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B−4−1 Effect of Nonuniformity in Temperature Distribution in a Stripe-geometry Double-heterostructure Laser

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The thermal property of the semiconductor laser can significantly affect the performance of the device. For example, it is well known that the threshold current of a laser increases exponentially while the differential quantum efficiency of the laser decreases with the temperature of heat sink. When the device is operated in continuous wave mode, the temperature rises because of internal heating in the active region of the device, which can lead to an undesirable shift in output spectrum and a change in radiation pattern.

A question naturally arises as to whether or not the thermal effect may be substantially reduced by proper design of the laser structure. The answer is not readily available because previous studies of the laser thermal properties were generally qualitative in nature and also because the thermal resistance was considered as an isolated problem from the other laser characteristics. Consequently a model which allows quantitative study of the internal heating effect is desired.

In this paper, a mathematical model which properly takes into account the current spreading, lateral carrier diffusion, two-dimensional heat diffusion and refractive index variation parallel to the junction plane has been developed and used to examine the waveguiding mechanism, radiation pattern and threshold current. The study involved several aspects: (a) The continuity equation is solved to determine the electron concentration distribution in the active layer. (b) The static thermal distribution due to the driving current is solved for CW operation, from the heat diffusion equation with properly imposed boundary conditions. The solution of this problem permits us to determine the average temperature rise in the active region from the heat sink temperature and also to determine the lateral thermal distribution in the active region. (c) The nonuniform dielectric constant is obtained from the electron concentration and temperature distribution. (d) The electromagnetic wave equation in the resulting nonhomogeneous slab waveguides is solved, with properly imposed boundary conditions, by using approximated distributions of gain constant and refractive index in the waveguiding layer, which are assumed to have parabolic spatial dependence. (e) Because of the difficulty in matching the boundary conditions in the active-inactive-layer interfaces, an effective dielectric constant concept is employed for the three layer waveguide. Thus the guided mode pattern is determined with the aid of the Hermite-Gaussian function, which is the eigen function of the problem under consideration.

Using the model developed, the thermal effect on some of the device parameters can be investigated; e.g., the effect on the mode-guiding characteristics can be discussed in terms of focusing or defocusing by the refractive index profile used. The increase of threshold current and spectrum shift due to the junction heating can also be examined.

As an illustration, sample calculations were made for a set of values of physical parameters and dimensions found in a typical stripe-geometry P-AlGaAs/p-GaAs/N-AlGaAs double heterostructure laser. The results of our calculations are generally in good agreement with the experimentally observed data reported previously by other workers.

It is of interest to note that according to our model, a lateral thermal guiding exists in addition to the gain-guiding for stripe-geometry DH laser with CW operation. The index focusing also affects the higher order mode intensity profiles. For example, the distance between the two intensity peaks for the first order lateral mode may be reduced by the focusing effect. This will eventually enhance the mode gain of the first order mode thus resulting in an optical non-linearity at a lower radiation power level. For a low duty cycle pulsed operation, where the internal heating is negligible, the defocusing of the guided mode resulting from the refractive index profile dip can increase the near-zone field beam width of the fundamental mode. Thermal guiding was found to be relatively important in a thin active layer, with a narrow stripe, photon-bombarded laser.

The results of our study also show that the product of thermal resistance and threshold current at room temperature should be reduced in order to improve the performance of the device at an elevated temperature. For example, a reduction of active layer thickness up to the vicinity of 0.1 μm decreases the junction heating by lowering the threshold current without substantial change in thermal resistance of the active region. Further reduction of the active layer thickness, however, will increase the threshold current and thus the junction heating because of poor optical confinement. On the other hand, to lower the junction heating, the P-AlGaAs layer should also be sufficiently thin since the thickness of this layer does influence the value of thermal resistance of the device significantly.

Using the model developed, a number of calculations were made to identify the optimal thermal design criterion. The effects of change in the laser dimensions, e.g., in the stripe-width and laser cavity length, were also investigated and discussed. Our model can also be profitably used for the study of different types of stripe-geometry lasers.