Quantum Well Width Effects on Type I GRIN SQW-InGaAsP/InP Nano-Heterostructure

Rashmi Yadav
Department of Physics, Biyani Girl's College, Jaipur-302039 (Rajasthan)

Abstract. This paper reports the optical amplification characteristics of Type I GRIN-SQW (Graded Index Single Quantum Well) InGaAsP/InP based nano-scale heterostructure, taking into account the variation in quantum well (active region) width with in TE (Transverse Electric) polarization mode. Apart from the lasing characteristics, we have also predicted the variation of modal gain spectra in terms of wavelength within both TE and TM polarization modes. The obtained outcomes suggest that the TE modal gain spectra in terms of well width are more pronounced rather than in TM mode. The evaluated consequences in the present work reveals, maximum gain is obtained at wavelength 1.40 µm for the minimum wavelength used (2nm) in TE mode polarization, therefore these nano-structures are very useful due to less attenuation, as a light source for the optical fiber based communication system functioning in the NIR region.

Keywords: III-V Semiconductors, Material Gain, Heterostructures.

INTRODUCTION

The GRIN (Graded Index) SCH (Separate confinement heterostructure) type lasing nano-heterostructures have several advantages over STIN SCH types such as higher carrier injection efficiency, noticeably shorter doping time, higher trapping efficiency and enhanced carrier confinement [1-4]. Moreover studied the modal gain behavior [5] as well as optical losses theoretical with in TE (Transverse Electric) and TM (Transverse Magnetic) polarization mode for MQW (Multiple quantum well) GRIN as well as STIN (Step Index) InGaAsP/InP Lasing Nano-Heterostructure and it has been observed that the gain spectra is more noticeable in TE mode rather than TM mode for MQW GRIN InGaAsP/InP [6, 7]. Recently, Nisha Yadav et al have been studied theoretically energy dispersion curve and optical absorption along with the variation of width of active region (well width) for type II InAs/AlSb Nano scale structure [8].

MODEL

The proposed modeled structure has SQW sandwiched between the barrier layers (eleven GRIN layers) of different compositions followed by the claddings. The whole structure is assumed to be grown on InP substrate. $In_{0.90}Ga_{0.10}As_{0.59}P_{0.41}$ composition has been utilized as an active region . The width of the active region is variable (~2, 4, 6, 8, 10 nm), while the barriers and claddings are of width ~ 5 and 10 nm, respectively, thereby creating a nano-heterostructure. In case of GRIN structure, it is important to note that the refractive indices of the barriers sandwiching the quantum wells (quantum regions) decrease continuously and gradually towards cladding. Behind the selection of InGaAsP as a layer active in this model of heterostructure are its main features, such as higher refractive index, better material gain, and higher conduction band discontinuity. The overall structure is develope on InP substrate.

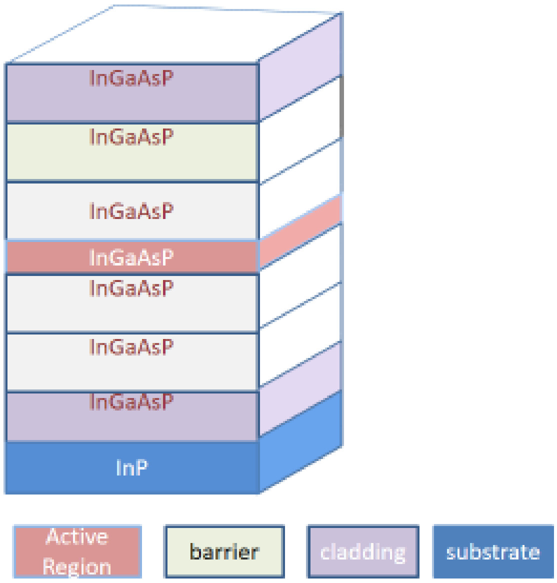

Figure 1. Schematic diagram of Type-I Graded Index SQW –InGaAsP/InP based nano-heterostructure

THEORETICAL DETAIL

The simulations of the gain in the quantum well of the lasers are intricate. Knowledge of the optical gain as a function of optical energy is required to find the suitable material composition for the quantum wells of the laser structure. The optical transition will depend on the polarization due to the planar symmetry characteristic of the quantum-well (active region) wave function. The optical material gain coefficient is a function of the photon energy and is given [9, 10] by;

$$G(E') = \frac{q^2 |M_B|^2}{E' \varepsilon_o m_o^2 c\hbar n_{eff} W} \sum_{i,j} \int_{E_g}^{E_{gb}} m_{r,ij} C_{ij} A_{ij} (f_c - f_v) L(E) dE \qquad \textbf{(1)}$$

where q -electron 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 are the conduction and valence band quantum numbers, $m_{r,ij}$ is spatially weighted reduced mass for transition, C_{ij} spatial overlap factor between the states i and j, Aij is angular anisotropy factor, f_c and f_v

are the electron quasi Fermi function in the conduction and valence band, L(E) Lorentzian lineshape function.

Differential gain is also plays an important role to determine the characteristics of a quantum well based lasing nano- heterostructure. The differential gain coefficient in terms of energy of photon is given as;

$$G^{'}(E) = \frac{dG(E)}{dN} = \frac{8\pi^2 m_r E}{c\varepsilon h^3 W} \cdot \int_{E^{'}}^{\infty} |M_B|^2 \cdot \left(\frac{df_c(E)}{dN} - \frac{df_v(E)}{dN} \right) \cdot L(E^{'}) dE^{'} \tag{2}$$

RESULTS AND DISCUSSIONS

The Quantum Well Width Effects on gain spectra have been studied and shown in figure 2. From figure 2, it is obvious that the optical material gain is decreasing with increase in width of quantum well. Figure 2 also demonstrates that the utmost gain is shifting towards to the higher wavelength region and maximum gain has been achieved at 1.40 μm with in TE mode. The behavior of differential gain with well width has been summarized in figure 3 and found that the differential gain is decrease as the well width increase of the nano-heterostructure. From Figure 4 it has been predicted that the variation of modal gain in terms of wavelength in both TE and TM polarization modes. The obtained results suggest that the TE modal gain spectra in terms of well width are more pronounced rather than in TM mode.

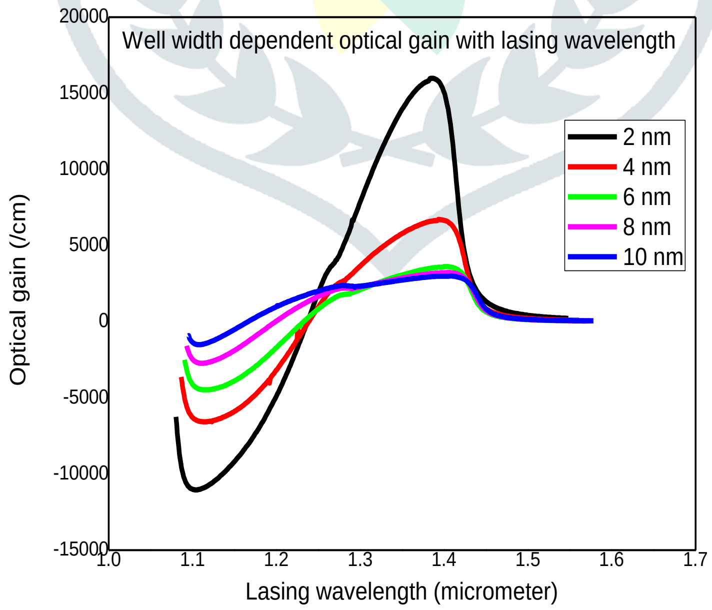

Figure 2. Well width dependent optical gain for Type-I Graded Index SQW $In_{0.90}Ga_{0.10}As_{0.59}P_{0.41}/InP$ heterostructures.

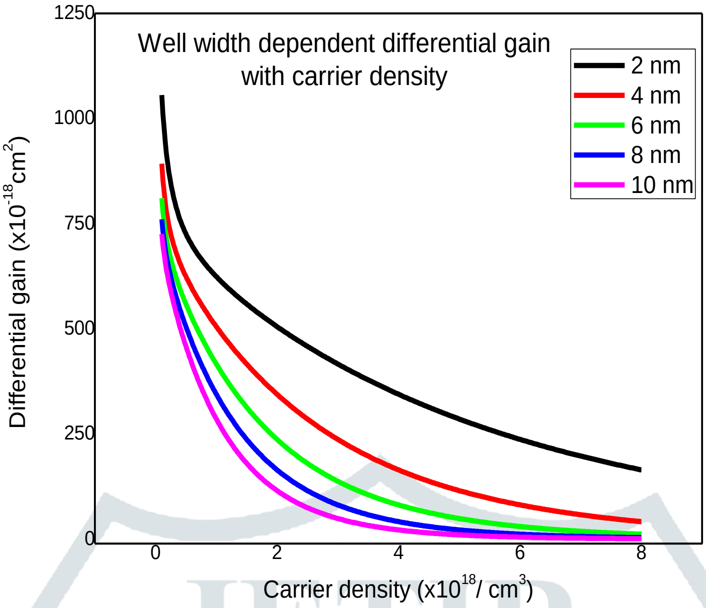

Figure 3. Well width dependent differential gain for Type-I Graded Index SQW $In_{0.90}Ga_{0.10}As_{0.59}P_{0.41}/InP$ Heterostructures.

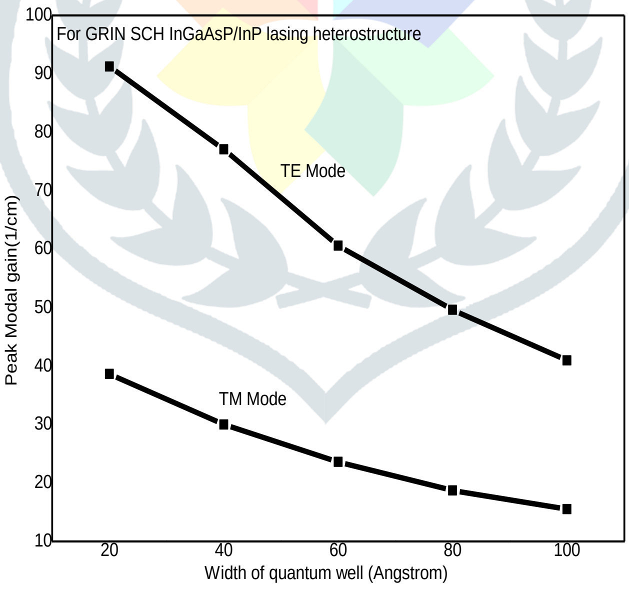

FIGURE 4. Polarization dependent peak modal gain in terms of well width dependent

From the outcomes, it has been observed that as well width grow smaller of the designed nano-scale structure, optical gain spectra achieved maximum value in the G-λ graph shown in figure 2 and also wavelength shifted towards longer wavelength region. Therefore, such heterostructure is useful in the optical fiber based communication systems.

ACKNOWLEDGMENTS

Authors are thankful to UGC, Government of India, New-Delhi for financial support (Ref. F. No. 42-1067/2013 (SR)).

REFERENCES

1. H. Hirayama, Y. Miyake, M. Asada, *IEEE J. Quantum Electron*. 28, 68 (1992).
2. J. Feldmann, G. Peter, E. O. Gobel, K. Leo, H-J. Poland, K. Ploog, K. Fujiwara, T. Nakayama, *Appl. Phys. Lett.* 51, 226 (1987).
3. S. Morin, B. Deveaud, F. Clerot, K. Fujiwara, K. Mitsunaga, *IEEE J. Quantum Electron*. 28 1669 (1991).
4. S. D. Hersee, B. de Cremoux, J. P. Duchemin, *Appl. Phys. Lett.* 44, 476 (1984).
5. Rashmi Yadav, Pyare Lal, F. Rahman, and P. A. Alvi, *AIP conf. Proceedings* 1536, 29 (2013).
6. Rashmi Yadav, Meha Sharma, Swati Jha, Pyare Lal, MJ Siddiqui, F Rahman, S Dalela and PA Alvi, *Indian Journal of Pure and Applied Physics*, 2015, 53, 447-455.
7. S. G. Anjum1 , Sandhya K.2 , A. B. Khan3 , A. M. Khan4 , M. J. Siddiqui5 , P. A. Alvi, Bulletin of Electrical Engineering and Informatics 6, No. 3, 2017, 301 – 310.
8. Nisha Yadav, Garima Bhardwaj, S. G. Anjum, K. Sandhya, M. J. Siddiqui, Optical and Wireless Technologies Proceedings of OWT 2017, 472, 191-197.
9. Zory, P.S.: Quantum well lasers. Academic Press, London, pp. 28–41, 132–154 (1993).
10. Vahid Bahrami Yekta and Hassan Kaatuzian, Commun. Theor. Phys. (Beijing, China) 54, 529 (2010).