CARRIER DISTRIBUTION IN INJECTION STRIPE LASERS

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It was shown in [1] that the limitation of the optical field along the p-n junction in stripe lasers is due to the nonuniform gain distribution associated with the nonuniform distribution of current carriers resulting from current spreading and the diffusion of carriers. To explain the transverse structure of the field along the p-n junction, one must therefore calculate the distribution of carriers in the active region of the laser. Attempts to perform such calculations were reported in [2-5] but were not entirely successful.

Calculations performed so far do not take into account the joint diffusion of electrons and holes that occurs when they are injected into the active region with similar concentrations [6]. Moreover, influence of current concentration on the current distribution is ignored. This effect ensures that the variation in concentration along the p-n junction produces a reduction in the potential on the active region and, consequently, on the layer separating this region from the contact. This gives rise to a redistribution of current along the p-n junction. Finally, the model used in [2-5] for the cross section of the stripe laser is valid only for contact [7] and planar [5] stripe lasers but is not valid for other structures [8] or for lasers produced by proton bombardment [9].

In this paper, we consider a more general model (Fig. 1). The active region of thickness d is separated from the p-type layer of width $d_1 + d_2$ from the contact at potential u_0. Outside the stripe of width 2w, this layer contains regions of enhanced resistance of thickness d_1, in which the current is 0. On the other side of the active region there is a contact at 0 potential.

We must now derive the system of equations describing the distribution of current carriers in the active region. Since injection is nonuniform along the y axis, and the electron and hole mobilities are different, an electric field E_y is produced in the active region in the direction of the y axis. The diffusion of the carriers is then described by the following equations [6]:

$$\frac{j_n}{qd} - \frac{N}{\tau} + D_n \frac{d^2N}{dy^2} + \mu_n \frac{d}{dy}(E_y N) = 0, \tag{1}$$

$$\frac{j}{qd} - \frac{N}{\tau} + D \frac{d^2N}{dy^2} = 0, \tag{2}$$

where

$$j = \frac{\mu_p j_n + \mu_n j_p}{\mu_n + \mu_p}, \qquad D = \frac{\mu_p D_n + \mu_n D_p}{\mu_n + \mu_p};$$

j_n, μ_n, D_n, j_p, μ_p, D_p are the injection currents, mobilities, and electron and hole diffusion coefficients; q is the electron charge; τ is the spontaneous carrier lifetime; and N is the electron concentration. We assume that d is much less than the carrier diffusion layer L_p.

The potential experiences a discontinuity across the p-n junctions defining the active region, and the discontinuity is equal to the voltage drop across the p-n junctions (V_1 or V_2). Hence,

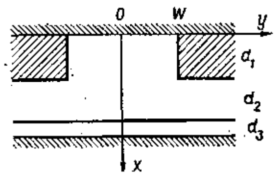

Fig. 1. Cross section of the stripe laser.

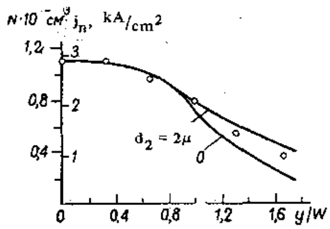

Fig. 2. Carrier concentration in the active region and the current density of injected electrons as functions of position. Open circles are experimental [3].

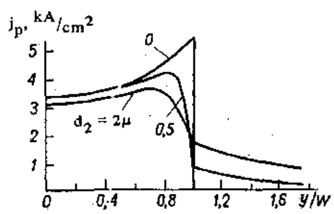

Fig. 3. Current density of injected holes as a function of position.

$$-\frac{dV_1}{dy}+\frac{du}{dy}+E_y=0, \quad \frac{dV_2}{dy}+E_y=0, \tag{3}$$

where u is the potential outside the active region in the plane $x = d_1 + d_2$; and V_1 and V_2 are complicated functions of N. However, over a small segment, we have the approximate relationship

$$N = n_0 \exp(\beta V), \tag{4}$$

where β is a coefficient introduced in [4, 5].

Finally, we must know the relationship between u and j_p, and this can be determined by solving the Laplace equation for the p-type layer (Fig. 1). When d_1 and $d_2 \leq L_p$, the Laplace equation yields (see also [4, 5]):

$$\rho j_p = d_2 \frac{d^2u}{dy^2} \tag{5}$$

for $|y| > w$, and

$$u_0 - u + c_1 \frac{d^2u}{dy^2} - \rho(d_1+d_2) j_p + \rho c_2 \frac{d^2 j_p}{dy^2} = 0 \tag{6}$$

for $|y| < w$. In these expressions, ρ is the resistivity of the p-type layer and

$$c_1 = \frac{d_2^2}{2} + \frac{d_1^2}{3} + d_1 d_2, \quad c_2 = \frac{d_1 d_2^2}{2} + \frac{d_1^2 d_2}{3} + \frac{d_2^3}{6}.$$

Equations (1)-(6) can be solved analytically by linearizing the dependence of V on N. Figures 2 and 3 show the results of calculations performed for the following parameter values: $\beta = 20\ V^{-1}$, $\tau = 3 \cdot 10^{-9}$ sec, $\rho = 0.04$ Ω·cm, $L_p = d_1 + d_2 = 2$ μ, d = 0.5 μ, and w = = 5μ.

Figure 2 shows the carrier concentration as a function of position. The open circles represent experimental data taken from [3]. It is clear that the agreement between theory and experiment is adequate under the contact. Figures 2 and 3 also show the function $j_n(y)$.

It is clear from the plot of $j_p(y)$ shown in Fig. 3 that the current density initially increases toward the edges (in contrast to the monotonic decrease obtained in [4]). This result is a consequence of the influence of carrier distribution on the current distribution.

We have thus solved the self-consistent problem on the distribution of carrier concentration and injection current density in the active region of stripe lasers of different geometry.

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