Wasit Journal for Science & Medicine **2011 4 (1): (1 - 11)**

Spectral Gain-Carrier Density Distribution of SQW GaAs/AlGaAs Laser

*Adawiya J. Haider & *Safaa A. Oudah Al-Qaysi & **Awatif Sabir Jassam
*School of Applied Sciences, University of Technology, Baghdad, IRAQ
** The University of Mustansiriya, College of Pharmacy.

الخلاصة

توزيع طيف حاملات الشُحن لجهد البئر المفرد لِليزر GaAs/AlGaAs .
هـذا البحـث أجـرى علـى موديـل الكسـب لليـزر بئـر الجهـد ذات الجـدار المفـرد نـوع GaAs/AlGaAsبأستخدام قاعدة فيرمي الذهبي (Fermi- Golden) مع تغير سمك الجدار المكمم L_z =(100,75) Å ، عند درجة حرارة $T=300^oK$ عند فجوة طاقة مقطعة ΔE_c = 0.1 eV ، هذه الحسابات انجزت بأستخدادم نموذجين البسيط و موديل الاستقطاب المعززعند كثافة حقن $N=3.348*10^{18}$ cm^{-3}.

Abstract:

In this work, the modal gain of SQW GaAs/AlGaAs has been calculated using the Fermi-Golden Rule with varying the quantum well thickness L_z =(100,75) Å, at a temperature of $T=300^oK$, at a bandgap discontinuity of ΔE_c of 0.1 eV , this calculation was achieved using two models, the simplified and the polarization enhancement model at a carrier injection condition of $N=3.348*10^{18}$ cm^{-3}.

Keywords: SQW GaAs/AlGaAs laser, Modal gain, Spectral gain.

I. Introduction:

Quantum well (QW) semiconductor lasers have attracted considerable interest because of their significant superiority in performance over conventional double heterostructure (DH) lasers; [1] they are attractive for research because they are both physically very interesting and technologically important. QW technology allows the crystal grower for the first time to control the range, depth, and the arrangement of the quantum mechanical potential wells. In the last decade, the importance of the quantum well laser has steadily grown until today it is preferred for most semiconductor laser applications, [2]. They offer the advantages of lower threshold current density, lower temperature sensitivity, high modulation speed; improved coherency wit reduced lasing linewidth and superior mode stability, and high efficiency, etc, [1].

Their growing popularity is because, in almost every respect, the quantum well laser is somewhat better than conventional lasers with bulk active layers. One obvious advantage is the ability to vary the lasing wavelength merely by changing the width of the quantum of the QW. A more fundamental advantage is that the QW lasers delivers more gain per injected carrier than conventional lasers, which results in lower threshold currents, [2,3].

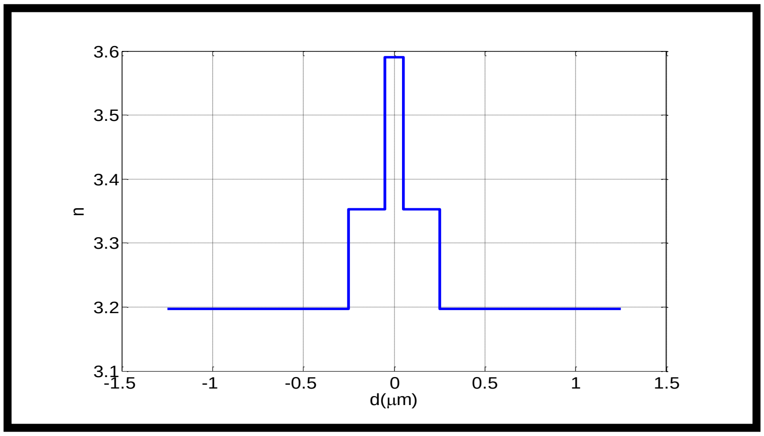
A principal feature of the QW laser is the extremely high optical gain that can be obtained in the QW for very current densities. This arises partly from greater population inversion at a given carrier density because of the lower quantized density of states, but mostly from the high carrier density in the QW because of its small width, [4].

In general, the QW lasers have the extremely high optical gain because of their high carrier confinement. The optical confinement factor of the QW lasers is relatively low due to their thin active region. To predict the lasing behavior, we must evaluate the modal gain of the QW lasers. The modal gain of QW lasers is determined by their optical confinement factor and their ability to collect injected carriers efficiently, [6].

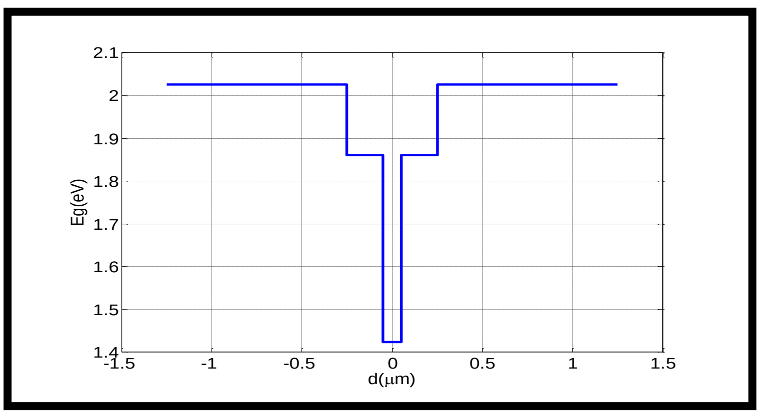
In this paper, the primary goal was to apply the two models of calculating the modal gain for SQW GaAs/AlGaAs laser (simplified and polarization enhancement models) with varying the well widths L_z at a bandgap discontinuity of ΔE_c of 0.1 eV, and at a temperature of $T=300^oK$.

II. Theoretical Concept:

Using the structure of the SQW GaAs/AlxGa$_{1-x}$As with x=0.2 for the barrier layer and a layer thickness of (d=0.2μm), x=0.6 for the cladding layer (d=1μm) and (d=0.01μm) for the active region, a detailed structure is shown in Fig.(1)..



(a)



(b)

Fig.(1) Schematic diagram of the laser structure shows (a) refractive index change for the proposed structure, (b) energygap change for the proposed structure.

The present model calculates the laser gain on the basis of band-to-band transitions, the following assumptions are used in this model: 1. the wells in the conduction and valence bands are approximated by infinitely deep square wells, 2. the bandgap discontinuity is ($\Delta E_c/\Delta E_v$=0.67/0.33), 3. transitions to light and heavy hole subbands, 4. transitions from subbands with the same quantum numbers.

For each quantized level, there is a continuum of energies arising from the lateral kinetic energy of the carriers in the plane of the QW. Associated with each discrete level, the resulting sheet density of states for energies above the minimum level is, [1]:

$$\rho_{QW}(E) = \sum_{n=1}^{all\,states} \frac{m_c}{\pi\hbar^2} H(E - E_{nc})$$,…………………...……………………(1)

where:

E_{nc} is the energy of subband n of the conduction band,

m_c is the effective mass of the electron at the bottom of the conduction band.

Since ρ_{QW} is constant in each subband, the density of electrons N_e and holes N_h can be calculated analytically and the result will be, [3]:

$$N_e = kT \sum_n \left(\frac{m_c}{\pi\hbar^2 L_z} \right) \ln\left[1 + \exp\left(\frac{E_{Fc} - E_{nc}}{kT} \right) \right]$$,
...……………………………………….…(2)

$$N_h = kT \sum_n \left(\frac{m_v}{\pi\hbar^2 L_z} \right) \ln\left[1 + \exp\left(\frac{E_{Fv} + E_{nv}}{kT} \right) \right]$$,...…………………………………….…(3)

where:

E_{Fc} is Fermi energy of the conduction band,

E_{Fv} is Fermi energy of the valence band,

L_z is the layer thickness, of the QW,

m_v is the effective mass of the electron at the top of the valence band.

The optical gain is calculated using standard perturbation theory Fermi's Golden Rule, (neglecting the effect of intraband scattering). For the simplified model the gain spectrum can be evaluated using the following equation, [2]:

$$g(E) = g_o(E) |M_b|^2 \sum_{j,n} \rho_{r,jn} [f_c - f_v]_{E,jn}$$, …………………………………(4)

here, the gain prefactor is given by:

$$g_o(E) = \pi\hbar e^2 / m_o{}^2 n_1 E c_o \varepsilon_o$$ …………………………………………………….….(5)

and M_b is the average, energy –independent, momentum matrix element for the dipole transition in the bulk semiconductor, i.e.:

$$|M_b|^2 = (2/3)|M|^2$$, ……………………………………………………………….(6)

Since the gain anisotropy favors lasing in TE modes, we calculate the gain only for this polarization. The spectrally dependent gain coefficient for the quantum well region is, [7]:

$$g(E) = \frac{q^2 |M|^2}{E \varepsilon_o m^2 c_o \hbar L_z} \sum_{i,j} m_r C_{ij} A_{ij} [f_c - (1 - f_v)] H(E - E_{ij})$$,…………………………....(7)

where:

$|M|^2$=bulk momentum transition matrix element,
ε_o =free-space permittivity,
m=free electron mass,
c_o=vacuum speed pf light,
N=effective refractive index,
i,j= conduction, valence quantum numbers (at Γ),
m_r=spatially weighted reduced mass,
C_{ij}=spatial overlap factor between states i and j,
A_{ij}=anisotropy factor for transition i, j,
f_c=Fermi population factor for conduction electrons,
f_v=Fermi population factor for valence holes,
H= Heaviside step function,
E_{ij}=transition energy between states i and j.

For TE transition, with the electric field vector in the plane of the QW, its values are, [2]

$$\begin{aligned} A_{ij} &= \left(3/4\right)\left(1+\cos^2\theta_{ij}\right) \qquad (heavy\,hole) \\ &= \left(1/4\right)\left(5-3\cos^2\theta_{ij}\right) \qquad (light\ hole) \end{aligned} \quad \ldots\ldots\ldots\ldots(8)$$

and for TM transitions, with the electric field normal to the QW, its values are, [2]:

$$\begin{aligned} A_{ij} &= \left(3/2\right)\left(\sin^2\theta_{ij}\right) \qquad (heavy\,hole) \\ &= \left(1/2\right)\left(4-3\sin^2\theta i_{ij}\right) \qquad (light\ hole) \end{aligned} \quad \ldots\ldots\ldots\ldots(9)$$

The angular factor is

$\cos^2\theta_{ij}=E_{ij}/E$

and shows decreasing anisotropy between nearby heavy and light hole transitions as the photon energy increases deeper into the band.

The bulk averaged momentum matrix element between conduction and valence states is, [8]:

$$|M|^2 = \frac{m^2 E_g\left(E_g+\Delta\right)}{6m_c\left(E_g+2\Delta/3\right)}, \quad \ldots\ldots\ldots\ldots(10)$$

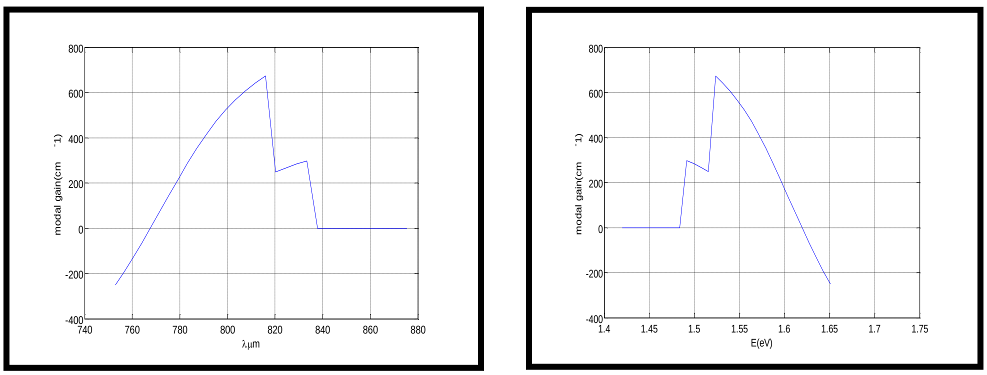
where:

$$E_g = \left[E_o - \frac{5.405\times10^{-4}\times T^2}{T+204}\right], \quad \ldots\ldots\ldots\ldots(11)$$

Eg = direct bandgap,
Eo = bandgap constant,
T = operating temperature,
$\Delta_{s\text{-}o}$ = split-off band separation,
mc = conduction band effective mass.

III. Results and Discussion:

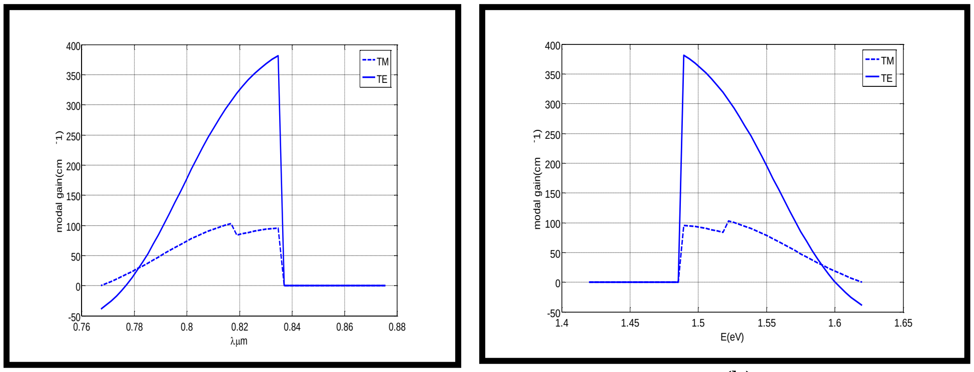
The results obtained by using the above equations are for SQW GaAs/AlGaAs laser. The modal gain has been calculated using the Fermi's-Golden Rule that is the product of the material gain coefficient times the optical confinement factor evaluated at the curve's spectral peak. Fig.(2a,b) represents the simplified gain model in which the spectral broadening effects as well as effects resulting from the anisotropy of the QW have been ignored. This curve is associated with a carrier density of $N=3.34\times10^{18}cm^{-3}$ at $300^{o}K$. Note the sharp features arising from the low-energy heavy-hole transition, and the higher energy light-hole transition. The gain cross-over between the n=1 heavy and light-hole transition energies. The first figure was plotted against the transition wavelength, while the second was plotted against the transition energy.



(a) (b)

Fig.(2) Plot of the modal gain versus (a) the transition wavelength, (b) the transition energy, at $T=300^{o}K$, $L_z=100$ Å.

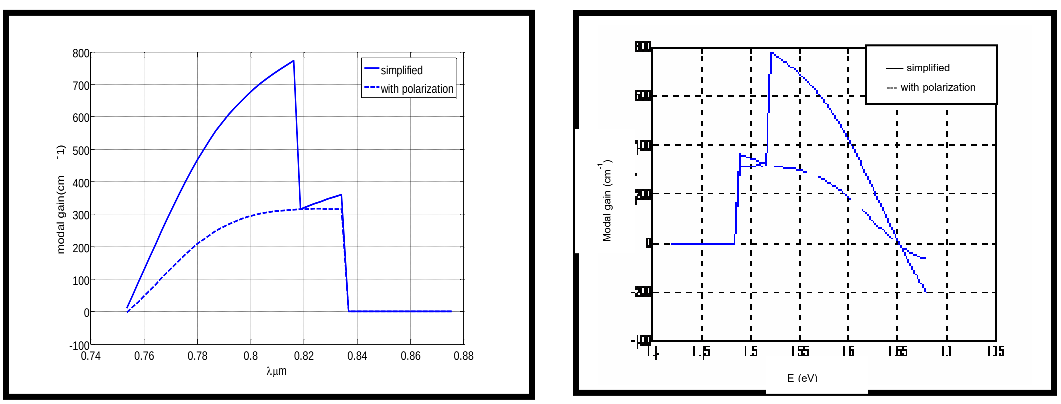
The relation between the modal gain for the same injection condition, $N=1.827\times10^{18}$, versus the wavelength transition and the transition energy, respectively, is shown in Fig.(3a, b), with TE and TM polarization enhancement, in which the feedback condition for lasing usually selects TE over TM polarization even when the gain is polarization-independent. The anisotropy factor in the QW provides an enhancement of the oscillator strength for TE polarization at photon energies near the gain peak as opposed to TM polrization, where the oscillator strength diminshed. Thus for QW structure, stability of lasing in the TE mode is improved further, and TM polarization need not to be considered.



(a) (b)

Fig.(3) Plot of the TE and TM modal gain versus, (a) the transition wavelength, (b) the transition energy.

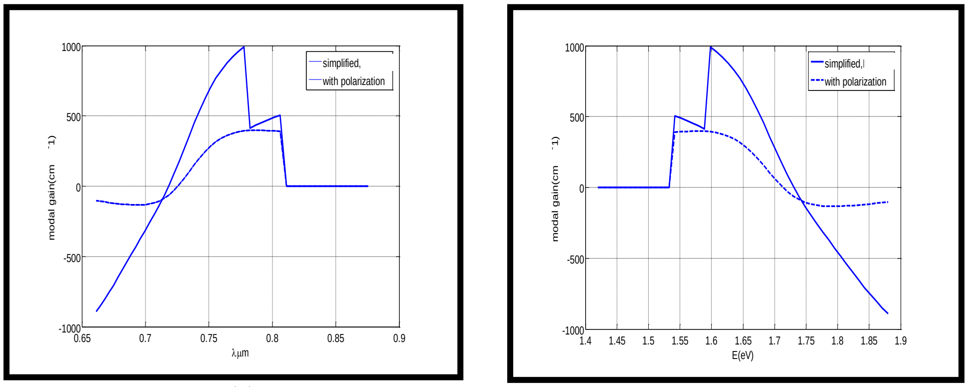
Fig.(4a,b) plot the modal gain for the same injection condition N=3.348×10^{18} cm^{-3}, versus the transition wavelength and transition energy, respectively. From the simplified model and the TE polarization enhancement, the planar symmetry of the electronic wavefunctions in a QW structure results in a polarization dependence of the stimulated optical transitions, which results in a difference between the dipole e-lh and e-hh.



(a) (b)

Fig.(4) Plot of the modal gain versus (a) the transition wavelength, (b) the transition energy at Lz=100 Å.

The relation between the modal gain for the same injection condition, N=3.348×10^{18} cm^{-3}, versus the wavelength transition and the transition energy, respectively using L_z=75 Å, T=300^{o}K is shown Fig.(5a,b). The transition energy and wavelength are varied due to the fact that varying the quantum well thickness will result in a change in transition energy. Also, reducing the active region thickness will result in an increase in both the simplified modal gain, and the TE enhanced polarized modal gain.



(a) (b)

Fig.(5) Plot of the modal gain versus (a) the transition wavelength, (b) the transition energy, Lz=75 Å.

a flow chart for the calculation of the gain profile is shown in Fig.(6).

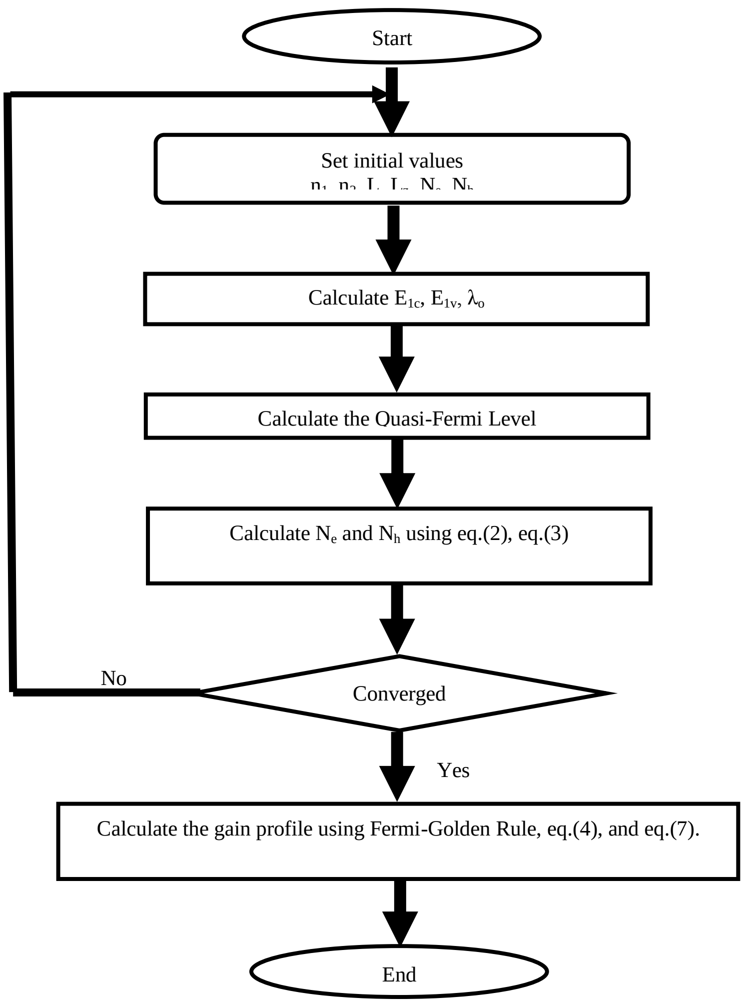


Fig.(6) Flow chart for solving the QW gain profile and the current

IV. Conclusions:

We have studied the spectral gain carrier distribution of SQW GaAs/AlGaAs, the modal gain of using the Fermi-Golden Rule with varying the quantum well thickness Lz =(100,75) Ǻ, at a temperature of T=300oK, at a bandgap discontinuity of ΔEc of 0.1 eV , this calculation was achieved using two models, the simplified and the polarization enhancement model at a carrier injection condition of N=3.348*1018 cm-3.

V. References:

[1] W.L.Li,Y.K.Su,and D.H.Jaw, "the Influence of Refractive Index Dispersion on The Modal Gain of a Quantum Well Laser", IEEE Journal of Quantum Electronics, Vol.33,No.3, March 1997.

[2] Peter S. Zory, "Quantum Well Lasers", 1993, Academic Press, Inc.

[3] Dr.W.Koechner, "Solid-state laser engineering", Sixth Edition, Springer Series, 2006.

[4] S. R. Chinn, P.S.Zory, A.R.Reisinger, "A Model for GRIN-SCH-SQW Diode Laser", IEEE Journal of Quantum Electronics, Vol. 24, No.11, pp.2191-2214, November 1988.

[5] O.Svelto, "Principles of Lasers", Plenum Press, New York, 1998.

[6] F.Gity, V.Ahmadi, M.Noshiravani, "Numerical Analysis of Void-Induced Thermal effects on GaAs/AlxGa1-xAs High Power Single-Quantum-Well Laser Diodes", Solid-State Electronics, Vol.50, pp.1767-1773, 2006.

[7] J. Hader, J.V. Moloney, S.W.Khoch, "Temperature Dependence of Radiative and Auger Loss in Quantum Wells", IEEE Journal of Quantum Electronics, Vol.44, No.2, February, 2008.

[8] R. Muller, "A Theoretical Study of the Dynamical Behavior of Single Quantum-Well Semiconductor Lasers", Vol.91, Optics Communication, pp.453-464, 1992.

[9] A. Yariv, "Optical Communication in Modern Communication", Oxford university Press, 1997.

Recived ……………………………………………..……………………… (9/6 /2010)
Accepted ……………………………………………………...……………... (22/9/2010)