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B-6-2 Reduction of the Threshold Current of Buried-Heterostructure Injection Lasers into the mA Range

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In a previous paper[1)], we described the fabrication and characteristics of buried-heterostructure(BH) lasers. These lasers have such unique properties as the low current operation, the stable lowest-order transverse mode, the isotropic beam divergence, and the easy dissipation of heat from the active region. In order to reduce the operating current of BH lasers, we adopted a stripe-geometry electrode 2 µm wide, thus obtaining a threshold current(I_{th}) as low as 15 mA. Although this value was by far the lowest I_{th} ever reported, there still existed a large discrepancy between this value and the expected I_{th}(several milliamperes).

In this paper, we present the theoretical calculation of the threshold current. This calculation explains the above mentioned discrepancy and has agreed fairly well with our experimental results. We also describe the methods for further reducing the I_{th}. We fabricated BH lasers according to this guidepost and succeeded in obtaining injection lasers which can operate in the mA range.

Figure 1 shows the light-emitting facet of a BH laser used for the calculation. The p-n junction is formed as indicated by a bold line(n-type active region is assumed), and we can formulate the current flow as follows;

$$\begin{aligned} I_t &= J_1W_1 + J_2W_2 \\ J_i &= J_{Si}\exp(eV_{Ji}/2kT) \qquad (i = 1,2) \qquad (1) \\ V_a &= R_{Si}J_i + V_{Ji} \end{aligned}$$

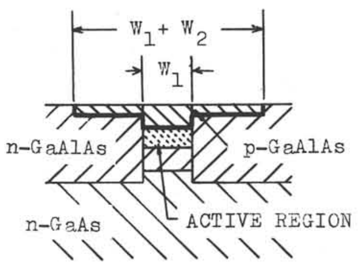

Fig. 1 Facet of a BH laser

where I_t is the diode current, W is the width of the p-n junction, J is the current density, J_S is the saturation current, V_J is the junction voltage, V_a is the applied voltage, R_S is the series resistance multiplied by the area, and the suffix i denotes the active region(i=1) and the GaAlAs junction(i=2) including their accompanying regions. Due to the energy gap difference between GaAs and GaAlAs, there is a large difference between saturation currents of these materials; J_{S1} is equal to 1.7×10^{-8} A/cm^2, while J_{S2} is equal to 1.1×10^{-11} A/cm^2. In spite of this difference, two current densities for GaAs and for GaAlAs become almost equal near the threshold current density of the laser($J \gtrsim 1$ kA/cm^2). In other words, the series resistance becomes effective in the range of this current density. The threshold current of the diode as a function of the threshold current density(J_{th}) of the active region is shown in Fig. 2, for the case of $R_S = 5 \times 10^{-4}\,\Omega\,\mathrm{cm}^2$. Both the total threshold current(I_{th})

and the current flowing through the active region at threshold are shown. The I_t is a few times greater than the current necessary for lasing. Experimental values of the threshold current are in the range of 10-30 mA. Broader lasers made from the same wafer showed J_{th} around 1.5 kA/cm^2. It can be seen from Fig. 2 that I_t is equal to 20 mA at $J_{th} \simeq 1.5$ kA/cm^2. Hence, the theoretical prediction is in good agreement with the above experimental results.

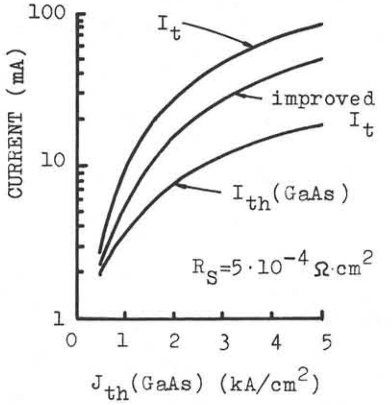

Fig. 2 Threshold current vs. J_{th} of the active region. W_1= 1 µm, W_2= 4 µm, L= 400 µm.

Although the I_{th} cited above is considerably low, the leakage current is preferable to be completely eliminated. For a further reduction of I_{th}, it is effective to make the series resistance of the GaAlAs junction higher than that of the active region. The theoretical calculation is also shown in Fig. 2(improved I_t) for the case of $R_{S1} = 3 \times 10^{-4}\Omega cm^2$ and $R_{S2} = 6 \times 10^{-4}\Omega cm^2$. The reduction of I_t by a factor of two is expected by this way. Though the increase of the contact resistance is more effective in realizing a sufficient difference between R_{S1} and R_{S2}, we tried a simpler method in which the bulk part of R_{S2} is increased. The burying layer grown in the secondary LPE was only lightly doped with n-type impurities. By this method, BH lasers operating in the mA range have been obtained. The lowest I_{th} so far obtained is 7 mA in a pulsed operation and 9.5 mA in dc in a diode 385 µm long.

Another way of lowering I_{th} is to reduce W_2. This may be realized by adopting finer photolithographic techniques, thus making 1 µm or submicron-wide window for metallic contacts. The shorting of the cavity length is also effective. A laser diode with the I_{th} of a few mA will be possible by combining these means.

The excellent heat dissipating characteristics of BH lasers have been predicted and verified experimentally[2]. Due to these characteristics, the device size of the laser or the heat sink can be made very small as shown in Fig. 3. Reliability data of cw BH lasers mounted like this will also be presented.

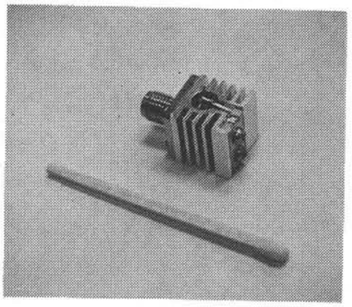

Fig. 3 Miniaturized cw BH laser.

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1) T. Tsukada, J. Appl. Phys. 45, 4899 (1974).

2) T. Tsukada et al., IEEE J. Quantum Electron. (to be published in the July issue of 1975).