A Comparative Study of Optical Characteristics of AlInGaAs/GaAs and InGaAs/InP SQW STIN SCH Nano-Heterostructures

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Abstract: In the work presented here, we evaluate the lasing characteristics of two STIN SCH (Step Index Separate confinement heterostructure) SQW nano-scale heterostructures. The first is a quaternary semiconductor laser of $Al_{0.15}In_{0.22}Ga_{0.63}As$ on a barrier of $Al_{0.2}Ga_{0.8}As$ and a cladding of GaAs grown on GaAS substrate and the other one being a ternary semiconductor laser comprising of a quantum well of $In_{0.45}Ga_{0.55}As$, barrier of $Al_{0.29}Ga_{0.17}In_{0.54}As$ and a cladding of $Ga_{0.48}In_{0.52}As$ grown on InP substrate. In this paper, the researcher not only explores the behaviour of optical (material) gain against the lasing wavelength and threshold current density in both Transverse Electric (TE) and Transverse Magnetic (TM) polarization modes for the two cases. We have also tried to draw a comparative picture of the two SQW heterostructures to evaluate and understand their usage and effectiveness as lasing heterostructures. At every stage a comparison is presented to understand the difference in behaviour of the two lasing heterostructures.

Keywords: Material Gain, SCH, STIN, Strain.

I. INTRODUCTION

With the miraculous investigation by Dingle et al.,[1] of the optical properties in quantum wells their application in semiconductor laser diodes [2], [3] has received noteworthy attention because of its finer characteristics, such as less dependency on temperature of threshold current [4]-[6], lower threshold current density [7]-[8], controlling the lasing wavelength and extraordinary dynamic properties [9]-[11]. In this paper, we present the structure details of the two different nano heterostructures and investigate their behavior in terms of optical/material gain as against their lasing wavelengths.

II. STRUCTURE DETAILS OF THE HETEROSTRUCTURES

Tabular representation of the first heterostructure comprising of a STIN SCH SQW quaternary semiconductor laser of $Al_{0.15}In_{0.22}Ga_{0.63}As$ with a barrier of $Al_{0.2}Ga_{0.8}As$ and a cladding of $Al_{0.61}Ga_{0.39}As$ grown on GaAS substrate has been presented in table I. In table II we present the details of our second heterostructure which consists of a STIN SCH SQW ternary semiconductor laser of $In_{0.45}Ga_{0.55}As$ with a barrier of $Al_{0.29}Ga_{0.17}In_{0.54}As$ and a cladding of $Ga_{0.48}In_{0.52}As$ grown on InP substrate.

Table I. $Al_{0.15}In_{0.22}Ga_{0.63}As$ Quantum well lasing heterostructure

Layer No	Layer Name	Material used	Width (nm)	CB offset (eV)	VB offset (eV)	Lattice constant (Å)
1	Cladding	$Al_{0.61}Ga_{0.39}As$	10	0.6084067	-0.2863090	5.815376
2	Barrier	$Al_{0.2}Ga_{0.8}As$	5	0.2405987	-0.1132229	5.970752
3	Quantum Well	$Al_{0.15}In_{0.22}Ga_{0.63}As$	6	0.0964814	-0.048240	5.909987

Table II. $In_{0.45}Ga_{0.55}As$ Quantum well lasing heterostructure

Layer No.	Layer Name	Material used	Width (nm)	CB offset (eV)	VB offset (eV)	Lattice constant (Å)
1	Cladding	$Ga_{0.48}In_{0.52}As$	10	0.4844044	-0.1883795	5.863952
2	Barrier	$Al_{0.29}Ga_{0.17}In_{0.54}As$	5	0.1062417	-0.0413162	5.873997
3	Quantum Well	$In_{0.45}Ga_{0.55}As$	6	-0.0283436	0.0141718	5.876105

This paper aims at evaluating their lasing characteristic and also compares the behaviour of optical gain against the lasing wavelength and threshold current density in the two cases in TE and TM modes. Where ever required we have drawn a comparative picture of the two SQW heterostructures to evaluate and understand their usage and effectiveness as lasing heterostructures. At every stage a comparison is presented to understand the difference in their behaviour.

III. RESULTS AND DISCUSSION

a) Material gain as a function of lasing wavelength

At the onset, we observe the optical (material) gain as a function of lasing wavelength in the two heterostructures in figure 1 (a) and (b) in both the polarization modes.

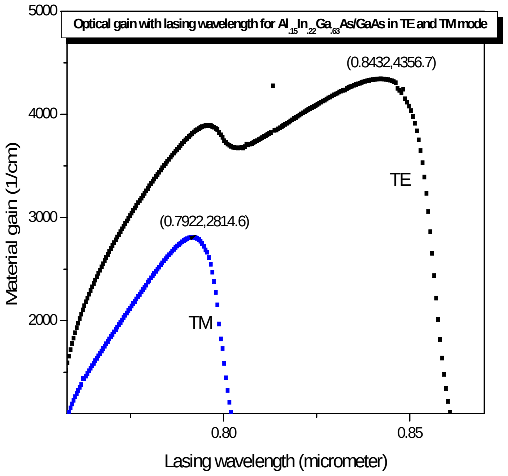

Fig. 1 (a) Material gain as a function of lasing wavelength for $Al_{0.15}In_{0.22}Ga_{0.63}As/GaAs$

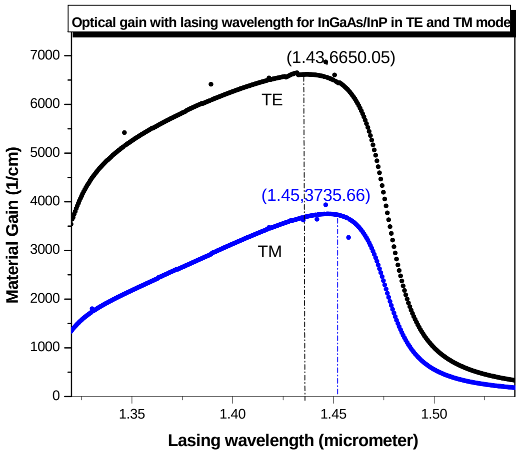

Fig. 1 (b) Material gain as a function of lasing wavelength for $In_{0.45}Ga_{0.55}As/InP$

Here it is noteworthy that TE mode has better gain characteristics than TM mode in both the cases. For $Al_{0.15}In_{0.22}Ga_{0.63}As/GaAs$ the lasing wavelength is 0.8432 micrometer in TE mode at which a gain of 4356.7 cm-1 is obtained while it is 0.7922 micrometer in TM mode at which a gain of only 2814.6 cm-1 is achieved. However for $In_{0.45}Ga_{0.55}As/InP$, we obtain a better gain value of 6650.05 cm-1 at a lasing wavelength of 1.43 micrometer in TE mode and a gain of 3735 cm-1 at a lasing wavelength of 1.45 micrometer in TM mode. While comparing the two STIN-SQW heterostructures, marked differences are observed. The lasing wavelength is found to be higher (1.45 micrometer) in TM mode than in TE mode (1.43 micrometer) in $In_{0.45}Ga_{0.55}As/InP$ which is just the reverse in $Al_{0.15}In_{0.22}Ga_{0.63}As/GaAs$. Also, there are two peaks in TE mode in $Al_{0.15}In_{0.22}Ga_{0.63}As/GaAs$ which has been attributed to transitions involving heavy holes and light holes. However there is only a single sharp peak in $In_{0.45}Ga_{0.55}As/InP$ indicating that heavy holes do not create much impact in this case.

b) Peak material gain as a function of threshold current density

Threshold current density of lasers is temperature sensitive. This may be due to several reasons. Auger recombination is one of the expected causes. Recombination of carriers increase with temperature leading to reduced carrier lifetime. Then, there also is, carrier leakage at the heterojunction which in turn reduces current density and can be yet another cause, apart from intervalance band absorption, which contributes to the reduction of carriers and can be attributed as the third major reason of reduced current density with rise in temperature. To sum up, the reduction in the injection efficiency and higher threshold hampers the optical signal at raised temperatures. Behavior of the material gain when plotted with respect to the threshold current density shows pronounced difference in the two heterostructures. We now plot material gain as a function of current density to observe the above mentioned facts in figure 2 (a) and 2 (b) for $Al_{0.15}In_{0.22}Ga_{0.63}As/GaAs$ and $In_{0.45}Ga_{0.55}As/InP$ respectively.

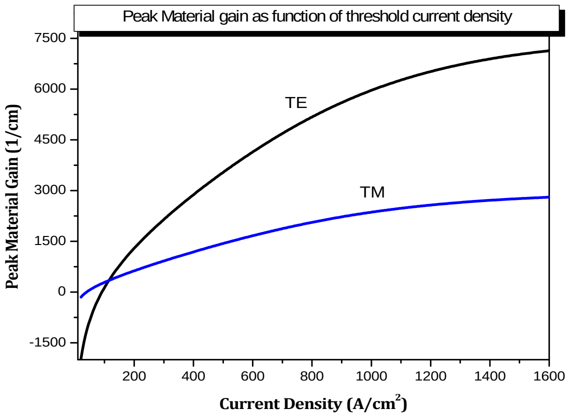

Fig. 2 (a) Peak material plotted with respect to threshold current density for $Al_{0.15}In_{0.22}Ga_{0.63}As/GaAs$

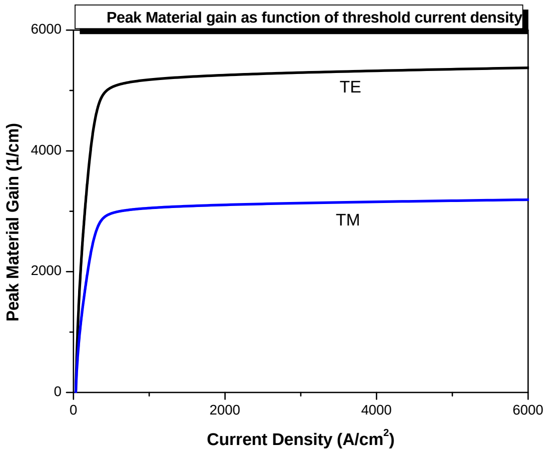

Fig. 2 (b) Peak material plotted with respect to threshold current density for $In_{0.45}Ga_{0.55}As/InP$.

For $In_{0.45}Ga_{0.55}As/InP$, as seen in figure 2 (b), we observe a sharp increase in the gain at lower current densities. After attaining its almost maximum values in both TE and TM modes, the gain shows saturation and remains constant with respect to the current density. Saturation starts at a current density of 558.41 A/cm^2 at which the gain is 3008.19 cm-1 in TM mode while it starts at a current density of 574.41 A/cm^2 at which the gain is 5092.29 cm-1 in TE mode. This is in contrast to the parabolic trend observed in $Al_{0.15}In_{0.22}Ga_{0.63}As/GaAs$ (Fig. 2 (a)).

IV. CONCLUSION

For both the heterostructures, gain is higher in TE mode than in TM mode. This is because in normal quantum well systems, heavy hole band gets to the top of the valence band owing to the quantum confinement and so the light polarized in TE mode is amplified to a larger extent than in TM mode. Using strained QW's solves this issue. Tensile strain increases the TM gain because it raises the light hole band. In TE mode, for $Al_{0.15}In_{0.22}Ga_{0.63}As/GaAs$ lasing wavelength is 0.8432 micrometer indicating its usage in the near infra red region and for $In_{0.45}Ga_{0.55}As/InP$, the lasing wavelength is found to be 1.43 micrometer illustrating the use in mid-infrared region.

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