Effect of δ doping concentration and location on $Al_{0.2}Ga_{0.8}As/In_{0.85}Ga_{0.15}As$ HEMT performance

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***Abstract*— A thin highly doped layer, known as δ doped layer instead of a uniformly doped barrier layer as the source of carriers for the 2DEG in an AlGaAs/InGaAs HEMT on SiC device is investigated in this paper. This is done by varying the proximity of the layer to the conducting channel, at a constant doping. Another analysis is done by varying the doping of the layer at a constant distance from the channel. Important device dimensions include: Gate length (Lg=200Aº), Gate to source/drain distance (L_{gd},L_{gs} =300Aº)). The δ doping layer width was kept constant at 10Aº. Device simulations were carried out using the MEDICI program and this paper also covers key considerations when modeling hetero-junctions with MEDICI.**

***Keywords*— AlGaAs; HEMT; HFET; delta-doping; MEDICI; SiC; Heterostructures**

I. INTRODUCTION

Wide bandgap HEMT is an important technology that has shown numerous potential and uses in applications like high-power and high-frequency electronics[2], telephones, smart ammunitions, deep space receivers, phased arrays, passive millimeter-wave radiometry and imaging, automotive sensing, ultra-fast digital and microwave applications[1-5]. HEMTs aren't novel devices and the high electron mobility of 2 terminal heterojunctions has been observed since the early 20s, and a working device using AlGaAs/GaAs was first introduced in 1978 at Bell Labs [7]. They are recently making a comeback however, due to their potential to be used in communications devices. HEMTs are attractive for communication where portability is an important factor due to their small size and operation using very low supply voltages [4-7].

The most important advantage of HEMT is the superior electron mobility and high breakdown voltage [12]. This comes about due to the isolation of the channel from the doping region, thereby avoiding impurity scattering. The most common material system is the AlGaAs/GaAs due to its high customizability by varying the mole ratio, which in turn modifies the threshold voltage. However, other III-V semiconductors like the Gan/AlGaN HEMT which has shown even higher breakdown voltage and thermal management and is ideal for use in power applications. Compared to MESFETs, the HEMTs can support higher gate biases due to the additional barrier layer.

Compared to the homogeneous doping of the barrier layer, the delta doping offers higher drain current, larger breakdown voltage, easier control of the threshold voltage and higher intrinsic trans-conductance. [1-7]

II. SIMULATION

Simulation was carried out using the TAURUS MEDICI® program. To simulate hetero-structures in MEDICI several considerations have to be taken. Different models need to be used for hetero-structures compared to continuous structures like MOSFETs or BJTS. Thermionic emission is one of the carrier mechanisms that don't come into consideration in MOSFETs, and to activate this, HJTEM needs to be included in the models statement. At high electric fields, mobility in the HEMT becomes field dependent [12], therefore the FLDMOB statement needs to be included. Schottky barrier tunneling is modeled with the SBT model statement. This is important because the gate contact is Schottky and at high doping concentrations, this mechanism comes into play.[8] Although there is negligible collision in the channel, there is collision in the barrier and δ-doped layers, therefore auger recombination and Shockley-Read-Hall recombination models are included with the AUGER and CONSRH statements.

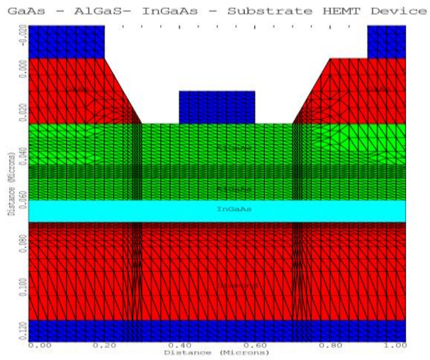


Fig. 1. Simulation mesh

Finally to accurately model abrupt hetero-structures, a different data structure needs to be used, this allows modelling discontinuous fermi levels without running into convergence errors when calculating the Poisson equations. This structure is known as the virtual node, and is activated by including the VIRTUAL statement in the mesh generation. The final structure including mesh redefinition based on doping profile can be seen in Fig.1. The mesh is redefined because, in locations of higher concentrations, a denser mesh triangle is required to adequately model the device.

A key point to note is the inclusion of the HJTUN model, this allows for tunneling. This can only be used at high doping concentrations and if used at low doping causes a convergence error. This was a hard bug to spot because the program didn't display any warning or error information to help.

Simulation is done by getting an initial solution with no carriers, just to set a start point for the forthcoming solutions. HEMTs work at really low voltages, so a small voltage at about the expected threshold voltage was chosen and then stepped down by 0.05 V until the device reached the OFF position. So the drain current was plotted against –Vth to +Vth swing. Fig. 2. shows the device in the on state and the current density in the channel can be seen in comparison to the doping of other segments across the channel. The electron density in the channel can be observed

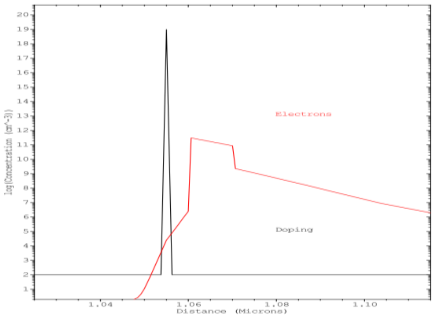


Fig. 2. Sample doping profile and electron density when device is on

The device structure is a simple HEMT, most HEMTs today have double delta layers and double heterojunctions, because it leads to reduction of traps that cause anomalous behavior of current collapse at low temperatures[12]. Since, there wasn't a temperature analysis; a single heterojunction device was used for the simulation.

III. Results and Discussion

Simulations were performed to measure key device parameters like threshold voltage, breakdown voltage, V_g vs. I_d curves, and V_d vs. I_d curves. An attempt was made to simulate the effect of the substrate material on electron mobility, but this was negligible and those results have been omitted in this section. The distance of the δ layer was placed in 5 different locations and the above analysis was carried out at a high doping concentration of 1E19. An optimum location was chosen and then the doping was varied from 5E17 to 1E19. The device parameters extracted using the MOS.PARA statement can be seen in the tables 1 and 2 below.

Distance from channel	Threshold voltage, Vth (V)
50 A°	-0.3538
75 A°	-0.334
100 A°	-0.2282
125 A°	-0.3455
150 A°	-0.089

Table. 1. Threshold voltage for each location

As can be seen in Fig. 3 doping concentration had more of an effect on the threshold voltage than the location of the layer. The breakdown voltage displayed in Fig.4 remained roughly the same and breakdown starts to occur at about 210 V – 250 V.

Doping	Threshold voltage, Vth (V)
5e17	-0.24
1e18	0.169
5 e18	0.319
1e19	0.351

Table. 2. Threshold voltage for each doping

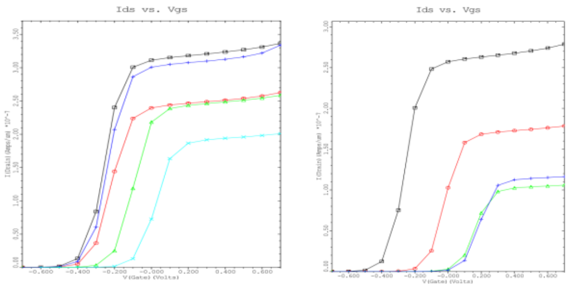


Fig. 3. Ids vs.Vgs showing effect on threshold voltage

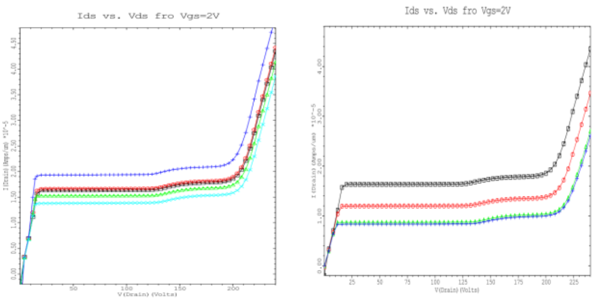
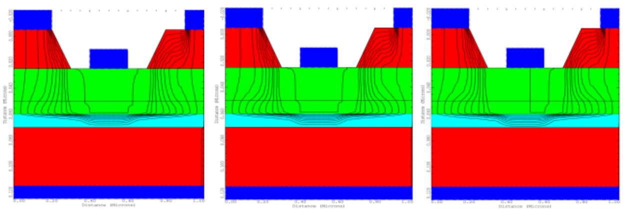
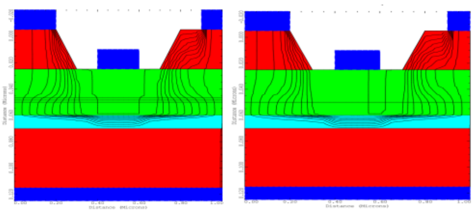


Fig. 4. Ids vs.Vds Breakdown Voltage at V_g= 2V

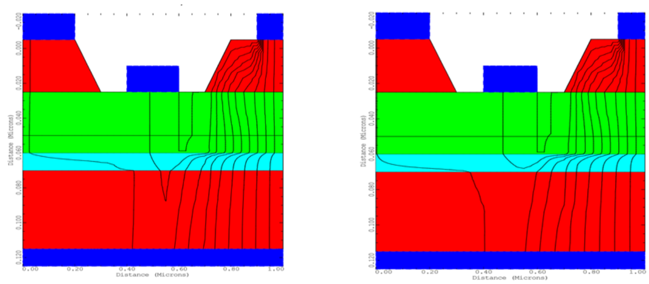


(a) (b) (c)

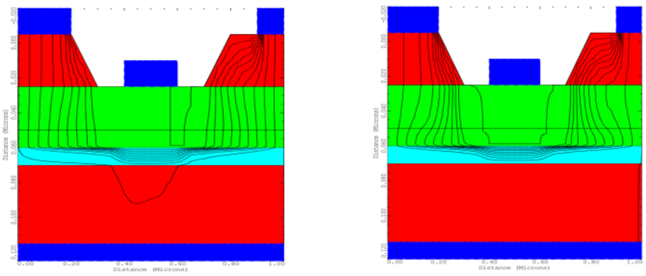


(d) (e)

Fig. 5. Current flow for device (a) 50 A° (b) 75A° (c) 100A° (d) 125 A° (e) 150A° away from channel



(a) (b)



(c) (d)

Fig. 6. Current flow for device doping of (a)5E17(b)1E18 (c)5E18 (d)1E19

IV. CONCLUSION

The advantages of delta-doping instead of homogenous doping have been extensively researched, and this paper tries to investigate the best configuration for this layer. From the current flow in Fig.5 that is varied from 50A° away from the surface to 150A° it can be seen that the closer the channel to the delta doped layer, the more carrier movement is confined to the channel. Oddly enough, once it got far away in Fig.5 (e), it seemed just as confined in the channel.

From the current flow plot in Fig.6 The higher the doping, the more confined the electron movement is in the channel. At low doping there was observable current flow in the substrate, this could be due to the doping concentration in the substrate. There wasn't a huge variation in the breakdown voltages, however there was consistently high values in the range of 225 to 240 V. A further analysis that could be done is to investigate the effect of substrate concentration and biasing (Body Effect) on the device performance.

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