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Field Plates Effects on the GaN HEMT Device for High Power and Speed Applications

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ABSTRACT

GaN devices are appropriate for power applications because of the unique material features of GaN, which provide GaN HEMTs with low R_on and high breakdown voltage (VB). Field Plates (FP) are used to improve the efficiency of a conventional HEMT for power applications while maintaining the device's dimensions. Field Plate (FP) technology has been shown to improve HEMT power performance significantly. The HEMT's break-down voltage has been increased as part of the improvement. Therefore, using Silvaco-ATLAS two-dimensional simulation, the principle and compute performance of the standard HEMT and the HEMT with the field plate (FP) have been explored in this paper. The results obtained may lead the path to an improved and efficient approach to the production of high-power devices that can be used in power electronics applications. The breakdown voltage of the device rises from 44 V of the device without FP to 125 V at SFP, 402 V at T-Gate, 429 V at both GFP and SFP and finally to 515 V at GFP by choosing the right field plate structure and field plate length. The result shows an excellent ability to improve the GaN HEMT for power applications by using different types of field plats without increasing the dimension of the simulated device. Also, the single-peak of the electric field is replaced with multi-peaks and the distribution of the electric field will be uniform by using a field plate.

Keywords:

GaN HEMT; Silvaco; Field plat; RF characteristics; C-V characteristics.

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1 INTRODUCTION

The basic component utilized in modern electronics is high electron mobility transistors (HEMT) devices, which are based on two-dimensional electron gas. It has been extensively reported in recent years [1], [2], [3], [4], that GaN HEMTs have been recognized to be better choices for high-frequency and high-power applications. High Electron Mobility Transistors (HEMTs) are Field Effect Transistors (FETs). HEMT devices exhibit the two-dimensional electron gas (2DEG) phenomenon. A 2DEG exists when electrons are limited to the contact of two different materials, such as the interface between GaN and AlGaN. In GaN HEMT devices, the field plate structure is essential for high frequency and high output power operations. Field plates reduce the vertical electric peak field along the gate edge toward the drain, which increases the breakdown voltage [5], [6], [7], [8]. Also, Field Plates (FP) are utilized to improve the typical HEMT's performance for power applications while maintaining the device's size. Many FP connection techniques, including air bridges [9], slant FPs [10], multiple FPs [11],[12], and others, have been used in device structure design over the years to push the breakdown voltages of these GaN-based devices to a higher level. In this paper, the rectangular GaN HEMT device that had been simulated in Silvaco Atlas must be developed with a gate field plate (GFP) and source field plate (SFP). The addition of these plates will increase the breakdown voltage of the device and then enhance the performance of the device.

2. SIMULATION MODEL AND DEVICE STRUCTURE

In [13], the AlGaN/GaN was compared with InAlGaN/GaN, and the InAlGaN/GaN heterostructure exhibits a significantly higher concentration of 2DEG as a result of the use of a thin InAlGaN barrier. Therefore, the simulated device of this work is InAlGaN/GaN HEMT which is designed on 1.5 micron SiC substrates as shown in Figure (1). The thickness of the passivation layer (Si3N4) is 500 nm. The electrical characteristics of the device will be improved using 500 nm thickness [14]. The simulation results of the HEMTs can be improved by adding a cap layer. So, the second layer of the simulated device is the cap layer with n-doped with a thickness is 1nm. Also, an Undoped barrier layer of InAlGaN 25nm thick has been used with an Undoped GaN layer 10nm thick to form a 2DEG channel layer. A 1nm buffer layer i.e. Aluminum Nitride AlN layer was inserted between the GaN layer and substrate. This layer is required to enable the growth of GaN on Silicon carbide [7].

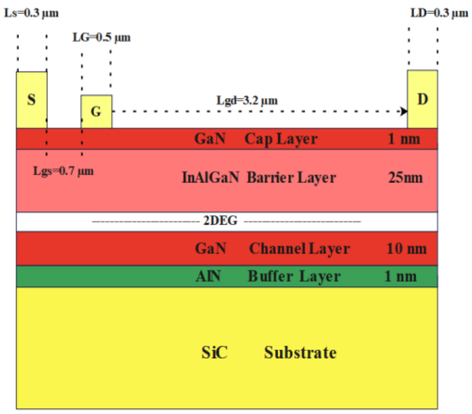


Figure (1): The Proposed Structure of the InAlGaN/GaN with Passivation Layer (Si3N4)

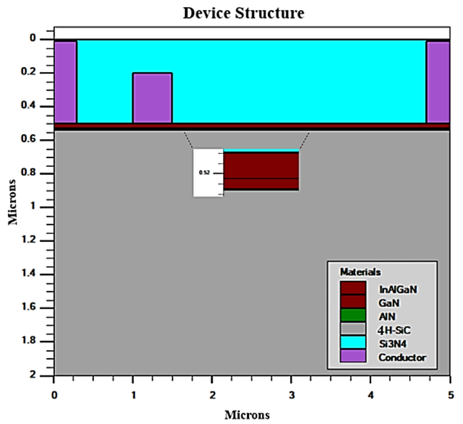


Figure (2): Rectangular Gate GaN HEMT Device Structure

Several studies on GaN-based HEMTs with various FP structures have been documented recently in an attempt to increase break-down voltage [15]. Firstly, to enhance the device's breakdown voltage (VB) of the simulated GaN HEMT device, the length of the field plate needs to be sufficiently extended to avoid overlapping between the neighboring FP edge and the high-field region at the gate edge. a source field pale (L_{SFP}) of about (3.7µm) is added to the source as shown in Figure (3).

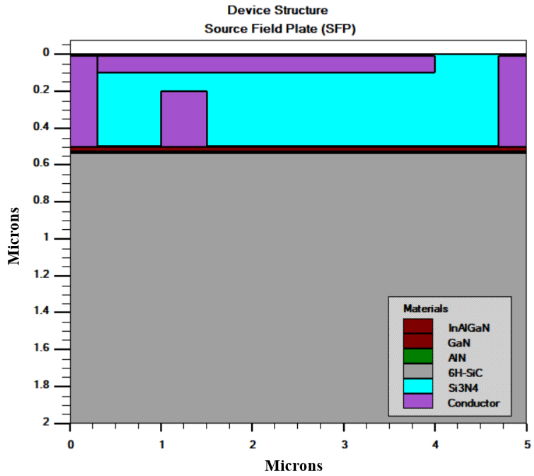


Figure (3): Device Structure of GaN HEMT with SFP

Another type of Field Plate (FP) that is utilized to improve the typical HEMT's performance for power applications while maintaining the device's size is Gate Field Plat (GFP). There are two types of GFP: Two Side GFP GaN HEMT (T-Gate) and Single Side GFP GaN HEMT. The T-gate is a rectangular gate with two field plates on both sides as displayed in Figure (4).

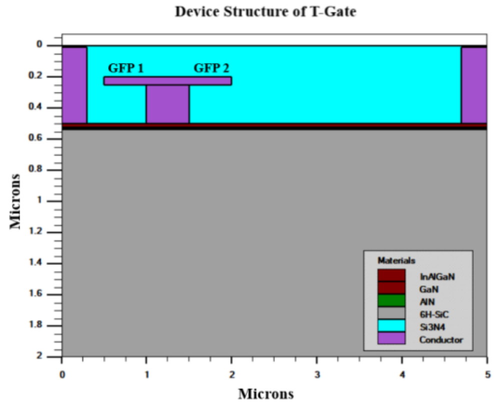


Figure (4): Device Structure of GaN HEMT with T-Gate

Another type of GFP is the single-side GFP. The structure of this type is shown in Figure (5). A field pale (L_{GFP}) length approximately (2µm) has been included within the rectangular gate towards the drain. Also, the field plates are added to the gate and source edge of the GaN HEMT as observed in Figure (6). A field pale (L_{SFP}) length of approximately (3.7µm) was attached to the source, and a field plate length (L_{GFP}) of about (2µm) was added to the gate.

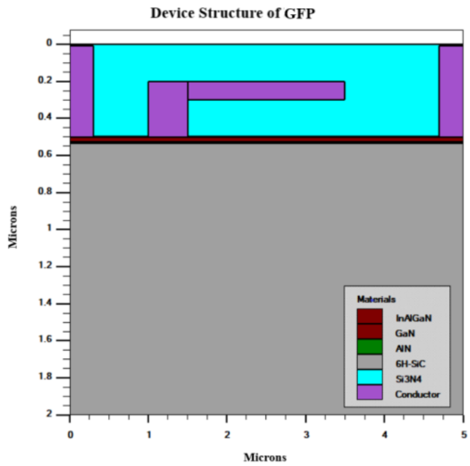


Figure (5): Device Structure of GaN HEMT with GFP

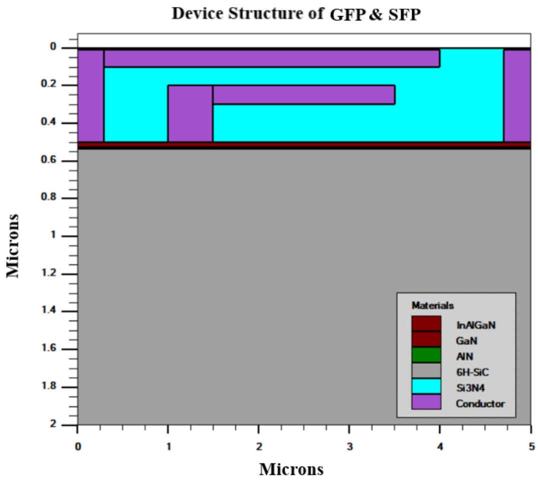
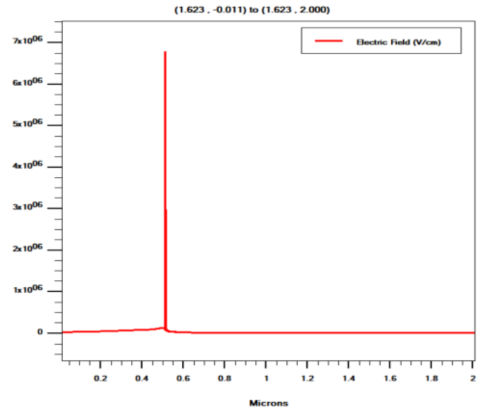
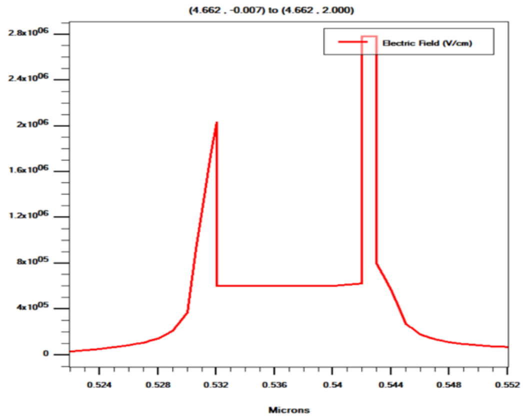


Figure (6): Device Structure of GaN HEMT with GFP and SFP

The gate metal's extension on a dielectric layer in a gate-connected field plate Figures (5) and (6) can modulate the channel beyond the primary gate, reducing the peak electric field by splitting it into two peaks as illustrated in Figure (7) [16]. Figure (8) displays the distribution of the electric field in a multiple field plating (gate and source coupled) HEMT.

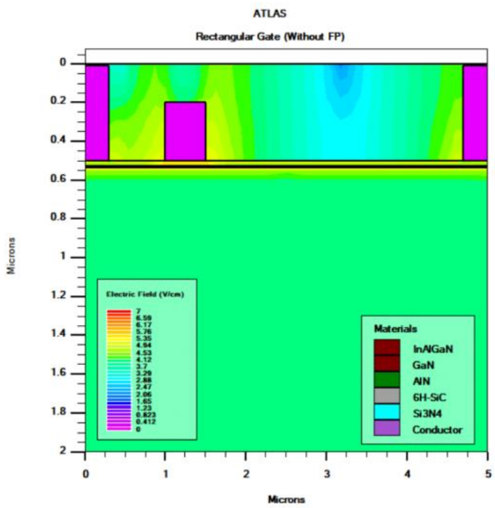


(a)



(b)

Figure (7): (a) single peak without FP, (b) Multi peak with FP



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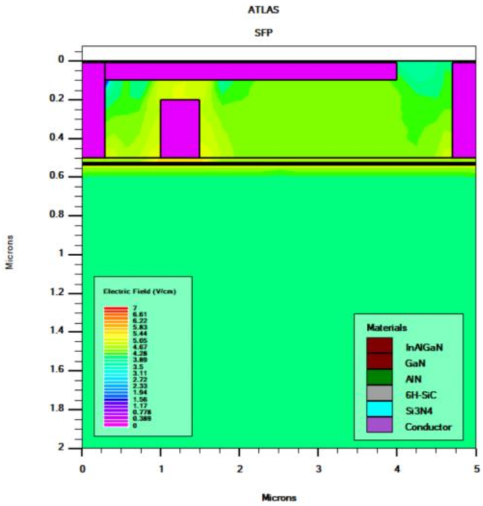

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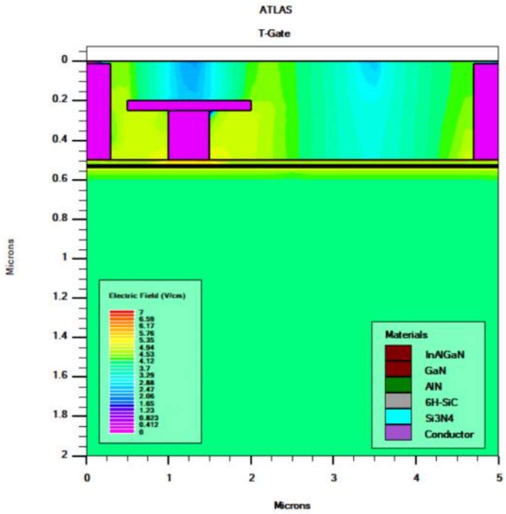
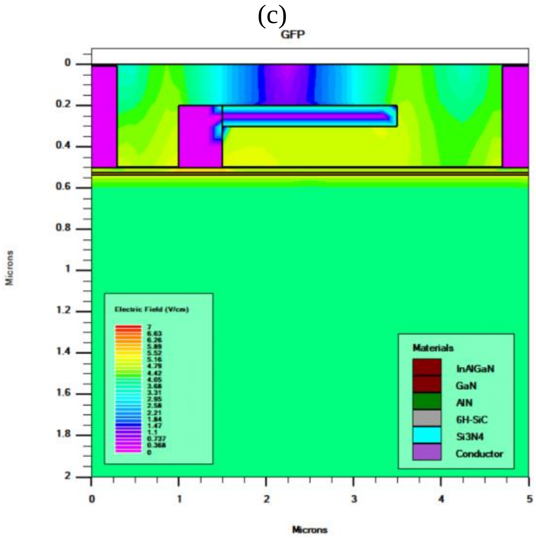
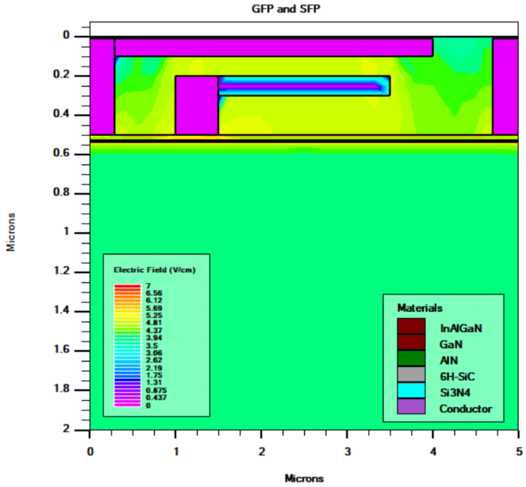


(c)



(d)



(e)

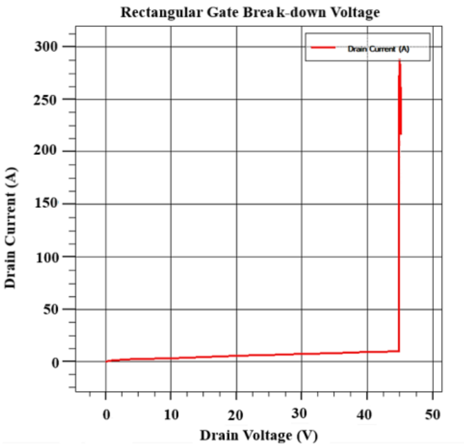
Figure (8); Electric field of different at types of the without FP, (b) T-Gate, (c)GFP, (d) SFP, (e) GFP, and SFP

The final result demonstrates a good ability to use a field plate to improve the GaN HEMT for power applications without expanding the simulated device's dimension. Additionally, the electric field's single peak is replaced with multiple peaks and field plates are used to make sure that the electric field is distributed uniformly as shown in Figure (8).

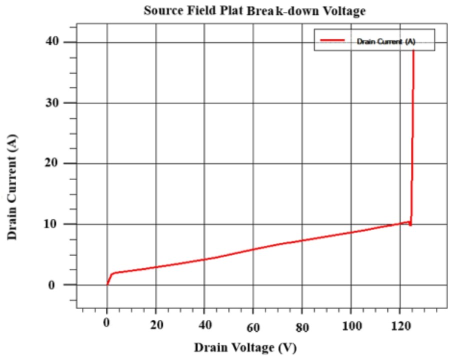
3. RESULTS AND DISCUSSION OF THE SIMULATED GAN HEMT DEVICE

3.1 Break-down Voltage

The break-down voltage of the typical GaN HEMT structure is about 44V as shown in Figure (9.a). The enhancement of the conventional GaN HEMT device and the VB of around (125 V) can be observed in Figure (9.b) by SFP. The break-down voltage of the T-gate increases (402 V) as illustrated in Figure (9.c). As indicated in Figure (9.d), the break-down voltage of the GFP increased to (515 V). From Figure (9.e) it is shown that adding gate and source field plate leads to increasing in the break-down voltage to about 429V.



(a)



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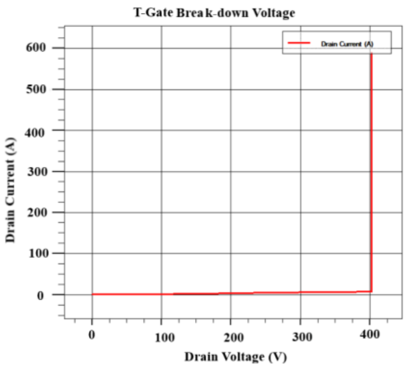

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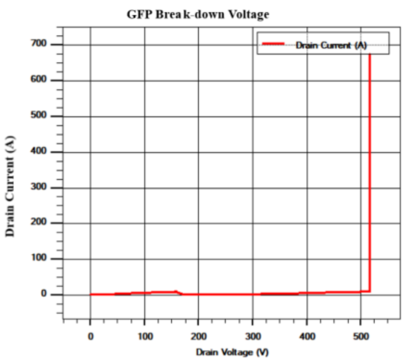

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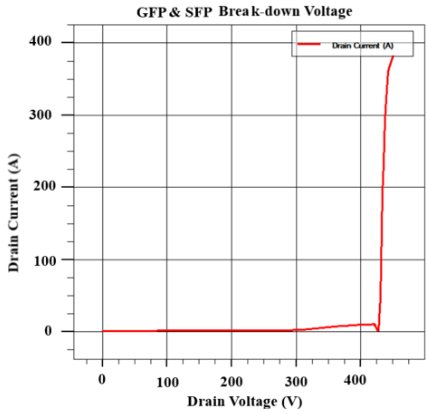

(e)

Figure (9): Break-down Voltage of the (a) Rectangular gate (b) SFP (c)T-gate (d) GFP (e)GFP and SFP

By using different field plats, the GaN HEMT for power applications may be greatly improved without growing the size of the simulated device, as the final result of the research indicates. Additionally, by employing field plates, the electric field's single peak is replaced by several peaks, resulting in a uniform distribution. Additionally, different features like threshold voltage, drain current I_{ds}, transconductance (g_m), output conductance (g_{ds}), and on-resistor (R_{on}) have been obtained. Hence, the field plate structure will affect the breakdown voltage while having little impact on the device's DC characteristics, transconductance (g_m), and output conductance (g_{ds}) of the device as shown in Table (1).

Table (1) displays features of the normal GaN HEMT and enhanced GaN HEMT with different types of field plates.

Table (1): Features of Normal and Enhanced HEMT

Parameters	*No. FP*	*SFP*	*GFP & SFP*	*GFP*	
				T-Gate	*GFP*
C_{gd} (PF)	0.44	0.42	0.96	0.56	0.99
C_{gs} (PF)	1.44	1.9	3.45	1.63	1.65
C_{ds} (PF)	1.49	1.84	1.48	1.49	1.37
f_t (GHz)	73	62	36	63	61
f_{max} (GHz)	353	212	76	75	73
Evaluation	-	Increase C_{ds} &C_{gs}	Increase C_{gs} &C_{gd}	Increase C_{gs} &C_{gd}	Increase C_{gs} &C_{gd}

3.2 C-V and RF Characteristics of the Simulated GaN HEMT

It is commonly known that the addition of GFP greatly increases the capacitance (C_{gd}), whereas the addition of SFP results increment in drain-source capacitance (C_{ds}) [16], [17]. For the device model, the CV characteristic is important, precise modeling of C_{gs}, C_{ds}, and C_{gd} in GaN HEMT transistors helps to illustrate the device's high-frequency capability, particularly when estimating f_t and f_{max} [18], [19]. The intrinsic capacitors between gate-source (C_{gs}), gate-drain (C_{gd}), and drain-source ((C_{ds}) of the device are extracted using 1GHz frequency with gate voltage from -5V to 1V with a step size of 0.01. Table (2) shows the value of the capacitors, the f_t and the f_{max} for different types of field plates.

Table (2): Comparison of capacitor value and frequency values for different types of FP

Parameters	*without FP*	*SFP*	*GFP & SFP*	*GFP*	
				T-Gate	*GFP*
I_{ds} (A)	1.35	1.35	1.35	1.35	1.35
V_{th} (V)	−4	−4	−4	−4	−4
$g_{ds}(ms)$	879	879	879	879	879
g_m (ms)	574	575	572	575	574
$R_{on}(\Omega)$	3.6	3.6	3.6	3.6	3.6
$V_B(V)$	44	125	429	402	515

4 CONCLUSION

In this paper, the principle and the compute performance of the conventional HEMT and the HEMT with the field plate (FP) have been studied using Silvaco-ATLAS two-dimensional simulation. The breakdown voltage of the typical device rises from 44 V of the device without FP to 125 V at SFP, 402 V at T-Gate, 429 V at both GFP and SFP and finally to 515 V at GFP by choosing the right field plate structure and field plate length. The result shows an excellent ability to improve the GaN HEMT for power applications by using different types of field plats without increasing the dimension of the simulated device. Also, the single-peak of the electric field is replaced with multi-peaks and the distribution of the electric field will be uniform by using a field plate. Additionally, the field plate structure will affect the breakdown voltage while having little impact on the device's DC characteristics, transconductance (g_m), and output conductance (g_{ds}) of the device. The main disadvantage of this method is the higher gate-drain capacitance, which affects the high-frequency operation, even though the breakdown voltage of the HEMT can be raised by employing the gate-linked field plate. To Enhance the performance of HEMT in RF application a discrete field plate can be used to improve the break-down voltage with cut-off frequency (f_t).

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تأثيرات Field plates على ترانزستور نوع GaN HEMT للتطبيقات ذات القدرة والسرعة العالية

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الملخص

تعد أجهزة GaN مناسبة لتطبيقات الطاقة نظرًا لميزات المواد الفريدة لـ GaN، والتي تزود GaN HEMTs بـ R_on منخفض وجهد انهيار عالي (VB). لتعزيز أداء HEMT العادي لتطبيقات الطاقة، والحفاظ على حجم الجهاز، يتم استخدام اللوحات الميدانية (FP). التقنيات المفترض أن تعزز أداء طاقة HEMT بشكل كبير هي تقنية Field Plate (FP). يتضمن التحسين زيادة جهد الانهيار لـ HEMT. لذلك، في هذا البحث، تمت دراسة المبدأ والأداء الحسابي لـ HEMT التقليدي و HEMT مع لوحة المجال (FP) باستخدام محاكاة Silvaco-ATLAS ثنائية الأبعاد. قد تؤدي النتائج التي تم الحصول عليها إلى تمهيد الطريق لنهج محسّن وفعال لإنتاج أجهزة عالية الطاقة يمكن استخدامها في تطبيقات إلكترونيات الطاقة. يرتفع جهد انهيار الجهاز من 44 فولت للجهاز بدون FP إلى 125 فولت عند SFP، و402 فولت عند T-Gate، و429 فولت عند كل من GFP و SFP، وأخيرًا إلى 515 فولت عند GFP عن طريق اختيار هيكل لوحة المجال الصحيح وطول لوحة المجال.

الكلمات الداله:

5G GaN خصائص RF، خصائص CV ، Field plat، Silvaco