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Design and Investigation of DC and Microwave Characteristics of InGaP/InGaAs/GaAs Dual Channel Pseudomorphic HEMT (DC-PHEMT)

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***Abstract*— A InGaP/InGaAs/GaAs dual channel pseudomorphic HEMT (DC- PHEMT) with interesting triple doped sheets having gate length 800nm is modeled and simulated by using 2-dimensional simulation package ATLAS from Silvaco. Different DC and microwave performances of the above device are analyzed and investigated to judge the potential of the device for high- performance digital device applications. Due to the schottky behavior of InGaP, good pinch-off and saturation characteristics, high drain saturation current, large and linear transconductance and excellent microwave characteristics are obtained. The studied dual channel HEMT with delta-doped sheet densities and proper layers; prove promise for electronic applications.**

***Keywords*— Dual channel, Pseudomorphic HEMT, δ-doped sheet, schottky behaviour, InGaP.**

I. Introduction

Due to the rapid progress in fabrication technology, many compound semiconductor devices such as light-emitting diodes (LEDs), laser diodes (LDs), switching devices , field effect transistors (FETs), hetero-junction bipolar transistors (HBTs) and high electron mobility transistors (HEMTs) have been extensively adopted [1-3]. Major limitation of silicon MOSFETs is that silicon itself is an inherently low mobility material. Most compound materials have significantly higher mobility than silicon; hence devices made using compound semiconductors can exhibit higher frequencies of operation. Modulation doping provides an important advantage which is, the free carrier concentration within the semiconductor layer can be increased significantly without the introduction of dopant impurities.

In case of doped channel FETs the presence of un-doped wide band-gap layer between the gate metal and channel can improve the turn-on voltage, breakdown voltage and linearity [4]. But the high impurity scattering effect degrades the electron mobility. So the device is restricted for high frequency operation. There-fore, because of high electron mobility, low power consumption , higher unity current gain frequency , high break-down and high power characteristics ; HEMTs have attracted much attention [5,6].

Among compound semiconductor materials ; InGaP , InGaAs and its related materials have superior properties that make them promising candidates for low noise, low power and high speed electronic applications. InGaAs has small band gap , small electron effective mass ,hence high electron mobility (can be 15000 cm^2/Vs) and high electron peak velocity which makes it a great choice for channel layer [7,8]. The high Indium content in InGaAs channel can offer high electron mobility and peak velocity [9,10]. Such InGaP/InGaAs/GaAs HEMT have been identified as one of the most promising device for high speed microwave applications. The applications include advanced communication, radar, passive imaging and remote sensing. Thus , this work focuses on the systematic study of DC and RF performances of InGaP/InGaAs/GaAs dual channel Pseudomorphic HEMT .

II. Device Structure

The Schematic cross section and different layers of studied DCPHEMT is shown in fig 1. Structure of studied device is developed on a 5000Å semi-insulating (S.I) GaAs substrate. It consists of a 450 Å i- $In_{0.49}Ga_{0.51}P$ buffer layer, a 30Å δ – doped sheet 3 with the doping density of $\delta_3(n^+)$, a 50 Å i- $In_{0.49}Ga_{0.51}P$ spacer layer, a 100 Å i- $In_{0.2}Ga_{0.8}As$ channel layer, a 40 Å i-GaAs spacer layer, a 30 Å δ -doped sheet 2 with the doping density of $\delta_2(n^+)$, a 40 Å i-GaAs spacer layer, a 100 Å i- $In_{0.2}Ga_{0.8}As$ channel layer, a 50 Å i-- $In_{0.49}Ga_{0.51}P$ spacer layer, a 30 Å δ -doped sheet 1 with the doping density of $\delta_1(n^+)$, a 160 Å $In_{0.49}Ga_{0.51}P$ Schottky barrier layer and a 300 Å GaAs cap layer.

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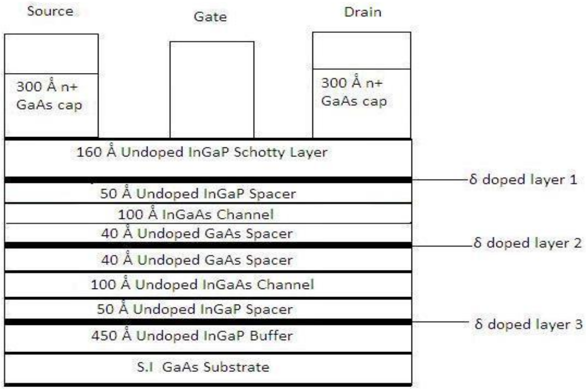


Figure 1. Schematic cross section of the studied dual channel pseudomorphic HEMT

The use of δ-doping layers is to provide high electron densities in the channel and therefore results in high transconductances, current densities and cut-off frequencies. The use of Spacer layer is to reduce impurity scattering and hence enhancing electron mobility. The n^+ - doped Cap layer minimizes the contact resistance of the source and drain contacts that provides protection from oxidation. Schottky-Barrier layer provides a Schottky contact between gate-metal and semiconductor material. As a result, excellent device properties with low leakage current through the leakage path and provide good carrier confinement in the InGaAs channel. In this paper, a two –dimensional simulator ATLAS is used to analyze the structure and to get DC and microwave characteristics. The different material parameters used in the simulation are stated in Table 1. The device is simulated by taking the gate length 800nm.

Table 1.
Physical parameters used for the simulation.

Parameter	Symbol	Value
$In_{0.49}Ga_{0.51}P$ energy gap (ev)	E_g	1.92
$In_{0.2}Ga_{0.8}As$ energy gap (ev)	E_g	0.75
GaAs energy gap(ev)	E_g	1.42
Saturation velocity (cm/s) $In_{0.49}Ga_{0.51}P$	γ	1.0×10^6
Saturation velocity (cm/s) $In_{0.2}Ga_{0.8}As$	γ	7.7×10^6
Saturation velocity (cm/s) GaAs	γ	7.7×10^6
Low field mobility GaAs (cm^2/Vs)	μ	1000
Low field mobility InGaAs (cm^2/Vs)	μ	6000

III. Result and Analysis

In this work three δ- doped sheets as carrier supplier layers are employed. The doping density of δ- doped sheets $\delta_1(n^+)$, $\delta_2(n^+)$, $\delta_3(n^+)$ are $10\times10^{12}\,cm^{-2}$, $5\times10^{12}\,cm^{-2}$ and $2\times10^{12}\,cm^{-2}$ respectively. This causes linear characteristics of the DC-HEMT including transconductance and frequency response . On the other hand, the high doping with high carrier density is advantageous to drive the current. The un-doped wide band gap $In_{0.49}Ga_{0.51}P$ material, used as the buffer and schottky layer reduces the leakage current. As a result good device performance is achieved.

A. *Energy Band Diagram*

The energy band diagram showing valence band and conduction band for DC HEMT structure is shown in fig-2. The band gap energy was found to be 1.4 eV for GaAs, 1.9 eV for InGaP and 1.1 eV for InGaAs which is same as that of the theoretical value.

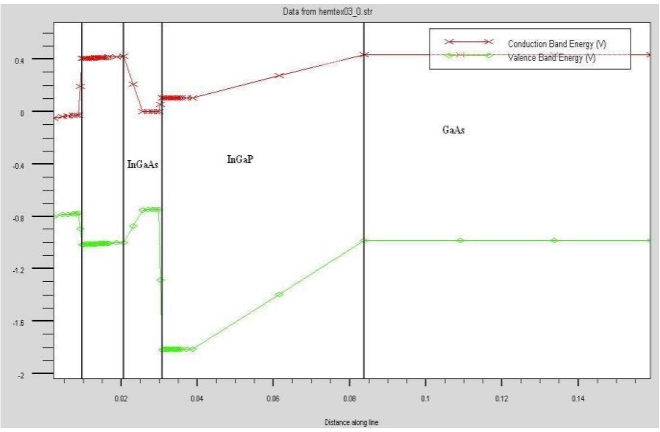


Figure 2. Energy Band Diagram of the DC HEMT

B. *DC Characteristics*

The DC current- voltage characteristics of the studied device are shown in fig. 3 and 4.

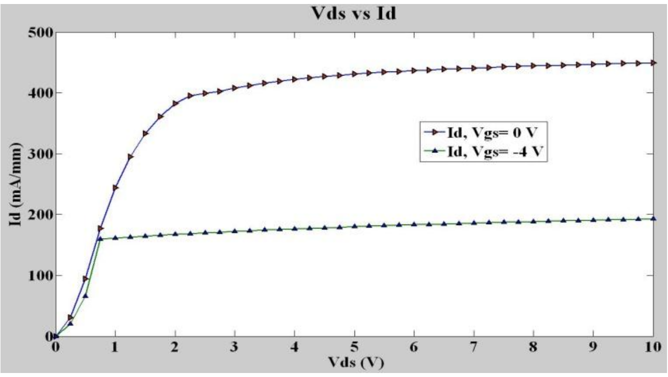
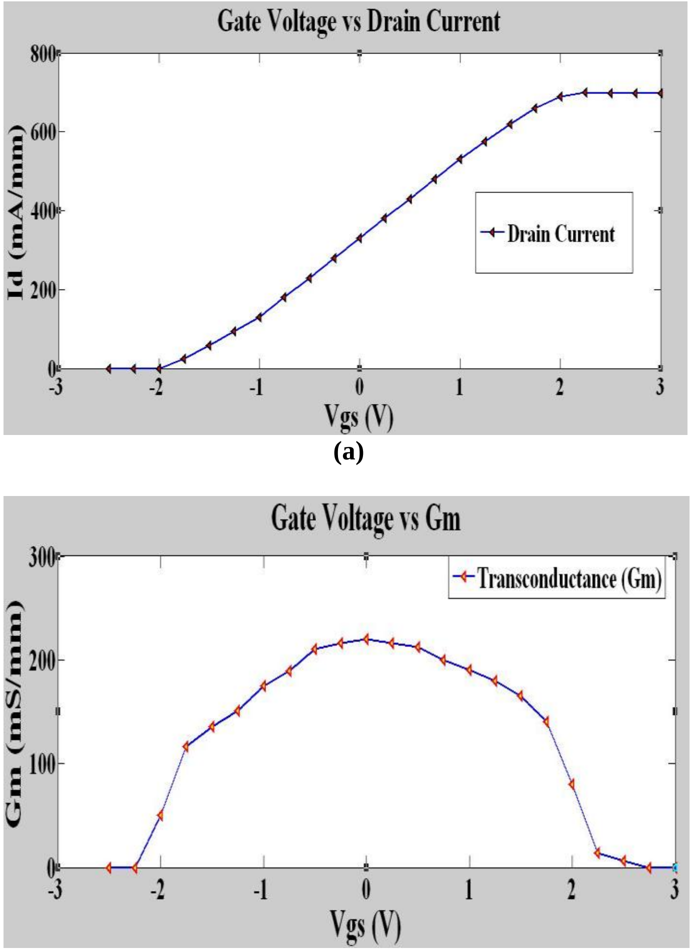


Figure 3. Drain characteristics of DC- PHEMT

Due to the suppression of leakage current , because of the presence of InGaP schottky and buffer layers , the device exhibits good pinch-off and saturation characteristics.. The obtained drain current of the simulated device at V_{GS}=0v is

410mA/mm as shown in fig. 3. Fig.4 shows drain saturation current (I_{DS}) and transconductance (g_m) versus gate- source voltage V_{GS} at drain-source voltage fixed at V_{DS}=3.5v. The maximum value of transconductance and drain saturation current at V_{DS}= 3.5V are 210 ms/mm and 620mA/mm respectively.



(a)

(b)

Figure 4. Drain saturation current and transconductance versus gate-source voltage at V_{DS}=3.5V

c. *RF Performance*

Fig.5. Shows the simulated response between frequency (Hz) and current gain (dB) from which unity gain cut off frequency f_T is calculated. The graph between frequency (Hz) and unilateral power gain (dB) is shown in fig. 6 from which maximum oscillation frequency f_{max} is obtained. The biased voltage is fixed at V_{DS}=3.5 V. The tail region of the two simulated curve is extrapolated to 0dB which gives the value of f_T and f_{max} .

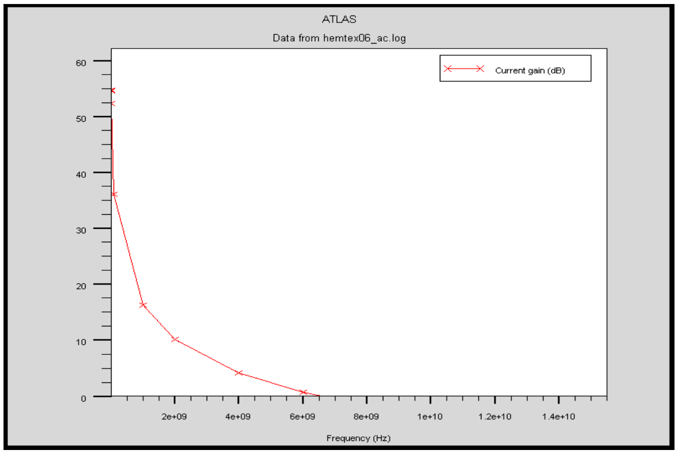


Figure 5. Frequency(Hz) vs current gain(dB)

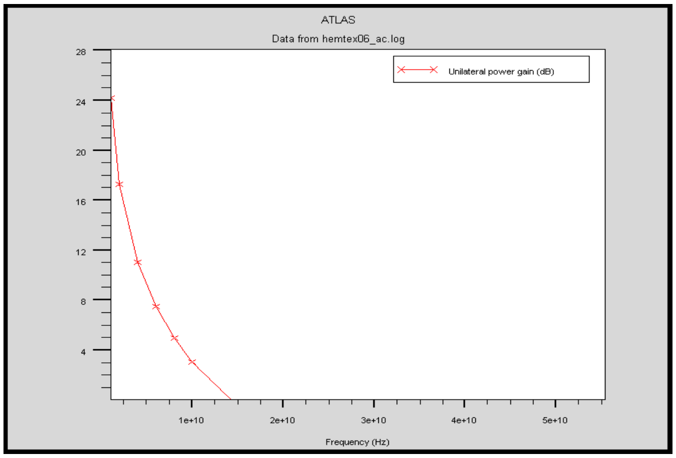


Figure 6. Frequency (Hz) vs Unilateral power gain(dB)

The measured f_T and fmax are 7 GHz and 15 GHz respectively at V_{DS}= 3.5v and V_{GS}=0v.

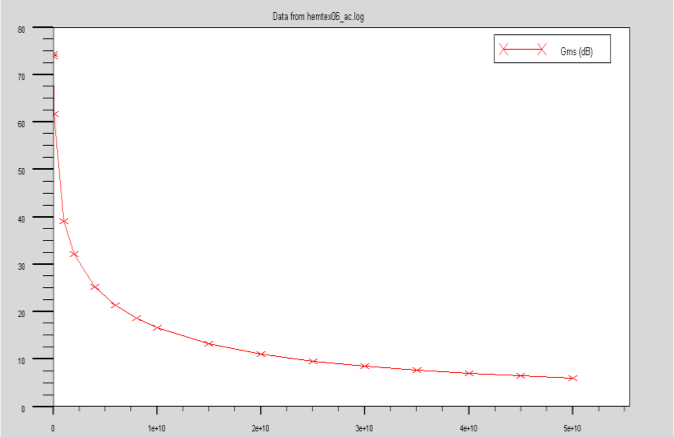


Figure 7. Frequency (GHz) vs Maximum stable gain G_{ms} (dB)

Fig. 7 shows the variation of maximum stable gain (G_{ms}) in dB with frequency. G_{ms} of the device is defined as the highest value of power-gain that is achieved by the device before the instability occurs. A steep decrease in Gms is obtained for low frequencies up to around 10 GHz. After that, the variation of G_{ms} with frequency becomes constant upto 50 GHz. This indicates good stability performance of the device making it suitable for microwave and low-noise amplifier applications.

IV. Conclusion

The DC and microwave characteristics of InGaP/InGaAs/GaAs dual channel pseudomorphic HEMT with interesting δ –doped sheets is successfully demonstrated by taking the gate length 800nm . A 2-dimensional simulation package ATLAS is used to study the device properties. High and linear transconductance, good saturation characteristics are obtained. It is observed that G_{ms} stays above 0 dB for frequencies up to 50GHz. This shows excellent stability performance of the device for low noise and high frequency applications. Thus this simulated device provides the promise for high performance microwave electronic applications

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