Simulation Study of AlN Spacer Layer Thickness on AlGaN/GaN HEMT

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Abstract: *High electron mobility transistor (HEMT)Two-dimensional electron gas (2DEG) formed at AlGaN/GaN interface is a critical part to tune the characteristic of AlGaN/GaN HEMT devices. Introduction of AlN spacer layer in between AlGaN and GaN layer is one of the way to improve 2DEG density, mobility, and drain current. Carrier concentration, mobility and conduction band offset for different spacer layer thickness was simulated by using Silvaco simulation tool. Our device simulations showed that carrier concentration, mobility are enhance on introduction of AlN spacer layer in HEMT. In addition, carrier properties of HEMT also depend on thickness of spacer layer. Our simulation showed that the mobility of 2DEG attains its maximum value at the 0.5 nm thick AlN layer but carrier concentration increases with spacer thickness. Finally, drain current increases with increasing spacer layer thickness and reach maximum value at 1.2nm thick spacer layer.*

Keywords: HEMT, Spacer layer, mobility, carrier concentration, scattering, simulation

1. INTRODUCTION

AlGaN/GaN high electron mobility transistor (HEMT) have been the cardinal subject of many recent investigations because of their material properties such as large band gap (3.45eV), high breakdown field(3MeV), high saturation velocity (2.2×10^7cm/sec)[1]etc. These crucial material properties lead the device has high potential for use in high-temperature, high-power devices. One of the most unusual features of these HEMT is that very high 2DEG densities (10^{13} cm^{-2}) can be found in even nominally or undoped heterostructures [2-4]. Usually, for high 2DEG carrier density at the AlGaN/GaN interface, higher Al mole fraction in the AlGaN barrier layer can be used [5]. However, Low quality AlGaN barrier layer for high Al content on GaN and alloy disorder scattering lead drop of mobility [6].

Therefore, the product of mobility and carrier concentration improvement is limited which is very crucial for high power density of device. To improve the electrical properties of HEMTs, Shen et al. had reported the AlGaN/AlN/GaN Microwave HEMT [7]. The AlN spacerlayer in between AlGaN and GaN layer eliminates the strain of the AlGaN layer [8] and the film quality of the AlGaN layer has been improved. An additional thin AlN spacer between AlGaN and GaN improves the mobility at low Temperatures, where the thickness of AlN is an important parameter for the mobility in AlN/GaN heterostructures [9-11]. In this study, the electron transport for different AlN spacer thickness is simulated by using Silvaco simulation tool. In addition, Ohmic electrode is recessed in order to reduce the ohmic resistance.

2. SIMULATION METHEDOLOGY

Fig. 1 shows the schematic of explored device; the device characteristic was simulated by solving a set of quantum mechanically corrected transport equations.

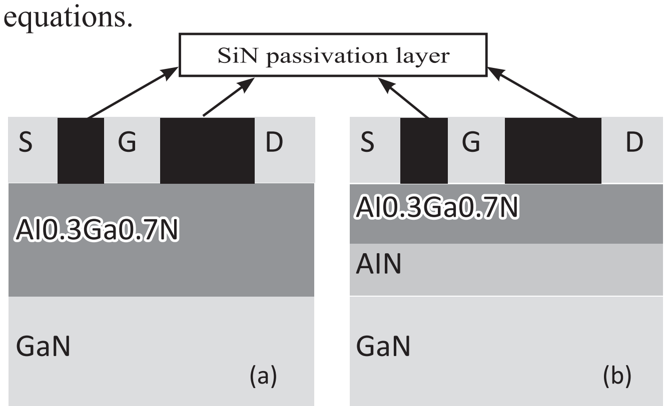


Fig.1. the simulated structure of HEMTs, where the plots (a) and (b) are without and with the AlN spacer Parameters used in this work are in table number 1.

Work function of gate	5.18eV
Gate width (w)	100µm
Source Gate space(L_{sg})	1.5µm
Drain Gate space(L_{gd})	4µm
Al fraction(x)	0.30
AlGaN thickness(t_{AlGaN})	25nm
GaN thickness(t_{GaN})	2µm
gate length (L_g)	1µm

In this device gate length, Source gate distance and gate drain distance are 1µm, 1.5µm and 4µm respectively. AlGaN and GaN layers thickness are 25nm and 2µm respectively. Al composition fraction of AlGaN layer is 30%. Work function of Gate metal is 5.18eV.Owing to n-type uniform doping concentration at Source and Drain regions are $1\times10^{18}cm^{-3}$, source and drain contacts become ohmic. To obtain numerical results for a device, the device is simulated by solving classical transport equations using the commercial tool ATLAS [12]. To adopt the current relationship Drift diffusion model [12] is used.

$$\vec{J} = qD_n\nabla n - qn\mu_n\nabla\psi - \mu_n n\{kT_L\nabla(ln n_{ie})\} \ldots. (1)$$

Where q is charge, D is diffusion coefficient, is electrostatic potential, T_L is lattice temperature, n_{ie} is intrinsic concentration

To study the effect of electric field on transport properties, low field and nitride specific field dependent mobility model are used in the simulation. Low field mobility is expressed [12]as

$$\frac{1}{\mu} = \frac{a\cdot N}{b}\left(\frac{T_L}{c}\right)^{-\frac{3}{2}} ln\left[1+3\left(\frac{T_L}{c}\right)^2\left(\frac{N}{b}\right)^{-\frac{3}{2}}\right] + d\left(\frac{T_L}{c}\right)^{\frac{3}{2}} + \frac{x}{exp^{\left(\frac{y}{T_L}\right)}-1} \quad \ldots.. (2)$$

Where µ is mobility depends on doping (N) and lattice temperature (T_L) and a, b, c, d, x and y are user specifiable parameters on the mobility statements.

The high field dependent mobility model [12] is given by

$$\mu = \frac{\mu_0(T,N)+v^{sat}\frac{E^{n1-1}}{E_C^{n1}}}{1+a\left(\frac{E}{E_C}\right)^{n2}+\left(\frac{E}{E_C}\right)^{n1}} \ldots\ldots.. (3)$$

Where µ is low filed mobility model, E is electric field and v^{sat}, E_c, a, n_1 and n_2 are model parameters. Polarization model is used to activate polarization .Newton method is used to solve the numerical problems. Tony plot was used to see the output results.

3. RESULT AND DISCUSSION

Mobility and carrier concentrations are calculated for both the conventional HEMT and the HEMT which is with the AlN spacer layer between the layers AlGaN and GaN. Fig. 2 shows that improved electron concentration on inserting AlN spacer layer, which is mainly due to the increase in the quantum well depth, as shown in Fig. 3.

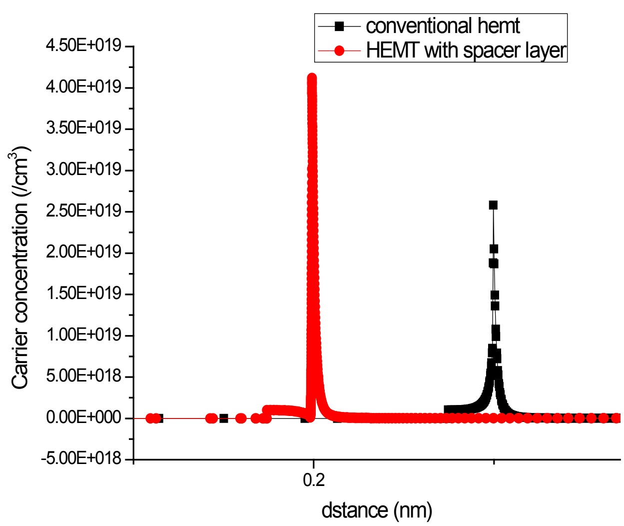


Fig. 2 The electron concentration for the device with and without AlN spacer layers.

Not shown here, the carrier mobility is also increased significantly. Due to the increase in quantum well depth, the scattering is lowered. In addition, alloy scattering is lowered because binary compound such as AlN has less alloy scattering in comparison to ternary compound [13]. As a result, the mobility is also increased, and, finally, the current is increased.

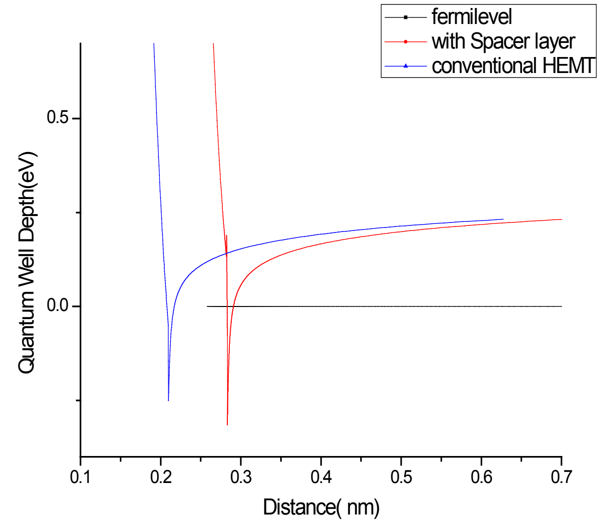
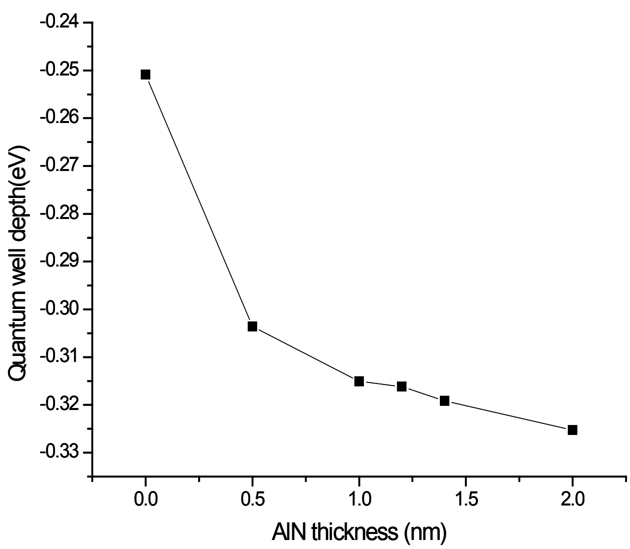
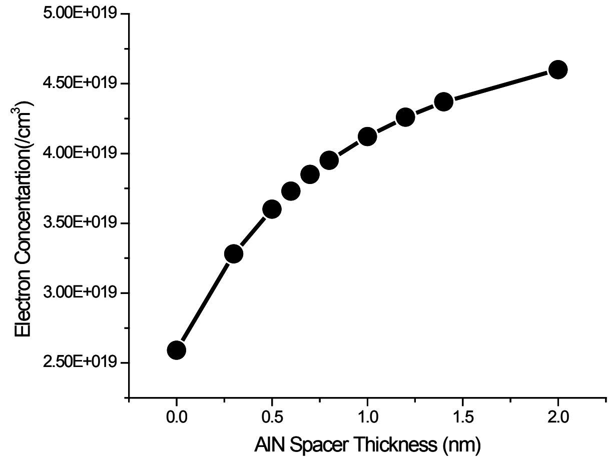


Fig. 3 The calculated quantum well depth for the device with and without AlN spacer layers.

We further explore the effect of AlN spacer layer thickness on the device characteristics. Quantum well depth and electron concentration are increased with AlN spacer layer thickness as shown Figs. 4(a) and 4(b). However, the electron mobility increases first, where the maximum appears at 0.5nm AlN layer, and reduces on further increasing AlN layer, as shown in Fig. 5.



(a)



(b)

Fig. 4 (a) The quantum well depth and (b) the electron concentration with the AlN thickness.

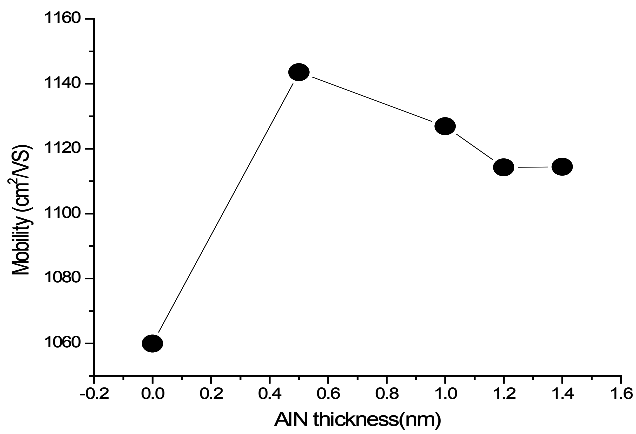


Fig.5 The mobility versus the AlN thickness.

This is owing to the Coulomb scattering between 2 DEG carriers when very thick spacer layer is used. As AlN spacer thickness is up to 0.5nm Coulomb force between ions and with lattice is lower, which reduce the scattering and mobility is increased on increasing. However, as the thickness further increase beyond 0.5nm width of quantum well is small enough and coulomb scattering between carriers become dominant. As a result, mobility is increased.

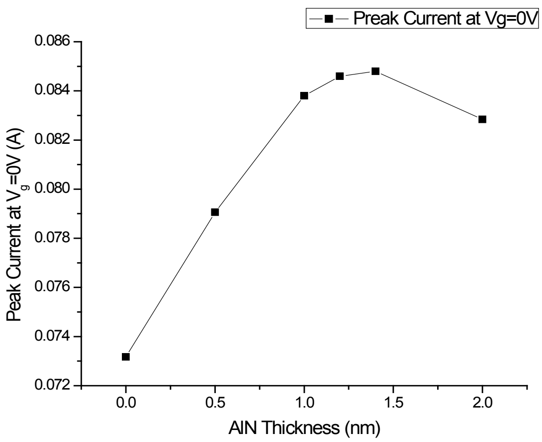


Fig.6. The simulated current for device with different AlN thicknesses

Fig. 6 shows the simulated drain current at the zero gate voltage. Current depend on carrier concentration and mobility. Up to AlN spacer layer thickness 1.2nm carrier concentration increase play dominating role in current and current increase. Beyond 1.2nm thickness decrease in mobility play dominating role on current. As a result, current is maximum at 1.2nm and decrease on further increase of thickness.

4. CONCLUSION

The findings of the different thickness of AlN spacer layer conclude that electron concentration increases with the increases of AlN thickness. The device's mobility reaches the maximum at 0.5-nm-thick AlN layer and the drain current's maximum at 1.2nm thick spacer.

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