Optical Gain in Double Semi-Parabolic Quantum Well Laser typical of AlGaAs/GaAs

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Abstract—**In this paper, the optical gain in GaAs/$Al_xGa_{1-x}As$ symmetric double semi-parabolic quantum well laser is calculated. For this purpose, first the Schrödinger equation using the fourth-order Runge-Kutta method is done in order to obtain the energy levels and their corresponding wave functions of electrons and holes in double semi-parabolic quantum well. Finally, we introduce the optimum structure of quantum well to obtain the maximum optical gain, which can be useful for quantum well laser designing.**

Keywords-component; Optical Gain; Quantum well laser.

I. INTRODUCTION

Well coupling between quantum wells is an important parameter which can be used to engineer properties of optoelectronic devices based on such systems. Recently, the effect of well coupling on optical gain, differential gain and electric field induced refractive index changes in double quantum well systems have been the subject of many theoretical investigations [1-3]. In all previous work, the effect of structures on optical gain are investigated and by controlling the thickness of QWs and barrier, electron and hole wavefunctions can be modified. This results in the improvement of laser characteristics, as well as the introduction of new semiconductor optical devices.

In the present work we report the numerical of optical gain for a double semi-parabolic quantum wells (DSPQWs) system based on AlGaAs/GaAs. By using the numerical method, the Schrödinger equation is solved in order to obtain the energy levels and wave functions of electrons and holes in DSPQW. After finding the energy levels and their corresponding wave functions, we investigated the optical gain of DSPQW laser.

II. THEORY

A. Band structure

For the calculation of the energy spectrums and related wave functions of electron and hole in the DSPQWs system, we solve the one dimensional Schrödinger equation that follow:

$$-\frac{\hbar^2}{2}\frac{d}{dx}\left[\frac{1}{m^*(x)}\frac{d\psi_{rl}(x)}{dx}\right]+V_{rl}(x)\psi_{rl}(x)=E_{rl}\psi_{rl}(x)\,, \qquad (1)$$

$V_{rl}(x)$ is the confinement potential of the DSPQWs and introduced as[4]:

$$V_{rl}(x)=\begin{cases}\frac{1}{2}m^*\omega_L^2\left(x+\frac{d_B}{2}\right)^2, & -\frac{d_B}{2}-d_W<x<-\frac{d_B}{2}\\ V_{e(h)}, & |x|\le\frac{d_B}{2},\ x>\frac{d_B}{2}+d_w,\ x\le-\frac{d_B}{2}-d_W\,,\\ \frac{1}{2}m^*\omega_R^2\left(x-\frac{d_B}{2}\right)^2, & \frac{d_B}{2}<x<\frac{d_B}{2}+d_W\end{cases} \qquad (4)$$

The Schrödinger equation with this potential cannot be solved analytically while the numerical calculation solutions are needed. Therefore, we use the fourth-order Runge-Kutta method to obtain eigenvalue and eigenfunctions of the system.

B. Optical gain

After the subband structures are obtained, we calculate the optical gain of the DSPQW laser.Using the density matrix approach the optical gain given as[5-8]:

$$g(E)=\left[1-\exp\left(\frac{E-\Delta F}{K_BT}\right)\right]\frac{\pi^2c^2\hbar^2}{n_r^2E^2}r_{sp}(E), \qquad (5)$$

Where

$$r_{sp}(E)=\frac{n_rq^2E}{\pi m_0^2\varepsilon_0\hbar c^3}\sum_{n_c,n_v}\iint\frac{|M_{nm}|^2}{4\pi^2(2d_W)}f_cf_v \times\frac{1}{\pi}\frac{\hbar/\tau}{(E_{eh}-E)^2+(\hbar/\tau)^2}dk_xdk_y, \qquad (6)$$

III. RESULTS AND DISCUSSION

In this section, we present and discuss the numerical results of optical gain in symmetric DSPQW laser for typical GaAs/$Al_xGa_{1-x}As$. The physical parameters used in our numerical work are: nr=3.2, x=0.3, dW=100A°, dB=40A°, carrier density 4×1018 cm-3, T=300°K and P=0kbar.

Fig. 1 represents the optical gain as function of photon energy. As can be seen from this figure, by increasing the carrier density in the active region, the optical gain increases because the separation of quasi-fermi levels increases, consequently more level can contribute to the optical gain and it increases.

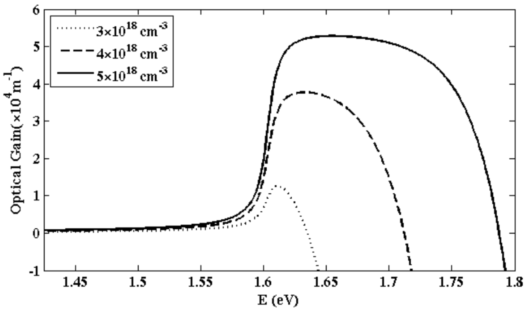

Figure1. TE mode optical gain for the three different carrier density.

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Fig. 2 represents the optical gain as a function of photon energy for three different values of temperature as 300, 350, 400°K. As it can be seen from this figure, with increasing the temperature, shrinkages and the carrier can scatter another subband, and consequently the spectrum range and the optical gain decreases.

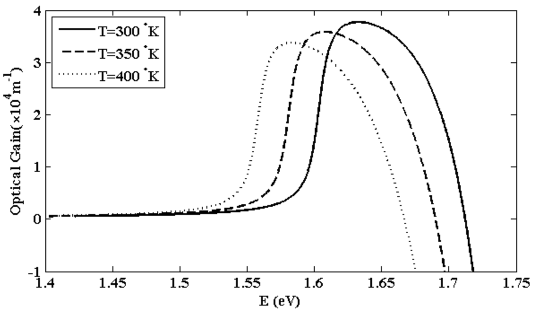

Figure2. Variation of the optical gain versus the photon energy for three different temperature.

In Fig 3, we have shown the pressure dependence of optical gain versus the photon energy. It is observed that the optical gain increases and shifts toward lower energies by decreasing the pressure. The main reason for this behavior is reduction in transition energy from hole first subband (in the valance band) to the electron first subband (in the conduction band).

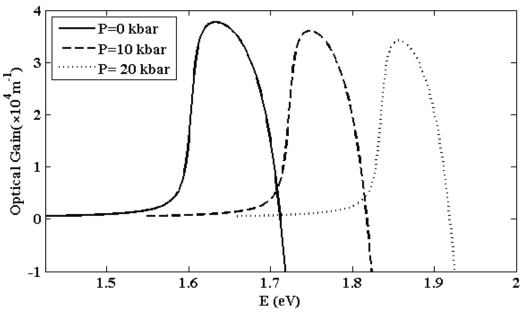

Figure3. The dependence of the optical gain on pressure in AlGaAs/GaAs DSPQW laser.

The Al concentration in the GaAs/$Al_xGa_{1-x}As$ quantum well has a great influence on many physical properties of the structure. In Fig. 4, we have plotted the optical gain as a function of photon energy for tree different concentration ratios as x=0.3, 0.35 and 0.4. From this figure, it can be seen that the optical gain is related to the stoichiometric ratio. As the Al concentration in material rises, the optical gain have been reduced in magnitude and also shifted towards higher energies. The main reason for this resonance shift is the increment in energy interval of two different electronic states between which an optical transition occurs.

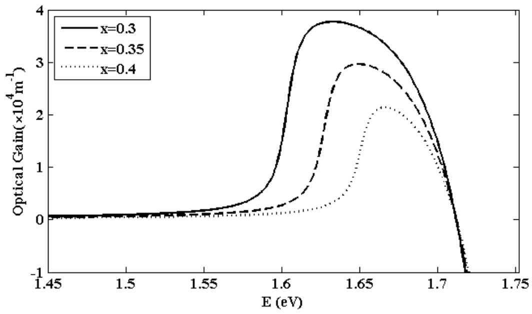

Figure4. TE mode optical gain as a function photon energy for the three different Al concentration.

IV. Conclusion

It is found that transition energy from hole first subband to the electron first subband decreases with increasing temperature, pressure and Al concentration. Results show that the optical gain increases by increasing the well width and carrier density. Also for carrier density about 5×1018 cm-3, the wells width of 120 A°, barrier width 20A°, temperature and pressure 300 °K and 0 kbar, respectively, the optical gain has optimum of value of 5.25×104 m-1at 1.587 eV.

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