Performance Analysis of doped and undoped AlGaN/GaN HEMTs

Smitha G S[1], Meghana V[2] , Narayan T. Deshpande[3]

[1] M. Tech Student, ECE, BMS College of Engineering, Bengaluru, Karnataka, India
[2]B.E. Student, TCE, BMS College of Engineering, Bengaluru, Karnataka, India
[3]Associate Professor, ECE, BMS College of Engineering, Bengaluru, Karnataka, India

---

Abstract - *In this paper, we describe the effect of varying the length between Gate and Source/Drain of doped and undoped High Electron Mobility Transistors using Sentaurus TCAD (Technology CAD) tool. First, we perform the DC characterization of the undoped HEMT with symmetrical gate structure. In symmetrical structure the distance from gate-to-drain (L_{gd}) and gate-to-source (L_{gs}) is equal. Then asymmetrical structures were created for performance analysis using device editor tool SDE (Sentaurus Structure Editor) of TCAD. The AC analysis was carried out for both symmetrical and asymmetrical structures keeping source-to-drain distance (L_{sd}) constant at 0.8 µm. Then the barrier and cap layers of the HEMT devices were doped with different concentration to form doped HEMTs. And then DC and AC characterization was carried out using the sdevice tool of TCAD. It presents that the electron density and drain current (I_d) increases as the gate-to-source length is reduced in case of doped HEMTs compared to undoped HEMTs. Also the threshold voltage increases in negative direction in case of doped HEMTs. Thus control over the device threshold voltage was obtained.*

Key Words: High Electron Mobility Transistor(HEMT), Heterointerface, Two Dimensional Electron Gas (2DEG), AlGaN, Fermi level, Shockley-Read-Hall (SRH) recombination, Sheet charge concentration and Silicon Nitride

1. INTRODUCTION

HEMTs based on AlGaN/GaN heterostructure are studied for their applications in high power, high frequency and high breakdown voltage. As the GaN technology is still in development stage it is very difficult to obtain the yield and device with high frequency and high power equal to the theoretical values. One of the ways to improve device performance is by varying the structure parameter. In this study, undoped and doped AlGaN/GaN HEMT structures with various L_{gs} and L_{gd} of asymmetrical and symmetrical structures with constant source-to-drain distance are simulated using Sdevice tool of TCAD. Then the DC and AC small signal analysis are carried out. The structure of the device and its physics is presented in next section, the results and discussion in section 3 and finally the conclusion in section 4.

2. STRUCTURE AND MODEL OF HEMTS

2.1 HEMT Structure

Figure 1.1 shows the structure of AlGaN/GaN HEMT device simulated with GaN as both substrate and channel of thickness 2 µm (channel thickness as 5 nm), AlGaN as spacer layer of thickness 2 nm, AlGaN as barrier layer with thickness of 20 nm (since it is reported that 20 nm of AlGaN barrier layer thickness is critical for 2DEG formation [1]) and GaN as cap layer with thickness of 3 nm. Total length of the device is set to 1 µm with silicon nitride as passivation layer of thickness 50 nm. Silicon nitride is chosen as passivation layer as in [2].

The HEMT device barrier layer is doped with the concentration of $1e^{+17}$ and the cap layer is doped with the concentration of $3e^{+18}$. The spacing of source-gate-drain terminals are varied to obtain the performance parameters for all different structures with and without doping the barrier and cap layers.

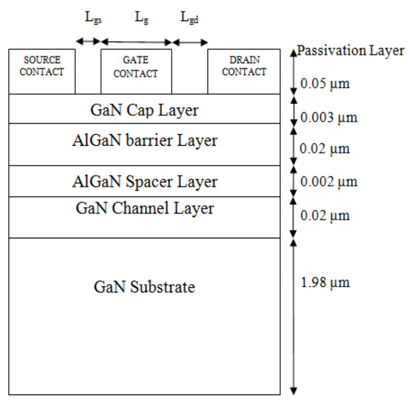

Figure-1.1: Structure of AlGaN/GaN HEMT

The different HEMT devices simulated with different spacing between gate-source (L_{gs}), gate-drain (L_{gd}) and gate length (L_g) are tabulated with labels as shown in Table 1. All eight structures have constant spacing between source-drain set to 0.8 µm.

HEMT/SPACING	L_{gs}(nm)	L_{gd}(nm)	L_g(nm)
h1f1	100	300	400
h1f2	150	150	500
h1f3	100	200	500
h1f4	100	100	600
h1f5	100	400	300
h1f6	200	300	300
h1f7	250	250	300
h1f8	200	200	400

Table-1: HEMTs with various L_{gs}, L_{gd} and L_g

The heterostructure is formed when two different band gap materials are grown one above the other. At the junction a thin sheet of electrons called two dimensional electron gas (2DEG) is formed if the thickness of the barrier layer is within critical level. As per Ambacher, in AlGaN/GaN based HEMTs the charge is induced at the interface due to both spontaneous and piezoelectric type of polarization [3]. When the charge induced is positive then electrons are generated at the low band gap material to compensate it. This is called 2DEG which forms the channel to conduct the current in the device.

The source and drain contacts of the device are made as linear type and the gate contact is made as rectifying type. As the device size is large and includes the heterojunction, the simulation of the device frequently undergoes convergence problems at the initial or intermediate stage. Thus meshing which represents the smallest discrete element of the device structure has to be carefully chosen so as to avoid the convergence problems and thus increase the speed of computation. The meshing used for the structures is as shown in figure 1.2. The size of meshing used is such that its variation does not cause any change in its characteristics. The meshing for all the structures is done following the similar procedure.

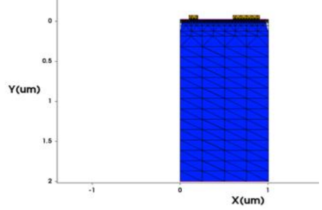

Figure-1.2: Meshing of HEMT structure

2.2 Analytical Model

For HEMTs the equation used to calculate the sheet charge concentration n_s in the channel at any point 'x' is in [4] as given by equation 1.

$$n_s(x) = \sigma(x)/e - (\varepsilon_0 \varepsilon(x)/(de^2))[e\phi_b(x) + E_F(x) - E_C(x)] \text{ ---- (1)}$$

where
$\sigma(x)$ = polarization sheet charge at point 'x',
d = AlGaN barrier layer thickness,
e = charge of an electron,
ε_0 = free space permittivity,
$\varepsilon(x)$ = dielectric constant of barrier layer at 'x',
$e\phi_b(x)$ = Schottky barrier of gate contact,
$E_F(x)$ = Fermi level with respect to GaN E_C and
$\Delta E_C(x)$ = Conduction band offset at heterointerface.

Using the above equation, the sheet charge concentration in the channel is calculated for AlGaN barrier layer thickness of 20 nm and aluminium mole fraction of 20 %.

The 2DEG formed at the interface of h1f1 AlGaN/GaN heterostructure with L_{gs}=100 nm, L_{gd}=300 nm and L_g=400 nm as given in table 1 structure is shown in figure 1.3.

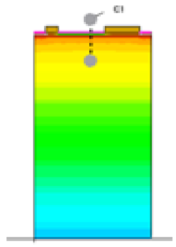

Figure-1.3: 2DEG formed at interface of AlGaN/GaN HEMT

The electron density in 2DEG formed at the interface of h1f1 undoped HEMT structure at a depth of 0.43 nm for x-cut is measured to be equal to 3.193e19/cm³ and is shown in figure 1.4.

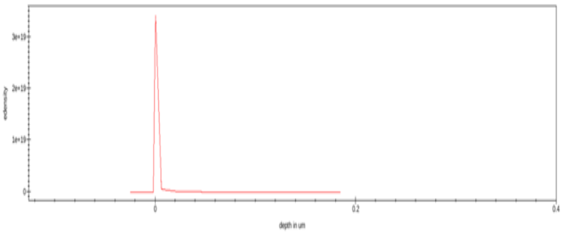

Figure-1.4: Electron density of undoped AlGaN/GaN HEMT

3. RESULTS AND DISCUSSION

3.1 DC and AC analysis of undoped HEMTs

As shown in table 1, all the eight structures are simulated using the Fermi and Shockley-Read-Hall models in the physics section of the device simulation tool sdevice of TCAD. As source-drain minimum spacing is reported in [5] and [6], it is set to 0.8 μm. The comparative I_d-V_g (transfer) and I_d-V_d (drain) characteristics obtained for different undoped device is shown in figure 3.1(a) and figure 3.1(b) respectively.

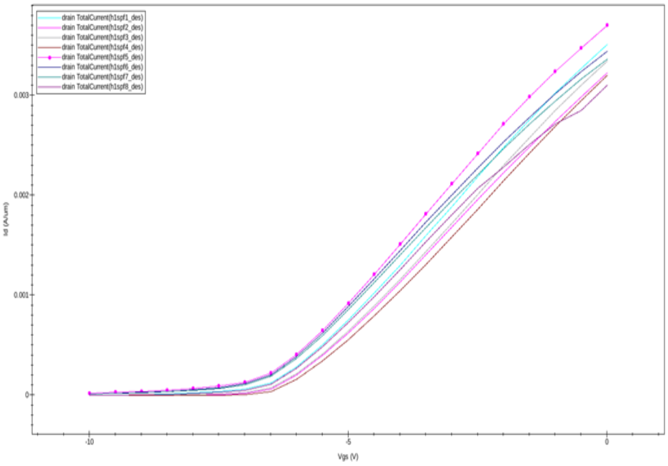

Figure-3.1(a): Comparison of transfer characteristics

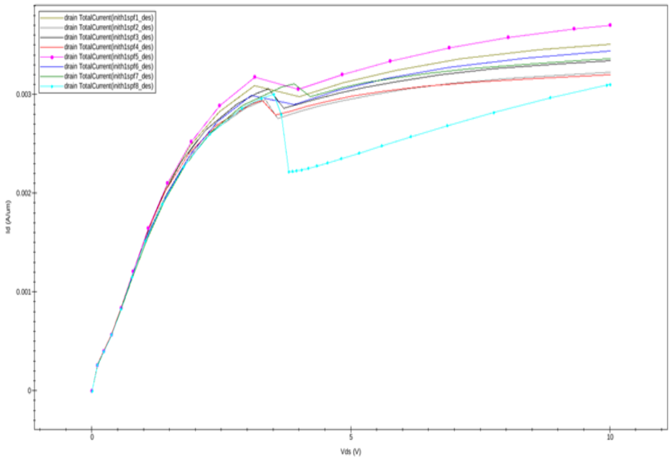

Figure-3.1(b): Comparison of drain characteristics

The AC analysis obtained for undoped HEMTs is shown in figure 3.2.

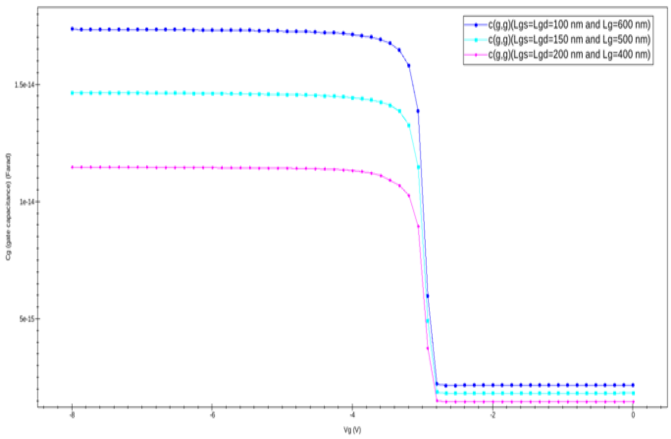

Figure-3.2: Comparison of C_g-V_g characteristics

3.2 DC and AC analysis of doped HEMTs

Similar to the simulation carried out for undoped HEMTs, same is carried out on doped HEMTs with the transfer and drain characteristics obtained as shown in figure 3.3(a) and figure 3.3(b).

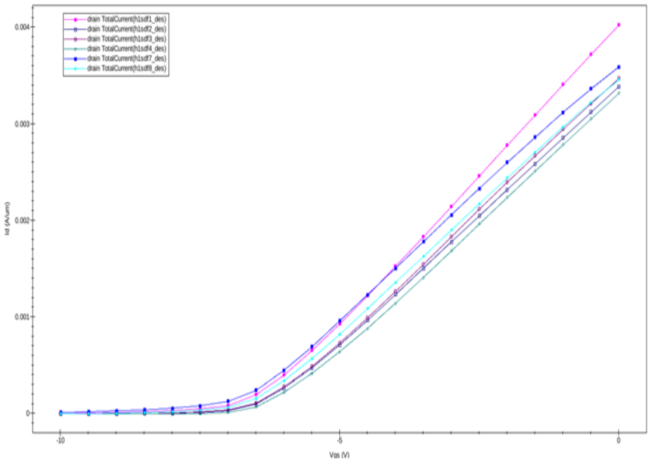

Figure-3.3(a): Comparison of transfer characteristics

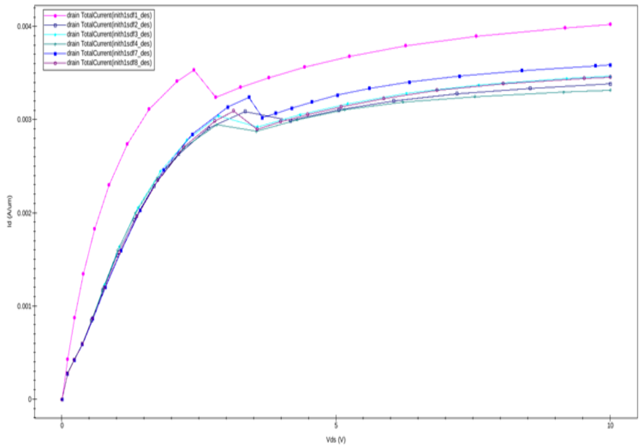

Figure-3.3(b): Comparison of drain characteristics

The AC analysis obtained for doped HEMTs is shown below in figure 3.4.

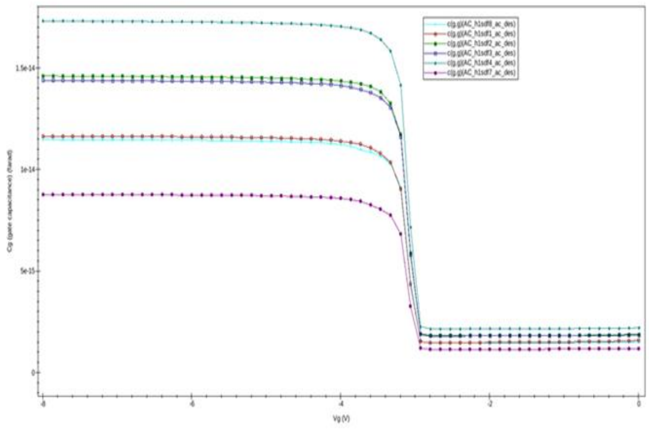

Figure-3.2: Comparison of C_g-V_g characteristics

4. CONCLUSIONS

From the characteristics obtained it is clear that the drain current in case of doped HEMTs is higher than that of undoped HEMTs. The table 2(a) and table 2(b) below shows the different parameter values obtained for doped and undoped HEMTs.

Device/ parameter	h1spf1	h1spf2	h1spf3	h1spf4	h1spf5(7th)	h1spf6(8th)
V_t(V)	-6.191	-6.049	-5.98	-5.83	-6.543	-6.284
g_m(S/μm)	5.97E-04	5.59E-04	5.81E-04	5.66E-04	5.62E-04	5.56E-04
I_d(A/μm)	0.003516	0.003232	0.00335	0.00321	0.00337	0.00311
I_{off}	1.37E-12	1.10E-17	2.41E-17	1.65E-22	1.40E-11	1.21E-12
$C_g(e^{-14}F)$	1.1703	1.464	1.44	1.733	0.878	1.147
ft(GHz)	8.078	6.077	6.4215	5.198	10.187	7.715
edensity(e^{+19}) (cm^{-3})	3.19307	3.18034	3.1847	3.18682	3.1936	2.90315

Table-2(a): Performance parameters of undoped HEMTs

Device/ parameter	h1sdf1	h1sdf2	h1sdf3	h1sdf4	h1sdf5 (7th)	h1sdf6 (8th)
V_t(V)	-6.382	-6.272	-6.219	-6.037	-6.761	-6.516
g_m(S/μm)	5.93E-4	5.51E-4	5.76E-4	5.59E-4	5.56E-4	5.50E-4
I_d(A/μm)	0.00364	0.0034	0.00347	0.00332	0.00359	0.00346
I_{off}	1.67E-12	1.07E-16	2.74E-16	2.03E-22	1.67E-11	2.03E-12
$C_g(e^{-14}F)$	1.1675	1.4582	1.4373	1.7282	0.8769	1.1465
ft(GHz)	8.084	6.014	6.378	5.148	10.091	7.635
edensity(e^{19}) (cm^{-3})	3.36486	3.383	3.38403	3.38957	3.38955	3.3806

Table-2(b): Performance parameters of doped HEMTs

When the gate length is reduced the effect of electric field distribution is as in [7]. This effect avoids the saturation of electron mobility which thus leads to increase in the electron velocity and hence the drain current. As observed from the table, electron density (edensity) of doped HEMTs is higher than that of undoped HEMTs. Also the threshold voltage increases in negative direction as the HEMTs are doped.

Further the different doping can be done on all structures to observe the effect of various doping concentration on HEMTs and also the temperature effects need to be studied.

ACKNOWLEDGEMENT

We thank B.M.S. college of Engineering for providing us the TCAD tool for completing this work and supporting us.

REFERENCES

[1] Tilak V et al. "Influence of Barrier Thickness on the High-Power Performance of AlGaN/GaN HEMTs", IEEE Electron Device Letters, Vol. 22, No. 11, November 2001.

[2] B. M. Green et al. "The effect of surface passivation on the microwave characteristics of undoped AlGaN/GaN HEMTs", Electron Device Letters, IEEE, Vol. 21, pp. 268-270, 2000.

[3] O. Ambacher et al. "Two-Dimensional electron gases induced by spontaneous and piezoelectric polarization charges in N- and Ga-face AlGaN/GaN heterostructures", Journal of Applied Physics, Vol. 85:3222-3233, March 1999.

[4] Rashmi et al. "2-D Analytical Model for Current-Voltage Characteristics and Output Conductance of AlGaN/GaN MODFET", Microwave and Optical Tech. Letters, Vol. 29, No. 2, pp. 117-123, April, 2001.

[5] Wang Dong fang et al. "High performance AlGaN/GaN HEMTs with 2.4 μm source-drain spacing", Journal of Semiconductors, Vol. 31, No. 3, March 2007.

[6] Guo Dechun et al. "A simulation about the influence of the Gate-Source-Drain distance on the AlGaN/GaN HEMT performance at Ka-band", IEEE MTT-S International Conference paper, Sep. 2012.

[7] Stefano Russo and Aldo Di Carlo, "Influence of the Source-Gate Distance on the AlGaN/GaN HEMT Performance", IEEE Transaction on Electron Devices, Vol. 54, No. 5, May 2007.

[8] Marino F. A. et al. "Effects of Threading Dislocations on AlGaN/GaN High-Electron Mobility Transistors", IEEE Trans., Vol.57, No. 1, January 2010.

[9] M. Hatano et al. "Comparative high-temperature DC characterization of HEMTs with GaN and AlGaN channel layers", CS MANTECH conference, May 2010.

[10] Trew R. J et al. "Nonlinear source resistance in high-voltage microwave AlGaN/GaN HFETs", IEEE Trans.,Vol.54, pp.2061-2067, 2006.

[11] H. Okumura "Present status and future prospect of wide gap semiconductor high power devices", Japanese Journal of Applied Physics, Vol. 45, No.10A, pp 7565-7586, 2006.
Shur M. S. "Low Ballistic Mobility in Submicron HEMTs", IEEE Electron Device Letters, Vol. 23, No.9, September 2002.

[12] Synopsys Sentaurus TCAD tutorial/user guide.

BIOGRAPHIES

Smitha G S received B.E. in Electronics & Communication Engineering from Kuvempu University in 1996. Currently, she is pursuing her M. Tech degree at B.M.S. College of Engineering from VTU. She is interested in electronics, semiconductors, VLSI and digital electronics.

Meghana V is pursuing her B.E. degree in Telecommunication Engineering at B.M.S. College of Engineering from VTU. She is interested in electronics, semiconductors and VLSI.

Narayan T. Deshpande received M.E. in Electronics from Bangalore Univeristy in 1996 and B.E. in Electronics & Communication Engineering from Bangalore University in 1990.
He is an associate professor in Electronics and Communication Department, B.M.S. College of Engineering, Bengaluru.

