InGaN Based HEMT with Quaternary Barrier for High Break Down and RF Applications

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ABSTRACT

Indium-Gallium-Nitride based High-Electron-Mobility Transistors (HEMTs) has been a potential candidate for future high power and RF applications. Presently, a precise increase in cut-off frequency (f_T) more prominent than 300 GHz has been realised utilizing both AlN/GaN and InGAN heterostructures. To additionally improve the high-recurrence execution, an InGaN channel has been proposed to supplant the regular AlGaN channel. Development of quaternary AlInGaN barrier structures with high mobilities are considered due to InGaN stability at high substrate temperatures, just as solid interface and combination dispersing. This work thoroughly summarizes the enhancement mode operation of the device with positive threshold thereby improving the breakdown voltage as well as the RF performance metrics suiting the device to be used for both high power and high frequency applications.

Keywords: Compound semiconductors, High-Electron-Mobility Transistors (HEMT), Sentaurus TCAD software, Quarternary barrier, Alumunium Nitride (AlN)

1. INTRODUCTION

A semiconductor can be viewed as a material having a conductivity extending between that of an encasing and a metal. A critical property of semiconductors is a scope of prohibited energies inside the electronic structure of the material. Semiconductors ordinarily have bandgaps running somewhere in the range of 1eV and 4eV, while protectors have bigger bandgaps, frequently more prominent than 5eV. The warm vitality accessible at room temperature, 300 K, is roughly 25meV and is consequently impressively littler than the vitality required to advance an electron over the bandgap. This implies there are few bearers present at room temperature. Using quaternary barrier helps in improving overall performance of device by reducing short channel effects.

Using quaternary AlInGaN barrier layers in GaN-based high-electron-mobility transistors (HEMTs) offers the possibility to realize depletion mode (d-mode) and enhancement-mode (e-mode) operation. By changing the composition and hence the spontaneous and piezoelectric polarization in a pseudo morphically grown AlInGaN layer, one can control the polarization difference between the AlInGaN barrier and the GaN buffer[1-4].

Tensile strained AlInGaN layers with high Al contents and lattice-matched pure AlInN both generate high two-dimensional electron gas (2DEG) densities. Compressively strained AlInN and AlInGaN layers have been used to generate a piezoelectric polarization which compensates a high spontaneous polarization to lower the 2DEG density and realize e- mode operation[5-7]. However, device performance is limited by the inferior crystal quality caused by the high In content. Further, barrier layers under high compressive strain show effects such as relaxation and In pulling, which degrade device characteristics even further and impede process control and reproducibility[8-13].

In this work we report the effect of Quarternary barrier on the channel by tuning the mole fraction of individual elements to make the device operate in enhancement mode thereby supressing the gate leakage and short channel effects. Moreover the device is optimized for superior performance in terms of increased drain current and transconductance, higher break down and increased RF figure of merits suiting it for high power and high frequency applications.

2. Device Architecture and Simulation procedure

Figure 1 shows the device structure of HEMT to improve the analog /RF performance and to reduce short channel effects (subthreshold swing). For achieving Enhancement mode operation, distance between Gate and Channel is reduced with better scaling to obtain a positive threshold.To improve the frequency performance of the device, InGaN is used as a channel layer because it has good carrier transport and electrostatic properties that lead to the overall RF performance of the Device. The electrostatic properties like High Breakdown and maximum threshold Frequency are explored in detail. The structure consists of

Barrier layer : wider band gap than channel layer and where band gap depends up on x mole fraction of material and we are using quaternary barrier layer to improve the overall device performance.

Channel layer : The material with lower band gap are used here and InGaN Channel.

Buffer layer : The purpose of this layer is to reduce stress and lattice mismatch.(GaN).

Substrate layer : This layer acts as a heat sink from the package (SIC).

In this work, we present the device performance of 0.8 μm gate length & The InGaN channel HEMT structure consists of an 0.02μm quaternary Barrier, a 0,002μm AlN spacer, a 2μm InGaN channel and GaN grown on SIC substrate. The Height of the GaN is chosen as 0.1 μm,Height of the Substrate of 0.01 μm , Length of the Source of 0.5 μm & length of drain of 0.5μm. A quaternary Barrier layer was utilized rather than a ternary InAlN boundary since higher channel mobilities have been reliably seen in the quaternary Barrier GaN-channel HEMTs

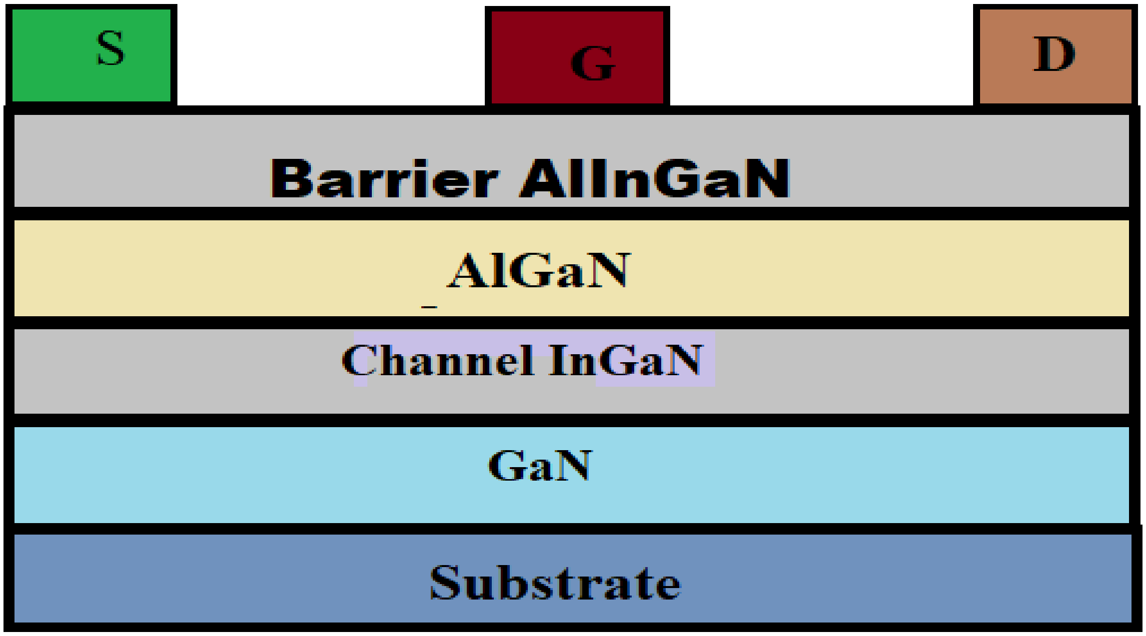


Figure 1: Fig**:** InGaN Based HEMT with Quaternary Barrier

The simulation of device described in above device structure is performed using sentaurus TCAD simulator. Using sentaurus TCAD simulator results in provides full stream 3-D procedure and the physical and structural performance can be clearly known followed by quick prototyping by reducing time and cost. We have used 2D hydrodynamic modelling Approach to analyse the physical behaviour of the device to achieve maximum accuracy as well as computational efficiency.

4. RESULTS AND DISCUSSION

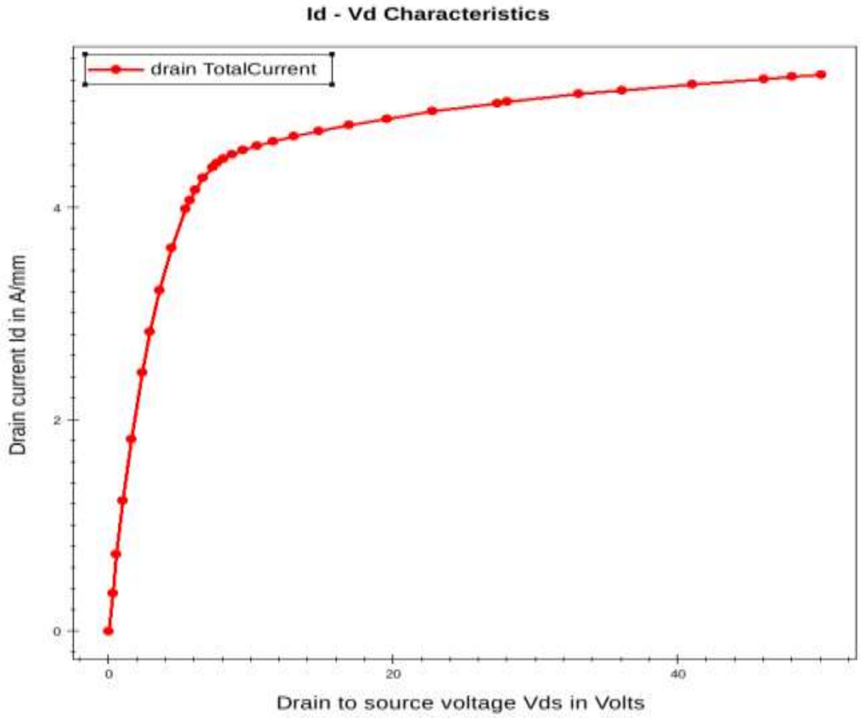


Figure a) Id- Vd characteristics

Figure (a) shows the Id- Vd characteristics of the InGaN HEMT with Quarternary barrier .The device is optimized for maximum current by tuning the molefraction of both the channel and the barrier for superior performance. The presence of Indium content will improve the transport properties leading to high current and transconductance.

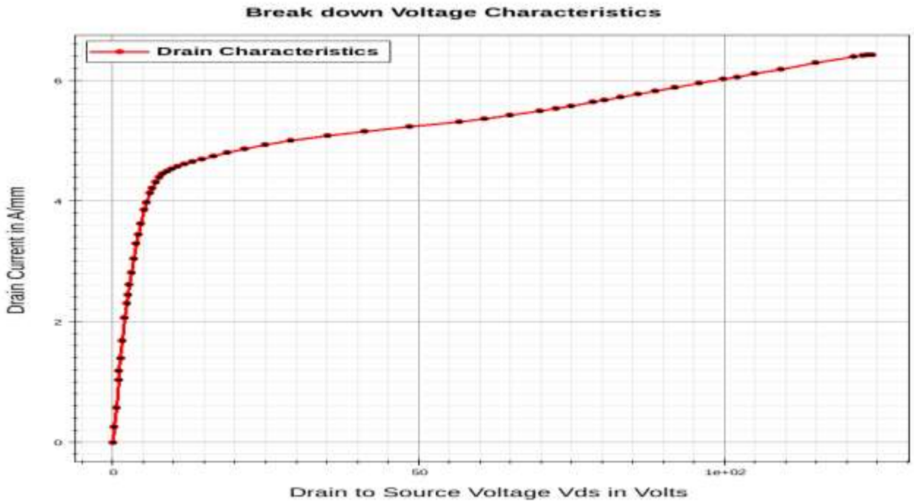


Figure b) Breakdown voltage characteristics

Figure (b) shows the break down voltage characteristics of the device and from the simulation results a break down voltage of 150V is achieved which is less compared to GaN based devices.

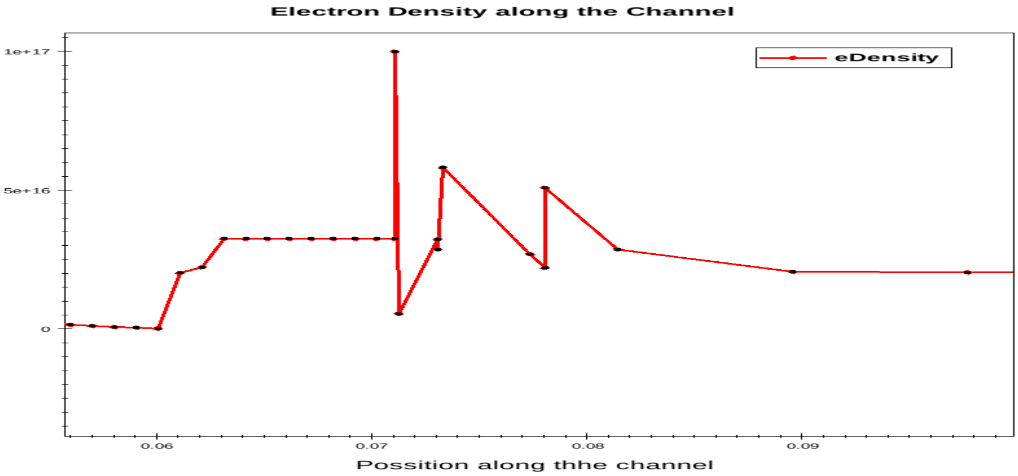


Figure c) Electron density along the channel

Figure (c) describes the variation of Electron Density along the channel. From the figure it is evident that the electron density is maximum in the channel region owing to reduced traps and increased conductivity and reduced leakage current.

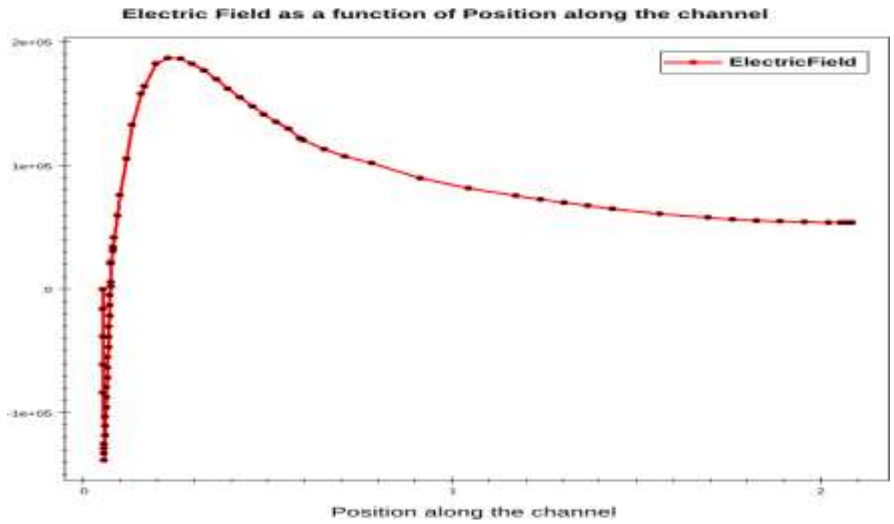


Figure d) Electric field as a function of position along the channel

Figure (d) Electric field as a function of position along the channel and it is clear that the electric field is more or less uniform in the channel owing to increased conductivity with reduced scattering.

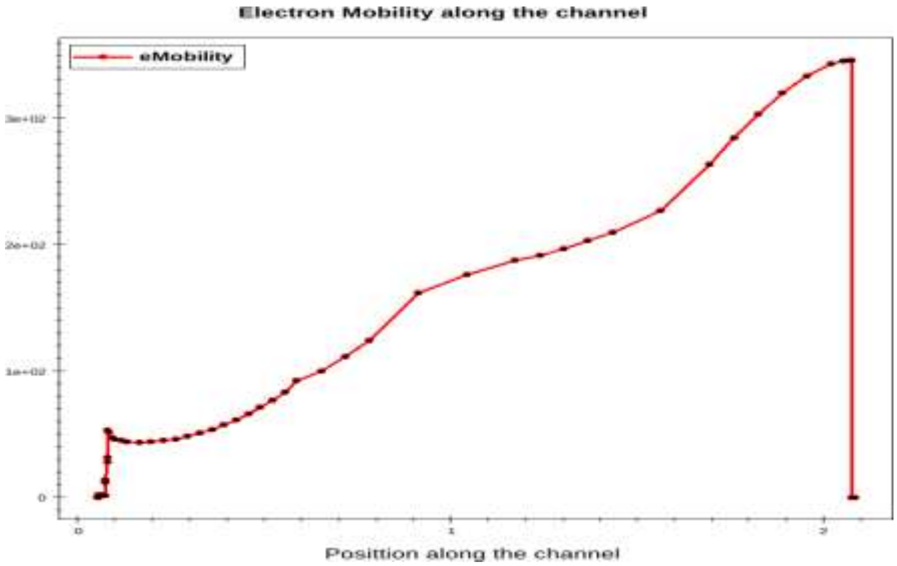
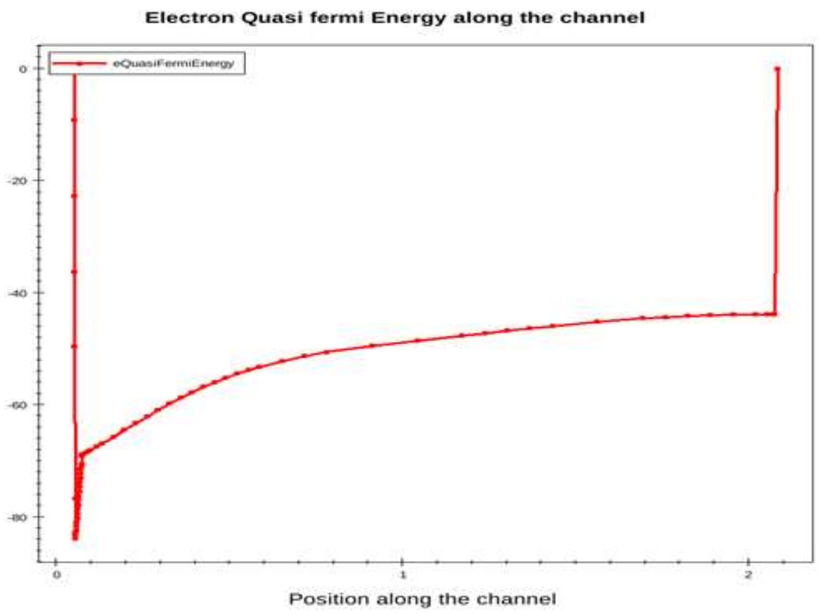


Figure (e) Electron Mobility along the channel

Figure (e) depicts the variation of Electron Mobility along the channel. Her we can clearly visualize that the mobility of the electrons is low at the source end and gradually increases to maximum at the drain end resulting in increased ON current of the device thereby improving the performance of the device.



Figure(f) :Electron Quasi fermi energy along the channel

Figure(f) explains the Electron Quasi fermi energy along the channel. This curve depicts the formation of the 2DEG due to the band gap difference between the channel and the barrier. This 2 DEG is responsible for reduced scattering and improved transport properties of the device.

5. CONCLUSION

In this work, a systematic investigation on the effect of Quarternary barrier on the performance of the InGaN/GaN channel based HEMTs was done. Tuning of InGaN Channel mole fraction leads to the enhancement operation of the device resulting in a positive threshold with reduced gate leakage and supressed short channel effects. The break down voltage of the device is improved by choosing a SiC substrate with high resistivity. Moreover the device performance is explored for increased transition frequency and reduced parasitics at higher frequencies enabling it to suit for RF applications.

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