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Study of GAN FET Using SILVACO

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Abstract: Wide bandgap Semiconductor plays a very vital role in the of power conditioning and microwave application. Wide bandgap semiconductor is found to be replacing silicon-based devices in the coming era because wide bandgap semiconductor has properties which are superior than silicon-based devices such as it can at operate high temperature,high voltage operation also it has bandgap of 3.4ev which is wide enough than 1.1ev bandgap of silicon.this paper basically describes virtual fabrication of GaN/AlGaN HEMT using SILVACO.It also describes the I_D-$V_{DS}$and I_D-V_{GS}characteristics.HEMT is an important device for high speed,high frequency and digital circuits and microwave circuits for with low noise application.These application include telecommunication,computing and Instrumentation

Keywords: GaN, High Electron Mobility Transistor, MISFET,MODFET(Modulation Doped FET),2DEG(Two Dimensional Electron Gas)

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I. INTRODUCTION

High electron mobility transistor is one of the fastest operatingdevices.GaN-based high electron mobility transistor(HEMTs) have become one of the replacing candidate in the field of technology industry because it can operate at a temperature high electron mobility,high temperature ,high voltage,high power operation[1].Silicon has been the backbone of technology industry but now it is reaching some limit in the point of application.All semiconductors have a bandgap which describes how well a device can conduct electricity.GaN has a wider bandgap which enable it to Sustain higher voltages as compared to silicon and current can run through the device faster [2].HEMT basically operate on principle that free carriers(electrons and holes) can move at a faster in an undoped semiconductor than doped semiconductor of the same material.As a result, scattering of free carrier with ionized impurities is much less in former case.However,in it is impossible to introduce holes and electron without introducing sharing same volume with ionized impurities in a bulk semiconductor.The main idea for providing separation between the parent donor/acceptor impurities might be possible using built in field at the heterojunction interfaces was released by Esaki &Tsu in 1969,tha actual effect was introduced by the bell laboratories group(Dingle et al 1978) using a GaAs/AlGaAs Superlattice in which only the AlGaAs layer was selectively doped and GaAs is completely undoped which leaves behind unionized donors in AlGaAs which results in the increase of electron mobility of this structure,as compared to the electron mobility in a GaAs sample especially at a low temperature (T<100k). Dingle et al. has mentioned this technique as modulation doping, and it was investigated that this effect can be utilized to make fast transistor using a single modulation-doped heterojunction structure, rather than a modulation-doped superlattice [3].

II. HEMT (HIGH ELECTRON MOBILITY TRANSISTOR)

The name HEMT can be defined as high electron mobility transistor. It is also another type of field effect transistor. Essentially device is a field a type of effect transistor that usually uses a junction between two different materials having different bandgap (i.e. a heterojunction) as the channel instead of doped region which is used in standard MOSFET. As a result of its structure, The HEMT may also be referred to as a heterojunction FET, HFET or modulation doped FET, or it also referred to as MODFET.

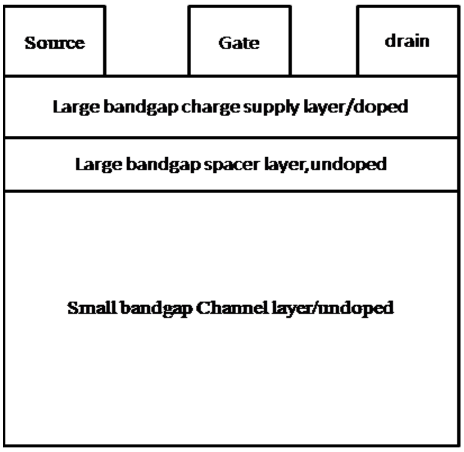

Fig. 1 layer structure of HEMT

2.1 Fundamentals of HEMT

As we have already explained earlier, HEMT stands for high electron mobility transistor. There are some structure which are similar to this namely,(Heterostructure field effect transistor).MODFET(Modulation doped field effect transistor),MISHEMT(Metal insulator Semiconductor Heterostructure field effect transistor).the main fundamental characteristic of HEMT is the conduction band offset between the materials that construct the barrier layer and channel layer.Barrier layer in structure has a higher conduction band than channel layer.due to discontinuity in the large conduction band,Therefore electron diffusing from large bandgap AlGaN into smaller bandgap GaN forms a Two dimensional electron gas(2DEG) in the triangular quantum well which is the hallmark of hemt[4].

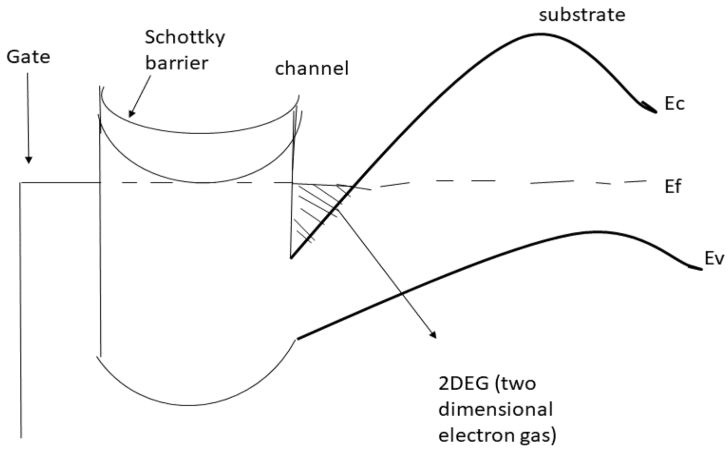

Fig. 2 Generalized energy band diagram of HEMTs

2.2 Current-Voltage Characteristics of HEMT

The current voltage characteristics of HEMT is very much related to the density variation for the 2DEG(two dimensional electron gas) under the influence of the application of the gate source voltages to the component.Infact any application of gate source voltages will have the effect to modify the electronic population of the channel which changes the electron density n_s. Many authors have developed several model in order to determine I_{DS}-V_{DS}characteristics electrical behavior of HEMT[5].First, we have specified conventional expression for drain source current I_{DS} according to drain source voltage V_{DS} in to determine the ideal characteristics $I_{DS}(V_{DS})$ for different values of V_{GS}. The drain-source current is proportional to the density of electron inside the channel which can be expressed as shown below in equation 3[5]:

$I_{DS}(x)=w\mu_n q n_s E(x)$

Where w is the channel width and $\mu_n$is the mobility of carriers. Since the current is constant throughout the channel, therefore we will be integrating above equation 3 from source to drain

$I_{DS}=W\mu_n c_O/L\ [(v_G-v_{th})v_{DS}-\frac{v^2_{DS}}{2}]$

III. RESULTS & DISCUSSION

In this model we have used a GaN substrate for HEMT structure AlGaN/GaN.The figure 3 shows the schematic structure of HEMT structure. the structure is basically described by specifying its dimension such x plane dimension and y plane dimension.After that specifying the region for the structure means which structure is specified to which region such as s Si_3N_4 is used as an insulator, AlGaN is used on top of the substrate. Electrode is specified to this specified region. After contact statement is specified for each electrode. Contact statement is used to specify metal workfunction for each electrode.

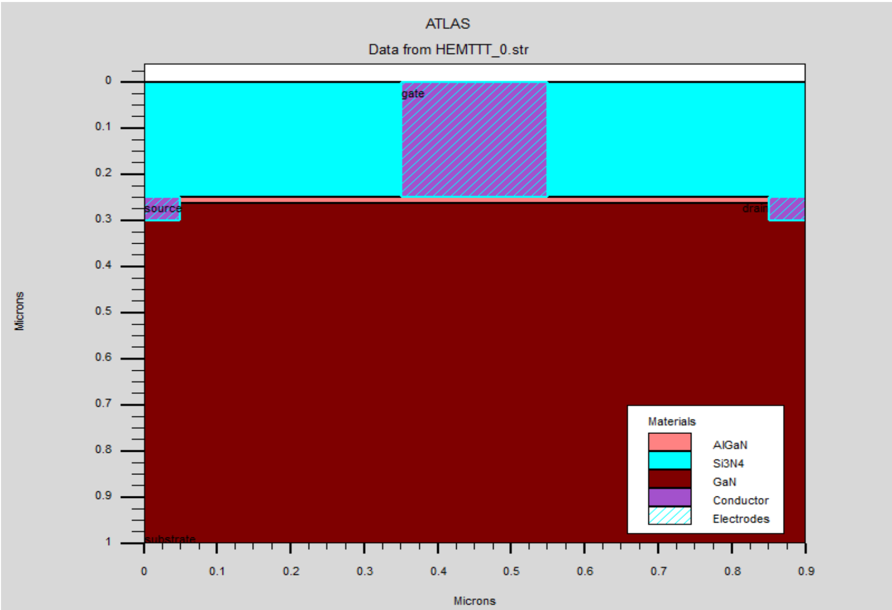

Fig. 3 Schematic structure of AlGaN/GaN HEMT structure

3.1 I_{DS}-V_{GS} Characteristic Curve

Drain characteristics of I_D-V_{GS}curve is shown in figure 4.this is obtained by solving the drain voltages at 1.0v. Initial solution is obtained by ramping the gate voltages at -10V.then, I_D-V_{GS} is extractedfrom V_G=-10V to 1.0V.the result shows that curve exactly behave like MOSFET transistor.It is the transfer characteristics of AlGaN/GaN HEMT.The transfer characteristics basically relates drain current (I_D) response to the input gate-source driving voltage (V_{GS}).the transfer charactersitics can locate the gate voltage at which the transistor passes current and leaves the off state.this is basically device threshold volatge (V_T).it is in seen from the graph that as V_{GS} in hemt transistor,the threshold voltage is reached where drain current elevates.For V_{GS} between -10V to -3V, I_D is nearly zero,once V_{GS} reaches -3V, device excited or reach in saturation region.here,V_{th}=-3V which means at this voltage it start conducting.this is not non linear relation nd is only valid for V_{GS}>$_{VT}$

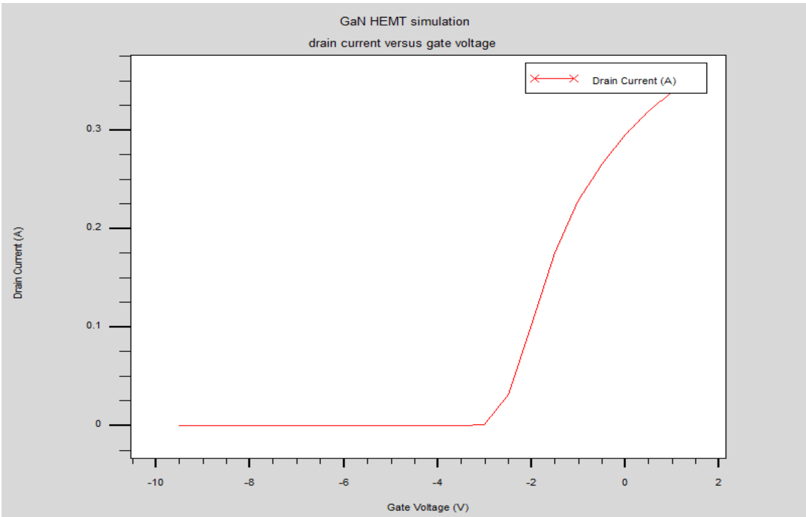

Fig. 4 I_D-V_{GS} Characteristics for HEMT structure

3.3 I_D-V_{DS} Characteristic for different values of V_{GS} with and without lattice heating

This is drain characteristics for drain current versus drain voltage at different values of gate source voltages without lattice heating.it can be seen from the graph by changing the values of gate source voltage we get desirable change in the drain voltage. Hence it behaves like a voltage control current source device.this device can be used for various purposes like switch,constant current source and basic building block in various VLSI circuits.

These characteristics are explained with two phenomena with lattice heating, graph is showing on changing values of gate source voltage drain current is changing.lattice heating basically tells about the presence of heat on SOI substrate which will affect the operation of the device therefore by applying lattice heating equation. Fig. 5 basically describes about the operation of GaN HEMT.it shows how drain current is changing on different values of $V_{GS.}$ Values of VGS are -2V, -1.5V, -1V.-0.5V,0V which is to be applied for seeing the result of change in current.

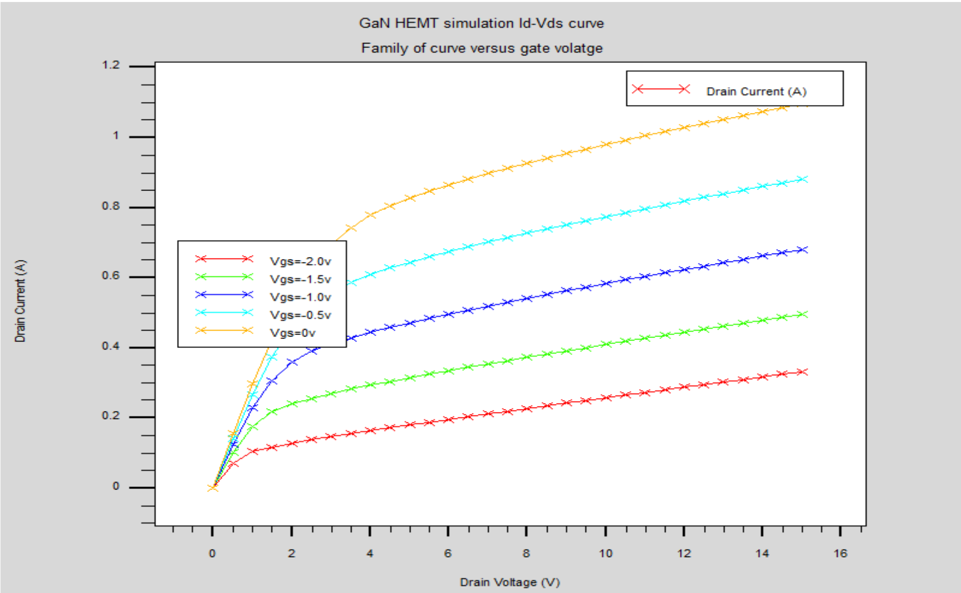

Fig.5 I_D-V_{DS} characteristics for different values of V_{GS} without lattice heating for AlGaN/GaN HEMT structure

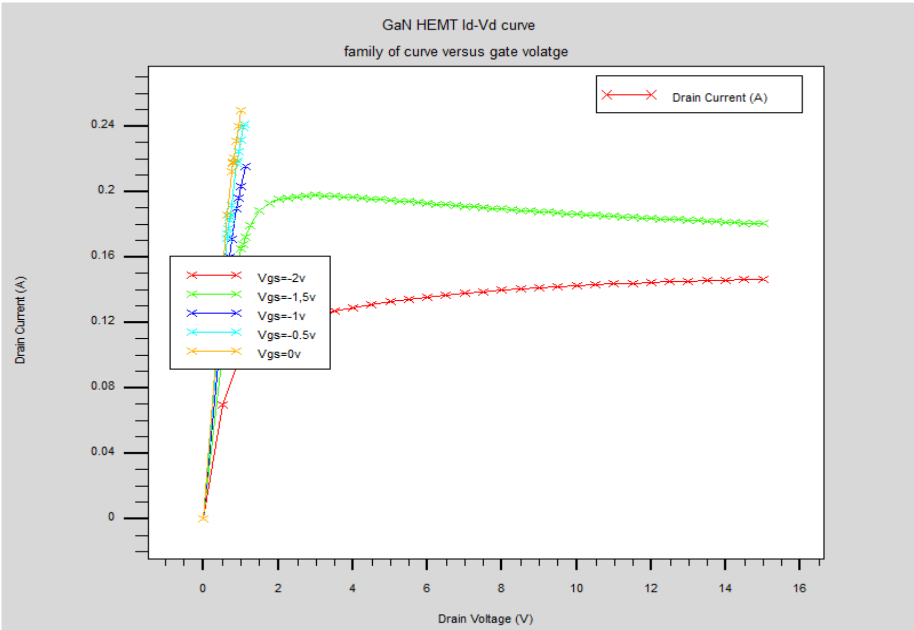

Fig.6 I_D-V_{DS} characteristics for different values of V_{GS} with lattice heating for AlGaN/GaN HEMT structure

IV. CONCLUSION

We have found the result of AlGaN/GaN HEMT Structure by using Silvaco coding. We also have taken out theI_D-V_{DS} characteristics with and without lattice heating and also, we have taken out the I_D-V_{GS} characteristics by ramping the gate voltage at V_G=-10V to V_G=1V.By observing at the result it's found that GaN HEMT behave like a MOSFET. It can be used as high frequency and high-power operations.

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