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TCAD Simulation Study of Algan/Gan High Electron Mobility Transistors(HEMT)

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Abstract

the requirement of higher frequency and high voltage applications led to have research based on GaN materials. This paper presents AlGaN/GaN High Electron Mobility Transistors (HEMT) and its DC characteristics are simulated using commercial software (Synopsys, Sentaurus TCAD). The Influence of SiC on the channel, thickness of AIN and AlGaN effects in 2DEG was discussed from the DC simulation. By adding thermal electrode in the HEMT structure also analyzed the self heating effect in this device.

Keywords: High Electron Mobility Transistors (HEMT), AlGaN/GaN,Higher frequency, substrate.

Introduction

The MODFET (Modulation Doped Field Effect Transistor) is also known as HEMT (High Electron Mobility Transistor), because of this high frequency operation than the other semiconductor material devices. The high frequency behaviour is due to the difference in band gab between the dissimilar semiconductor materials such as GaN and AlGaN or GaAs and AlGaAs.

A Johnson's figure merit (JM) is used for check the suitability of particular material in high frequency and high power application. The value of JM for a material should be high for high power and high frequency applications [1]. From the table 1 the materials which have the better properties for high frequency and high power applications are SiC and GaN.

When two different materials are joined together or grown one over the other keeping the same structure the hetro-structure will form. Because of large band gab in AlGaN/GaN leads to band gab discontinuity in structure, results formation of notch and valley in conduction band and valence band respectively. The notch and valley will form only in lower band gab material, so which is present in GaN.

Due to the presence of notch at the hetero junction, electrons accumulate at the interface which form the 2DEG (2 Dimensional Electron Gas) close to the interface. This 2 Dimensional Electron Gas (2DEG) forms even without any significant doping.

The absence of doping and spatial separation of channel electrons from ionized donors leads to the reduction of ionized impurity scattering and, consequently, an increase in electron mobility. The resulting 2DEG density in GaN-based devices has been reported to be around and, in many cases, above 1013cm2, making it almost six times larger than that of a GaAs HEMT. A higher mobility and electron density leads to higher output current density. Nowadays, the reported output power density of 30-40 W/mm is more than ten times higher than that of GaAs based transistors.

AlGaN/GaN based HEMT structure satisfies the high frequency and high voltage application requirements. But still many issues are degrading the performance of the AlGaN/GaN based device. One of the main issue is self heating. Because of high current flow in GaN based semiconductor material leads to generate lot of heat which is referred to as self-heating but the heat dissipation mainly depends on the type of substrate on which device has been fabricated. So in this paper we have analysed the self heating effect with different substrate materials.

Device and Physical Models

The AlGaN/AlN/GaN/AlN/SiC High Electron Mobility Transistor (HEMT) is shown in fig 1. The gate electrode length 0.250µm, gate to source length 0.7µm, gate to drain length 2 µm, the length of source electrode 50µm, length of drain electrode 66µm, and a SiN passivation layer has been provided on the un-gated AlGaN surface to reduce the surface defects and current lagging [3] [4]. An AlN have wide band gab, it reduces the 2DEG electron wave-function penetration into the AlGaN barrier layer. So AlN layer is added in between the AlGaN and GaN layers. Sic does not have a any electrical effect in a design.

The whole device, except the sorce/drain contacts, has been assumed to be undoped. Although it is not an accurate representation of an actual device, it is to reduce the complexity of device simulation and confusion on the type and concentration of any unintentional doping present in an actual device. The drain and source contacts have been assumed to be ohmic and modeled in the device by doping the region under source and drain contacts with phosphorus of concentration 1e15.

The substrate has chosen with respect the following parameters 1. Lattice mismatch with materials, 2. Thermal conductivity and coefficient of thermal expansion, 3. Maximum electrical isolation, 4. Price and price per area, 5. Availability with respect to the diameter, 6. Crystal quality and residual defect density, 7. Surface properties and residual defect density, 8. Wafer warp and wafer bowing, 9. Mechanical and chemical properties with respect to thinning and viahole etching. [5]

Because of semi-insulating, the Sapphire is the most commonly used substrate for GaN hetero-epitaxial and 10 times better power result for GaN than the GaAs HEMT devices. But it has large thermal expansion coefficient (TEC) mismatch with the GaN epilayers, so not good for high power application. [6]

The SiC substrate good choice for high power application, it has high thermal conductivity, low lattice mismatch, and relatively low thermal expansion coefficient. [5]

DC Simulations

The AlGaN/AlN/GaN/AlN/SiC High Electron Mobility Transistor (HEMT) is simulated with commercially available TCAD tool. Simulated I/V characteristics of above mentioned structure are shown in figure 3.

The AlGaN/GaN device was simulated for different gate voltages (Vg= -4.0V, Vg= -2.0V, Vg= -0.0V, Vg= -2.0V) and observed the drain current (Id) vs drain voltage (Vd) characteristics of the device. As the drain voltage increases, the longitudinal field, current and carrier energy increase. The device get saturated in the I/V characteristics cure as can see after Vd=10V in figure3. Similarly the drain current (Id) Vs gate voltage(Vg) curve obtained for AlGaN/AlN/GaN/AlN/SiC High Electron Mobility Transistor and shown in figure 4.

Electron current density of AlGaN/GaN HEMT device shown in figure 6. From the conduction band and electron current density simulation we observed that, formation of a 2DEG very near to the interface. Due to presence of AIN layer between AlGAN and GaN polarization at the interface is very large which leads the electron current density large at the interface. Also the large band discontinuity leads to mobility improvement.

The thermal electrode was added at the bottom of AIN buffer layer for self heating analysis. GaN based HEMT devices have the advantage of high electron density, large band gap and hence high output current, but the drain voltage increase in the material generates a lot of heat because of high current flow, which is referred to as self-heating. The linear rise of the lattice temperature is concentrated at the drain side of the device because high electric field and electron current density experienced in this region. Due do these increasing temperatures affect the temperature dependent parameters in device; it leads to degradation of device performance.

When the operating voltage increased to large, it leads to reduction in mobility and also reduction in output current [7]. The AlGaN/GaN HEMT have a large power density then the silicon and GaAs devices [8]. The total self-heating at the drain side depends upon the thermal conductivity of the materials used in the device and the heat dissipation is depends on which material has been used as a substrate for fabrication. Various research groups has been found that the temperature rise in a GaN device fabricated on a SiC substrate is less than in those fabricated on sapphire substrates because of the relatively smaller thermal resistance of SiC as compared to sapphire. Thus the reason that SiC is the preferred as a substrate material for fabrication.

Conclusion

In this paper we simulated AlGaN/GaN HEMT device with commercially available TCAD tool. In the Dc simulation we observed that the thickness of AlGaN and AIN is affects the threshold voltage, lesser thickness of AlGaN and AIN leads to effect of gate voltage (Vg) on the channel due to variation in the 2DEG density. When the distance between gate and channel increase with AIN thickness the drain current and gate voltage curve shifts to the left and reducing the gate control.

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Table 1: Material Properties of three semiconductors [1,2]

Property	***4H-SiC***	***GaAs***	***GaN***
Eg(eV)	3.26 (Indurect)	1.42(Direct)	3.42(Direct)
$\mu(cm^2.V^{-1}.S^{-1})$	700	8500	2000
Vsat(10^7m/s)	2	1	2.5
Ebr(MV/cm)	3	0.4	3.3
JM	60	3.5	80

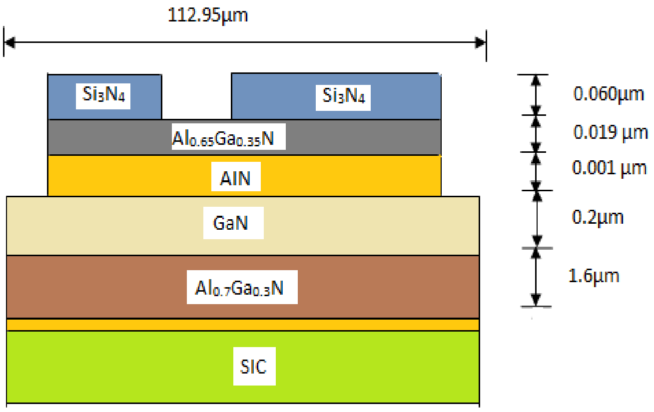

Figure 1: Schematic 2-D section of the AlGaN/GaN HEMT

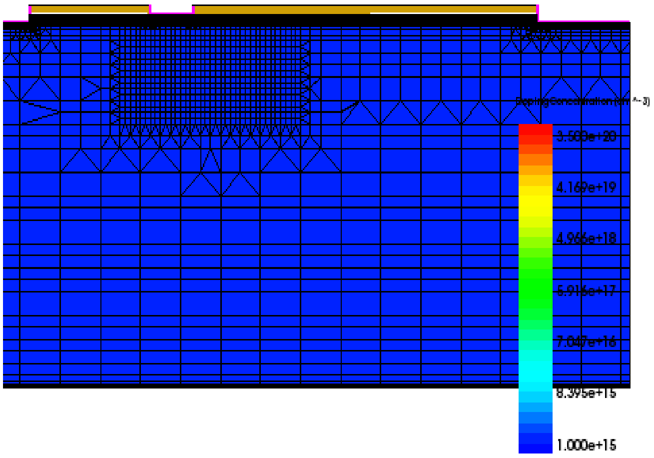

Figure 2: Meshing Structure of the AlGaN/GaN HEMT

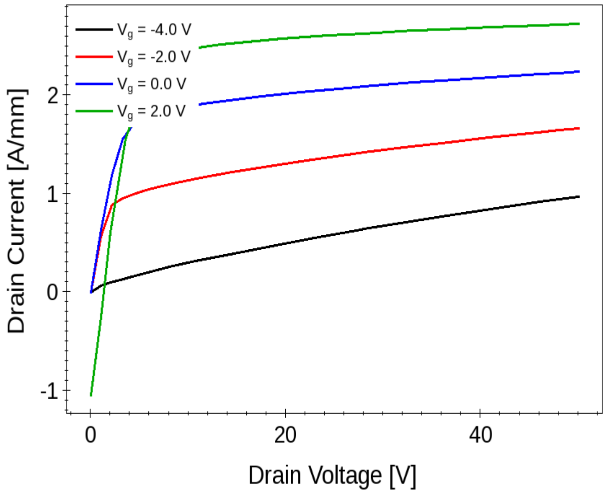

Figure 3: Id Vs Vd Characteristic of The Device For Different Gate Voltages

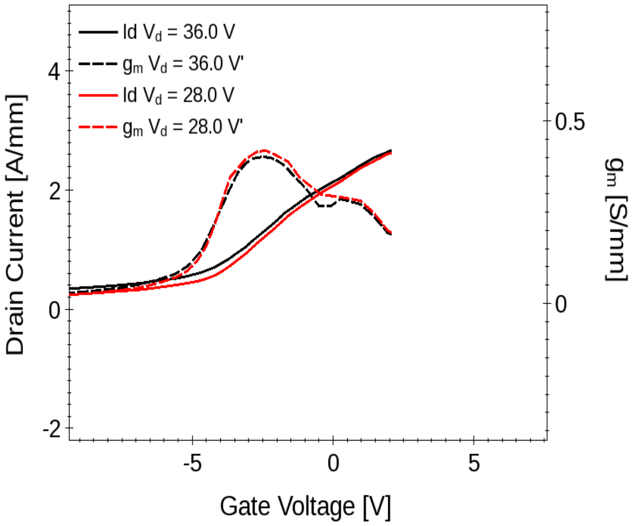

Figure 4: Id Vs Vg characteristic of the device

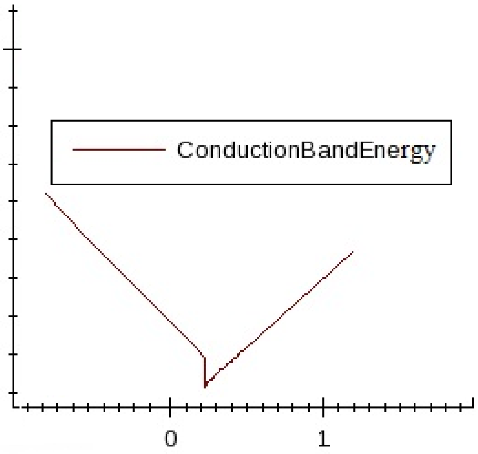

Figure 5: Conduction Band Energy Across The Channel of The Device

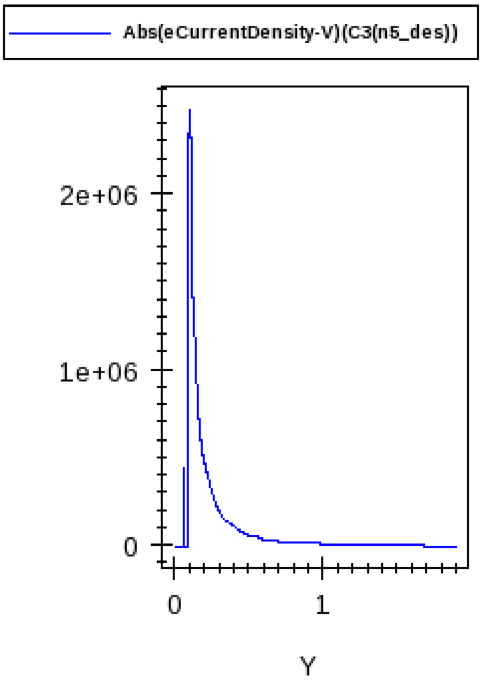

Figure 6: Electron Current Density Across The Channel of The Device

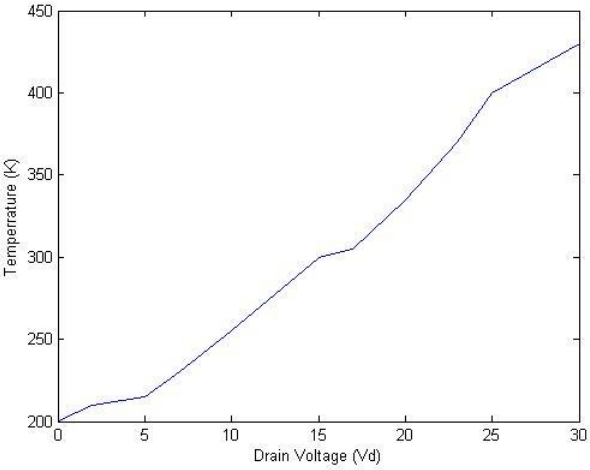

Figure 7: Device temperature (K) rise with drain voltage(Vg)