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Performance Analysis of AlGaN/GaN HEMT with Asymmetrical passivation layer

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ABSTRACT

In this paper, we describe the effect of varying the length between Gate and Source/Drain of High Electron Mobility Transistor using Sentaurus TCAD(Technology CAD) tool. In this regard, first we perform the DC characterization of the HEMT with symmetrical gate structure in which the distance from gate-to-drain (L_{gd}) and gate-to-source (L_{gs}) is equal. Then the small signal AC analysis is carried out for both symmetrical and asymmetrical structures keeping source-to-drain distance (L_{sd}) constant at 1µm. It presents that the transconductance (g_m), cutoff frequency (f_T) and drain current (I_d) increases as the gate-to-source length is reduced.

Keywords: High Electron Mobility Transistor (HEMT), Shockley-Read-Hall(SRH) recombination, Two Dimensional Electron Gas (2DEG),

1. INTRODUCTION

HEMTs based on AlGaN/GaN heterostructure are studied for their applications in high power, high frequency and high breakdown voltage. Because of the limitations in GaN technology, it is very difficult to end up with the device with high frequency and high power of theoretical value. The performance of the device can be improved by varying the structural parameters.

In this study, three 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 DC and small signal AC analysis are carried out using the tool. The structure of the device and its physics is presented in next section, the result and discussion in section 3 then finally the conclusion in section 4.

2. HEMT STRUCTURE

The structure of AlGaN/GaN HEMT simulated is shown in Fig.1 with GaN as both substrate and channel layer and AlGaN as barrier layer (all dimensions are in µm). Total length of the device is 2.0 µm with silicon nitride as passivation layer of 500 nm. All the three devices are undoped and Al mole fraction is set to 20%. Fermi and SRH models are used in the physics section of the device for the device simulation which gives accurate results.

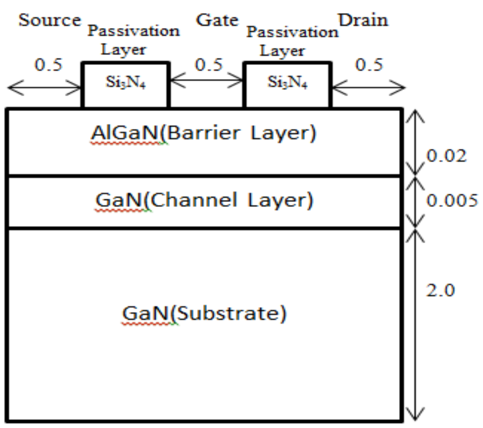

Fig.1 Structure of AlGaN/GaN HEMT

The growth of wide band gap AlGaN material over low band gap GaN material results in the formation of 2DEG at the heterointerface due to large discontinuity in the conduction bands of the two materials at the interface. The polarization charge at the heterointerface is as [1] and the passivation layer of Silicon Nitride (Si_3N_4) is used for the reduction of current collapse due to gate lag as [2]. The device uses source and drain contacts of ohmic type, whereas for the gate contact it uses schottky type. All three electrodes can be of schottky type for the better device characteristics.

Since the size of the device is large and as it includes heterointerface, HEMT device simulation frequently catches convergence problems at the initial stage or during the intermediate stage. So the meshing of the device plays an important role for increasing the speed of computation with accurate results. After solving the problems of convergence faced during the simulation step, meshing of the structure used is as shown in Fig. 2. Meshing size is selected in such a way that its variation does not cause any change in the characteristics obtained.

Similarly, the other two asymmetrical structures are designed and proper meshing is done.

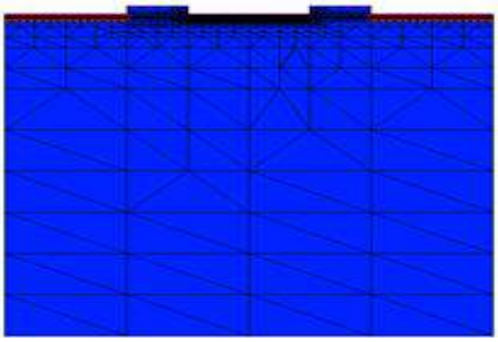

Fig.2 Meshing used for the device

Table 1 lists the different values of L_{gs}, L_{gd} and gate length (L_g) for the HEMT structures used for the simulation.

Table 1. HEMT with different L_{gs}, L_{gd} and L_g

HEMT / SPACING	Asymmetrical		Symmetrical
	1	2	3
L_{gs} (nm)	100	200	250
L_{gd} (nm)	400	300	250
L_g (nm)	500	500	500

In [8] the source-to-drain distance is set to 1.2 µm but in our work it is set constant at 1.0 µm thus reducing the device dimension.

3. RESULTS AND DISCUSSION

3.1 DC Analysis of Symmetrical HEMT

The transfer and output (drain) characteristics of the symmetrical HEMT with spacing of gate-to-source and gate-to-drain of 250 nm length, are shown in Fig. 3.

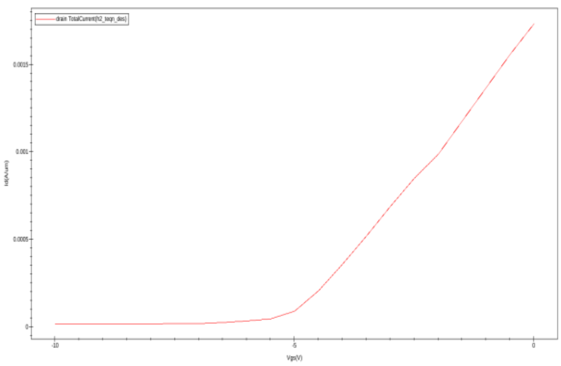

Fig. 3(a) Transfer Characteristics of symmetrical HEMT of L_{gs}= L_{gd}=250 nm(V_{ds}=10 V)

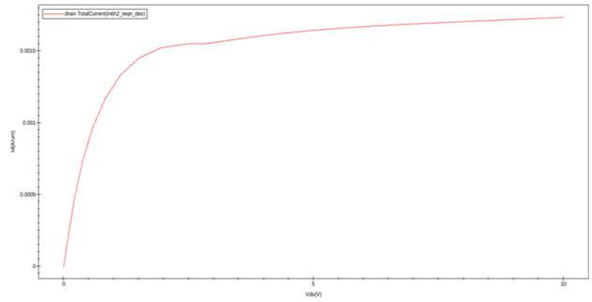

Fig.3(b) Drain Characteristics of symmetrical HEMT of L_{gs}= L_{gd}=250 nm (V_{gs}=0 V)

The results of symmetrical HEMT obtained are listed in table 2 below. As per the DC analysis, it is observed that the drain current(I_d) and transconductance(g_m) of the symmetrical HEMT structure is less than the asymmetrical HEMT structure. Also the symmetrical HEMT has more negative threshold voltage. From small signal AC analysis it is observed that the symmetrical HEMT has higher gate capacitance thus leading to lower cutoff frequency (f_T) than the asymmetrical HEMT.

3.2 DC Analysis of Asymmetrical HEMT

The transfer and output characteristics of two asymmetrical HEMTs with different silicon nitride passivation layer spacing from source/drain and 500 nm of gate as listed in table 1 are shown in Fig. 4.

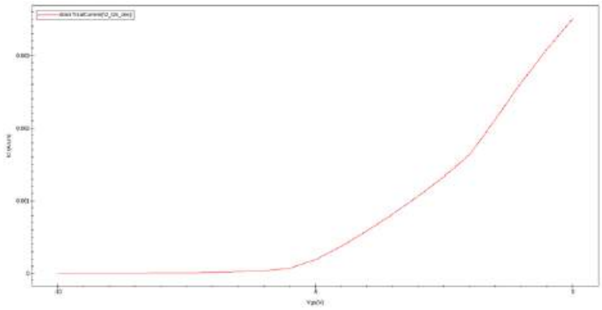

Fig. 4(a) Transfer Characteristics of asymmetrical HEMT of L_{gs}=100 nm and L_{gd}=400 nm(V_{ds}=10 V)

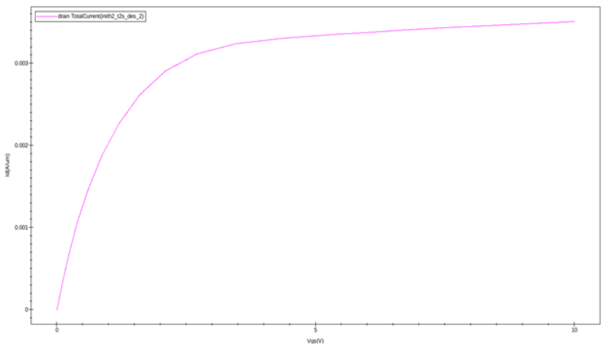

Fig. 4(b) Drain Characteristics of asymmetrical HEMT of

L_{gs}=100 nm and L_{gd}=400 nm (V_{gs}=0 V)

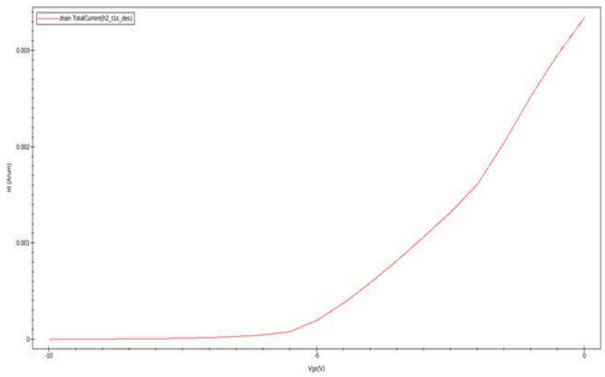

Fig.4(c) Transfer Characteristics of asymmetrical HEMT of L_{gs}=200 nm and L_{gd}=300 nm(V_{ds}=10 V)

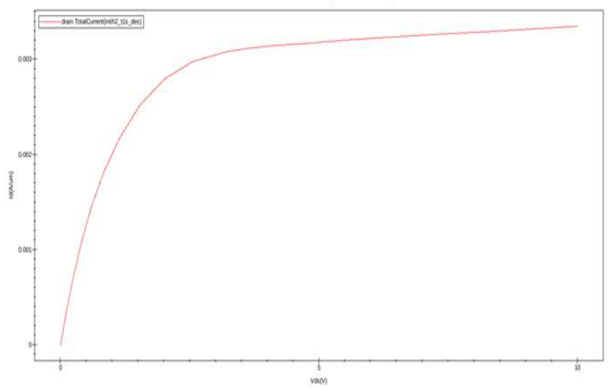

Fig. 4(d) Drain Characteristics of asymmetrical HEMT of L_{gs}=200 nm and L_{gd}=300 nm (V_{gs}=0 V)

The 2DEG formed at the heterointerface and the electron density at zero bias for symmetrical HEMT is shown in Fig. 5.

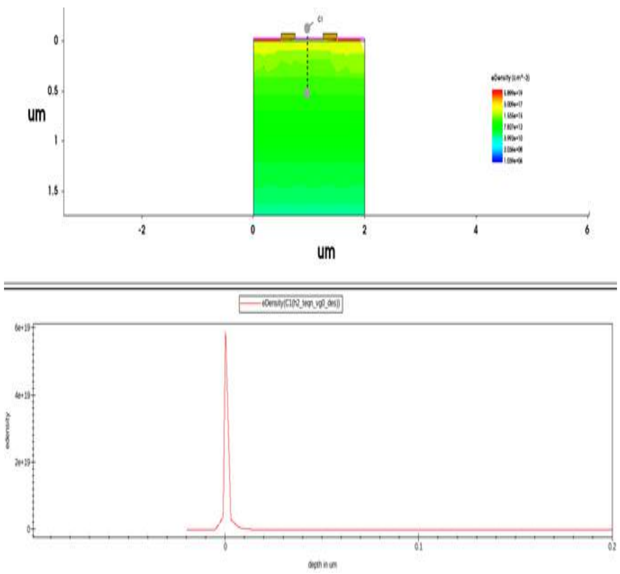

Fig.5 2DEG and electron density at the heterojunction of AlGaN/GaN HEMT in the channel layer

From the DC and AC Analysis carried out using Sentaurus Device tool of TCAD, the results obtained are listed in table 2. From the AC analysis(C-V characteristics) the gate capacitance (C_g) is noted. Then the cutoff frequency (f_T) of the devices is calculated using the equation 1as given below. Values obtained are listed in table 2.

$$f_T = G_m / (2\pi C_g) \qquad \text{----------------------------- (1)}$$

Table 2. Comparison of Threshold Voltage(V_{th}), Drain Current(I_d), Transconductance(g_m), Gate capacitance(C_g) and Cutoff- frequency(f_T) of HEMTs

HEMT / PARAMETER	Asymmetrical		Symmetrical
	1	2	3
V_{th}(V)	-3.6088	-3.9278	-5.6648
I_d(A/um)	0.003513	0.003349	0.002828
G_m(S/um) (DC Analysis)	0.0010064	0.0009294	0.0006018
C_g (fF)	4.54530	5.62032	17.4002
f_T(GHz)	35.24	26.32	5.50

The variation of the performance parameters of three devices are shown in Fig. 6

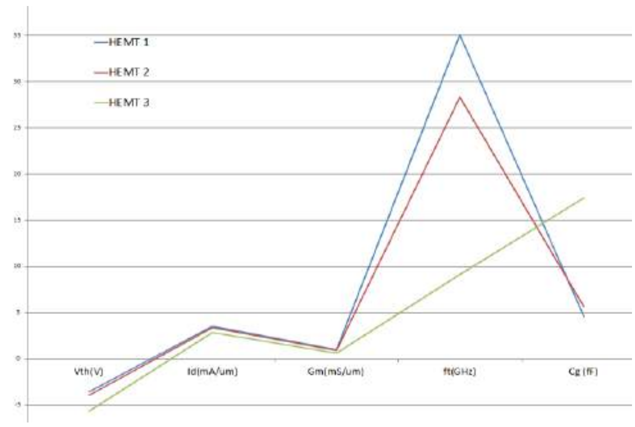

Fig. 6 Comparison of performance parameters of the devices

3.3 Comparison of Characteristics

The comparison of transfer and drain characteristics of symmetrical HEMT and asymmetrical HEMTs are shown in Fig. 7.

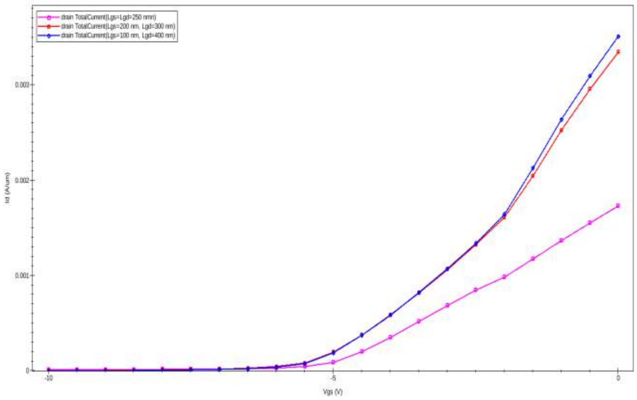

Fig. 7(a) Transfer Characteristics of symmetrical and asymmetrical HEMTs withV_{ds}=10 V

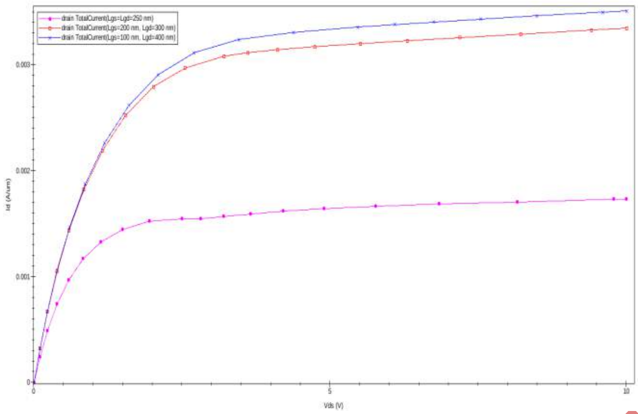

Fig 7(b). Drain Characteristics of symmetrical and asymmetrical HEMTs withV_{gs}=0 V

From the results obtained it is seen that there is increase in drain current with decrease in L_{gs} which is due to effect of electric field distribution between source and gate as [6]. As the electric field under the gate and drain is increased, the effect is so as to avoid the saturation of electron mobility. This in turn improves speed of the electrons and hence the current in the 2DEG channel. The threshold voltage becomes less negative as the L_{gs} distance is decreased. The device with lower L_{gs} distance has the cutoff frequency which is higher than the other types. The reason for this is the decrease in gate capacitance of the device with decrease in L_{gs} distance.

4. CONCLUSION

In this work we have studied the effect of gate-to-source and gate-to-drain distance variation successfully and observed that the 2 µm device with lower gate-to-source distance has better performance parameters than the others. In the further study the self-heating effects and temperature effects for device degradation can be considered.

5. ACKNOWLEDGMENTS

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