W1B-(2)-3

Improved temperature characteristics of semiconductor lasers due to carrier redistribution among nonidentical multiple quantum wells

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Abstract *-- Carriers among nonidentical multiple quantum wells (MQWs) will redistribute as temperature varies. This is due to strongly temperature-dependent Fermi-Dirac distribution, which favors carriers in high energy states in high temperature. As a result, the temperature characteristic of semiconductor can be improved.*

INTRODUCTION

For laser diodes with nonidentical MQWs, the temperature-induced carrier redistribution could be observed by different experimental results. It causes the lasing wavelength much less dependent on temperature, compared to the bandgap shrinkage. We also find that there are two lasing wavelength peaks in the spectrum of this laser diode at room temperature. The relative amplitude of these two lasing peaks will change as ambient temperature increases. Meanwhile, the relationship of threshold current and temperature at two different lasing wavelengths shows that more carriers move to short wavelength QW at high temperature.

THEORETICAL BACKGROUND

Assume that the quantum-well (QW) structure has only two different QWs. QW A has one quantized energy at E1 and QW B has one quantized energy at E2, and E1 < E2. For a certain injection level of carriers, the Fermi level (E_F) is assumed to be slightly above energy E_2. As temperature increases, carriers in QW A and in QW B change the different numbers respectively because of the Fermi-Dirac distribution varies with temperature. For a certain injection current, the total amount of carriers in the QWs is approximately constant. Thus carriers flow from QW A to QW B as temperature increases and vise versa as temperature decreases.

EXPERIMENT

The QW structure for the experiment has two In0.53Ga0.47As QWs near the p-cladding layer and three In0.67Ga0.33As0.72P0.28 QWs near the n-cladding layer. The QWs are separated by In0.86Ga0.14As0.3P0.7 barriers. At room temperature, the In0.53Ga0.47As QWs (QW A) and In0.67Ga0.33As0.72P0.28 QWs (QW B) have their first quantized transition energies of 0.8 eV and 0.954 eV, respectively. Because the bandgap shrinks with temperature, those transition energies decrease with temperature. When we put theoretical values and experimental values together, we find the measured wavelength of the above laser diode shows much less temperature dependence. For temperature varying from 33 K to 260 K, its corresponding energy changes less than 5 meV, while the bandgap energy changes more than 50 meV.

It is interesting that when we increase the ambient temperature, the spectrum of the device has double lasing peaks. One is at 1365nm and the other at 1418nm. The short wavelength peak emerges and the spacing between these two lasing peaks is quite large. It is significant because it means more carriers move to the 1.3um quantum well at high temperature. If we use a grating in an external cavity to control the lasing wavelength, we see that there is a higher characteristic temperature T_0 at short wavelength. The measurement of threshold currents for these two lasing wavelengths reveals the relative modal gain of two different quantum wells. When the ambient temperature is lower than 24°c, light at 1418nm has lower threshold current. If the temperature is increased up to 24°c, light at 1368nm has lower threshold current. We also see that the light of 1368nm has "minus characteristic temperature" from 21°c to 24°c. It could be the result of the carriers transferring between two quantum wells and the competition between two lasing peaks.

CONCLUSION

Using nonidentical MQWs structure, temperature sensitivity of long-wavelength semiconductor lasers can be efficiently reduced. Carrier redistribute when temperature increases due to temperature-dependent Fermi-Dirac distribution. In nonidentical MQWs, carriers favor short wavelength QWs as ambient temperature increases. The temperature-induced carrier redistribution among nonidentical MQWs has been observed to contribute larger characteristic temperature and less temperature dependence compared to conventional InGaAsP/InP semiconductor lasers. With the less temperature-sensitive QW located in the proper location, significant improvement on temperature characteristics of semiconductor lasers is possible.

0-7803-7766-4/03/$17.00 ©2003 IEEE