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# THICKNESS OPTIMIZATION OF EFFICIENT GaInNAs / GaAs SINGLE QUANTUM WELL LASERS

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## ABSTRACT

The effect of the single quantum well thickness on the optical and electrical parameters of a GaInNAs/GaAs quantum-well lasers are presented. It was found that the material gain spectrum is red-shifted along with increment of the FWHM as the well-layer thickness is increased. Moreover, it has been observed that the photoluminescence spectrum intensity for various thicknesses of well-layer declines as the well-layer thickness increases. The mode spectrum for different well-layer thickness is presented. The threshold current density and slope efficiency are measured and found to be decreased with the thickness increment of the well-layer.

*Keywords: Quantum well; GaInNAs; GaAs; III-V semiconductor laser;*

## INTRODUCTION

The current GaInPAs/InP laser cannot provide the laser characteristics desired for high-performance low-cost applications, since it's lasing characteristics degrade at moderately high temperatures due to the fact that it has a poor electron confinement in the active region. Accordingly, thermoelectric coolers are extremely needed in practical applications and as a consequence this would increase cost. Novel semiconductor material systems, in which the electron overflow suppressed, are therefore being studied and investigated in this paper with the aim of improving the high-temperature performance of 1.3 µm or/and 1.5 µm wavelength laser diode devices. For that reason, the use of GaInNAs as an active layer is extremely promising. This material system has the appropriate bandgap required for present optical fiber communications due to the large bandgap bowing near the region lattice-matched of GaAs. Moreover, GaInNAs can be grown pseudomorphically on GaAs substrate and a large bangap discontinuity in the conduction band ($\Delta E_c$) of over 350 meV can be obtained by combining GaInNAs with wide-gap materials such as GaAlAs [1].

Thus the use of GaInNAs at the active region results in lasers with improved temperature characteristics ($T_0$) and such lasers should be very much suitable for the light sources to be used in either current or future networks since the requirements for

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the future light sources of such networks includes a reduction of cost as well as higher performance. Moreover, to meet the explosive increase in users of optical-access networks, such as local area networks (LAN), the demand for massive data transmission capacity of up to 10 Gb/s has rapidly increased.

## DEVICE STRUCTURE

The schematic cross-section of the device structure is illustrated in Figure 1. A single quantum well (SQW) layer of $Ga_{0.66}In_{0.34}N_{0.014}As_{0.986}$ sandwiched with a 0.15µm GaAs barrier layers. The single quantum well layer thickness has been varied from 7 nm to 9 nm at step of 1 nm. The active region has been sandwiched with an undoped 0.2 µm thick on top as a p-spacer and 0.3 µm thick on bottom as an n-spacer of $Al_{0.3}Ga_{0.7}As$. The p-spacer is topped with a 2.2 µm p-doped $Al_{0.3}Ga_{0.7}As$ and the n-spacer is topping a 1.8 µm n-doped $Al_{0.3}Ga_{0.7}As$. The amount of doping for both p- and n-doped layers of $Al_{0.3}Ga_{0.7}As$ is $7\times10^{17}$ $cm^{-3}$. The whole device is then covered with a 0.235 µm thick highly doped layer ($1\times10^{19}$ $cm^{-3}$) of p-GaAs. The contact layer (p-GaAs) is highly doped in order to decrease the contact resistance. The entire device is grown on a 2µm thick n-doped GaAs substrate. The amount of n-doping of the substrate was $5\times10^{17}$ $cm^{-3}$. This ridge wave guide laser device has the width of 2µm and cavity length of 800 µm.

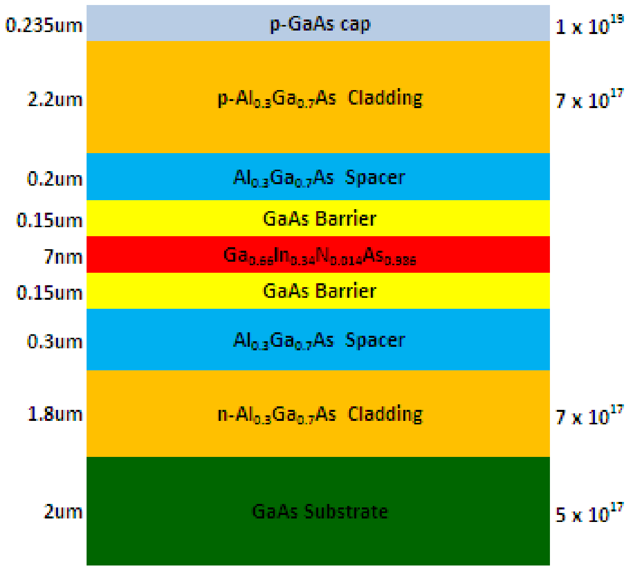


Figure 1: The schematic cross-section of the device structure

## RESULTS AND DISCUSSION

The material gain spectrum for different quantum well thicknesses is illustrated in Figure 2. From the figure, it has been observed that as the quantum well thickness increased from 7 nm to 9 nm, the operational wavelength has red shifted significantly from 1.26 µm to 1.32 µm. This shift of the operational wavelength has been expected and reported by other researchers at the same field [2]. The red-shift of the operational wavelength could be associated to the incorporation of N atoms which have a smaller optical energy gap compared to GaAs. Moreover, it has been noticed that as the thickness of the quantum well increases, the material gain peak reduced and the full width at half maximum (FWHM) increased. This observation related to the fact that incorporating N atoms to the structure would jeopardize its crystallinity [3]. Accordingly, the effective mass of electrons in the conduction band increases with the extension of diffusion, while there is little change on the holes in the valence band. This is since the increase in the conduction band edge with increasing atomic diffusion as well as the repulsion from the isolated N states, which are slightly above the conduction band edge, will cause the energy of electronic states to converge in high momentum space.

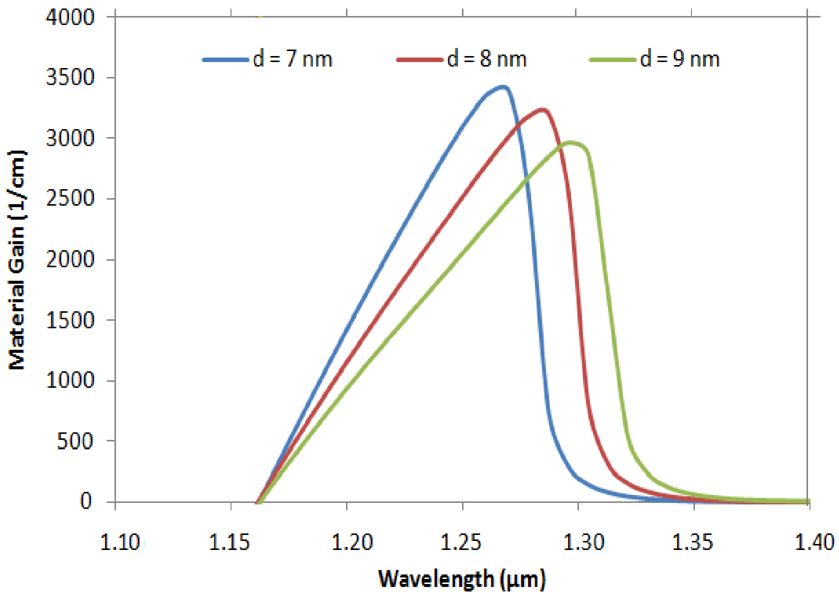


Figure 2: Gain material spectrum with different quantum well thicknesses (7 nm, 8 nm and 9 nm)

The Photoluminescence spectrum for different quantum well thicknesses is shown in Figure 3. It is clearly seen that the photoluminescence intensity significantly decreased with increasing the thickness of the quantum well layer. it is a well-established fact that increasing the thickness of the quantum well layer would definitely increase N concentration in GaInNAs. Consequently, the photoluminescence intensity would decrease due to the serious degradation of optical properties which is accompanied with the incorporation of nitrogen [4].

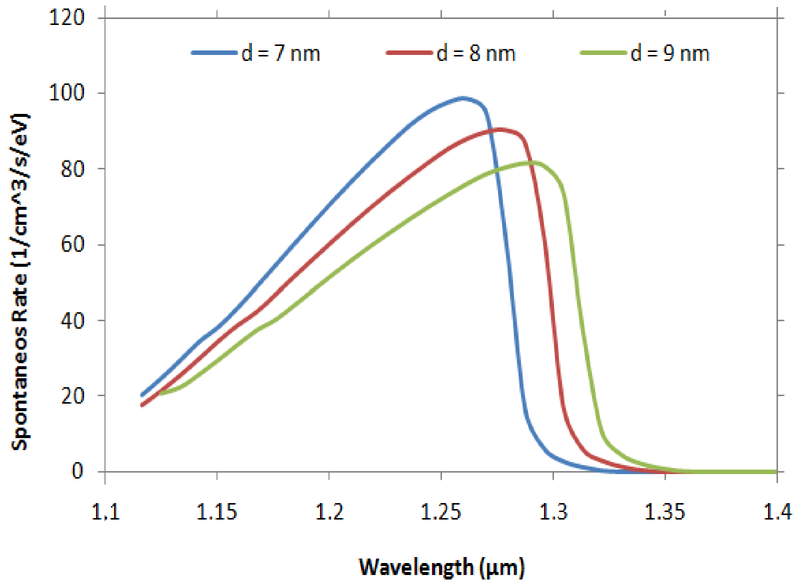


Figure 3: Potoluminescence spectrum with different quantum well thicknesses (7 nm, 8 nm and 9 nm)

Moreover, it should be noted that as the thickness of the quantum well increased, the operational wavelength is red-shifted due to the degradation of the crystallinity structure.

The mode spectrum for different quantum well layer thicknesses is shown in Figure 4. As the quantum well layer thickness increased from 7 nm to 9 nm, the mode spectrum red-shifted from 1.268 µm to 1.302 µm respectively. It is expected that the level of nitrogen incorporation increases as the quantum well layer thickness increased. The increased level of nitrogen incorporation in the AlGaNAs quantum well would increase the growth rate of the material, this assumed to be due to the decreased rate of nitrogen desorption from the film surface during growth. However, a lower growth in the quantum well layer is required to achieve good optical properties and emitting a longer wavelength. The results that have been obtained due to the increment of the nitrogen percentage on the operational wavelength have been displayed in Figure 5. These results are of great agreement with our analysis due to the fact that the red-shift at the operational wavelength is very clearly observed as the nitrogen content increased from 1.0% to 1.6%. On the other hand, it has been clearly seen that the red-shift increased gradually in a diminutive rate when nitrogen content increased but it red-shifted rapidly once the nitrogen introduced.

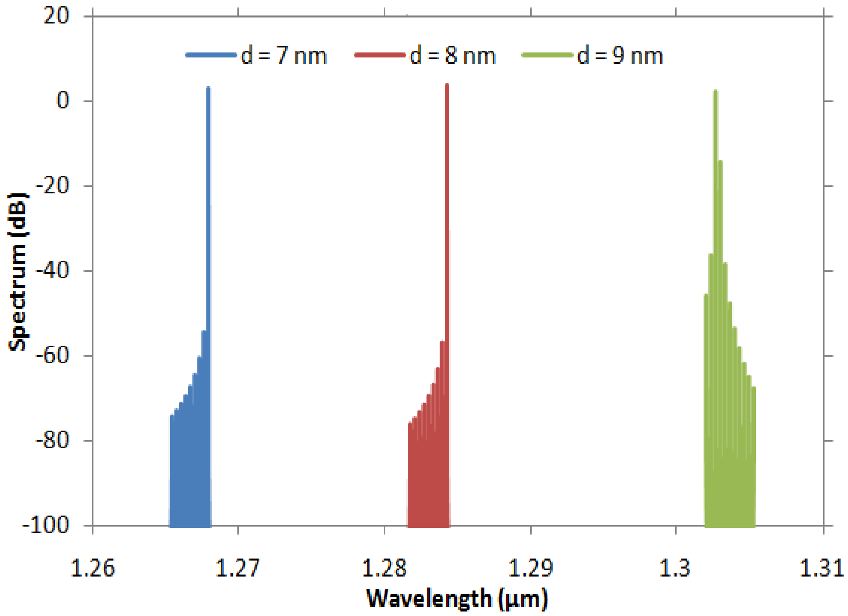


Figure 4: The mode spectrum with different quantum well thicknesses (7 nm, 8 nm and 9 nm)

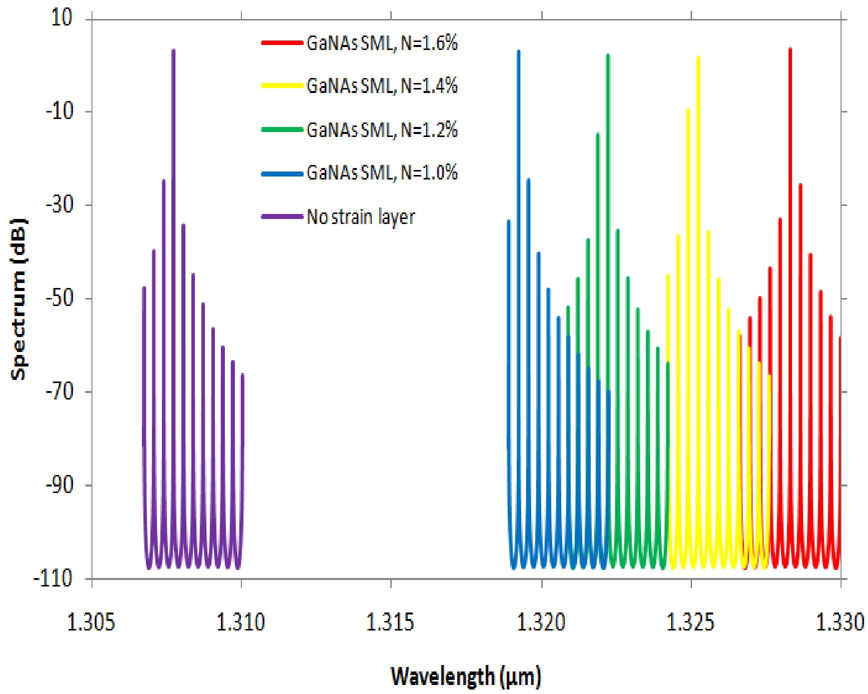


Figure 5: The mode spectrum with different nitrogen percentage in the quantum well layer (1.6%, 1.4%, 1.2% and 1.0%)

The threshold current ($I_{th}$) for different GaInNAs quantum well layer thicknesses is shown in Figure6. It has been observed that the lowest threshold current (0.0855 A) has been recorded for the thickest quantum well (9 μm). The reason for this is a great confinement in active layer by using single quantum well structure [5]. However, is it clearly observed that the threshold current ($I_{th}$) has increased a bit when the quantum well layer thickness has decreased to 7 μm. The spectra suggest good quality crystal with no major dislocations or defects due to the higher incorporation of nitrogen in the thicker quantum well. The samples with thicker quantum well layers exhibit longer peak wavelength, as shown in Figures (Figures 3, 4 and 5). The large shift of the operational wavelength peak is qualitatively explained by the removal of quantum confinement effects. The lower threshold current for the thicker quantum well structures could be due to the fact that nitrogen has a smaller optical energy gap which accordingly needs miniature current to excide the electrons in the valance band to the conduction band. While the amount of the nitrogen atoms in the thinner quantum well structure is less than that of the thick ones, on that base a higher threshold current is needed to be injected to the device to get it in the operational status.

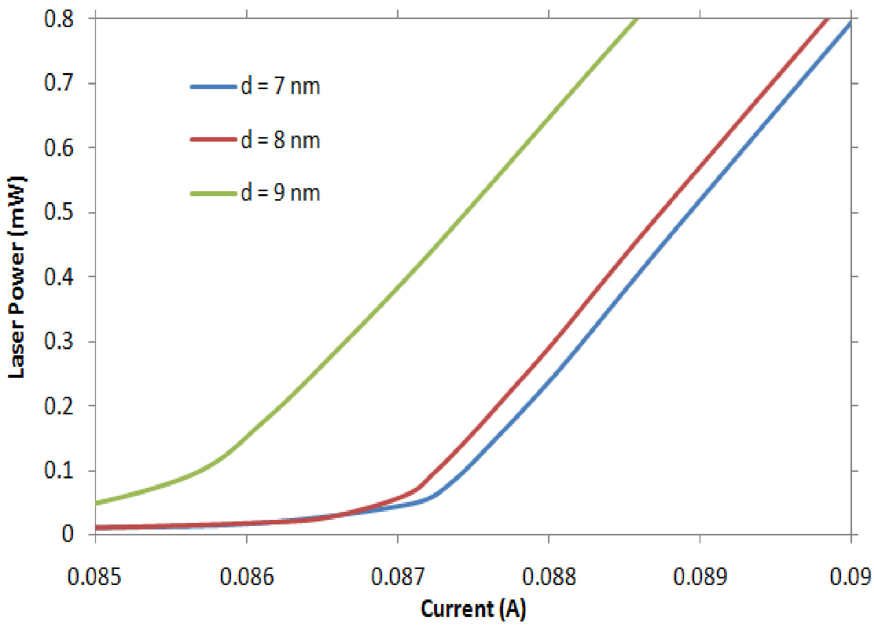


Figure 6: Threshold current ($I_{th}$) with different quantum well thicknesses (7 nm, 8 nm and 9 nm)

## CONCLUSION

To investigate the thickness effect of GaInNAs quantum well layer structure, we carried out structural analysis on three GaInNAs/GaAs single quantum well samples with various well layer thicknesses (7 nm, 8 nm and 9 nm). The optical gain, Photoluminescence, operational wavelength showed a red-shifted spectrum with a decrease of peak's intensity due to the higher amount of incorporated nitrogen atoms which in turns effect the crystallinity structure. The LI curve showed a lower threshold current is needed for the thicker quantum wells suggest a good confinement effect.

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