INVESTIGATION OF WAVELENGTH
GaInNAs 1300-1550 nm
STRAINED QUANTUM WELLS ON GaAs SUBSTRATES

A. AISSAT*, S. NACER*, D.BERKANI*, J.P. VILCOT**
* LASICOM Laboratory, Faculty of the Engineering Sciences,
University Saad Dahlab Blida, ALGERIA
Corresponding author
** Institut d'Electronique, de Microélectronique et de Nanotechnologie,
UMR CNRS 8520, Université des Sciences et Technologies de Lille,
Avenue Poincaré, BP 60069,
59652 Villeneuve d'Ascq, FRANCE
IEMN Lille1, France

Abstract
In this paper the band structures of Ga_xIn_1-xNyAs_1-y/GaAs strained quantum wells are investigated using 4x4 k.p Hamiltonian including the heavy hole, light hole and spin-orbit splitting bands. The III–V-nitride semiconductor alloys, Ga_xIn_1-xNyAs_1-y, operating at optical fibre telecommunications wavelengths around 1.3 µm, attract an increasing amount of attention in the last couple of years not only due to its promising application but also due to its unusual optical and physical properties. By changing the well width, x composition and nitrogen composition (y), the effects of quantum confinement and compressive strain are examined. We also studied the influence of the incorporation of nitrogen (y) and antimony (Sb) in our structure.

Key words: lasers diode -strained quantum wells s - GaInNAs/GaAs– GaInNAsSb/GaAs optoelectronics

1. INTRODUCTION
Ever since the GaInNAs/GaAs material was introduced as a possible candidate to replace GaInAsP/InP material as the conventional long-wavelength laser emitter and detector, it has continued to attract attention from the research community. Not only that samples were grown by both molecular beam epitaxy (MBE) to explore the possibility of achieving 1.3µm [1] and near 1.55µm [2] emission, but also various theories were proposed in an attempt to predict the compositional dependence of the Ga_xIn_1-xNyAs_1-y bulk material. The Ga_xIn_1-xAs/GaAs quantum well has been shown to exhibit very low threshold current density due to the presence of compressive strain in the well layer under lattice mismatch [3]. However, the compressive strain will build up when more indium are being added to the well layer to increase the emission wavelength and thus imposed a limit to the thickness of the quantum well. By adding nitrogen atom into the matrix to form Ga_xIn_1-xNyAs_1-y/GaAs, it was found to further reduce the band gap energy and simultaneously reduce the compressive strain present in the well layer. This special material exhibits very different behaviours, including the larger than normal band gap bowing factor and enhancement of electron effective mass m_e* by the addition of a nitrogen atom. The dependence of band gap energy on nitrogen composition has been predicted very well by the band anticrossing (BAC) model, which states that the large reduction of the fundamental band gap energy of Ga_xIn_1-xNyAs_1-y is due to the repulsion between a localized nitrogen-related energy level E_N and the extended conduction band of the Ga_xIn_1-xAs host matrix [4]. To date, the BAC model is used extensively and successfully in the prediction of the energy band gap of Ga_xIn_1-xNyAs_1-y with low gallium composition and GaN_NyAs_1-y [5].

2. Strained Quantum Well
The energy of the band gap of a semi conducting material depends on its strained state, if the active lattice parameter is higher than that of the substrate the strain is a compression, in the contrary case the strain is extensive. In the case of two-dimensional and pseudo morphic deposit lattice on a substrate, the
strain is bi axial and the strains tensor can always break up into two components:

- a hydrostatic component, which decreases the band energy gap in the case of an increase in volume or which increases it in the contrary case
- a shearing component, which causes to take the heavy holes-light holes degeneration from the band of the valence band.

In a compressive strained quantum well the lattice parameter of the well is larger than that of the barrier.

\[ \varepsilon(x,y) = \frac{a_{GaAs} - a_{GaInNAs}(x,y)}{a_{GaAs}} \]  

(1)

\[ P = 2a_v \left(1 - \frac{C_{12}}{C_{11}} \right) \varepsilon(x,y) \]  

(2)

\[ Q = b \left(1 + \frac{C_{12}}{C_{11}} \right) \varepsilon(x,y) \]  

(3)

\[ E_v = E_{v,av} + \frac{\Delta}{3} + \Delta E_{hh} \]  

(4)

\[ \Delta E_{hh} = -P - Q \]  

(5)

\[ \Delta E_c = 2a_v \left(1 - \frac{C_{12}}{C_{11}} \right) \varepsilon(x,y) \]  

(6)

\[ E_{g-} = E_{g-} + \Delta E_c - \Delta E_{hh} \]  

(7)

\[ E_{g-}(GaIn_{\theta,Ny}As_{\gamma}) = \frac{1}{2} \left[ E_G(GaIn_{\theta,Ny}As_{\gamma}) + E_N \right] - \sqrt{\left[ E_G(GaIn_{\theta,Ny}As_{\gamma}) - E_N \right]^2 + 4\Delta^2} \]  

(8)

Fig.1: compressive strained quantum well

\[ \Delta a/a = 3\% \]

In order to calculate the band offsets of the conduction band and valence band we use the Model Solid Theory. The model-solid theory was first proposed by van de Walle and Martin to calculate strain effects on the band lineups. Conduction band position calculated by adding strained band gap energy to the valence band position fig.2.

\[ P_{hh} + Q_{hh} + E_{hh} < P_{vv} + Q_{vv} + E_{vv} \]  

(9)

\[ P_{hh} + Q_{hh} + E_{hh} > P_{vv} + Q_{vv} + E_{vv} \]  

(10)

Fig.2: alignments of bands of GaInN compressive strained on GaAs

2. Band model

In order to take into account the influence of the band structure by the nitrogen-induced level, \( E_N \), a 10-band \( k \cdot p \) model was proposed which add two more spin-degenerated states to the 8-band Hamiltonian through the following matrix \[6,7]:
3. Determination of Wavelength

For the determination of the quantification energy in the finished potential quantum well of a structure based on GaInAs/GaAs the simplest formalism is the use of the approximation of the function envelope. The theory of the function envelope applies well to the structures such as the quantum wells. The function envelope is given to a good approximation with the Schrödinger equation:

$$\frac{-\hbar^2}{2m^*} \frac{d^2\psi(z)}{dz^2} + (V(z) - E_n)\psi(z) = 0$$  \hspace{1cm} (16)$$

where $\psi$ is an envelope wave function, $E_n$ the level $n$ quantification energy and $V(z)$ the potential barrier. The connecting conditions are given by continuities of the envelope function and the current density at the interfaces. The energy of transition is given by the following equation:

$$E_{tr} = E^*_{hh} + E_n + E_{hh}$$  \hspace{1cm} (17)$$

The potential $V(z)$ is a fraction of the variation of energy of the band gap $\Delta E_g$ on both sides of the heterojunction well/barrier, given by $V=Q\Delta E_g$, with $Q=72\%$ [11]. The wavelength of emission is given by the following relation:

$$\lambda_{e-hh} = \frac{1.24}{E_{tr}}$$  \hspace{1cm} (18)$$

Fig. 3 shows the behavior of the quantification energy of the electrons and heavy holes under the effect of the width well for level $n=1$. When $L_P$ becomes significant “higher than 120Å” the quantification energy tends towards the energy conduction band (not of quantification). Fig. 4 illustrates the evolution wavelength according to the width well. From the structure Ga$_{0.70}$In$_{0.30}$N$_{0.005}$As$_{0.995}$/GaAs we can determine a range wavelength which varies from 0.850-1µm table. I.

<table>
<thead>
<tr>
<th>x(%)</th>
<th>y(%)</th>
<th>$L_p$(Å)</th>
<th>$\lambda_e$(µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0.05</td>
<td>30</td>
<td>0.920</td>
</tr>
<tr>
<td>70</td>
<td>0.05</td>
<td>50</td>
<td>0.960</td>
</tr>
<tr>
<td>70</td>
<td>0.05</td>
<td>95</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table. I: parameters for changed the emission wavelength
If we change the parameters (composition of gallium, nitrogen concentration, width well, concentration of injection) the emission wavelength varies. Then starting from these structures we can reach the range 1.3-1.55 µm fig.5.

4. Conclusion

The effect of the strain on the conduction and valence bands causes a shift of the conduction gravity centre of the two bands and changes the energy of the band gap of the structure. The incorporation of nitrogen on these GaInAs, GaInAsSb structures induced a split of the conduction band in two bands $E_-$ and $E_+$ for a composition of nitrogen ranging between 0.05% and 4%. The optical and electronic properties of nitride alloys with weak band gap are very particular, because the nitrogen atom is very different from the arsenide atom for which it is substituted. These differences are at the origin of the rigorous reduction in the band gap non strain and strain compressive with the composition of nitrogen, which in particular makes it possible to acquire the emission at 1.3 to 1.55 µm. The BAC model makes it possible quantitatively to show the evolution of the energy of the band gap with the nitrogen concentration. One may study the evolution of the optical gain as a function of the wavelength and starting from these results one
calculates the current of threshold of the laser diode with strained quantum well of the proposed structure. It can be deduced that the increase in nitrogen introduction decreases the threshold current of the laser diode with strained quantum well. From these structures we can build lasers diode with reliable strained quantum well for the applications such as safety, telecommunications and space communications.

References:


