layer. The threshold current density J_{th} is, therefore, expressed by the following equation:

$$J_{th} = \frac{(\sum_i^N d_i)^2}{(\sum_i^N \sqrt{d_i})^2} \cdot \frac{eB_{eff}}{A_0^2} \left\{ \alpha_i + \alpha_{ac} + (L - \sum_i^N d_i)\frac{\alpha_{ex}}{\sum_i^N d_i} + \frac{1}{\sum_i^N d_i} \ln\frac{1}{R} \right\}^2 \tag{3}$$

where

d_i is the i-th active layer thickness,

We show in Fig. 2 the calculated threshold current density of the multi-layered SE laser with the same thickness of active layers ($=d_0$) for various N. For example, if we make two active layers (N=2), the threshold current can be reduced by a factor of 1.4-2.5 as compared with that of SE laser with single active layer. The reduction of threshold current density would be expected with increasing N, but only technically limited by thermal dissipation from the stacked active layers.

3. Fabrication

The GaInAsP/InP layers were grown by a two-step LPE on (100) oriented n^+-InP substrate. The active layers were doped with Zn and their bandgap wavelength is 1.3 µm at room temperature. Each active layer thickness is 1.55 µm, so total active region thickness is 3.1 µm. Figure 3 shows a cross-sectional view of a grown wafer. In order to reduce a reverse break down voltage, a p^+-GaInAsP-n^+-InP tunnel junction was used where the bandgap of the p^+-GaInAsP was wider than that of the active layer.

First we fabricated conventional broad contact lasers to confirm whether the tunnel junction has a low reverse break down voltage. Figure 4 shows a voltage-current (V-I) characteristic. It was about 0.8-1.0 V which was reasonable for a p^+-GaInAsP (Zn:$4\times10^{18}cm^{-3}$) -n^+-InP (Te:$2\times10^{19}cm^{-3}$) junction. Figure 5 shows near field pattern of this laser. Both layers lased uniformly with the same threshold current.

Next, we fabricated a round mesa SE laser with two active layers as illustrated in Fig. 6. It is essential to terminated the n^+-InP in the transverse direction since the current spreads at the lower resistance n^+-InP layer between two active layers. After evaporating a Au/Sn metal to the n-side surface, an SiO_2 film was sputtered and circular window of 400 µm were opened to etch-off the substrate. The exposed Au/Sn was etched by a mixed solution of KKI-121 ($HCl:2CH_3COOH:H_2O_2$) at 15°C for a few minutes. The n-InP substrate was etched by a mixed solutions of ($4HCl:H_2O$) at 20°C. It took about 20 minutes to reach a GaInAsP etch/stop layer. Then the etch/stop layer was etched off to reach the surface of an n-InP cladding layer by a mixed solution ($3H_2SO_4:H_2O:H_2O_2$). The bottom of the etched well was about 100x400 µm. Then a SiO_2 film was sputtered on p-side and a ring window which has 50 µm of the inner diameter and 100 µm of the outer one was opened for etching mask to make circular channel. The channel was etched over the tunnel junction in order to prevent the current spreading at a low resistance n^+-InP layer. We etched the channel by KKI-121 at 10°C for a few minutes. The channel was buried by photo-resist to make a planar surface. A SiO_2 film was sputtered on its center and circular windows of 20 µm were opened for a p-type contact. The p-side circular dot electrodes of 20 µm were formed by evaporating Au/Zn/Au in sequence onto circular windows and annealing. Finally, the etched surface was coated with a gold film for increasing the reflectivity. Figure 7 shows cross-sectional view of a laser chip. The total cavity length was about 9.1 µm.

4. Characteristics

Figure 8 shows a light output vs. current characteristic of the SE laser with two active layers at 77 K under pulsed operation. The threshold current was 145 mA. It was higher than the previous SE laser (50 mA).[1] But the diameter of mesa was 50 µm and the current spread to entire the n^+-InP layer. So, the threshold current density ($J_{th} \simeq 7.4 kA/cm^2$) is smaller than the previous case ($J_{th} \simeq 16 kA/cm^2$).

The pulsed lasing spectra at 77 K are shown in Fig. 9. Above the threshold, only one of the longitudinal Fabry-Perot modes dominated. Almost single longitudinal mode operation was maintained up to 1.4 times the threshold.

5. Summary

We demonstrated a new GaInAsP/InP SE laser with two active layers which were connected by highly doped reverse biased tunnel junction. The threshold current was 145 mA at 77 K and single mode operation was achieved up to 1.4 times threshold. By optimizing the doping and tunnel junction and introducing BH structure, it would be expected to much decrease threshold current density and to obtain the room temperature operation.

Acknowledgment

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Reference

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2) A. Ibaraki, S. Ishikawa, S. Ohkouchi and K. Iga: IQEC'84, Anaheim, MLL7 (1984).
3) Patent pending No. 55-508
4) Patent pending No. 58-191459
5) J. P. van der Ziel and W. T. Tsang: Appl. Phys. Lett., 41, pp.499-501 (1982).

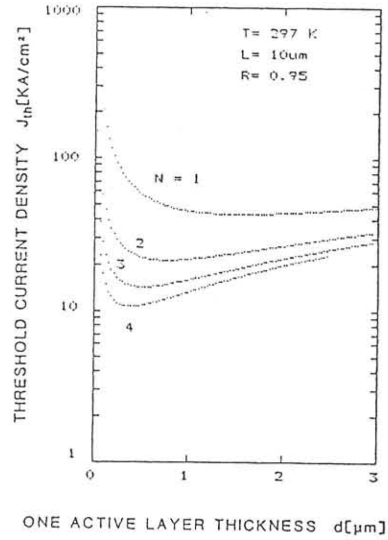

Fig. 2 Calculated threshold current density of the multi-layered SE laser with the same thickness of active layers.

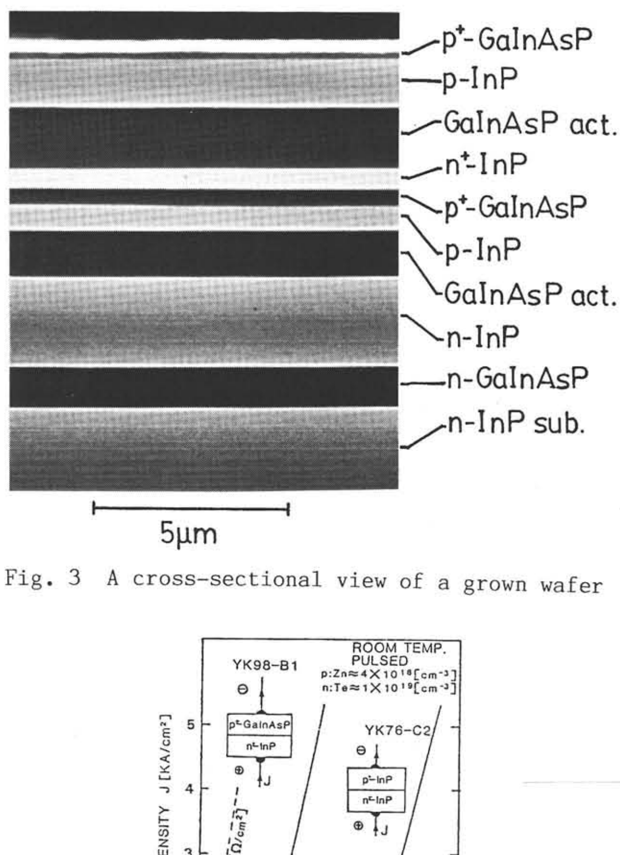

Fig. 3 A cross-sectional view of a grown wafer

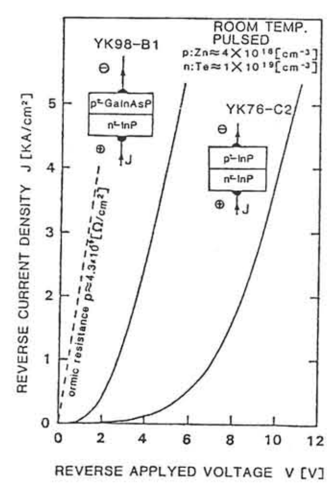

Fig. 4 A voltage-current (V-I) characteristic.

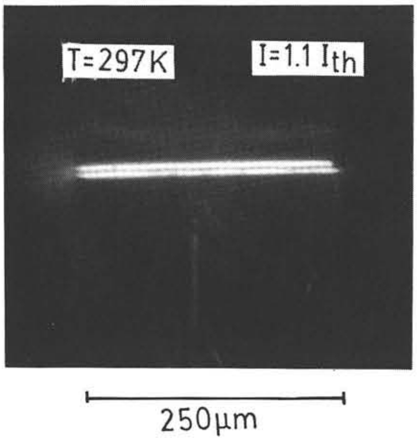

Fig. 5 A near field pattern of a broad contact laser.

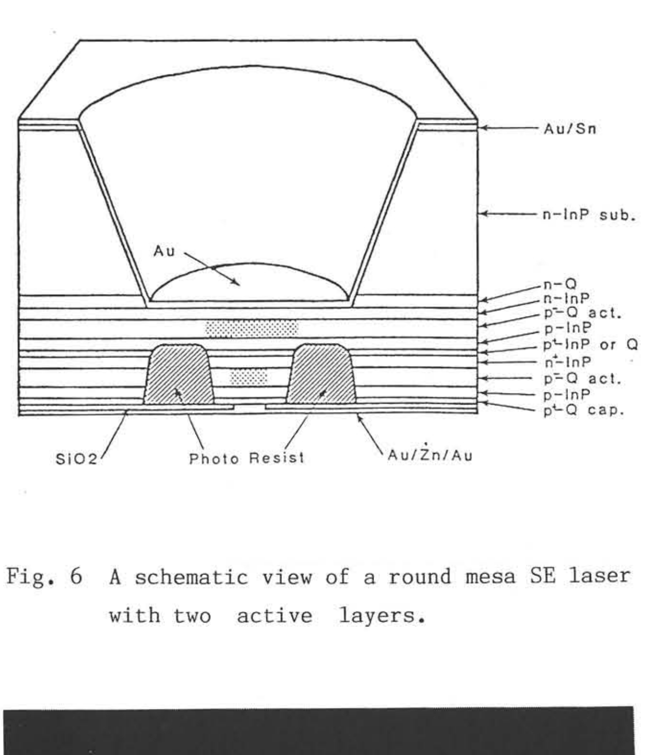

Fig. 6 A schematic view of a round mesa SE laser with two active layers.

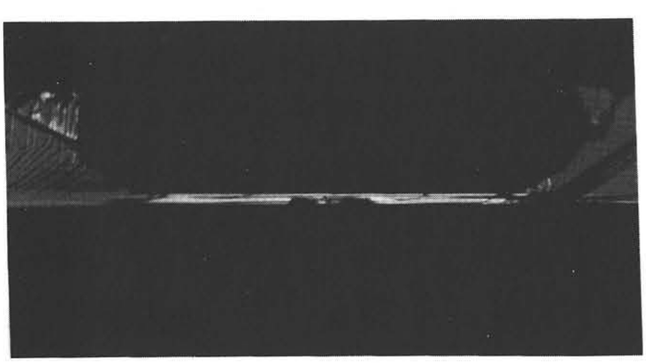

Fig. 7 A cross-sectional view of a laser chip.

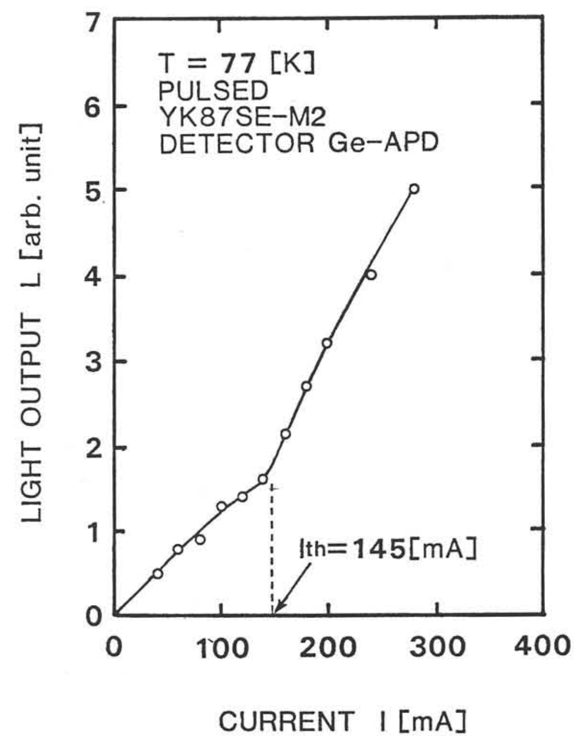

Fig. 8 A light output vs. current characteristic of a round mesa SE laser with two active layers at 77K under pulsed condition.

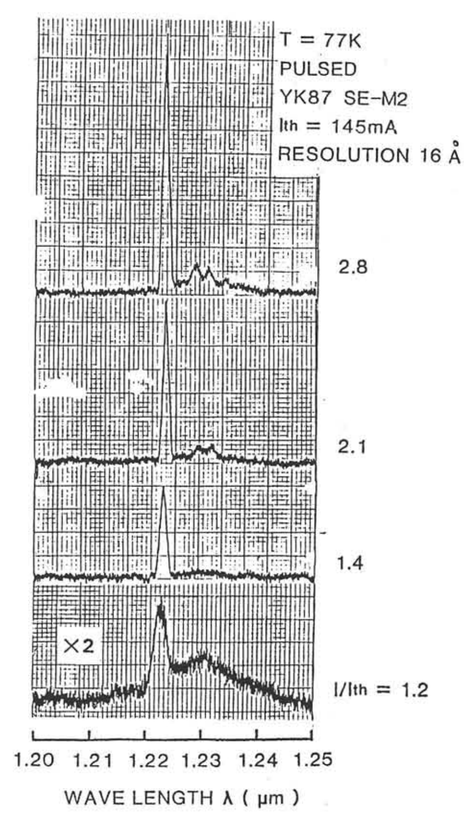

Fig. 9 Emission spectra of a round mesa SE laser with two active layers at 77K.