RF/Analog and Linearity Performance Evaluation of Lattice-matched Ultra-thin AlGaN/GaN Gate Recessed MOSHEMT with Silicon Substrate

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Abstract

In this article, the authors have demonstrated and analyzed various analog/RF, and linearity performances of an AlGaN/GaN gate recessed MOSHEMT (GR-MOSHEMT) grown on a Si substrate with mathematical modeling based Technology Computer-Aided Design (TCAD) simulation. Specifically, an Al2O3 dielectric GR-MOSHEMT has shown tremendous potential in terms of AC/DC figure of merits (FOM’s) such as low leakage current, high transconductance, high Ion/Ioff current ratio, and excellent linear properties corresponding to conventional AlGaN/GaN HEMT and MOSHEMT. The figure-of-merit metrics such as VIP2, VIP3, IIP3, and IDM3 are performed for the different drain to source voltages (VDS) of 2.5 V, 5 V, and 10 V. All the modeling and simulation results are generated by Commercial Silvaco TCAD and found to be satisfactory in terms of high frequency and power applications. The present GR-MOSHEMT device shows superior performance with a threshold voltage of 0.5 V, a Current density of 888 mA, a high transconductance of 225 mS/mm, and a high unit gain cut-off frequency 0.91GHz. The developed AlGaN/GaN GR-MOSHEMT considerably improves the device performance and is also suitable for high power distortion-less RF applications.

Keywords AlGaN/GaN · HEMT · MOSHEMT · GR-MOSHEMT · Leakage current · Ion/Ioff current ratio

1 Introduction

Recently, AlGaN/GaN HEMT based devices have achieved much recognition for high power and high-frequency applications due to high breakdown voltage [1], high thermal conductivity, high saturation velocity, low effective mass, and high two-dimensional electron gas (2DEG) at the GaN/AlGaN interface [2–7]. But the performance of HEMT based devices is limited in RF power applications due to high gate leakage and drain leakage current. AlGaN/GaN-based heterostructures provide 2DEG (2-dimensional electron Gas) at AlGaN-barrier and GaN-Channel layer interface, which provides higher carrier mobility and current density generation of Spontaneous and Piezoelectric Polarizations. Recently, AlGaN/GaN-based metal-oxide-semiconductor MOSHEMT with an insulating dielectric oxide layer (Al2O3) primarily targeted the RF power applications due to its low gate leakage current and improved drain and threshold voltage [8–12]. But HEMT and MOSHEMT based devices suffer from high contact and high on-resistance due to metallic ohmic contacts and significant source/drain distance. However, the modified gate structure reduced the gate resistance while maintaining the modified gate length and reduced the gate capacitance [13–17]. Generally, AlGaN/GaN HEMTs are normally-on devices and operate in depletion mode. The corresponding MOSHEMTs with an extra dielectric between the metal gate and thin barrier also operate as on-device. Still, the threshold voltage moves towards positive compared to HEMT based on-devices [18, 19].

The gate recessed MOSHEMT device structure combines the advantages of the MOS gate structure and the recessed gate. In the gate-recessed MOSHEMT structure (GR-MOSHEMT), the distance between the gate and channel is reduced, so the controlling ability of the gate increases. With this effect, the peak transconductance of the recessed-gate MOSHEMT is increased. The dielectric gate structure increases the distance of the gate to the channel. In contrast,
the recessed-gate structure reduces the distance. The threshold voltage of GR-MOSHEMT increases due to the weak impact of thin gate dielectrics. The recessed-gate mechanism mainly dominates the positive shift of the threshold. The gate recess can be achieved by making T-type and L-type gates, dual-gate integration, tri-gate structures, etc. However, Gate recessed MOSHEMTs generally work as normally-off device and operates in enhancement mode. These normally-off devices are more suitable in the case of high power amplifier circuits, high power switching applications, and millimeter-wave applications due to their high gate dielectric, low leakage current, and positive threshold voltage [20, 21].

Many literature works are available about modeling and simulation of analog and linearity performance of AlGaN/GaN HEMT [22–24]. However, as per the Author’s knowledge, in-depth analytical modeling and simulation work is yet to be done for conventional MOSHEMT and gate recessed MOSHEMT, as evident in the literature explaining the RF and linearity parameters.

This work demonstrated the lattice-matched AlGaN/GaN-based HEMT, MOSHEMT and gate recessed MOSHEMT to analyze and compare the analog and linearity performances. Section 2 describes the device structures and simulation models. In Section 3, the simulated results are compared with experimental results along with physical models. Finally, the conclusion is drawn in Section 4.

2 Device Structure and Modeling Equations

2.1 Device Structure

Figure 1 shows the cross-sectional schematics of the conventional AlGaN/GaN HEMT, normally on MOSHEMT and normally-off gate recessed MOSHEMT. The GaN-Channel, AlGaN-barrier, Si₃N₄-passivation layer and AlN-nucleation layer thicknesses in all the devices are 1.47 μm, 20 nm, 5 nm, and 1 nm, respectively. The Al composition in the AlGaN layer is kept at 0.3 to maintain good interface property between AlGaN and GaN [25–27]. In the case of MOSHEMT, Al₂O₃ is used as a gate dielectric with a thickness of 5 nm to minimize the leakage current density. The thin Al₂O₃ dielectric oxide layer is used due to its relatively high bandgap (9 eV), high dielectric constant (k~10), high breakdown field (10⁷ V/cm), and good thermal stability. The dielectric oxide reduces the gate leakage current when it contacts under the gate contact, which allows the application of high positive gate voltage further to increase the sheet electron density in the 2-DEG channel. AlGaN works as a barrier layer with 0.3 Al composition and GaN as a channel layer in the device. The doping value of the AlGaN barrier region is 1e17 cm⁻³ at the ambient temperature of 300 K. After introducing the passivation layer, the devices exhibit better pinch-off behavior, low gate leakage current, increased the average output power by eliminating surface states and improved the RF performance of the device. The gate leakage current after passivation is lowered, which indicates a higher gate-to-drain breakdown voltage. The purpose of inserting the nucleation layer between the GaN Channel
and the substrate is to minimize the stress and related lattice mismatch. Due to spontaneous and piezoelectric polarization charges, there is strong confinement of 2DEG at the AlGaN/GaN interface [26]. Donors are created near the source and drain junctions to reduce the access and contact resistance. The Gate and metal-electrodes (for Source/Drain) work functions are 5 eV and 3.9 eV (Hafnium) respectively. The gate-source spacing ($L_{GS}=2.5 \mu m$) and gate-drain spacing ($L_{GD}=2.5 \mu m$) are equal in all the device structures. Silicon substrate is used to achieve excellent thermal characteristics.

### 2.2 Modeling Equations

#### 2.2.1 Calculation of Sheet Charge Density Due to Polarization

Spontaneous and piezoelectric polarization charges exist at the Al$_2$O$_3$/AlGaN and AlGaN/GaN interface boundary. To calculate the spontaneous and piezoelectric polarization charges at the heterogeneous interface, the following Eqs. (1) - (9) have been used [27].

\[
|\sigma(x)| = \left| P_{PE}(Al_xGa_{1-x}N) + P_{SP}(Al_xGa_{1-x}N) - P_{SP}(GaN) \right| \\
|\sigma(x)| = \frac{2a(0) - a(x)}{a(x)} \left( e_{13}(x) + e_{33}(x) \frac{C_{13}(x)}{C_{33}(x)} \right) + P_{SP}(x) - P_{SP}(0) \\
a(x) = (-0.077x + 3.189) \times 10^{-10} \\
\text{Where} \ a(x) \text{ and } a(x) \text{ is sheet charge density and lattice constant respectively.} \\
a(0) = a_{GaN} \\
\text{and } C_{13}, C_{33} \text{ are the elastic constant, } e_{13} \text{ and } e_{33} \text{ are the piezoelectric constants given as follows:} \\
C_{13}(x) = (5x + 103) \\
C_{33}(x) = (-32x + 405) \\
e_{13}(x) = (-0.11x - 0.49) \\
e_{33}(x) = (0.73x + 0.73) \\
\text{The spontaneous polarization of } Al_xGa_{1-x}N \text{ is also a function of the Al mole fraction } x \text{ and is given by:} \\
P_{SP}(x) = (-0.052x - 0.029) \\
\text{The extensive simulations are done using Commercial Silvaco TCAD [28] with Newton numerical methods, and the models such as Gansat, SRH (Shockley–Read–Hall recombination), Allbrct, and spontaneous and piezoelectric polarization are taken into consideration. The drift-diffusion model has been taken into consideration for the carrier transport in the channel of devices. Low-field mobility model establishes a variation of carrier mobility with doping concentration. The mesh value of the device structures for the crucial regions is chosen precisely for accurate simulation and accelerating computational efficiency.}

#### 2.2.2 Calculations of Electrical and Thermal Parameters for Al$_x$Ga$_{1-x}$N

The energy bandgap of III-Nitride binary compounds are calculated as a function of temperature using [29]:

\[
E_g(GaN) = 3.507 - \frac{0.909 \times 10^{-3}T^2}{T + 830} \\
(10)
\]

\[
E_g(AlN) = 6.23 - \frac{1.799 \times 10^{-3}T^2}{T + 1462} \\
(11)
\]

Now, Vegard’s law is used to find the ternary compound’s bandgap energy [30, 31].

\[
E_g(Al_xGa_{1-x}N) = xE_g(AlN) + (1-x)E_g(GaN) - bx(1-x) \\
(12)
\]

Where b and x is the bowing parameter and Al mole fraction, respectively.

The electron affinity is calculated by adequately maintaining the band edge offset ratio and is given by [32].

\[
\Delta E_c = \frac{0.7}{0.3} \\
(13)
\]

Electron affinity and permittivity of Al$_x$Ga$_{1-x}$N is computed as by the following equations [33]:

\[
\chi(Al_xGa_{1-x}N) = \chi(GaN) - 1.89x + 0.91x(1-x) \\
(14)
\]

\[
\epsilon(Al_xGa_{1-x}N) = 8.5x + 8.9(1-x) \\
(15)
\]

The ternary compound materials density of states masses a function of mole fraction associated with compound material and is given by linear interpolations [29]:

\[
m_e(Al_xGa_{1-x}N) = 0.314x + 0.2(1-x) \\
(16)
\]

\[
m_h(Al_xGa_{1-x}N) = 0.417x + 1.0(1-x) \\
(17)
\]

Where $m_e$ and $m_h$ are the electron and hole mass density of Al$_x$Ga$_{1-x}$N material.
2.2.3 Calculation of Analog/RF Parameters for HEMT and MOSHEMT

Transconductance should be high for High linearity devices to achieve maximum gain. Generally, it is divided into the gate and drain transconductances. Most of the device provides the flat transconductance. Still, HEMT and MOSHEMT structures show the bell-shaped curve due to the self-heating thermal effects, low to moderate drain voltage, and nonlinearity source/drain resistances. Gate transconductance \( g_m \) is the ratio of the change in \( I_D \) concerning the change in \( V_{GS} \) with constant \( V_{DS} \). In the same way, output or drain transconductance \( g_{ds} \) is the ratio of change in drain current to the drain voltage and constant gate voltage. Mathematical equations used for the measurement of transconductances are \([34]\):

\[
\frac{\partial I_D}{\partial V_{GS}} \bigg|_{V_{DS} = \text{const}} = g_m
\]

\[
\frac{\partial I_D}{\partial V_{DS}} \bigg|_{V_{GS} = \text{const}} = g_{ds}
\]

Primarily there are two types of capacitance effects which are Gate-to-source and gate-to-drain capacitance. For gate-to-source capacitance, the variation of gate charge for change in the gate voltage and gate charge variation with change in drain voltage is referred to as gate-to-drain capacitance. Gate-to-source and gate-to-drain capacitances are represented as \([34]\):

\[
C_{gs} = \frac{\partial Q}{\partial V_{gs}}
\]

\[
C_{gd} = \frac{\partial Q}{\partial V_{ds}}
\]

The cut-off frequency is proportional to the transconductance. It is also inversely proportional to the summation of the intrinsic capacitances of gate-to-drain and gate-to-source. The maximum oscillation frequency varies by the cut-off frequency. It also depends on various factors like gate-on resistance and gate-to-drain capacitance. In the case of MOSHEMT, the reduced on-resistance and gate capacitance increase the oscillation frequency. Mathematically equations related to the cut off and maximum oscillation frequencies are expressed as \([35, 36]\):

\[
f_T = \frac{g_m}{2\pi C_{gs}}
\]

Where

\[
f_{\text{max}} = \frac{f_T}{2\pi \sqrt{g_{ds} \left(R_s + R_g\right) + 2\pi f_T R_s C_{gd}}}
\]

Where

\[
R_s = \frac{1}{G_{ss}}
\]

2.2.4 Intermodulation distortion and linearity performance parameters

In Analog/RF-based circuits, Intermodulation distortion and higher-order harmonics are introduced at the output end, which causes the degradation of device performance by reducing the output power component. For better device performance, distortion and harmonics types of error must be removed. Linearity Characteristics can be analyzed using different parameters like High order trans-conductance, interception points, and intermodulation distortion for smooth device operation.

For a Linear device, Transconductance and its higher-order coefficients should be expressed by following modeling Eqs. \((26)-(30)\) \([37]\):

\[
\frac{\partial^n I_d}{\partial V_{gs}^n}, \text{ where } n = 1, 2, 3
\]

Different Figure of merits (FOM’s) is used in this paper to analyze the AlGaN/GaN-based devices’ behavior in linearity mode \([38, 39]\). Second-order intercept point (VIP2) and Third-order intercept point (VIP3) are defined as the extrapolated input voltage and gate voltage, respectively, at which the second-order and third-order harmonics become equal to the fundamental tone in the device’s drain current \(I_d\). So II-order and III-order harmonics, VIP2 and VIP3, are mathematically represented as follows:

\[
\text{VIP2} = 4 \times \frac{g_{m1}}{g_{m2}}
\]

\[
\text{VIP3} = \sqrt{24 \times \frac{g_{m1}}{g_{m3}}}
\]
point of the third harmonic (IIP3). Intermodulation distortion of the third harmonic is defined for nonlinear devices when two or more signals are mixed. Mathematically IIP3 and IDM3 are represented as:

\[
IIP3 = \frac{2}{3} \times \frac{g_{m1}}{g_{m3} \times R_s}
\]

\[
IDM3 = \left[ \frac{9}{2} \times (VIP3)^2 \times g_{m3} \right]^2 \times R_s
\]

All the above mention FOM’s are used to differentiate between the proposed AlGaN/GaN gate recessed MOSHEMT device structure for different changes in drain-to-source voltages in terms of linearity performance and intermodulation distortions.

3 Simulation Results and Discussions

The accuracy and efficiency depend on proper meshing, dimensions, and precise parameters with minute observations. So, a fine meshing at the critical region of operations such as channel and source/drain edge is chosen for the device simulations. Results are generated for all the proposed structures and verified with the data available in the literature.

3.1 DC Analysis of the AlGaN/GaN HEMT, MOSHEMT and GR-MOSHEMT

Figure 2 represents the Transfer, Output, and Transconductance characteristics of the Conventional HEMT, MOSHEMT and Gate Recessed MOSHEMT. Figure 2(a) represents the transfer characteristics of AlGaN/GaN HEMT, MOSHEMT and Gate recessed MOSHEMT with fixed oxide and barrier layer thickness. The recessed gate shows a higher drain current than HEMT and MOSHEMT due to adding an extra dielectric oxide layer with the change in gate structure. It is observed that Recessed gate MOSHEMT achieved a maximum current density of 888 mA/mm compared to 651 mA/mm (in case of HEMT) and 781 mA/mm (in case of MOSHEMT) due to the structural modification of the gate. If I_on current increases sustainable way, it shows better improvement in the simulation results and device performance. The threshold voltage obtained for HEMT, MOSHEMT, and gate recessed MOSHEMT are -2.18 V, -1.23 V, and 0.5, respectively, from the \( I_{ds} vs. V_{gs} \) curve linear scale. Figure 2(b) shows the output characteristics curve of differently structured devices. The maximum current density of recessed gate MOSHEMT is 687 mA/mm for \( V_{gs}=1 \) V, 28.2% and 8.5% higher than HEMT and MOSHEMT, respectively. From this curve, we observed that a reduction in gate length and increment in width of gate recessed MOSHEMT structure leads to an increase
in DC characteristics. Figure 2(c) shows the transconductance \( g_m \) of differently structured devices at the drain bias of \( V_{DS}=10 \) V. It is calculated from the derivative of drain current to gate voltage at fixed drain voltage and expressed in Siemens. The high peak extrinsic \( g_m \) of gate recessed MOSHEMT was 225 mS/mm, much higher than HEMT and MOSHEMT devices. Gate controlling ability of recessed gate MOSHEMT increases due to reduction in the distance between gate and GaN-channel, so it shows better improvement than HEMT and MOSHEMT. So gate recessed MOSHEMT peak transconductance increases arbitrarily as compared to HEMT and MOSHEMT device structures. Threshold voltage and transconductance of recessed gate MOSHEMT show a strong impact due to the dielectric layer of \( Al_2O_3 \) (5nm) inserted between the gate and the AlGaN barrier layer and changes in gate structure.

Figure 3 shows a comparison of the gate leakage current performance of GaN/AlGaN HEMT, MOSHEMT and gate recessed MOSHEMT with the exact device dimensions in the log scale. The leakage current of gate recessed MOSHEMT is significantly lower than that of HEMT and MOSHEMT. The gate leakage current density of gate recessed MOSHEMT is almost 2-3 orders of magnitude lower than that of the MOSHEMT. Similarly, this way, the HEMT gate leakage current is almost 2-3 orders of magnitude lower than MOSHEMT. It is observed that there is an improvement in drain current due to the excellent insulating properties of \( Al_2O_3 \) for MOSHEMT and gate recessed MOSHEMT.

The insertion of \( Al_2O_3 \) between the gate electrode and the AlGaN barrier layer will work as an efficient gate insulator and decrease gate leakage current compared to HEMT. Furthermore, modification of gate electrodes also reduced the gate leakage current for gate recessed MOSHEMT.

Transconductance and gate-to-source capacitance behave oppositely concerning increment in gate-to-source voltage. The unit gain cut-off frequencies \( f_T \) are plotted for gate-to-source voltage \( V_g \) for different drain-to-source voltages in Fig. 5(a). It shows that cut-off frequency shows much better improvement when drain-to-source voltage increases linearly. Figure 5(b) shows the variation of Maximum Oscillation frequency concerning the gate-to-source voltage for different drain-to-source voltages. The maximum oscillation frequency is proportional to the cut-off frequency and anti-proportional to the gate-to-drain capacitance. It shows relative upward movements for increasing drain-to-source voltages.

### 3.2 AlGaN/GaN gate recessed MOSHEMT Analog/RF performance

Figure 4 shows the analog/RF behavior of AlGaN/GaN gate recessed MOSHEMT. Figure 4(a) shows the variations of drain current for gate-to-source voltage of GaN/AlGaN gate recessed MOSHEMT for different drain-to-source voltages. It shows that a higher current density of 888 mA/mm is achieved when \( V_{DS}=10 \) V compared to \( V_{DS}=5 \) V and 2.5 V. It is found that there is High transconductance of gate recessed MOSHEMT for \( V_{DS}=10 \) V compared to \( V_{DS}=2.5 \) and 5 V due to sustainable increases in ON Current, as shown in Fig. 4(b). In a strong inversion region, transconductance linearly increases with the increment of drain-to-source voltages. Figure 4(c) shows the intrinsic parasitic gate-to-source capacitance \( C_{gs} \), which is plotted with gate-to-source voltage \( V_g \) for different drain-to-source voltages. Parasitic capacitances depend on bias conditions, so there is variation in the values with changes in drain voltages. As seen in the figure, the parasitic capacitance shows a decrement for increasing drain-to-source voltages because the channel is tapered and pinched off near the drain region, so the channel will not be uniform. It shows a decrement when drain voltages increase.

Transconductance and gate-to-source capacitance behave oppositely concerning increment in gate-to-source voltage. The unit gain cut-off frequencies \( f_T \) are plotted for gate-to-source voltage \( V_g \) for different drain-to-source voltages in Fig. 5(a). It shows that cut-off frequency shows much better improvement when drain-to-source voltage increases linearly. Figure 5(b) shows the variation of Maximum Oscillation frequency concerning the gate-to-source voltage for different drain-to-source voltages. The maximum oscillation frequency is proportional to the cut-off frequency and anti-proportional to the gate-to-drain capacitance. It shows relative upward movements for increasing drain-to-source voltages.

### 3.3 Improved Linearity Parameters of the AlGaN/GaN GR-MOSHEMT

Device Linearity is the essential requirement for the proper functioning of electronic circuit elements. Different FOM’s parameters for linearity are \( g_{m2} \), \( g_{m3} \), VIP2, VIP3.
IIP3, and IDM3. High FOMs determine better device performance. Figures 6 and 7, and 8 show the different FOM parameters curves for proposed models.

Higher-order terms of transconductances (g_m's) are essential parameters for linearity analysis of the device. These are more important for applications like mobile

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**Fig. 4** Performance parameters analysis of gate recessed MOSHEMT for different drain voltages (a) I_d-V_g characteristic curves (b) g_m-V_g characteristic curves (c) C_{gs}-V_g characteristic curves

**Fig. 5** RF Performance parameters analysis of gate recessed MOSHEMT for different drain voltages (a) f_T-V_g characteristic curves (b) F_{Max}×V_g characteristic curves

**Fig. 6** Transconductance parameter analysis of gate recessed MOSHEMT for different drain voltages (a) g_{m2}×V_g characteristic curves (b) g_{m3}×V_g characteristic curves
communications, where mobile receivers are extensively analyzed and designed for high linearity. Higher-order transconductances like $g_{m2}$ and $g_{m3}$ have to be suppressed for making the circuit work in a real-time environment. Figure 6 shows the variation of second-order and third-order differential of transconductances, $g_{m2}$ and $g_{m3}$, for the gate-to-source voltage for different drain-to-source voltages.

For low distortion and higher linearity, a high value of VIP2 and VIP3 is required. When the gate is in a moderate region, it will generate a peak for low gate bias. Second and third order Voltage intercepts points VIP2 and VIP3 for the gate-to-source voltage variation in drain-to-source voltages are shown in Fig. 7.

Input Intercept point of the third-harmonic (IIP3) and Intermodulation distortion of third-harmonic (IDM3) to gate-to-source voltage is demonstrated by Fig. 8.

Carrier transport efficiency and better gate control over the channel lead to improve the IIP3. When the drain-to-source voltage increases, IIP3 also shows better improvement.

The comparative analysis of gate recessed MOSHEMT for different drain-to-source voltages is shown in Table 1. It is clearly understood from the table that gate recessed MOSHEMT shows better results for $V_{ds}=10$ V due to sustainable increment in higher current density and transconductance.

### Table 1: AlGaN/GaN gate recessed MOSHEMT simulation Results for different drain-to-source voltages

| S.No. | Parameters              | Unit  | $V_{ds}=2.5$ V | $V_{ds}=5$ V | $V_{ds}=10$ V |
|-------|-------------------------|-------|----------------|--------------|---------------|
| 1.    | Threshold voltage       | V     | 0.5            | 0.5          | 0.5           |
| 2.    | Current density         | mA/mm | 481            | 673          | 888           |
| 3.    | Trans conductance       | mS/mm | 140            | 180          | 225           |
| 4.    | Gate-to-source capacitance | pF  | 38.75          | 40.65        | 42.75         |
| 5.    | Cut-off Frequency       | GHz   | 0.50           | 0.69         | 0.91          |
| 6.    | Max. Oscillation Freq.  | Hz    | $6.81 \times 10^{-6}$ | $7.45 \times 10^{-6}$ | $8.52 \times 10^{-6}$ |
| 7.    | VIP2                    | V     | 53.77          | 23.70        | 17.87         |
| 8.    | VIP3                    | V     | 55.64          | 61.80        | 68.07         |
| 9.    | IIP3                    | dBm   | 1.72           | 2.17         | 2.57          |
| 10.   | IDM3                    | dBm   | $1.50 \times 10^{10}$ | $1.89 \times 10^{10}$ | $2.96 \times 10^{10}$ |
4 Conclusion

This work presents a comparative analysis of analog/RF parameters for AlGaN/GaN HEMT, MOSHEMT, and Gate recessed MOSHEMT, which may provide a basic idea for new researchers for starting research in this field. Analog/RF and High linearity parameters of AlGaN/GaN on-state (HEMT), off-state (MOSHEMT), and Gate recessed MOSHEMT have been investigated by developing analytical models, and the results have been verified using simulations. Both on-state and Off-State devices are very much suited for GaN RF and power device applications. The Al2O3 oxide layer between the Schottky-gate and AlGaN barrier-layer in the Off-state device structure improves the on current. It reduces the gate leakage current compared to the on-state device structure. For high power applications, a modified gate recessed MOSHEMT structure is best suited on HEMT state device structure. For high power applications, a modified gate recessed MOSHEMT structure is best suited on HEMT and MOSHEMT. The maximum transconductance gate recessed MOSHEMT structure is best suited on HEMT state device structure. For high power applications, a modified gate recessed MOSHEMT structure is best suited on HEMT and MOSHEMT. The maximum transconductance (g_m) for GR-MOSHEMT at VDS=10 V is higher than 37.7% and 25% for VDS=2.5 and 5 V, respectively. Likewise, The maximum Cut-off frequency (fT) for GR-MOSHEMT at VDS=10 V is higher than 82% and 31.8% for VDS=2.5 and 5 V, respectively. In comparison to HEMT and MOSHEMT devices, gate recessed MOSHEMT shows better improvement in gate leakage current, transconductance, breakdown voltage, 2-DEG charge density, the gate to drain capacitance, and Ion/Ioff ratio. It shows a better improvement in the high linearity parameters of VIP2, VIP3, IIP3, and IDM3.

Author Contributions The authors have contributed mutually regarding this paper.

Data Availability All data available within the manuscript.

Declarations

Ethics Approval and Consent to Participate The authors declared that the manuscript ethics is approved as per the journal.

Consent for Publication The authors give full consent for the publication of this research work.

Conflict of Interest Not applicable.

Conflict of Interest The authors declare that they have no conflict of interest.

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