Design and Simulation of AlGaAs / InGaAs / GaAs based Pseudomorphic HEMT using SILVACO ATLAS^{TM}

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Abstract- **The High Electron Mobility Transistor (HEMT) is a field effect transistor which is used to give very high performance at microwave and radio frequencies, exhibiting a low noise figure. The HEMT works on the principle of formation of Two Dimensional Electron Gas (2DEG) where there are very less electron collisions. In this work we have designed and observed the characteristics of a Pseudomorphic HEMT (P-HEMT) with an AlGaAs supply layer, InGaAs channel layer and a GaAs substrate which is of p-type. The output characterstics curve (I_D-V_{DS}), transfer characterstics curve, transconductance (g_m) and cutoff frequency (f_T) have been observed. A transconductance of 281.296mS/mm, threshold voltage V_{th}= -1.1V at V_{DS}=6V and a cut-off frequency of 18GHz can be easily seen from the simulation result of the HEMT. The design is simulated using SILVACO ATLAS.**

Keywords: **Pseudomorphic HEMTs , transconductance , unity current gain cutoff frequency.**

I. INTRODUCTION

HEMT finds application in RF design, which includes cellular telecommunications, direct broadcast receivers, radars, satellites and instrumentation [1-3]. Due to the fact that they exhibit low noise figure, with a utmost efficiency for microwave frequencies, they are used in the field of microwave design. HEMT gives high current at negligible gate voltages, which is a result of high mobility of free electrons due to significantly less scattering in the region of 2DEG[4]. HEMTs are also used in millimeter wave applications [5, 6].

The late 70s saw the advancement of the molecular beam epitaxy development procedure and regulation doping together with a clear enthusiasm for the conduct of quantum well structures [7]. T. Mimura and his partners at Fujitsu were dealing with GaAs MESFETs. They confronted issues with a high-density of the surface states close to the interface and in this manner they chose to utilize a modulation doped heterojunction superlattice and could produce depletion type MOSFETs [8]. While those structures were still afflicted with a few issues, the plan to control the electrons in the superlattice jumped out at him. He accomplished this by presenting a Schottky door contact over a solitary heterojunction. Hence, the AlGaAs/GaAs HEMT was conceived [9]. Along these lines the main HEMT based incorporated circuit was reported [10].

With a specific end goal to counter unique issues, a few outlines were proposed: AlGaAs/GaAs HEMTs, AlGaAs/InGaAs pseudomorphic HEMTs (pHEMTs), AlInAs/InGaAs/InP (with the goal of increased cutoff frequency f_t). Just in the 90s the innovation entered the consumer market in satellite recipients and rising cell phone frameworks. In the start of the most recent decade new techniques for testimony of GaN on sapphire by MOCVD were developed. Consequently, the generation of AlGaN/GaN-based HEMTs was possible.

Our goal is to design a high electron mobility transistor which would provide high drain current for very less drain voltage, high transconductance and very high cut off frequency, so that the device can be suitable for application in RF region. Our goal is to analyze the drain current at different gate voltages, transconductance at different drain voltages, cut off frequency at variable gate and drain voltages and finally drawing a comparative study and reaching a suitable conclusion.

II. DEVICE STRUCTURE

An AlGaAs/InGaAs/GaAs based Pseudomorphic HEMT is designed where the AlGaAs/GaAs heterojunction helps in obtaining maximal mobility of electrons. This is because the 2DEG layer limits the scattering of electrons promoting high mobility device.

PHEMTs are efficient because they improve the barrier between the two important layer i.e channel and substrate and for which it is able to prevent the leakage of mobile carriers (electrons) into the GaAs substrate.

A schematic representation of the proposed AlGaAs/ InGaAs/GaAs HEMT device is presented in Fig1. The structure consists of a 517nm thick p-type GaAs substrate on top of which an AlGaAs buffer layer of thickness 170nm is placed. The structure also consists of a 30nm thick layer of

AlGaAs which is used as a supply layer, 1nm of thin AlGaAs region which is delta doped and InGaAs channel layer of thickness 18nm. A 2nm spacer layer of AlGaAs is also used.

The source and drain are made up of GaAs cap layers. They are doped with a concentration of $9 \times 10^{19}/cm^3$. The gate is fabricated using Gold of 0.35µm which has a work function of 4.43eV. The length of source and drain is 0.12µm and they are also made of Gold.

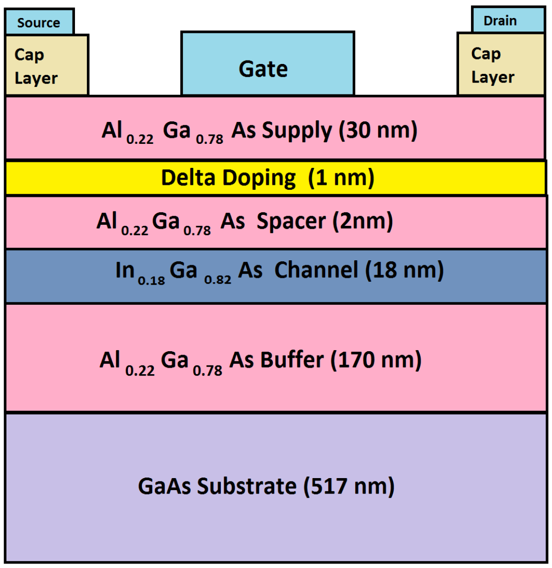

Fig 1: Schematic diagram of AlGaAs/InGaAs/GaAs Pseudomorphic HEMT device

The parameters used for fabrication of device are given in table 1:

TABLBE I. The PARAMETERS USED FOR FABRICATION OF DEVICE

PARAMETERS USED FOR FABRICATION OF DEVICE	VALUES
Length of the Gate (L_G)	0.35µm
Length of Source and Drain	0.12µm
Length of separation between Source and Gate (L_{SG})	0.06µm
Gate to Drain length (L_{DG})	0.08µm
Gate work function	4.43eV
Doping concentration of supply layer	$14 \times 10^{17}/cm^3$
GaAs substrate doping (p-type)	$15 \times 10^{13}/cm^3$
Delta doping concentration	$16 \times 10^{19}/cm^3$
Cap layer doping	$9 \times 10^{19}/cm^3$
Mole fraction of Al in AlGaAs	22%
Mole fraction of In in InGaAs	18%

A GaAs substrate layer is chosen as it offers superior electron mobility which enables high frequency operation. It is also used for the purpose of low noise and high power applications in microwave and millimeter wave frequency range.

An InGaAs channel layer is placed between the supply layer and buffer layer. Indium is used in the channel because it improves the high frequency performance of the device. Also, the channel layer binds the Two Dimensional Electron Gas (2DEG) which improves the output conductance. The AlGaAs spacer layer thickness is important for 2DEG mobility and density.

A region of high delta doping of concentration $16 \times 10^{19}/cm^3$ is used instead of uniform doping to increase transconductance which in turn increases the charge transfer.

In this device, the percentage composition of Aluminum, x is chosen as 22% or 0.22, that is $x < 0.24$. This value of composition is taken because higher mole fractions may lead to traps which are sufficient to reduce the performance of the device. The traps would reduce the current flowing through the drain and also it is sufficient for increase in noise in low frequency range, therby reducing the efficiency of the device.

AlGaAs is used in the supply layer because of its large bandgap energy, as a result of which a layer of 2DEG is formed where the low band gap material GaAs is sandwiched between two wide band gap materials.

III. RESULT AND DISCUSSION

Drain current and transconductance are important parameters for characterization of device. Here the current flowing through the drain is found for three different gate voltages i.e -1 V, 0V and 0.4V. The output characteristics resulted in an utmost current of 397.927mA/mm at a gate to source biasing of $V_{GS} = 0.4$ V and optimum channel width of 18nm. The output characteristics curve for different gate voltages are plotted where the drain voltage varies between 0-20V. Doping concentration for different layer of the AlGaAs/InGaAs/GaAs HEMT is shown in fig 2. Family of I_D-V_{DS} curve for the AlGaAs/InGaAs/GaAs HEMT for varying values of V_{GS} is shown in fig 3.

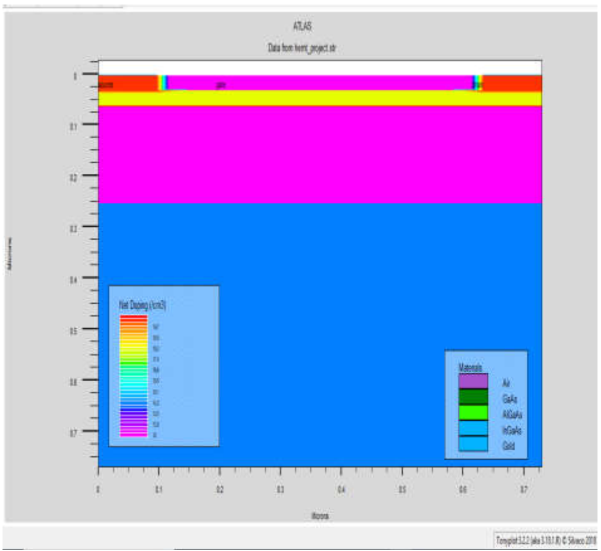

Fig 2: Doping concentration of different layers of AlGaAs/InGaAs/GaAs HEMT

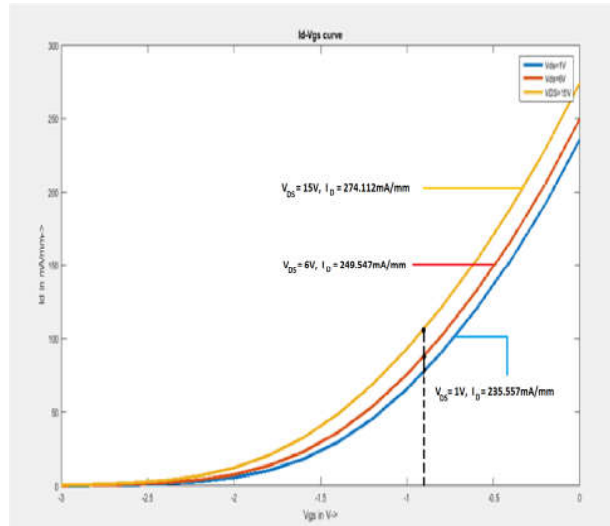

Fig 4: Transfer characterstics (I_D-V_{GS}) of AlGaAs/InGaAs/GaAs HEMT which is shown for drain voltage of 1V, 6V and 15V

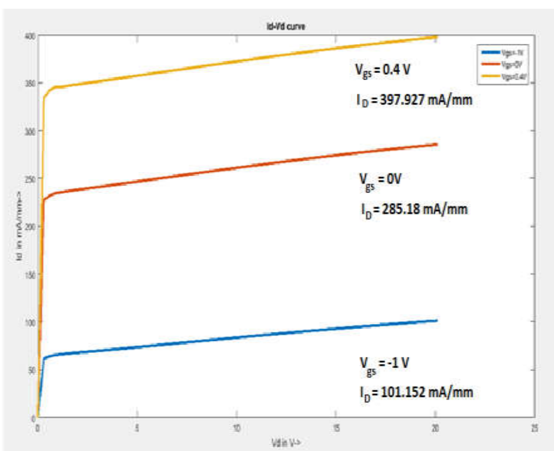

Fig 3: Group of I_D-V_{DS} curve for AlGaAs/InGaAs/GaAs HEMT, plotted by taking different values of gate voltage

Transfer characterstics (I_D-V_{GS}) of the AlGaAs/InGaAs/GaAs HEMT is plotted for drain voltage of 1V, 6V and 15V is shown in fig 4. It is observed that for V_{ds} 15V, utmost current of 274.112mA/mm is obtained.

Transconductance of the device is the ratio of change in drain current with respect to change in gate to source voltage. For this device, the maximum value of transconductance is 281.296mS/mm. The ransconductance variation is shown in fig 5. Transconductance variation is plotted for gate to source voltage range of -3V to 0V.

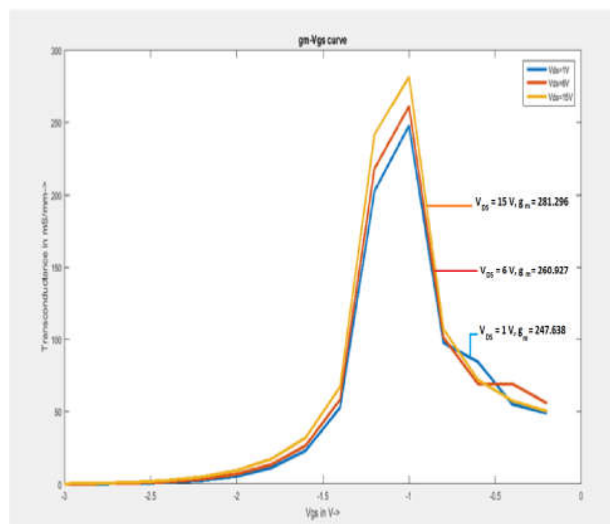

Fig 5: Transconductance variation of AlGaAs/InGaAs/GaAs HEMT, for gate to source voltage range of -3V to 0 V.

The microwave characteristics of the device mostly depend upon two important parameter i.e cut-off frequency and the maximum oscillation frequency. Cut-off frequency is the frequency on the current gain/frequency plot where the current gain of the device is one and maximum oscillation frequency is the frequency on the plot where the unilateral power gain of the device is unity. The cut-off frequency of the device is 18GHz. The current gain variation with frequency is shown in fig. 3.

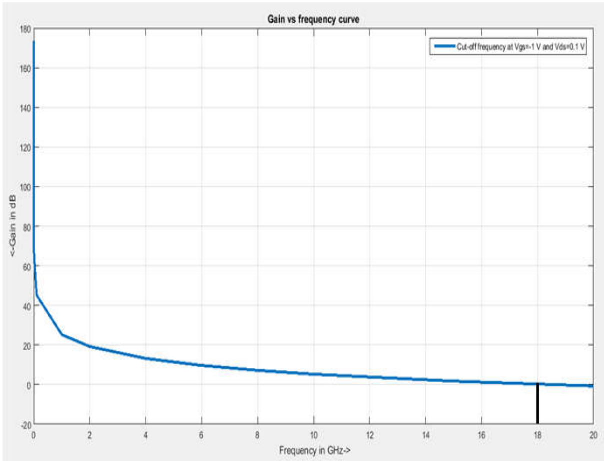

Fig 6: Current Gain / frequency curve for proposed AlGaAs/InGaAs/GaAs HEMT showing cut-off frequency of 18 GHz.

IV. CONCLUSION

In this work, The characteristic of AlGaAs/InGaAs/GaAs HEMT is observed and analyzed to evaluate its performance for DC and Microwave range. This structure shows better output current characteristics and an excessive transconductance of 281.296mS/mm. This is achieved by enhancing the channel layer width and reducing the gate to channel separation. Also by increasing the doping concentration of the supply layer and of delta doping and reducing the doping concentration of p-type substrate, the drain current can be increased. The cut-off frequency is 18 GHz which is achieved at V_{gs}= -1V and V_{ds}= 0.1V.

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