Design and Enhancement of Gate-Stacked Recessed-Gate HEMTs with Back-Barrier for RF Applications

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Abstract. Gate electrostatic control has become crucial for the reliable working of enhancement-mode GaN based high-frequency and power transistors. In this work, recessed-gate GaN HEMT with a stacked gate dielectric and an AlGaN back-barrier layer is analyzed using TCAD simulations and is compared with a former recessed-gate design with the same back-barrier arrangement.The presence of stacked dielectric improves gate-to-channel electrostatic coupling and increases the vertical electric-field control resulting in the effective improved transconductance and higher drain current drive capability.The effect of changing the work function of gate metal is analyzed regarding threshold voltage, transconductance, and transfer characteristics. The results of the simulations suggest that the proposed design shows much less off-state leakage and greater electrostatic integrity than the device in the benchmark. Also, the characteristics of the device such as threshold voltage, transconductance, drain current that show a direct current response, improve greatly as a result of the confinement of the carriers increased by the AlGaN backbarrier layer. The synergistic design approach of the proposed HEMT shows a very promising prospect to be military grade augmented.

Keywords: Back-barrier layer (BBL) · TCAD device simulation · AlGaN/GaN HEMTs · Stacked gate dielectrics · Two-dimensional electron gas (2DEG) · Gate-recessed HEMT.

1 Introduction

HEMTs utilizing wide bandgap semiconductors have emerged as critical building blocks toward high-frequency, high-power, and high-temperature electronic systems. Among the available platforms, AlGaN/GaN HEMTs have achieved superior performance owning to their better material properties, such as wide energy bandgap, high breakdown electric field, high electron saturation velocity, and excellent thermal stability. These advantages make GaN-based HEMTs particularly popular in RF, microwave, and power switching applications where conventional silicon-based devices face fundamental limits.The basic operating mechanism of AlGaN/GaN HEMTs involves the creation of a high-density

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two-dimensional electron gas at the heterointerface, which occurs via spontaneous and piezoelectric polarization, without any doping. As a result, it has been possible to achieve high mobility values, in addition to being able to handle high current, in AlGaN/GaN HEMTs, making them popular in applications requiring high output power, switching speed, and tolerance to high temperatures [3-5]. Consequently, many researchers have focused their attention on AlGaN/GaN HEMTs in applications requiring high output power, switching speed, and high temperature tolerance [6-8].

Nevertheless, due to those benefits, conventional AlGaN/GaN HEMTs are inherently depletion-mode devices (normally-on devices), which requires a negative gate bias to turn them off. Although this characteristic may be acceptable for specific RF applications, it presents safety and complexity issues for power electronics systems, for which fail-safe operations are mandatory. Recently, there has been a great interest in developing enhancement-mode devices with positive threshold voltage for any kind of high-power and high-speed switching systems to minimize standby power dissipation and reduce the complexity of gate drive circuits [1, 9].

Various methods have been suggested to achieve normally off GaN HEMTs, such as thinning the barrier, F ion implantation, p-type GaN gates, or others using gate recesses [10-11]. Among these methods, recessed-gate technology has received particular interest because it not only integrates well within existing manufacturing processes, but it also allows for unified control of effective barrier thickness. In this approach, an etched AlGaN barrier in the region under the gate increases the distance between AlGaN and the metal of the gate, thus reducing the 2DEG to zero, turning off the transistor, and making it an enhancement mode device with enhanced control over the threshold voltage [7].

In recessed-gate HEMTs, the appropriate gate insulator choice is critical for achieving an optimized electrostatic control, minimization of gate leakage current, and improvement in the interface quality. High-κ gate insulators, like Al_2O_3, Si_3N_4, and SiO_2, were explored to suppress gate leakage currents and promote gate–channel coupling [9,12]. Among the various candidates of insulator, Al_2O_3 holds a particular potential owing to its higher κ value and superior stability at the interface with III–nitride semiconductor materials.

Another critical challenge in scaled GaN HEMTs is carrier leakage into the buffer layer, which degrades off-state performance and limits high-frequency operation. In this respect, this issue has been overcome by the incorporation of a back-barrier layer normally made of AlGaN with tailored aluminum mole fraction. The back barrier increases the conduction band offset beneath the channel, effectively confining the 2DEG and suppressing the parasitic buffer leakage paths [1,8,14]. This improved carrier confinement enhances the off-state leakage, threshold voltage stability, and short-channel behavior; therefore, BBL-assisted HEMTs are highly suitable for RF and power applications.

It has been shown in recent works that the optimization of Al composition and thickness of the AlGaN backbarrier layer can noticeably affect selected parameters of device performance like drain current, transconductance, threshold voltage, and Ion/Ioff current ratio [1, 8, 14, 21]. In addition, recessed gate configurations, gate dielectric, and backbarrier engineering add further degrees of freedom to optimize the electric field in GaN HEMT structures.

On the other hand, HEMTs based on GaN have their own strengths compared with other wide bandgap materials such as silicon carbide (SiC) [16, 17]. For example, despite low thermal conductivity, SiC has a number of disadvantages such as high price, limited wafer diameter, and low polarization strengths, which hinder flexibility in designing HEMT heterostructures. On the contrary, it is possible to lay down a thick layer of GaN on a large-scaled substrate with a high degree of flexibility provided by polarization-induced charge in heterostructure engineering. Presently, HEMTs on GaN are being extensively used for RF amplifiers, power convertors, terahertz applications, and optoelectronic devices [17-24].

In this regard, the current study aims to design and optimize recessed gate AlGaN/GaN HEMTs with a stacked gate design featuring an AlGaN back barrier layer for application in RF circuits. The effect of stacked dielectrics in the gates, work function variation in gates, and the AlGaN back barrier on the electric fields and electrical characteristics of a recessed gate AlGaN/GaN HEMT is computationally assessed with a TCAD tool. The efficacy of the proposed recessed gate AlGaN/GaN HEMT is compared to a standard recessed gate AlGaN/GaN HEMT with an identical AlGaN back barrier layer to illustrate the efficacy of stacked gates in these devices. Such an approach will be helpful in understanding improved threshold voltage control, reduced leakage current, increased transconductance, and improved electric field characteristics of AlGaN/GaN HEMTs to be designed for application in modern RF circuits.

The novelty of this work stems from the synergy of gate dielectric stacking and AlGaN back-barrier implementation in a recessed-gate GaN HEMT. In contrast to previous works that have emphasized optimization using single strategies, the methodology adopted herein enables not only better electrostatics but also suppression of leakage current and improved transconductance. The effect of variation in gate work function has been considered as well.

2 Device Structure and Simulation Parameters

The device here is a gate stacked recessed gate AlGaN/GaN high electron mobility transistor structure with the inclusion of an$Al_xGa_{1-x}N$ back barrier layer. This structure is grown on a sapphire substrate with a subsequent gallium nitride nucleation layer followed by an unintentionally doped gallium nitride buffer layer that improves the crystal quality and transport properties of the device. A thin layer of aluminium gallium nitride is then deposited on the gallium nitride layer, which induces the 2DEG at the AlGaN/GaN interface that acts as the principal conduction channel.

For the purpose of achieving the enhancement-mode, the barrier is selectively etched under the gate. In this process, the barrier is thinned down, which leads to the depletion of the 2DEG with zero voltage. In the device for threshold voltage control with sufficient current drive capability, a thin barrier of AlN is placed on top of the barrier. The main purpose of implementing this barrier is to allow for less scattering in the interface region with high electron mobility [7,9].

In accordance with the proposed concept of the presented device, the stacked gate dielectric concept is used for improved gate electrostatic coupling. Additionally, gate leakage current is suppressed with the help of a high-κ Al_2O_3 dielectric, which is placed directly underneath the gate. This ensures improved gate channel density. Moreover, the stacked gate concept helps to effectively modulate the channel charge density, thereby playing an impactful role in achieving improved gate transconductance.

An AlGaN back-barrier layer (BBL) is added below the GaN channel region for enhancing the carrier confinement properties. Adding a BBL enhances the conduction band offset value in the region below the channel, thereby suppressing the electron spill-out into the buffer layer. As a matter of fact, an Aluminum fraction $x = 0.25$ is incorporated in the back barrier to enhance confinement by maximizing the energy barrier between the well and the buffer by making the conduction band have a quantum well potential.

The lateral size of the device are chosen to ensure suitability for RF applications, and the gate length is fixed at 1 μm to achieve balanced device performance. The source and drain contacts are modeled with perfect ohmic contact to the 2DEG channel region. The simulations of all devices are carried out using the Silvaco ATLAS TCAD simulator, where a 2D simulation model is adopted. The polarization at AlGaN/GaN hetero-interface boundaries is taken into account for a correct 2DEG modeling process. Field-dependent and physis-controlled mobilities are adopted for describing transport phenomena of charge carriers, and Shockley-Read-Hall recombination is modeled for describing carrier recombination effects. The Fermi-Dirac statistics model is turned on to provide a correct result for a high-density carrier system.

The simulation study is focused on correlating the combined effects of gate recessing, stacked gate dielectrics, and back-barrier engineering on the main DC and RF performance parameters, namely threshold voltage, drain current, transconductance and off-state leakage current. The proposed gate-stacked recessedgate HEMT with back-barrier is benchmarked against the conventional recessedgate structure to put into perspective the clear performance improvements achieved through the synergistic device design approach. Table 1 presents a comparative overview of key material properties of Silicon (Si), Silicon Carbide (SiC), and Gallium Nitride (GaN), highlighting the advantages of GaN for high-power and high-frequency device applications. GaN has a substantially larger bandgap and a much higher critical electric field than Si and SiC, making it possible to support higher voltage and lower probabilities of breakdown. Furthermore, GaN supports higher electron mobility and electron saturation velocity, which are critical for fast switching and better transconductance for HEMT. Although SiC supports remarkably high thermal conductivity, GaN is preferred for better compromises on electrical performance and ability

Table 1. Comparison of Key Material Properties of Si, SiC, and GaN [1]

Property	**Si**	**SiC**	**GaN**
Energy bandgap, E_g (eV)	1.1	2.86	3.39
Critical electric field, E_c (MV/cm)	0.3	2.0	3.33
Dielectric constant	11.9	9.8	9
Electron mobility (cm^2/V·s)	1350	650	1700
Electron saturation velocity (cm/s)	1×10^7	2×10^7	2.5×10^7
Melting point (°C)	1415	650	1700
Thermal conductivity (W/cm·K)	1.3	4.9	1.3

to form the heterostructure, primarily because GaN supports high polarization levels, making it easier to provide a high-density two-dimensional electron gas (2DEG). GaN is thus selected as the channel material for the proposed RecessedGate HEMT structure based on back-barrier enhancement.

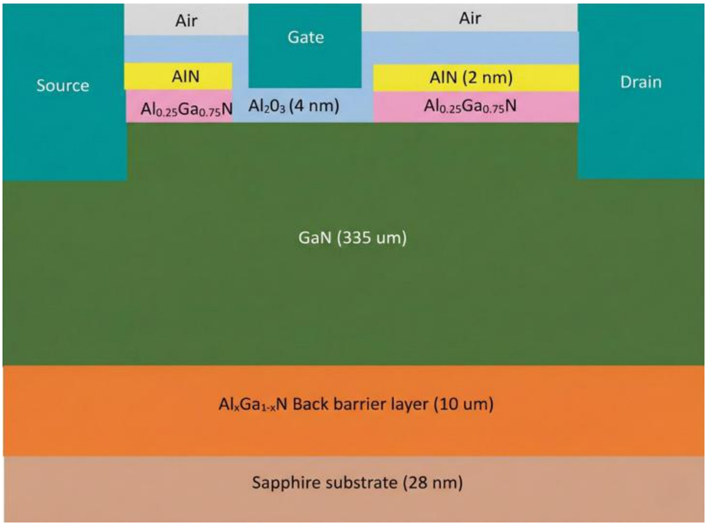

Fig. 1. Structure of a recessed-gate GaN HEMT with a back barrier layer (BBL).

Figure 1 depicts the conventional recessed-gate structure of the GaN HEMT with an AlGaN back-barrier layer (BBL) but without gate dielectric stacking. In this conventional structure, the recessed-gate configuration is obtained using the selective etching of the

AlGaN barrier layer, allowing the depletion of the twodimensional electron gas (2DEG) without the help of gate bias, thus realizing a normally-off device [2, 4]. The inclusion of the AlGaN back-barrier layer in this conventional structure enhances the carrier confinement properties, thus blocking the electrons from flowing into the buffer layer, thus decreasing the off-state current [1, 5]. Nevertheless, since the conventional structure in this case involves a single gate dielectric, the lack of optimization in the gate-channel coupling and the vertical field cannot match the efficiency of the gate-stacked structure, thus the need for the comparison, as explained in the following sections.

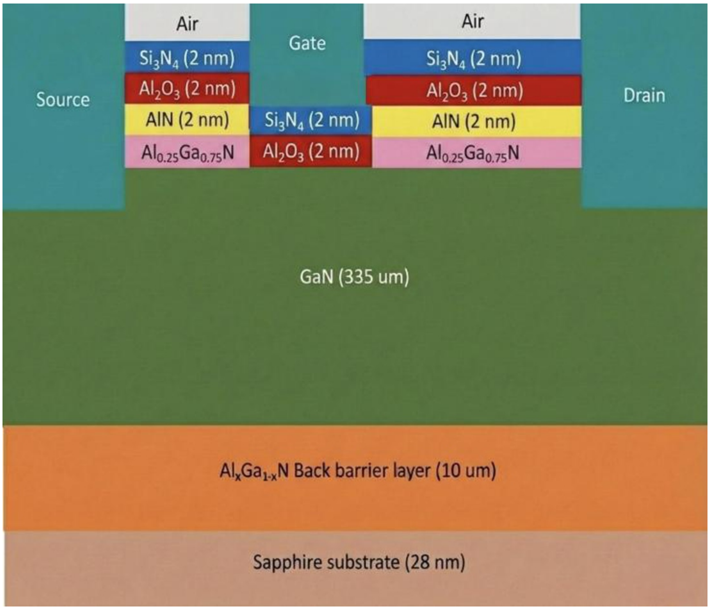

Fig. 2. Structure of a recessed-gate GaN HEMT with gate stacking and a back barrier layer (BBL).

In order to achieve the normally off mode in the device, AlGaN back barrier layer is selectively etched under the gate area. Thus, in this way, this particular device structure will result in a recessed-gate type of structure for the device, leading to thinning of the barrier and depletion of two-dimensional electron gas at zero-bias conditions [2,4]. In order to achieve efficient gate to channel, the stacking type of gate structure has been developed, which aids in handling single dielectric for coupling or modulation of vertical electric field in combination with single gate coupling or modulation in an effective way, improving electrostatic control or threshold voltage of a particular device [4,6]. By using all these methods together, overall performance of devices will be enhanced [1,3]. The key difference between the proposed device and the benchmark device is based on their gate insulator structure, as depicted in Figure 2. In contrast to the benchmark device with a single 4 nm thick Al_2O_3 gate insulator layer, the proposed device uses a stacked gate insulator structure with 2 nm Si_3N_4 and another 2 nm Al_2O_3 layer. The above-described device structure design is expected to provide stronger gate-channel electrostatic control and thus facilitate fast-switching action as well as efficient processing of higher-level power with less power dissipation.

This device configuration is suitable for the current technology of GaN fabrication . The recessed gate can be formed through etching procedures, while the Si_3N_4/Al_2O_3 dielectrics can be grown using conventional techniques like Atomic Layer Deposition (ALD) and Chemical Vapor Deposition (CVD). Thus, the proposed device is practical and realistic for manufacturing within the constraints of conventional procedures.

3 Results and Discussion

The gate recess confines the two-dimensional electron gas (2DEG) to a well-defined region directly beneath the gate, thereby providing improved channel control and enhanced enhancement-mode operation [1, 7]. This localized confinement reduces the effective source-to-channel resistance, which leads to an increase in the transconductance (g_m). In addition to having a stacked gate dielectric in the designed device, a higher extent of electrostatic coupling between the gate and the channel is achieved, ensuring a successful modulation of the 2DEG. As a result, DIBL effects are suppressed in addition to there being no noticeable current leakage. Because of the improved material properties and compatibility and because of the inherent qualities associated with the AlGaN heterostructure, the presented gate-stacked recessed-gate HEMT structure is suitable for high-frequency, high-power, and high-temperature operations as cited in [2, 14, 18].

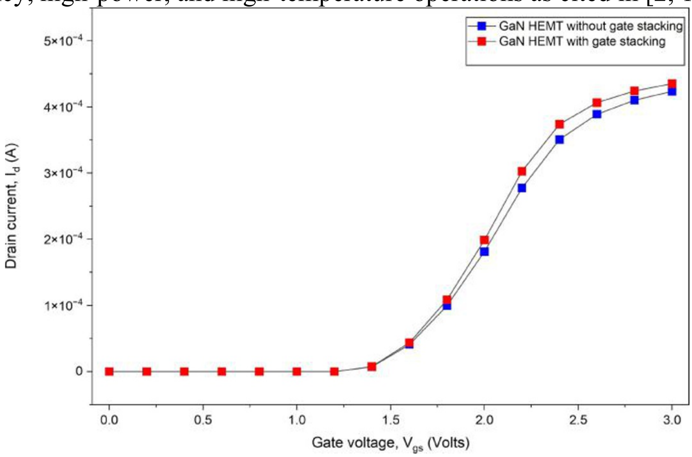

Fig. 3. Transfer characteristics (I_d–V_{gs}) of recessed-gate GaN HEMTs with and without stacked gate dielectric and AlGaN back-barrier layer.

From Fig.3 above, it is very clear that the gate-stacked recessed-gate HEMT has a sharper turn-on device operation than the conventional recessed-gate HEMT. A sharper turn-on is a very desired condition especially at high-frequency device operations. Moreover, the drain current has an enhancement in the entire current operation for the gate-stacked recessed-gate HEMT as compared to the conventional HEMT. Higher drain current values are a result of the stronger modulation of the electric field and carrier confinement by the use of the back barrier composed of the AlGaN layer. The high gate work function of 5.7 eV suggests that the device can operate stably in the enhancement mode. The improvement of device performance seen from the results may be ascribed to the stronger electrostatic control presented by the stacked gate dielectric structure. The multi-dielectric structure enhances the gate capacitance without increasing gate leakage currents. The result is stronger gate-to-channel electrostatic coupling. Additionally, this increases vertical control of the two-dimensional electron gas (2DEG). The vertical control of 2DEG facilitates improved confinement and transport of carriers. The other factor is that there is a back-barrier created by the AlGaN layer. The back-barrier prevents spillover of carriers into the buffer layer. The back-barrier prevents leakage currents. The sum of gate stacking and back-barriers causes improved drain-to-source current drive and transconductance, thus verifying the success of the recessed gate HEMT with gate stacking.

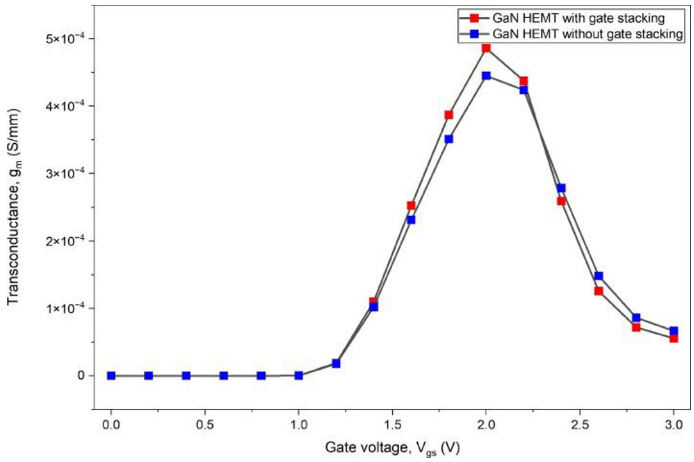

Fig. 4. Comparison of transconductance (g_m–V_{gs}) for recessed gate GaN HEMTs with and without stacked gate dielectric.

Figure 4 shows the variation of transconductance as a function of gate voltage for recessed-gate GaN HEMTs with and without a stacked gate dielectric, both with an AlGaN back-barrier layer. The gate-stacked device evidently has a much higher peak transconductance than its counterpart conventional recessed-gate HEMT, and has a wider profile around the peak region. This is indicative of a much improved gate modulation efficiency and better channel charge control in the proposed structure. The peak transconductance shifting to slightly higher gate bias also indicates better electrostatic coupling between the gate and the channel.

The transconductance enhancement (g_m) is mostly related to the improved electrostatic gate control, which is achieved in the stacked dielectric structure. Increasing the effective capacitance (C_{gs}) leads to an improved connection between the applied gate electric potential and 2DEG, making it possible to have efficient modulation of the 2DEG. In addition, reducing electric-field crowding near the edge of the gate in the stacked dielectric structure improves mobility, hence leading to an enhancement in peak transconductance values.

Such an improvement is further realized with the *AlGaN* back-barrier layer, which confines the carriers in the channel region and suppresses buffer leakage, thereby enhancing the efficiency of carrier transport. Consequently, the gatestacked recessed-gate HEMT demonstrates enhanced transconductance performance, therefore being very suitable for applications at RF and high-frequency, where gain, linearity, and frequency response heavily rely on g_m.

Table 2. Device Structural Parameters Used for Simulation

No.	Device Parameter	Value
1	Gate electrode thickness (T_g)	0.028 μm
2	Source region thickness (T_s)	0.036 μm
3	Drain region thickness (T_d)	0.036 μm
4	Physical gate length (L_g)	1 μm
5	Source-side access length (L_s)	1 μm
6	Drain-side access length (L_d)	1 μm
7	Source-to-gate spacing (L_{SG})	1 μm
8	Gate-to-drain spacing (L_{GD})	3 μm
9	AlN layer thickness (T_{AlN})	2 nm
10	Al_2O_3 layer thickness (stacked gate dielectric) ($T_{Al_2O_3}$)	2 nm
11	Si_3N_4 layer thickness (stacked gate dielectric) ($T_{Si_3N_4}$)	2 nm

Table 2 summarizes the key structural parameters used for the TCAD simulation of the proposed gate-stacked recessed-gate GaN HEMT. These optimum device dimensions are chosen to ensure strong electrostatic control and suitability for RF operation. A gate length of 1 μm with optimized source-to-gate and gate-to-drain spacings is used, providing an excellent trade-off between the current drive capability and short-channel effects. The thin AlN spacer layer leads to an improved interface quality and carrier transport, while the stacked gate dielectric composed of Al_2O_3 and Si_3N_4 enhances the gate-to-channel coupling and suppresses the gate leakage. Further, the use of the AlGaN back-barrier layer improves the carrier confinement in the channel region. Improved transconductance, reduced off-state leakage, and stable threshold voltage collectively arise from these structural parameters, proving that the proposed device structure is indeed effective for RF applications. The advantage of this stack is that dielectrics provide a synergistic improvement in the electrostatic integrity of the gate. A combination of Si_3N_4 and Al_2O_3 imparts a better gate-to-channel coupling while enhancing the vertical electric field significantly higher than for a single-layer oxide. This design suppresses offstate leakage, which is commonly one of the weak points in high-frequency GaN transistors, due to reduced interface trap density. This stack enables a higher transconductance-the gate becomes more sensitive and efficient in controlling the current-and allows better stability for the threshold voltage. In this way, the device becomes more reliable for "military-grade" applications where the transistor must work with consistency under very extreme high-power and high-frequency conditions.

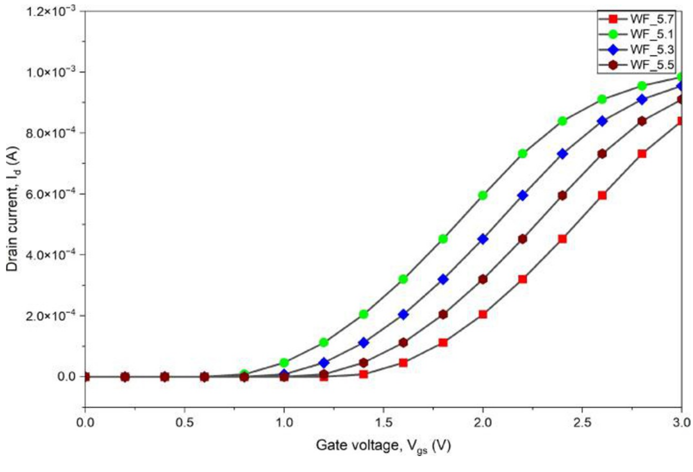

Fig. 5. Transfer characteristics (I_d–V_{gs}) of gate-stacked recessed-gate GaN HEMTs for different gate metal work functions.

Figure 5 shows the transfer curves (I_d vs V_{gs}) of the designed GaN HEMT with the gate-stacked recessed-gate structure for different gate metal work functions. It has been noticed that with an increase in the gate metal work function ranging from 5.1 eV to 5.7 eV, there has been an increase in the threshold voltage and the drain current curves accordingly. The higher the threshold voltage, the higher the gate metal work function, thus making it harder to activate the device. With a lower work function of 5.1 eV, there is a larger drain current I_d with a given gate voltage, suggesting a stronger ability of the gate to control channel creation and a more efficient transport of carriers. Conversely, an increased work function leads to a lowering of I_d due to a delay in creating channels and a decrease in carrier concentration in the 2DEG. The stacked gate dielectric increases the electrostatic coupling between the gate and the channel. On the other side of the structure, the AlGaN back-barrier layer prevents the confinement of the carriers inside the buffer. The effect of these two aspects is that gate work function engineering becomes very important for improvement of gate-stacked recessed-gate GaN HEMTs.

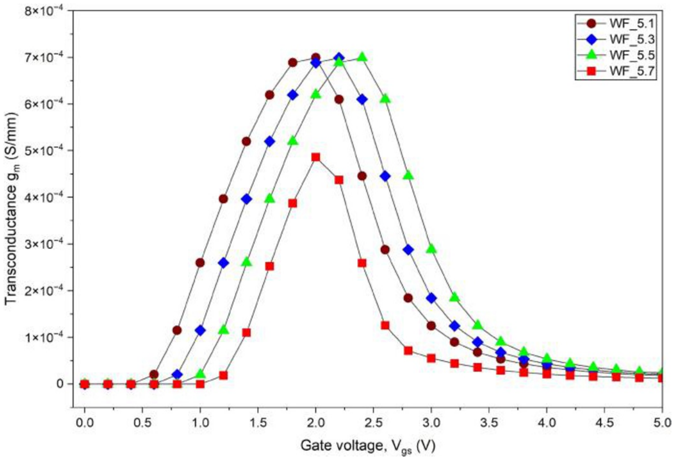

Fig. 6. Transconductance (g_m–V_{gs}) characteristics of gate-stacked recessed-gate GaN HEMTs for different gate metal work functions.

In Figure 6, the transconductance (g_m) versus gate voltage (V_{gs}) is represented for the proposed gate-stacked recessed-gate GaN HEMT for various values of the gate material work function. From the graph, the peak transconductance value is noted to decrease and shift towards a greater value of the gate voltage with the rise in the value of the gate material work function from 5.1 eV to 5.7 eV. The shift in the peak transconductance is due to the rise in the threshold voltage for the materials with greater work functions, requiring a greater gate voltage for obtaining a high charge concentration in the channel region. It can be observed that the structure with the lower work function (5.1 eV) supports maximum peak transconductance, signifying stronger coupling between the gate and the channel, along with a greater effect of modulation of the two-dimensional electron gas (2DEG). On the other hand, an increase in work function values leads to weaker peak g_m due to a substantial delay in forming the channel along with an increase in carrier concentration in the buffer region. However, due to the stacked gate dielectric design, electrostatic control is improved, along with an effective carrier confinement in the channel facilitated by the existence of the AlGaN back-barriers, therefore suppressing buffer leakage without affecting transconductance.

Table 3. Mapping of Gate Work Function to Practical Metal Gate Materials

Work Function (eV)	Corresponding Gate Metal
5.1	Titanium Nitride (TiN)
5.3	Nickel (Ni)
5.5	Nickel (Ni) / Palladium (Pd)
5.7	Platinum (Pt)

Table 3 shows the correlation between the selected gate work function and the gate material used during implementation. The selection of the range of work function (5.1 5.7 eV) is based on common metals used in GaN device design. It can be seen from the table above that the use of a low work function value such as 5.1 eV, which corresponds to TiN, increases the flow of electrons to the channel, hence increasing the drain current and transconductance, while a high work function such as 5.7 eV results in a higher threshold voltage. A trade-off exists between the two states of the transistor, where a low work function is favorable for RF applications, where high current drive is desired. On the other hand, high work functions allow for normally off state operation and energy savings.

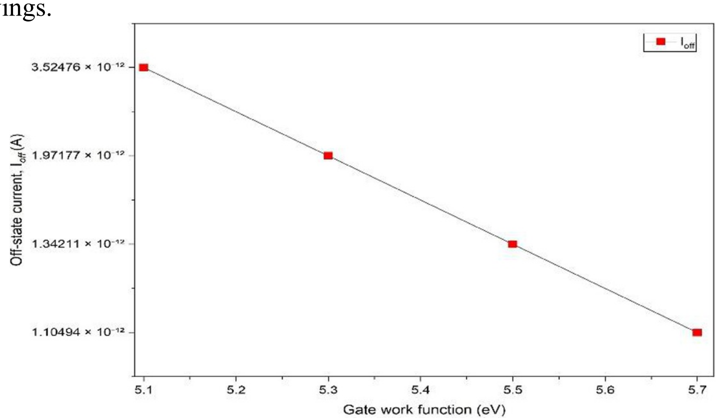

Fig. 7. Variation of off-state current (I_{off}) with gate metal work function for gatestacked recessed-gate GaN HEMTs.

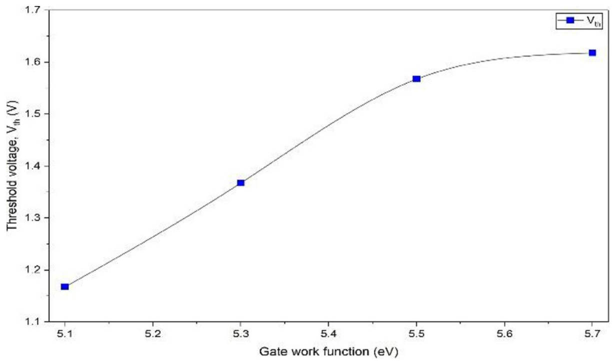

Fig. 8. Variation of threshold voltage (V_{th}) with gate metal work function for gate-stacked recessed-gate GaN HEMTs

Figure 7 illustrates the effect of off-state current (I_{off}) with respect to gate metal work function in the proposed gate-stacked recessed-gate GaN HEMT design. It is observable that when the gate metal work function varies from 5.1 eV to 5.7 eV, there is a monotonically decreasing effect in I_{off} . This is because, for higher I_{off} values, it requires an increase in the threshold voltage, hence preventing an increase in the current due to reduced metallurgical gating effects at zero bias.

The reduction in off-current signifies an improvement in the control capability of the gate and the electrostatic integrity of the device. The strong electrostatic coupling between the gate and the channel due to the stacking effect in the gate dielectric and the effective carrier confinement in the channel due to the backbarrier layer of AlGaN efficiently lower the off-state currents in the proposed gate-stacked recessed-gate HEMT structure, which is necessary for proper functioning in the enhancement mode as well as for low power consumption in RF circuits.

Figure 8 illustrates how the threshold voltage (V_{th}) depends on the gate work function for the proposed gate-stacked recessed gate GaN HEMT. From the result, it can be found that with the increase of gate work function value from 5.1 eV to 5.7 eV, the threshold voltage also gradually increases with a monotonically increasing trend. The reason for this trend is that a higher work function represents a higher barrier at the gate-channel interface, which leads to a higher gate voltage for channel formation.

The positive threshold voltage with increasing work function indicates the effective enhancement-mode operation of the device. The gate dielectric stack helps increase the electrostatic field coupling for a better gate-channel potential. The back-barrier layer of AlGaN helps improve the carrier confinement capabilities for the channel region. Thus, a high threshold voltage with less current degradation has been obtained. Accordingly, the proposed gate stack recessedgate HEMT device is appropriate for use in RF power applications.

Table 4. Comparison of Key Device Parameters between Conventional and Proposed Gate-Stacked HEMTs

Parameter	Conventional HEMT	Proposed (Stacked) HEMT	% Change
V_{th} (V)	1.02375	1.16734	↑ 14.02%
$I_{D,max}$ (A/mm)	4.08676×10^{-5}	4.61337×10^{-5}	↑ 12.89%
$g_{m,peak}$ (S/mm)	2.31293×10^{-4}	2.59906×10^{-4}	↑ 12.36%
I_{off} (A)	3.75725×10^{-12}	3.52476×10^{-12}	↓ 6.18%

From the comparative analysis shown in Table 4, it is evident that there is a performance gain of the proposed gate-stacked recessed-gate GaN HEMT when compared to the conventional one under similar operating conditions, while maintaining the same gate work function of 5.1 eV. As seen from the table above, the proposed HEMT shows an improvement of 12.36% in peak transconductance (g_m) and 12.89% in maximum drain current ($I_{D,max}$), indicating higher level of gate control and carrier transport in the proposed one. The threshold voltage (V_{th}) also improves by 14.02%, which clearly implies better enhancement-mode characteristics. In addition, the off-state leakage current (I_{off}) is significantly reduced by 6.18%, proving its effectiveness in leakage suppression due to its stacked gate structure along with the presence of a back barrier layer. Thus, the performance of the proposed gate-stacked HEMT structure is validated from the above analysis.

Though the current study mainly emphasizes the parameters of the DC analysis, the improvement in the value of the transconductance and the drain current can be considered an indication of better RF performance. The increased value of the transconductance (g_m) leads to an increase in the cutoff frequency (f_T), while the decrease in the leakage current improves signal efficiency.

4 Conclusions

In this work, the use of a gate-stacked recessed-gate GaN HEMT with a backbarrier layer of AlGaN has been investigated to enhance electrostatic control and RF performance. The recessed-gate structure effectively confines the 2DEG below the gate, facilitating stable enhancement-mode operation with improved threshold voltage characteristics. The introduction of a stacked gate dielectric significantly enhances the gate-to-channel electrostatic coupling, leading to a better modulation in channel charge that results in a higher drain current and transconductance, as confirmed by the transfer and g_m characteristics. The AlGaN back-barrier effectively suppresses the carrier leakage into the buffer region leading to a significant off-state current reduction and improved electrostatic integrity. Moreover, variation in gate metal work function shows effective tunability of threshold voltage, drain current, and transconductance, thereby optimizing the trade-off between current drive and leakage. The combined effects of recessed-gate geometry, gate stacking, and back-barrier confinement validate the proposed device as a reliable enhancement-mode GaN HEMT, making it very suitable for low off-state leakage, stable threshold voltage, and improved transconductance in RF applications.

Disclosure of Interest: The authors have no competing interests to declare that are relevant to the content of this article.

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