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Optical Gain of InGaAlAs Quantum well with Different Barriers, Claddings and Substrates

Vibha Kumari[1], Ashish[1], Swati Jha[1], Amit Rathi[1], H. K. Nirmal[2], Pyare Lal[2], P. A. Alvi[2,*]

[1]Department of Electronics, Banasthali Vidyapith-304022, Rajasthan (INDIA)
[2]Department of Physics, Banasthali Vidyapith-304022, Rajasthan (INDIA)
*Corresponding author: drpaalvi@gmail.com

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Abstract The fundamental characteristic of the quantum well heterostructures is the optical gain. In this paper, the effect of barriers (InGaAlAs and AlGaAs), claddings (InAlAs and AlGaAs) and substrates (InP and GaAs) materials on the optical gain of InGaAlAs quantum well of 6 nm width has been studied with in TE and TM polarization modes. The overall size (width) of the STIN-SCH (step index – separate confinement heterostructure) based nano-heterostructure including single quantum well along with barrier and claddings is 36 nm. In TE mode, the maximum optical gain for nano-heterostructure consisting of single quantum well (SQW) of InGaAlAs material with barriers of InGaAlAs and claddings of InAlAs is found at 1.55 µm wavelength; while for the SQW of the same material with barriers of AlGaAs and claddings of AlGaAs is found at 0.84 µm. For both types of heterostructures, the maximum gain corresponding to lasing wavelengths have been plotted on logarithmic scale and discussed. In order to support the obtained optical gain, the anti-guiding factors for both the structures have also been discussed.

Keywords: *optical gain, InGaAlAs, AlGaAs, InAlAs, heterostructures*

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1. Introduction

For opto-electronic device applications, heterojunction structures are very important [1], because of its minimal intra-modal delay effects and minimal losses at wavelengths of 1.30 and 1.55 µm exhibited in silica fiber [2]. In the recent research, the nano-heterostructures InGaAlAs/InP have got wide publicity due to its lasing action at 1.55 µm wavelength; the wavelength of low loss and minimum attenuation within the optical fiber [3-7]. The informative modal gain characteristics of InGaAlAs/InP heterostructures taking into account the maximum optical gain within the TE and TM modes have also been discussed and analyzed in ref. [3].

In a recent research, for 1.55 µm wavelength, the multi-quantum wells (MQWs) based vertical cavity surface emitting lasers (VCSEL) of InGaAlAs/InP materials have been designed along with computation of their characteristics [8]. The bandwidth of such structures have been reported ~ 14.2 GHz that indicated a high speed performance for the application in optical fiber communications. Yong et al. have studied theoretical material gain for 1.3 nm quantum-well based InGaAsP, AlGaInAs, and InGaAsN lasers [9].

In the following sections of the paper, the structure details, the optical gain and the anti-guiding factors calculations and their comparative discussion has been made. For both types of heterostructures, the maximum gain corresponding to lasing wavelengths have been plotted on logarithmic scale and discussed.

2. Structures Detail and Numerical Calculations

The present paper is aimed to calculate the optical gain and compare them for two nano-scaled heterostructures-I and –II. The detail of these structures has been given in Table 1 and Table 2.

The valence band and conduction band profiles, as well as size quantized levels and wave functions of electrons and holes in the investigated nano-scale heterostructures – I and II have been numerically calculated. Single effective mass and Kohn–Luttinger Hamiltonian equations have been solved to obtain quantum states and envelope wave functions in the heterostructure [10]. The description does not take into account the split- off valence sub-band.

For the purpose of optical gain calculation, the following model has been utilized [11,12];

$$G(E) = \frac{q^2 |M_B|^2}{E\varepsilon_o m_o^2 c\hbar n_{eff} W} \sum_{i,j} \int_{E_g}^{E_{gb}} m_{r,ij} C_{ij} A_{ij} (f_c - f_v) L(E - E') dE$$

where

q: elementary charge

$|M_B|^2$: bulk momentum transition matrix element

ε_o: free space permittivity

c: speed of light in vacuum

n_{eff}: effective refractive index of the laser structure

W: width of the quantum well

i,j: conduction and valence band quantum numbers

$m_{r,ij}$: spatially weighted reduced mass for transition

C_{ij}: spatial overlap factor between the states i and j

A_{ij} :angular anisotropy factor

f_c and f_v: electron quasi Fermi function in the conduction and valence band

L(E): Lorentzian lineshape function

In order to support the gain calculation, the knowledge of anti-guiding is also very important. The anti-guiding factor plays a very important role in the lasing nano-heterostructure. The anti-guiding can be expressed in terms of differential gain and refractive index change as;

$$\alpha = -4\pi n' / \lambda G'$$

where n' and G' are the differential refractive index and differential gain, respectively for the heterostructure.

Table 1. Structure Parameters for Nano-Heterostructure –I

Layers Specification	Width of Layers	Role of Layers	Energy Band gap (eV)	Lattice constants (Å)	Strain	Conduction band edge-offset (eV)	Valence band edge-offset (eV)
$In_{0.71}Ga_{0.21}Al_{0.08}As$	6 nm	Quantum well	0.80	5.93	-0.0117	0.0538058	-0.0269029
$In_{0.41}Ga_{0.34}Al_{0.25}As$	5 nm	Barrier	1.42	5.86	0.0087	0.3327401	-0.1241536
$In_{0.52}Al_{0.48}As$	10 nm	Cladding	1.67	5.86	0.0012	0.5859193	-0.2278575
InP	-	Substrate	1.34	5.86	-	-	-

Table 2. Structure Parameters for Nano-Heterostructure–II

Layers Specification	Width of Layers	Role of Layers	Energy Band gap (eV)	Lattice constants (Å)	Strain	Conduction band edge-offset (eV)	Valence band edge-offset (eV)
$Al_{0.15}In_{0.22}Ga_{0.63}As$	6 nm	Quantum well	1.32	5.743	-0.0157	0.0964814	-0.0482407
$Al_{0.2}Ga_{0.8}As$	5 nm	Barrier	1.67	5.667	0.0112	0.2405987	-0.1132229
$Al_{0.6}Ga_{0.4}As$	10 nm	Cladding	2.026	5.65	-0.0138	0.6084067	-0.2863090
GaAs	-	Substrate	1.42	5.65	-	-	-

3. Results and Discussion

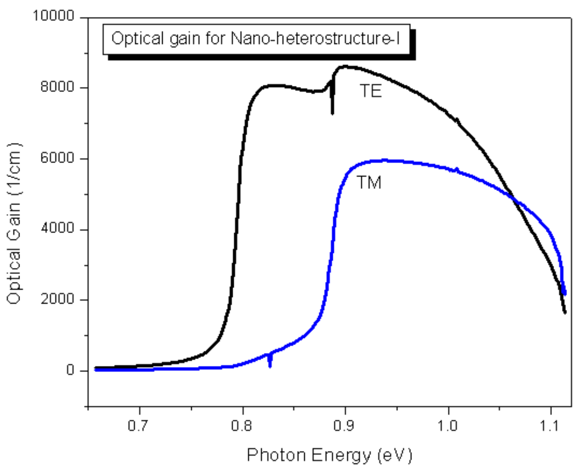

Figure 1. Optical gain as a function of photon energy for nano-heterostructure-I

For both type heterostructures, as detailed in Table 1 and Table 2, the optical gain as a function energy and wavelength has been calculated by using the GAIN package and plotted in figure 1, figure 2, figure 3 and figure 4. In figure 1, for heterostructure – I, the optical gain as a function of photonic energy within TE and TM modes has been predicted. Referring to figure 1 and 2, In TE mode, the optical gain has larger value than that in TM mode. Moreover, for TE mode two broadened peaks are observed while in TM mode, there is single peak. The two peaks, perhaps, may be due to the transitions of electrons in conduction band and light and heavy holes in valence sub-bands. Form figure 2, it is clear that the optical gain in TE mode has maximum values on two lasing wavelengths ~ 1.33 µm and 1.55 µm; these are the wavelengths of low loss and minimum attenuation within the optical fiber; obviously the intensities of lasing beam emitted from such nano-heterostructures corresponding to these wavelengths will be maximum. In contrast to TE mode, the optical gain in TM mode has maximum value on a single wavelength ~ 1.33 µm.

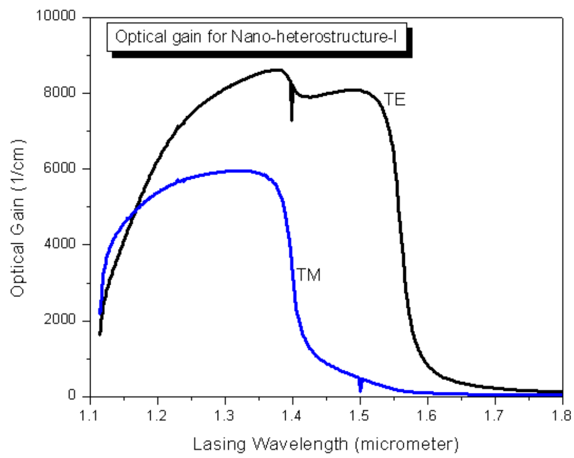

Figure 2. Optical gain as a function of lasing wavelength for nano-heterostructure-I

In figure 3 and figure 4, the optical gain for the heterostructure – II has been calculated with in TE and TM modes. The similar behavior of optical gain has been observed as in the case of heterostructure – I; but in this case the, maximum optical gain is available on two wavelengths ~ 0.79 µm and 0.85 µm (in TE mode). In TM mode the maximum optical gain is available on a single wavelength ~ 0.79 µm.

Next, the anti-guiding factor has also been calculated and plotted in figure 5, in order to support the calculated optical gain for both the heterostructures. The anti-guiding factor is a key parameter and responsible for optical or material gain associated with the nano-heterostructures. In figure 5, it is found that the range of anti-guiding factor for the heterostructure – I lies between 1.25 and 3.75; while for heterostructure – II, it ranges from 1.25 to 2.15. Here, the notable point is that anti-guiding factor has always smaller or non-zero values. The anti-guiding factor is directly proportional to the ratio of refractive index change with respect to carrier density and differential gain.

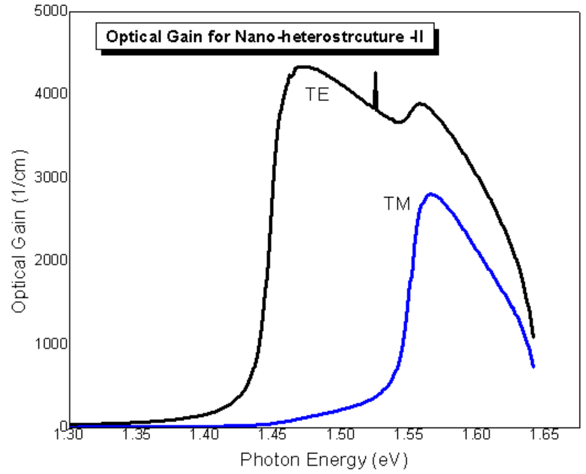

Figure 3. Optical gain as a function of photon energy for nano-heterostructure-II

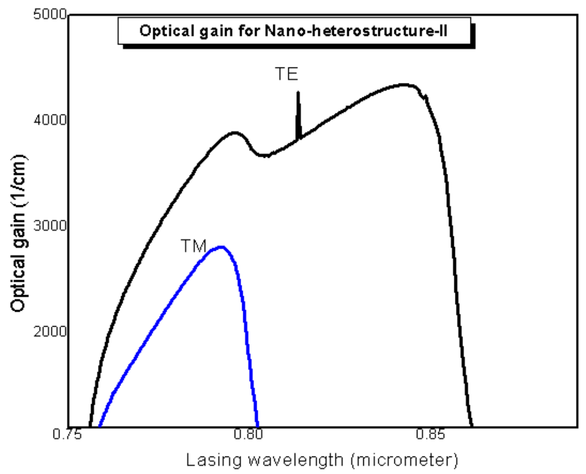

Figure 4. Optical gain as a function of lasing wavelength for nano-heterostructure-II

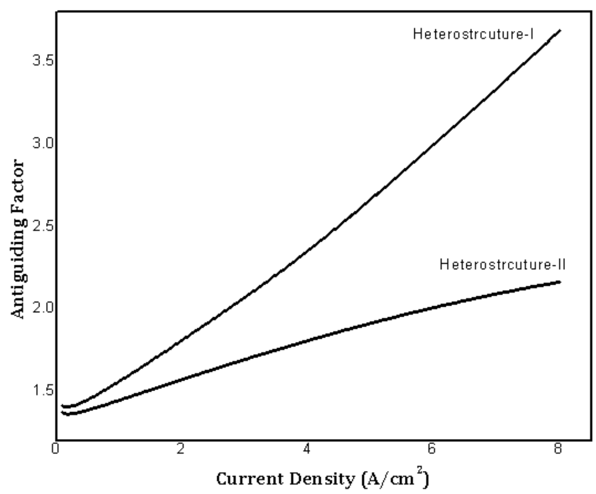

Figure 5. Anti-guiding factors for nano-heterostructure-I and II

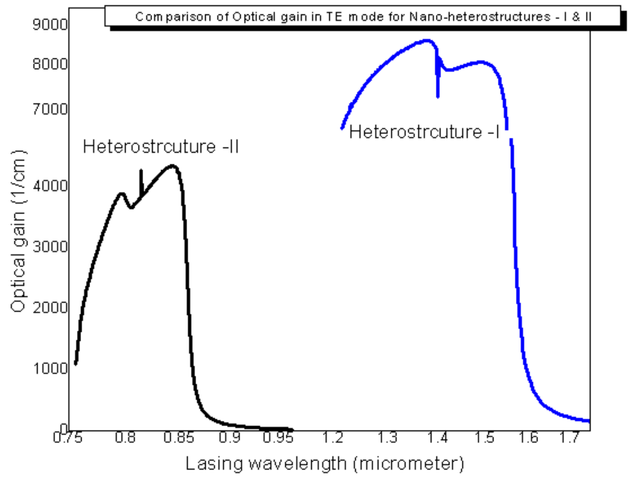

Figure 6. Comparison of optical gain for nano-heterostructure-I and II

The optical gain for both the heterostructures have been plotted and compared on logarithmic scale in figure 6. The comparative study of both the heterostructures suggests that the heterostructure –I is better than the heterostructure – II due to its lasing wavelengths of low loss and minimum attenuation within the optical fiber.

4. Conclusion

The effect of barriers (InGaAlAs and AlGaAs), claddings (InAlAs and AlGaAs) and substrates (InP and GaAs) on the optical gain of InGaAlAs quantum well of 6 nm width within the nano-heterostructures (as defined in Table 1 and 2) of size 36 nm (including quantum well, barriers and claddings only) has been studied with in TE and TM polarization modes. The anti-guiding factors have also been calculated for both the heterostructures and discussed. On behalf of the comparative study of both the heterostructures, it is suggested that the heterostructure –I is better than the heterostructure – II due to its lasing wavelengths of low loss and minimum attenuation within the optical fiber.

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References

[1] P. A. Alvi, Sapna Gupta, Puja Vijay, G. Sharma, M. J. Siddiqui, Physica B: Condensed Matter, Vol. 405, Issue 17, pp. 3624-3629 (2010).

[2] T. Miya, Y. Terunuma, T. Hosaka, T. Miyashita, Electron. Lett. 15, 3624 (1979).

[3] Sandra R. Selmic, Tso-Min Chou, Jiehping Sih, Jay B. Kirk, Art Mantie, Jerome K. Butler, Gary A. Evans, *IEEE J.* On Selected Topics in Quantum Electronics, 7, No. 2 (2001).

[4] P. A. Alvi, Pyare Lal, S. Dalela, and M. J. Siddiqui, Physica Scripta 85, 035402 (2012).

[5] P. A. Alvi, Pyare Lal, Rashmi Yadav, Shobhna Dixit, S. Dalela, Superlattices and Microstructures, 61, pp. 1-12 (2013).

[6] Pyare Lal, Rashmi Yadav, F. Rahman, P. A. Alvi, “Adv. Sci. Eng. Med. 5, 918-925 (2013).

[7] Y. S. Yong , H. K. Yow, M. Sorel, Proc. SPIE 7750, Photonics North 2010, 77501 (September 22, 2010);

[8] R. R. Hasan, Rinku Basak, International Journal of Multidisciplinary Sciences and Engineering, Vol. 4, No.1, pp. 5-9 (2013).

[9] J.C. Yong, J.M. Rorison, I.H. White, IEEE J. Quantum electron. 38 (12) pp. 1553-1564 (2002).

[10] Vahid Bahrami Yekta and Hassan Kaatuzian, “Commun. Theor. Phys. (Beijing, China) 54, 529 (2010).

[11] Zory, P.S.: Quantum well lasers. Academic Press, London, pp. 28-41, 132-154 (1993).

[12] Rashmi Yadav, Pyare Lal, F. Rahman, S. Dalela, P. A. Alvi, International Journal of Modern Physics B, Vol. 28, No. 10, pp. 1450068 (2014).