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# AlGaN/GaN based HEMT Device for High Power Applications

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***Abstract-*** **AlGaN/GaN High Electron Mobility Transistors (HEMTs) have wide bandgap and therefore, it offers to be used at higher output power than other III-V semiconductor devices. As compared to conventional semiconductor materials, these wide bandgap materials have several modeling constraints and fabrication challenges. This paper models the complex fabrication process flow of HEMT device in simpler way that will be used at high power applications. In addition, Choice of materials for each layer with layered structure is also presented. A comparative study in between conventional Si based transistor and HEMT is also included here.**

**Index Terms- AlGaN/GaN, HEMTs, hetero-structure,Wide band gap material, Silvaco.**

## I. INTRODUCTION

A HEMT (high electron mobility transistor) is well known as heterostructure FET (HFET) or modulation doped FET(MOSFET), is a field-effect transistor which consist of a junction between two materials with different band gap (i.e. a heterojunction) as the channel instead of a doped region (similar to MOSFET). Since HEMT has a low noise figure, therefore, it will operate at very high microwave frequencies applications [1]. BJTs are current controlled rather than voltage, this leads to higher power consumption. Also, the switching frequency of BJT is low which limits the speed of the BJTs devices. In addition, BJTs suffer from thermal runaway and leakage problems which make BJTs thermally unstable and produce high noise [2].To overcome these limitations of BJTs, HEMT were introduced in 1980. Table 1, shows the comparison of performance parameters in between HEMT and BJTs.

Table 1: Comparison in BJT and HEMT [3]

| S.No | Parameters | BJT | HEMT |
|---|---|---|---|
| 1. | Input resistance | Low | High |
| 2. | Output resistance | Low | High |
| 3. | Noise | High | Very low |
| 4. | Speed | Good | Excellent |
| 5. | Power Consumption | High | High |
| 6. | Gain | High | High |
| 7. | Thermal Stability | Low | Excellent |

As from the above table, it is clear that HEMTs provide high thermal stability and low noise which makes HEMTs to operate on high frequencies and more reliable than BJTs.AlGaN/GaN high electron mobility transistors (AlGaN/GaN HEMTs) can be used for high frequency, high-power and high-temperature applications because of their wide band-gap, high breakdown field and high electron saturation velocity for which BJT devices have failed [4]. A general cross section view of HEMT, with Source, Gate and Drain terminal on Sapphire substrate, is shown in fig 1:

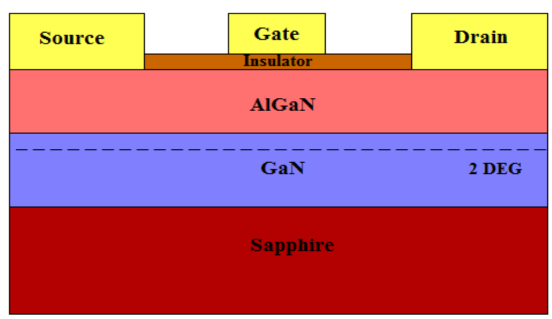


Fig 1: Cross section view of HEMT

On the basis of materials applied, several HEMT device structures are there for variety of applications such as AlGaAs/GaAsHEMTs, AlGaAs/InGaAs pseudomorphic HEMTs (pHEMTs), AlInAs/InGaAs/InPHEMTs. Table 2, shows various electrical properties of HEMT devices.

Table 2: Electrical Properties of HEMT material [5]

| Properties | GaAs | GaN | InP | AlGaN |
|---|---|---|---|---|
| Thermal conductivity | 0.56W/(cm-K) | 1.3W/(cm-K) | 0.68W/(cm-K) | 3.1 W/(m-K) |
| Stability | High | Very high | High | High |
| Band gap | 1.441eV | 3.4eV | 1.344eV | 6.2eV |
| Mobility | High | High | Excellent | High |
| Operating frequency | 250 GHz | 200 THz | 600GHz | 500GHz |

The table above stated that, on the basis of used material in devices, it can be used in various high frequency applications. Therefore, in design of HEMTs, choice of materials with related fabrication challenges are taken into consideration.

## II FABRICATION CHALLENGES IN HEMT DEVICES

1. GaAs HEMT: The most commonly degrading mechanism in GaAs based HEMT device include hot carrier injection mechanism, high mechanical stress, avalanche breakdown in semiconductors.
2. GaN HEMT: The main challenge of fabricating a GaN HEMT device is the trap generation. These traps can be generated in so many ways, it includes hot electron injection, and inverse piezoelectric effect Also, AlGaN is lattice mismatched to GaN, resulting in significant tensile strain, even in the absence of an electric field; after the electric field is applied it leads to the formation of crystallographic defect. In addition to defects, Contact degradation above 400°Ctemperature leads to damage of the device at high temperatures. [6]
3. InP HEMT: InP based HEMT device suffers from the high mechanical stress, high cost and brittle nature. These HEMT devices also have degradation mechanisms such as hot carrier injection, contact degradation at high temperatures and avalanche breakdown. To improve the device stability a burn-in step is required [7].
4. AlGaNHEMT: The formation of defect in AlGaN HEMT is the main fabrication challenge. Both AlGaN and GaN are intrinsically piezoelectric, which leads to increase in stress at high electric fields. The defects could be electrically active and may lead to device degradation [8].

The reliability of AlGaN/GaN HEMT can be improved by using a highly stable gate material such as Pt for high electric field applications. Also, careful design of device geometry is required to avoid large current densities through contact. Therefore, it is clear that from the fabrication challenges, choice of material for HEMT depends on its applications used.

## III. MODELING THE FABRICATION PROCESS FLOW OF HEMT ON SILVACO

A layered architecture of AlGaN/GaN HEMT is shown in fig 2. It is composed of mainly three layers on insulating substrate i.e. Sapphire.

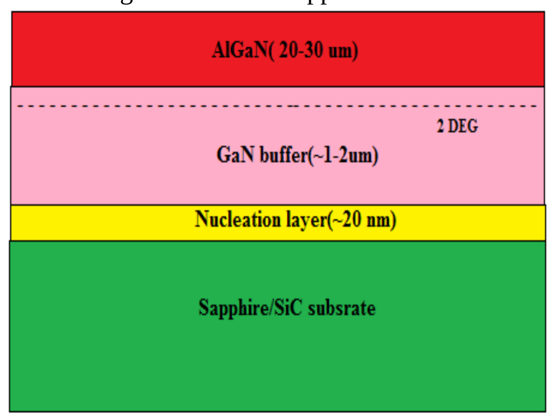


Fig 2: Layered structure of AlGaN/GaN HEMT

I Layer AlGaN: Device fabrication commences with the formation of active area on the AlGaN. A higher Al content in AlGaN/GaN heterostructure is more suitable for higher temperature applications and higher device mobility.
II Layer GaN: This layer provides high electron mobility and saturation velocity, high sheet carrier concentration at heterojunction interface, high breakdown field and low thermal impedance which is grown over the substrate.
III Layer AIN:This layer acts as a nucleation layer. The growth of the AIN nucleation layer is crucial, since GaN cannot directly nucleate on Si substrate; it is used to reduce the lattice mismatch. It ensures high quality of GaN on large Si substrate.
The basic fabrication steps to be followed are-

1. Define a sapphire substrate.
2. Deposition of AlN layer as a nucleation Layer.

3. Deposition of GaN buffer layer on the nucleation layer.
4. Depositionof AlGaN layer on the top of the GaN layer.
5. Deposition of heavily doped n+ layer.
6. Partially etch n+ layer.
7. Deposition of SiO2.
8. Etching of the unwanted SiO2.
9. Deposition of polysilicon as a gate material.
10. Partially etch the poly-silicon material.
11. Deposition of aluminum material for metallization process.

Therefore, choice of material with layered structured and material dependent fabrication challenges makes process flow of HEMT devices complex.

## IV.EXPERIMENTATION

Step 1: Click on the Dev Edit icon in Silvaco tool, Dev edit window then appears as

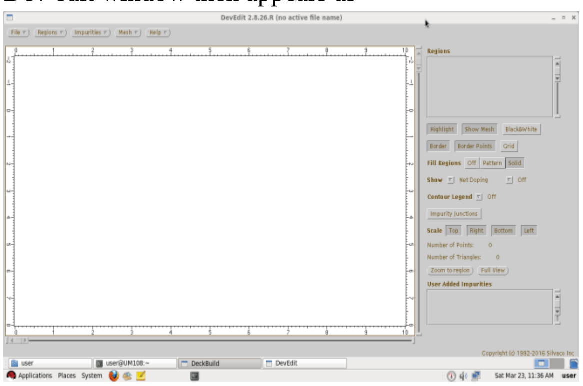

Fig 3: Dev edit window

Step 2: From the region menu, select the given parameters

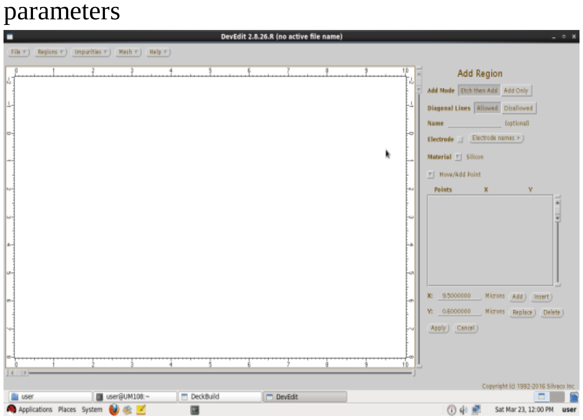

Fig 4: Add region box

Step 3: Select add region from the region menu, from the add menu select sapphire as the substrate material, click apply

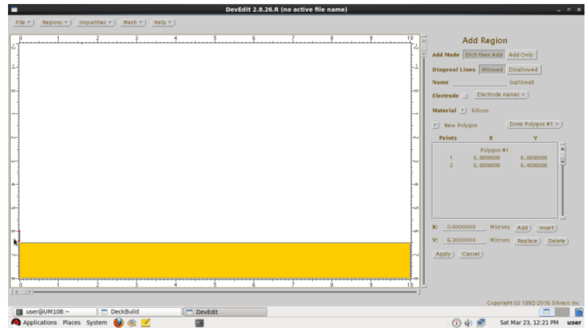

Fig 5: Defining a sapphire substrate

Step 4: For the nucleation layer as, select the material and click apply

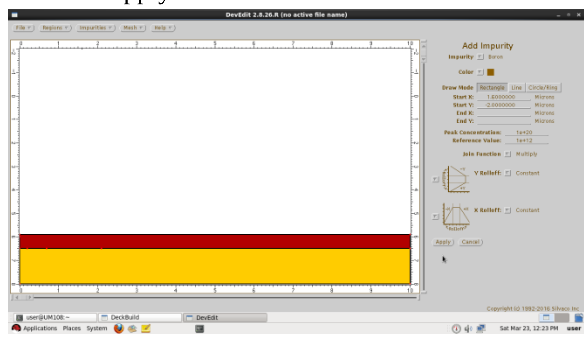

Fig 6: Deposition of nucleation layer

Step 5: Deposition of GaN layer is again done in the same way by selecting materials as GaN, click apply

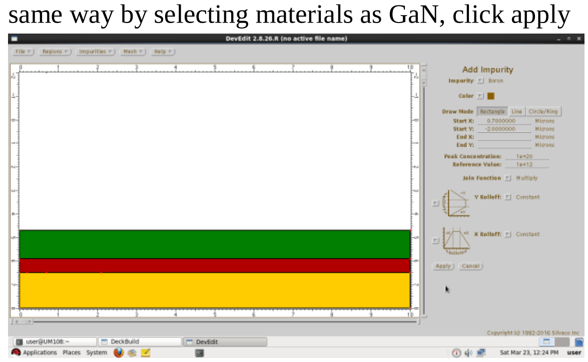

Fig 7: Deposition of GaN layer

Step 6: For deposition of AlGaN layer, select material from the region and click apply

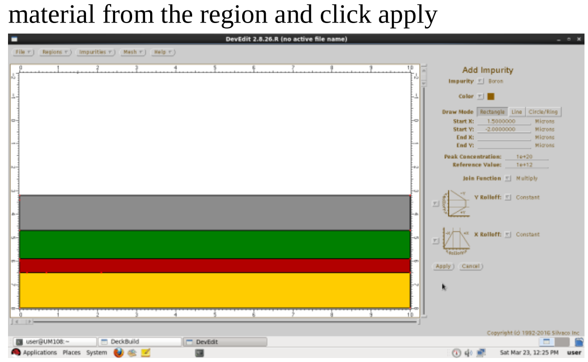

Fig 8: Deposition of AlGaN layer

Step 7: Deposit the n+ phosphorus layer over the AlGaN layer by selecting the proper impurity concentration

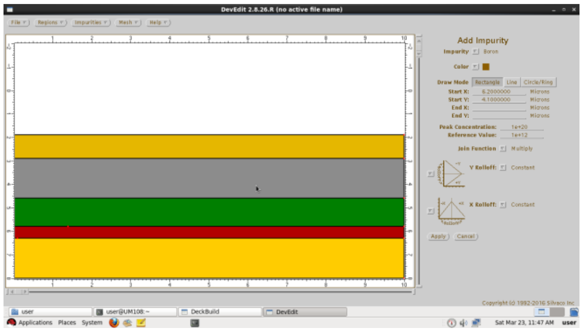

Fig 9: Deposition of n+ layer

Step 8: Perform the etching of the unwanted n+ layer

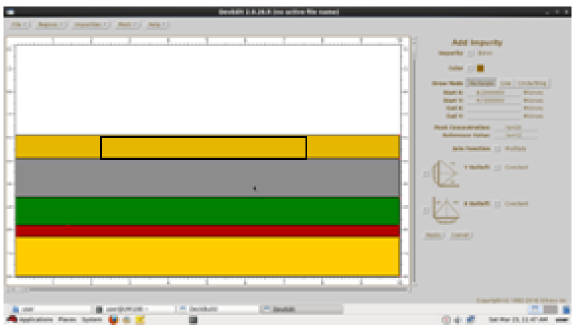

Fig 10: Etching the SiO2

Step 9: Finally the etched layer is shown below

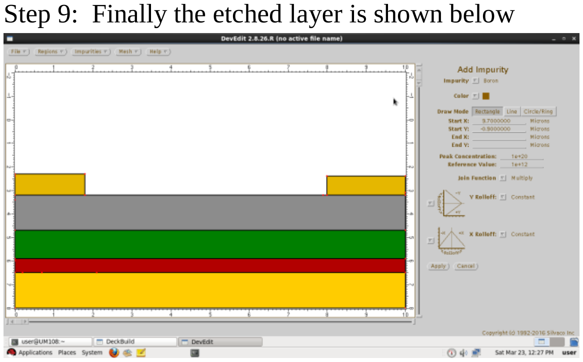

Fig 11: Etched layer

Step 10: Deposit the insulating layer by selectingthe SiO2 layer from the material section and click apply

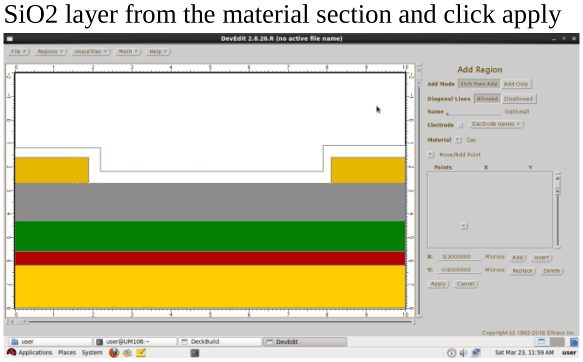

Fig 12: Deposition of SiO2 layer

Step 11: Etch the unwanted SiO2 dielectric layer as done before

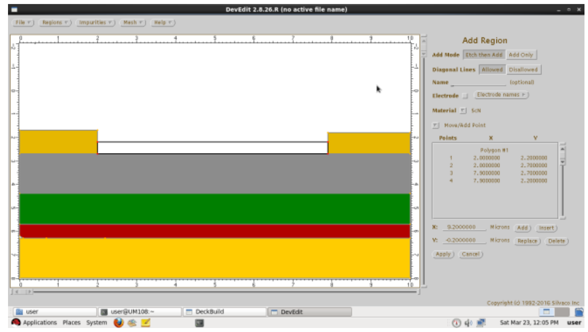

Fig 13: Etching of the SiO2

Step 12: Deposit polysilicon as the gate material by selecting material as polysilicon and click apply

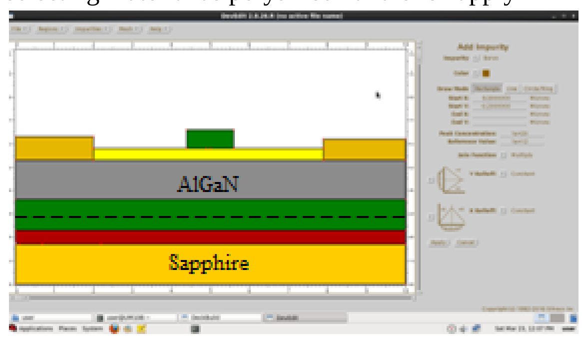


Fig 14: Deposition of polysilicon

Final structure of AlGaN based HEMT.

## V. RESULTS &DISCUSSIONS

The AlGaN/GaN HEMT has improved power density as compared to conventional HEMTs .In spite of many fabrication challenges, these devices offer high frequency, high power and high temperature applications. The Dev edit tool has been utilized to describe the fabrication steps, the dimensions of these layers are in micron range as in the layered architecture.

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