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Analysis of bias voltage's effect on triple barrier of gallium nitride/aluminum gallium nitride quantum well

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At room temperature, we have simulated resonance tunneling currents in a ($GaN/Al_X\ Ga_{1-X}N$) quantum well where electrons have a lower energy than the potential of the height barrier (V_b) and we have determined that resonance tunneling current density (J_0) is dependent on aluminum mole fractions at (x= 55%, 60%, and 65%) in ($Al_xGa_{1-x}N$) barrier regions for number of barriers (N=3) and the well width equals the barrier width ($L_a = L_b$ =1.27) nm with a bias voltage (V_{bias}) is applied. The MathCad2001 application provides a simple and accurate method for determining the solution. It is observed that the transmission probability gradually decreases when the bias voltage is increased. Furthermore, the energy of the (E1) growths with high mole fractions of (Al) in the system Al 0.14 eV for x =0.1 to 0.51 eV for x =0.5 in (GaN/ N) superlattice structure. Such quantum wells could be used for laser diodes, biological sensors, and optical storage quantum wells based on our results.

Keywords: GaN/AlGaN quantum well, bias voltage, resonant tunneling current density.

1. INTRODUCTION

The large band gap of GaN/AlGaN quantum wells, make these materials extremely useful in optoelectronics [1]. Additionally, nitride materials have the advantage of strong interatomic bonding in high-power and temperature quantum wells also have a wide range of emission capabilities from blue to ultraviolet [2, 3]. Due to their wide band gap, nitride materials are often used in optical communication systems [2, 4]. To improve the performance of quantum wells must be understand how the differences in well width, barrier height, and doping rate on peak current density [1]. It is extremely good electron confinement when (GaN) quantum wells are sandwiched between (N) barriers of (AlGaN) [5]. Energy electrons can tunnel through quantum structures via discrete levels of energy called resonant states [6].

It is known that when an electron strikes a superlattice ($GaN/Al_X\ Ga_{1-X}N$), it undergoes resonant tunneling [7,8]. By solving Schrödinger's equation inside the periodic potential of the lattice, carrier wave functions are localized in space, while evaluating eigen energy values is discrete [9, 10], the simulation is accomplished making use of MathCad programming**.**

The tunneling current density of fundamental quasi-bound states (J_0) has been studied in triple barriers (N=3) of structure ($GaN/Al_X\ Ga_{1-X}N$) based on incident particle energy below potential of height barrier ($E < V_b$). Additionally, with applied bias voltage (V_{bias}), we examined the transmission coefficient, the dependence of the current density (J_0) and the fundamental quasibound state (E_0) on the aluminum mole fraction (x= 55%, 60%, and 65%) of the barrier region ($Al_xGa_{1-x}N$) at the same width as the well (= 1.27nm).

2. SIMULATION MODEL

The flowchart in fig.1. Explains the steps relied upon in applying the MathCAD program, solving the Schrödinger equation and relying on the boundary condition, we arrived at the permeability equation. Using the transfer matrix and the electron energy of the longitudinal component being smaller than the height of the potential barrier, we also obtained the current density equation based on the permeability equation.

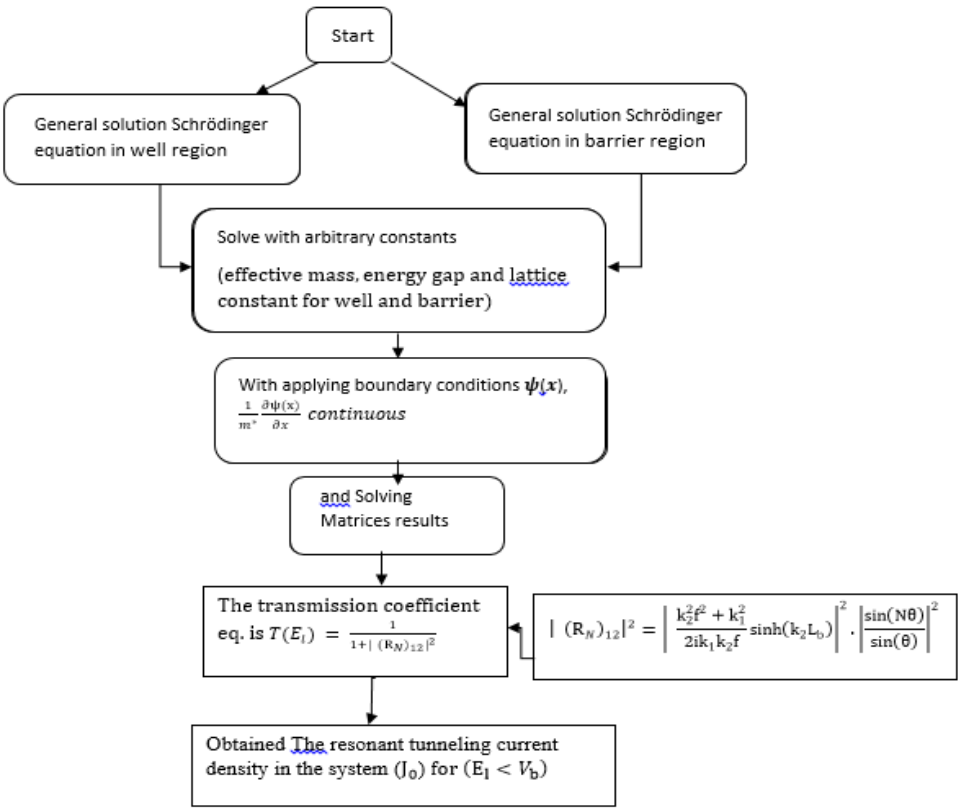

Figure 1 Steps to be used in the calculations.

The theoretical method used in this paper contains alternately semiconductor heterojunction of ($Ga\ N/Al_{0.55}\ Ga_{0.45}N$), ($Ga\ N/Al_{0.6}\ Ga_{0.4}N$), ($Ga\ N/Al_{0.65}\ Ga_{0.35}N$) superlattices. In our calculations we use conservation matrix approach, which is fit for giving illogical effort wall and find tunneling current density in the system (J_0) for longitudinal incident electron energy less than height of barrier ($E_l < V_b$) under bias voltage [11], based on the Tsu-Esaki formalism [12]:

$$J_0 = \frac{e\, m_w^* k_2\, T}{2\pi^2 \hbar^3}\left(1 - \exp\left(\frac{-eV_{bias}}{K_b T}\right)\right)\int_0^{\infty} \frac{1}{1 + \left|\frac{k_2^2 f^2 + k_1^2}{2ik_1k_2f}\sinh(k_2 L_b)\right|^2 . \left|\frac{\sin(N\theta)}{\sin(\theta)}\right|^2} . exp\left(\frac{E_f - E_l}{K_b T}\right) . dE_l \quad (1)$$

Where $f = \frac{m_w^*}{m_b^*}$

$$k_1 = \frac{\sqrt{2m_w^* E}}{\hbar} \qquad k_2 = \frac{\sqrt{2m_b^*(V_b - E)}}{\hbar} \quad (2)$$

E_f: is the energy Femi level, m_w^* is the electron restricted mass in hole section of GaN =$0.20m_0$. m_b^* is the electron restricted quantity of ($Al_X\ Ga_{1-X}N$) can obtained with respect to mole fraction as formula [13, 14]:

$m^*_b = (0.2 + 0.2x)\ \ m_0$, $m_0 = 9.1 * 10^{-31}$ (3)

V_b is the barrier height = 0.7 ΔE_g (4)

$\Delta E_g = x(E_{gAlN} - E_{g\,GaN}) + b.x(1-x)$ (5)

$E_{g\,AlN}$ =6.28eV, $E_{g\,GaN}$ =3.5eV

b = is the bowing parameter ≈ leV.

3. RESULT AND DISCUSSION

In fig. 2, the transmission coefficient $T(E_l)$for ($GaN/Al_{0.55}\ Ga_{0.45}N$) triple barrier is calculated by using the transfer-matrix method. Transmission coefficients show resonant peaks at (0.1, 0.5, 0.9) volts and well dimensions equal to barriers ($L_a = L_b$ =1.27nm). Since the quantum states within the well, in fact, produce peaks when the particle's energy coincides with a state within the well for ($E<V_b$). As a result, these electrons suffer resonant tunneling, namely, the first peak (E_0) and a second peak (E_1) [4, 15, 16].t is observed that the transmission probability gradually decreases when the bias voltage is increased, i.e. all resonant transmission peaks are hidden due to the decline of the barrier potential, Simion et al. [17] and Djelti et al. [18] have also observed this behavior in similar structures. While the transparence coefficient drops exponentially with applied voltage and drops sharply with aluminum concentration, the increase in eigen energy as Al mole fracturing increases is credited to a boost of conduction group due to the increase aluminum mole fraction [5].

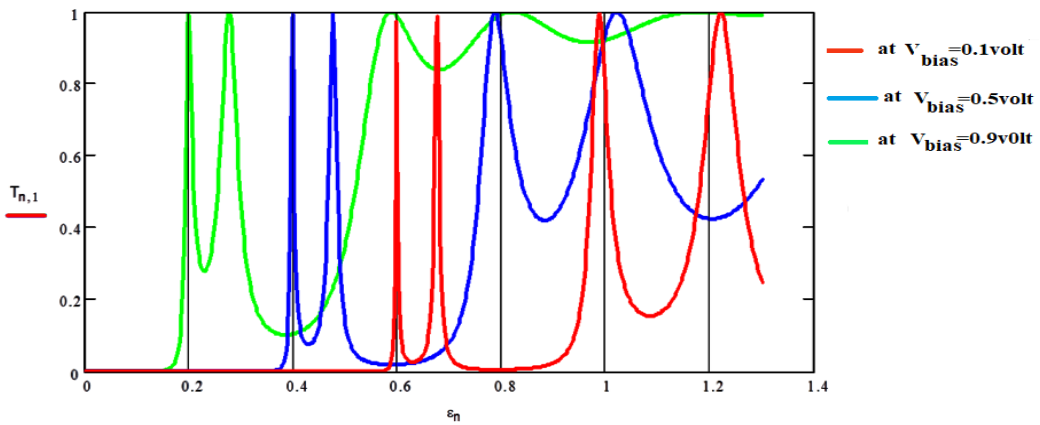

Figure 2 Transmission coefficient versus longitudinal energy for triple barrier of ($GaN/Al_{0.55}\ Ga_{0.45}N$) with ($V_{bias}$ = 0.1, 0.5 and 0.9) volt.

As shown in fig. 3, we examine the (E_0) in triple barrier superlattice structures (Ga N/$Al_{0.55}$ $Ga_{0.45}$N), (Ga N/$Al_{0.6}$ $Ga_{0.4}$N), (Ga N/$Al_{0.65}$ $Ga_{0.35}$N) with with (L_a= L_b =1.27nm) for different bias voltages applied. Based on these results, we can conclude that as bias voltage increases, the band of common energies will decrease, see table 1. Because of the restrict of the eigen states [19, 20].
Furthermore, high mole fractions of (Al) in the system confine electrons in the well region, which causes the density of electrons to increase while the scattering rate is reduced due to the very thin region. This is agreement with Yang et al. [21] when they predicted that numerical simulation of AlGaN/GaN heterostructure GaN substantial hole, a reduction of Al concentration reasons a dropping of the energy analogous to the T(E) highest, while Rached et al. [4] show the energy of the (E1) growths with Al 0.14 eV for x =0.1 to 0.51 eV for x =0.5 in (GaN/ N) superlattice structure explained that firstly the conduction band offset is function of aluminum concentration and rises when growing x, and then is dependent on the structure and barrier heights [22,23].

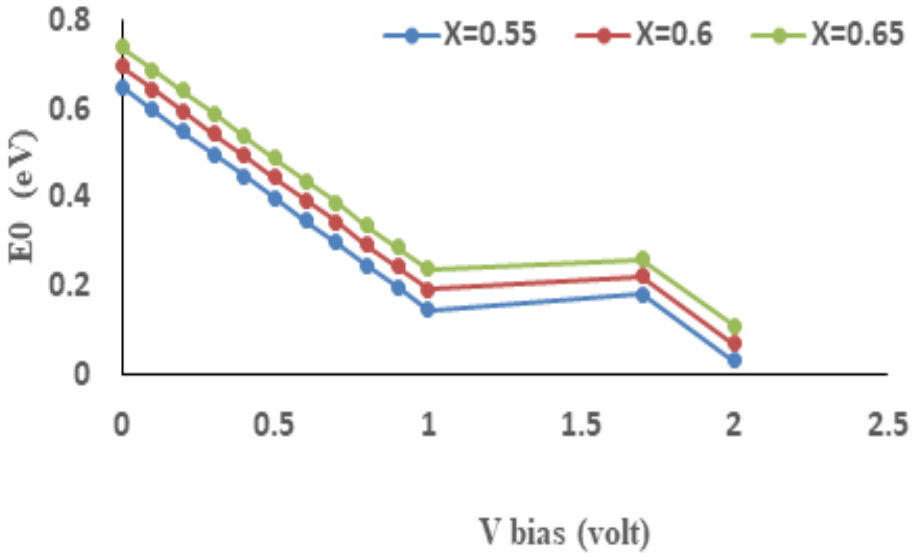

Figure 3 Dependence of ground state level E_0 on the bias voltage for (Ga N/$Al_{0.55}$ $Ga_{0.45}$N), (Ga N/$Al_{0.6}$ $Ga_{0.4}$N), (Ga N/$Al_{0.65}$ $Ga_{0.35}$N).

Table 1 displays the values of ground state level E_0 for (Ga N/$Al_{0.55}$ $Ga_{0.45}$N), (Ga N/$Al_{0.6}$ $Ga_{0.4}$N), (Ga N/$Al_{0.65}$ $Ga_{0.35}$N) with L_a= L_b =1.27nm and varying bias voltage.

L_a= L_b =1.27nm N=3		V_{bias}								
		0	0.1	0.3	0.5	0.7	0.9	1	1.7	2
E_0(eV)	X=0.55	0.648	0.598	0.49	0.398	0.298	0.19	0.148	0.132	0.032
	X=0.6	0.694	0.644	0.54	0.444	0.344	0.24	0.194	0.142	0.072
	X=0.65	0.738	0.688	0.58	0.488	0.388	0.28	0.238	0.226	0.112

The (J_0) (at room temperature) is obtained by integrated the T(E) over all states in the basis of equ.1. The (J_0) as a function of (V_{bias}) for triple barrier (GaN/$Al_{0.6}$ $Ga_{1-X0.4}$N) superlattice structure with (L_a= L_b =1.27nm) is calculated as in fig. 4. The (J_0), at (V_{bias} = 0), is zero, as region (a) in fig. 4 when (V_{bias} = 0.1 V) to the structure, a small (J_0) flow. The current increases strongly as ($J_{0(p)} = 3.16 * 10^{-3} A/nm^2$) at peak voltage ($V_{bias(p)}$ = 1.5 V), see region (b). Additional rise (V_{bias}) detunes the resonance and current decreases sharply as ($J_{0(v)} = 1.29 * 10^{-6} A/nm^2$) at valley voltage ($V_{bias(v)}$ = 1.7 V), and creates the negative differential resistance (NDR), see region (c) fig. 4 still with further

increase of the voltage (V_{bias} = 2 V), the excess current starts to dominant, region (d) of fig. 4. It is also noteworthy by Li et al. [24] who observed experimentally NDR at temperature=77 K from small Al-structure AlGaN/GaN double-barrier RTDs deposited by MBE in numerous slight dimension ($4 \times 4\mu m^2$). No NDR characteristics, however, were detected from any greater range quantum wells ($6 \times 6\mu m^2$ *to* $30 \times 30\mu m^2$).

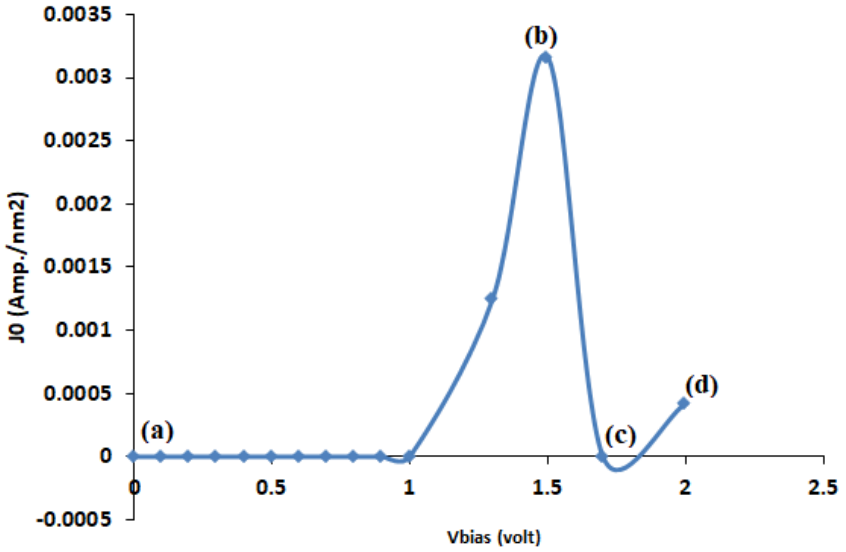

Figure 4 (J-V) characteristics in triple barrier (GaN/$Al_{0.6}$ $Ga_{0.4}$N).

Enormous doubts in the described current top to valley (GaN/AlGaN) RTDs. Though, our achieved PVR ideals fluctuate marginally since investigational workings, when Li et al. [24] showed the NDR autographs were perceived from ($4 \times 4\mu m^2$). The comparatively slight value of the determined PVR (1.03) at alignment AlGaN/GaN RT assemblies were mature by plasma-assisted molecular-beam-epitaxy.

Bayram et al. [25] illuminate the energy of the electron situations in the rod bring into line with the separate energy state of the well, I_P = 83.41 mA is attained. This agrees to V_p = 6.24 V. With extra growth in bias, the emitter electron energy state drops lower the edge of the conduction group into the gap and the current is reduced. In this case, the current and voltage are characterized as valley current I_V=75.36 mA and V_V =6.62 V.

The (J_0) vs. bias voltage (V_{bias}) for triple barrier (GaN/Al_X Ga_{1-X}N) superlattice structure and both L_b and t L_a have the thickness of (1.27nm) and the Al structure of AlGaN barrier varieties from (x = 0.55, 0.6, 0.65) can be studied in fig. 5. We point out that while growing the mole fraction of the composite the (J_0) will decline, as shown in table 2. This result is in favor with the result of Saker et al. [22] who showed theoretically that increasing aluminum concentration, which forms the barrier in (GaN/AlyGa1-yN), the current value is also reduced, also this result is agreement with Bhouri et al. [1] who study the diode of AlGaN/GaN/AlGaN where both the potential barrier and the potential well have the thickness of 1.5 nm, and the Al concentration of AlGaN barrier arrays from 0.1 to 0.3 and originate that the Al composition affects the NDR characteristic of RTD. Additionally, *M. Boucherit et. al* [23] study the (V_{bias}) is red-shifted and the value of the valley current is rather reduced and point out that the current peak value varies to a lesser extent when increasing x=0, 0.1, 0.5 in due to its resonant nature, which explains the low obtained PVR values [26-28].

The description of this performance is ordinary when growing the mole fraction of (Al) it will reason a rise in the barrier height (V_b) as a result of deprived tunneling over the barriers, since the tunneling happen when potential barrier height is small and the energy gap of quantum wells also the ($T(El)$) will be decline so (J_0) will decrease.

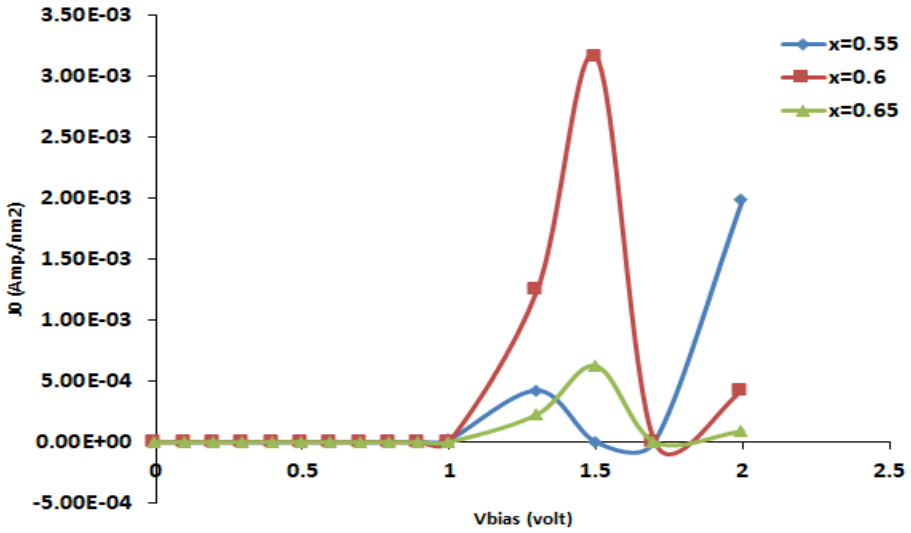

Figure 5 The current density (J_0) versus bias voltage (V_{bias}) for triple barrier (GaN/Al_X $Ga_{1-X}N$) superlattice by changing the mole fraction.

Table 2 Shows the values of the (J_0)for triple barrier (GaN/Al_X $Ga_{1-X}N$) with (x=0.55, 0.6, 0.65, L_a= L_b =1.27nm) and varying bias voltage.

L_a= L_b =1.27nm N=3		V_{bias}								
J_0(A /nm^2)		0	0.1	0.3	0.5	0.7	0.9	1	1.7	2
	X=0.55	0	5.9E-13	2.9E-11	1.4E-9	6.7E-8	3.2E-6	2.2E-5	6.0E-6	1.9E-3
	X=0.6	0	9.3E-14	4.7E-12	2.3E-10	1.1E-8	5.4E-7	3.7E-6	1.2E-6	4.2E-4
	X=0.65	0	1.6E-14	8.5E-13	4.2E-11	2.0E-9	9.9E-8	6.8E-7	2.9E-7	9.0E-5

4. CONCLUSIONS

In this paper we have numerically determined the transmission coefficient and effect each of well width and aluminum mole fraction on the ground state level for (GaN/Al_X $Ga_{1-X}N$) superlattice. The MathCad2001 application provides a simple and accurate method for determining the solution. It is observed that the transmission probability gradually decreases when the bias voltage is increased. Furthermore, the energy of the (E1) growths with high mole fractions of (Al) in the system Al 0.14 eV for x =0.1 to 0.51 eV for x =0.5 in (GaN/ N) superlattice structure. The results are very sensitive to the geometry of tunneling system (barrier and well dimensions). For increase of barrier height, the ground state energy increases while decrease with increase well width.

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