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CONTRIBUTION TO THE MODELING OF A 2DEG CURRENT A HIGH ELECTRON MOBILITY TRANSISTOR BASED ON GAN/ALGAN HETEROSTRUCTURES

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ABSTRACT: The development of systems using microwaves for military telecommunications and consumer, requires discrete components and power that can operate at high frequencies. It is efficient components for operating systems such as high electron mobility transistor (HEMT).
The potential of transistors HEMTs based heterostructure AlGaN / GaN high interest to the international scientific community and are certainly the most currently studied worldwide. They have emerged as attractive candidates for applications in high voltage, high frequency to microwave power. By the spontaneous and piezoelectric polarization, they have the facility to produce a two-dimensional electron gas (2DEG) at the interface with a high concentration without doping intensional. The market for power components based on this material is booming for many applications.
In this article we studied some properties of nitride materials existing in the structure for a better functioning of the component, it is necessary to have a physical simulation model for describing the heterojunction AlGaN / GaN, and the fundamental principles of electrical operation a HEMT transistor. In this model, this electron mobility 2DEG depending on the gate voltage in the transistor channel and the Al concentration.

KEYWORDS: SEMICONDUCTOR, ALGAN, GAN, HETEROJUNCTION, HEMT, 2DEG.

1 INTRODUCTION

Since its resurgence in the early 1990s, gallium nitride (GaN) has been considered as a very interesting and very promising semiconductor material for its potential applications in optoelectronics for the emission and absorption in the ultraviolet and power electronics. In this area, the physical properties of III nitrides element such as wide band gap energy, a reasonable electron mobility, a high breakdown field and high chemical stability have allowed this material system to be a good candidate for high power microwave applications, and high temperature. Demonstrated the first high electron mobility transistor (HEMT) based on a heterostructure AlGaN / GaN has confirmed the great potential for this sector approached [1]. Today, these components have almost the best compromise between power and frequency in a wide range of applications. Spread applications of power electronics through communications without son to the radar stations and bases and soon they will cover the area of millimeter waves.

Transistors high electron mobility GaN / AlGaN (HEMT) have recently received considerable attention because of their potential use for high voltage operation and high power at microwave frequencies [2,3] . The performance of heterostructure AlGaN / GaN is assigned to a high density two-dimensional electron gas (2DEG) at the heterointerface limited. Due to the effects of the spontaneous and piezoelectric polarization in heterostructures AlGaN / GaN, the density of 2DEG interface obtained in AlGaN / GaN is as high as 10^{13} cm^{-2} [4]. In the HEMT, a high current capacity results from the combination of high carrier density and good transmission characteristic. It is therefore essential to further improve the mobility and density of 2DEG in the channel, the conduction band offset between AlGaN and GaN and the large piezoelectric effect (fig 1). In AlGaN / GaN HEMT, the charge bias, the conduction band discontinuity and the molar fraction are important parameters which affect the carrier density (2DEG) at the interface. The existence of spontaneous polarization fields and piezoelectric change the

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2DEG density. An increase in the aluminum composition (mole fraction) increases the density of two-dimensional electron gas and the electrons are closer to the interface.

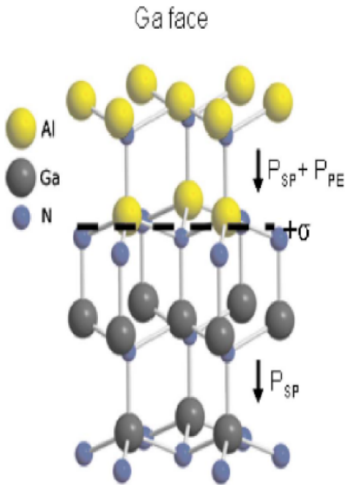

Fig. 1. Schema structure of AlGaN / GaN indicating the presence of the polarized piezoelectric load interface between the two materials [5].

In this work, we highlight the structure of the AlGaN alloy, the variation of the lattice parameter of this structure depends on the concentration of aluminum (Al%) which affects the energy band which also varies depending on the temperature. A model was constructed showing the variation of the current density functions of the concentration of the aluminum (Al%) and the gate voltage (Vg).

2 STRUCTURE OF DEVICE

The HEMT structure as shown in Figure 2 was used to verify the analytical model. It generally consists of 3 µm thick GaN buffer layer undoped, 30Å thick $Al_{0.3}Ga_{0.7}N$ spacer layer, and a thickness of 220 Å of $Al_{0.3}Ga_{0.7}N$ doped Si active layer. The doped epitaxial layers are grown undoped and by phase organometallic chemical vapor deposition on the thin buffer layer GaN and the sapphire substrate. Mesa isolation is realized with inductively coupled plasma. The ohmic contacts are made of Ti / Al / Pt / Au, deposited by electron beam [6].

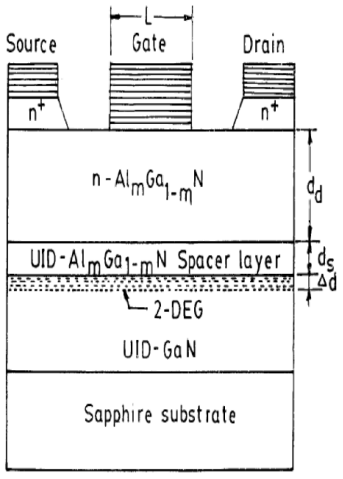

Fig. 2. Cross section HEMT AlGaN / GaN [7].

3 MODEL FORMULATION

The basic structure of HEMT AlGaN / GaN considered in this analysis is illustrated in Figure 2. To determine the carrier concentration of the 2DEG channel from the charge density induced by the polarization from equation1, we use the following approximations [8].

$$n_s = \frac{\varepsilon(x)}{qd}(V_g - V_{th}(x) - E_F)$$

Vg :voltage the gate

EF: Fermi energy level

ε (x): The dielectric permittivity as a function of the aluminum mole fraction (x) can be written as [9]:

$$\varepsilon(x) = 9.5 - 0.5x$$

The threshold voltage Vth is given by the following expression which depends on the temperature T and the molar fraction x [10]:

$$V_{th}(T,x) = \emptyset(x) - \Delta E_c(T,x) - \frac{qN_D d_d^2}{2\varepsilon(x)} - \frac{\sigma(x)}{\varepsilon(x)}(d_d + d_s)$$

With:

σ (x): The charge density at the interface of a heterostructure AlxGa1-xN/GaN Face Ga and given by the following function [9]:

$$\sigma(x) = [\, P_{spontanseous}(Al_xGa_{1-x}N) - P_{spontanseous}(GaN) + P_{piezoelectric}(Al_xGa_{1-x}N)]$$

With

$$P_{piezoelectric}(Al_xGa_{1-x}N) = 2\left(\frac{a(0)-a(x)}{a(x)}\right) * \left(e_{31}(x) - \frac{e_{33}(x)c_{13}(x)}{c_{33}(x)}\right) \text{C}/m^2$$

$$P_{spontanseous}(Al_xGa_{1-x}N) = -0{,}52x - 0{,}029 \text{ C}/m^2$$
$$P_{spontanseous}(GaN) = -0{,}029 \text{ C}/m^2$$

Where a (x) is constant lattice$Al_xGa_{1-x}N$, e31 (x) and e33 (x) are piezoelectric constants, c13 (x) and c33 (x) are elastic constants, and a (0) is the value of lattice GaN = 3.189 a °.

d = (dd + ds) is the separation between the gate and the channel (2DEG) or d_d is the thickness of the doped AlGaN layer and d_i is the thickness of the undoped layer (spacer).

Ø (x): The height of the Schottky barrier metal / AlGaN based on the mole fraction of aluminum (Al), given by [9]:

$$\emptyset(x) = 0.84 + 1.3x$$

The discontinuity of the conduction band $\Delta E_c(T,x)$) at the interface $Al_xGa_{1-x}N$/GaN is written [10]:

$$\Delta E_c(T,x) = 0.70[E_g^{AlGaN}(T.x) - E_g^{GaN}(T)]$$

The width of the gap of the ternary AlxGa1-xN can be written as:

$$E_g^{AlGaN}(T.x) = xE_g^{AlN}(T) + (1-x)E_g^{GaN}(T) - 0.6x(1-x)$$

The width of the band gap of GaN following the empirical law of Varshni and writes [11]:

$$E_g(T) = E_g(0) - \alpha\frac{T^2}{T+\beta}$$

Eg (0) is the bandgap temperature (T_0=0K), $E_g(0)$ = 3.39 eV for GaN. The adaptation of the parameters Varshni equation for bandwidth variation with temperature are α (meV / K) and β = -1.08 (K) = 745

4 RESULTS AND DISCUSSION

Figure 3 shows the variation of the lattice constant (a) of the AlxGa1-xN layer depending on the concentration of aluminum (x). By increasing the rate of (Al), a perturbation in the lattice occurs because the location of the Al atom in the GaN material thereby inducing a decrease of the lattice constant a.

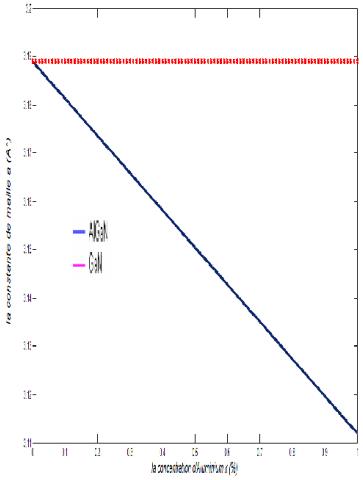

Figure 3. The variation of the lattice constant a (x) as a function of the concentration of aluminum.

Figure 4 shows the effect of temperature on the energy gap of GaN and AlGaN for the x = 0.3 as an example, which shows a decrease in the energy (GaN, AlGaN) by increasing the temperature and this effect is due to the thermal expansion which modifies the interatomic distances in the crystal lattice, which causes a change of the positions of the valence band and the conduction band as well the electron-phonon interactions that change the width of the forbidden band

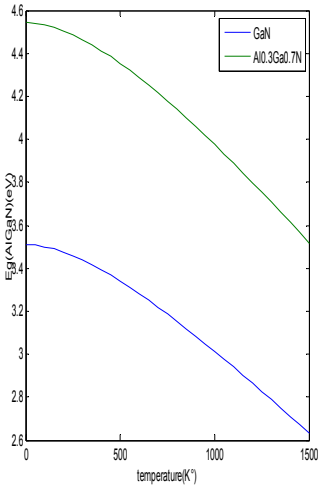

Fig. 4. Bandgap of AlxGa1-xN versus temperature

Figure (5) represents the variation of the energy gap as a function of increasing temperature and the aluminium concentration x (of 0% to 1%), a disturbance in the forbidden energy which involves a decrease in forbidden depending on two parameters band is shown.

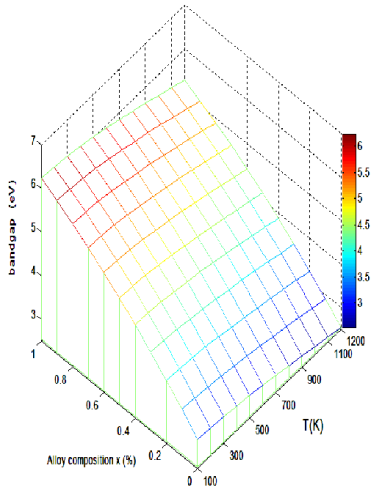

Fig. 5. Bandgap of $Al_xGa_{1-x}N$ versus Al content x and temperature

Figure 6 shows the variation of the density of the 2DEG in the quantum well as a function of the mole fraction of aluminum (%) in the layer of AlxGa1-xN, and the 2DEG is important value, in the range of Al variation of 0 to 1%, the 2DEG concentration increases. And this increase proportional to the aluminum content due to the spontaneous and piezoelectric polarization in the interface of the heterostructure of AlGaN / GaN to Ga face is favorable for a HEMT operation.

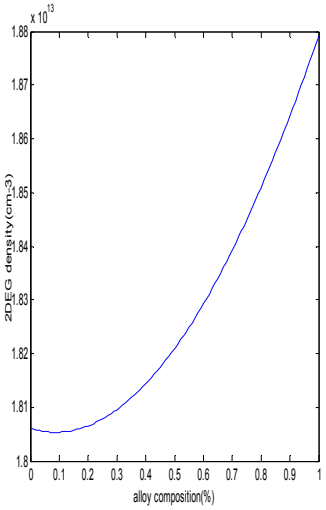

Figure 6. Variation of density of 2DEG with mole fraction for AlGaN

We note in Figure 7, the increase of the 2DEG density (Ns) according to the gate bias (Vg). The major values (ns) are attributed to the presence of polarization charges in the HEMT. The slope of this curve corresponds to the capacity of the structure, which is directly related to the separation between the gate and the (2-DEG), more precisely to the donor layer of AlGaN, the density increases further more capacity and performance increase, and to have a high density (2-DEG), and the lower ability of gate, avoid the disappearance of channel HEMT.

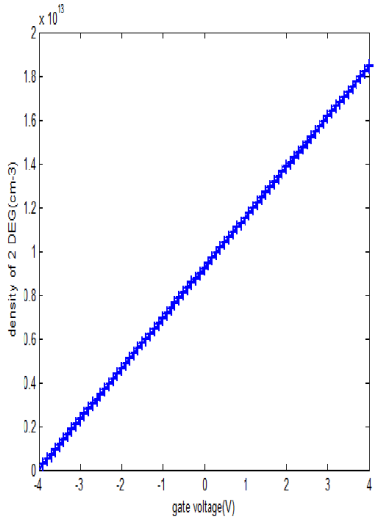

Fig. 7. The 2DEG density verse Vg for AlGaN/GaN heterostructure

5 CONCLUSION

The basic principle of a high electron mobility transistor (HEMT) is to take advantage of the properties of high mobility two-dimensional electron gas a 2DEG from the physical separation of free electrons ionized donors which they come . The HEMTs are electronic devices operating at high frequencies with very high speeds through the appropriate base material. The HEMTs are electronic devices operating at high frequencies with very high speeds through the appropriate base material. The GaN hexagonal structure is a promising candidate for these transistors thanks to its physical properties

In this model, we studied the effect of the Al mole fraction and the gate voltage for the 2DEG density using the variation of the band gap with temperature and the mole fraction of (Al), which also indicate the dependency spontaneous and piezoelectric polarization on the Al composition is extremely useful for determining the performance of the device for high performance applications.

The results of this analysis show clearly that the increase of the gate voltage leads to an increase of the 2DEG density. These behaviours depend upon the thickness of the 2DEG channel and the Al molar fraction

REFERENCES

[1] M. A. Khan, J. N. Kuznia, D. T. Olson, W. J. Schaff, J. W. Burm, and M. S. Shur, "Microwave performance of a 0.25 µm gate AlGaN/GaN heterostructure field effect transistor," Applied Physics Letters, vol. 65, no. 9, pp. 1121–1123, 1994.

[2] Chen Z, Pei Y et al 2009 Appl. Phys. Lett. 94 112108

[3] Chang C T, Hsiao S K, Chang E Y, Lu C Y, Huang J C and Lee C T 2009 IEEE Electron. Device Lett. 30 213

[4] Ambacher O, Smart J et al 1999 J. Appl. Phys. 85 3222

[5] B. S. Kang, H. T. Wang, F. Ren, and S. J. Pearton,Elec-trical detection of biomaterials using AlGaN/GaN high electron mobility transistors, J. Appl. Phys. 104, 031101 (2008).

[6] B. S. Kang, H. T. Wang, F. Ren, S. J. Pearton, T. E. Morey et al, Enzymatic glucose detection using ZnO nanorods on the gate region of AlGaN/GaN high electron mobility transistors , Appl. Phys. Lett. 91, 252103

[7] ManjuKorwal, S. Haldar, Mridula Gupta, and R. S. Gupta, Parasitic resistance and polarization dependent polynomial-based non-linear analytical charge-control model for algan/gan modfet for microwave frequency applications, Microwave and Optical Technology Letters / Vol. 38, No. 5, September 5 2003

[8] P. Jeong, W. S. Moo, and C. L. Chin, "Thermal modeling and measurement of AlGaN-GaNHFETs built on sapphire and SiCsubstrates,"IEEE Trans Electron Device, vol. 51, no. 11, pp. 1753-1759, 2004.

[9] O. Ambacher, J. Smart, J. R. Shealy, N. G. Weimann, K. Chu, M. Murphy, W. J. Schaff, and L. F. Eastman ,Two-dimensional electron gases induced by spontaneous and piezoelectric polarization charges in N- and Ga-face AlGaN/GaN heterostructures, Journal Of Applied Physics volume 85, number 6 (1999)

[10] Jiang Xia, Yang Ruixia, Zhao Zhengping, Zhang Zhiguo, Feng Zhihong, Analytical Model and Simulation for AlGaN/GaN High Electron Mobility Transistor, 2011 International Conference on Internet Computing and Information Services

[11] HasinaF.Huq ,BashirulPolash, Physics-based numerical simulation and device characterizations of AlGaN/GaN HEMTs with temperature effects, Microelectronics Journal 42 (2011) 923–928