V-I Characterization and Modelling of GaN HEMT

P. S. Arthy, A. Kavitha and S. Manjula

June 10, 2020

V-I CHARACTERIZATION AND MODELLING OF GaN HEMT

Arthy P.S [1],Dr.A.Kavitha[2],Dr.S.Manjula[3]
Research scholar[1],Professor[2] ,Associate Professor[3] ,
Department of Electronics and Communication Engnieering[1,2,3],
VelTech MultiTech Dr.RR Dr.SR Engineering College[1,2] ,Rajalakshmi Institute of Technology[3]

ABSTRACT: This paper proposes the study of warmness consequences on Gallium Nitride (GaN) High Electron Mobility Transistors (HEMTs). The output and transfer features are observed at warmness varying from 5°C to 105°C. The warmness dependence on static factors of GaN HEMT is observed, as like: drain power (IDS), Drain Source Potential difference (VDS).Gallium Nitride (GaN)High-Electron-Mobility Transistor (HEMT) models is required to prevent simulation problems and artifacts in the prediction. The experimentally recorded I–V parameters and this permits to calculate the intensities of block exists in the GaN buffer.

Keywords: Semiconductor equipment modelling, HEMT-high electron mobility transistor,framework equations,physical mechanism of HEMT, GaN

I. INTRODUCTION

GaN is measured as the major standard semiconductor element for great frequency, extraordinary effectiveness, and extreme power density power change usages with more benefits than silicon due to its outstanding electrical characteritics, as like broad bandgap, more thermal behavior, and huge significant breakdown electric field. The GaN high-electron-mobility transistor (HEMT) is the most hopeful functioning component in GaN and is presently obtainable from different production team, as like efficient power conversion (EPC), International Rectifier, Transform, GaN Schemes, and others. GaN HEMT has a good efficiency when compared to modern Si MOSFETs, as GaN HEMT displays low on-state resistance, small parasitic equipment capacitance, and more critical electric field. Hence, GaN HEMT can change at high speeds and display reduced conduction and switching losses. Because power semiconductor equipment presentation serves a main part in power electronics usages, power electronics designers require tested circuit-based piece of equipment models to compute the functioning of GaN HEMTs in various usages. The objective of the work is to build an easy and precision circuit-simulator miniature equipment framework, and authenticate it for existing GaN HEMT equipments during static and switching situations[11].

Gallium Arsenide (GaAs)metal-semiconductor area consequence transistor (MOSFETs) are broadly used as microwave and radio frequency (RF)semiconductor control elements [1–2].Huge quantity of direct power (DC) power is generally utilized, which is not appropriate for reduced loss usages. GaAs MOSFETs can offer reduced insertion loss and more switching speed with no DC bias power usage in theory. Conversely, the comparatively small breakdown potential difference (<10 V)restricts the usages of GaAs MOS FETs in different power electronics[1].

Experimental huge signal frameworks comprising electrothermal framework for

GaN HEMTs have been broadly gained interest nowadays. The electrothermal consequences for self-heating consequence are generally modeled by single or a few layers of thermal resistances-capacitance networks parallel with thermal power and then executed in nonlinear drain-source power , which has shown to be precision. Conversely, the surrounding climate consequences are normally modeled observed through linear interpolation by computing the equipment at certain environment warmness, which produces low precision and reduced steadiness for circuit design[2].

GaN HEMTs power transistors can function at superior power levels, frequencies and warmness, and with an increased energy efficiency with respect to that assured by Si equipments. These excellent features are due to the excellent physical properties of GaN semiconductor.In fact, they can allow a decrease of the on-state resistance and parasitic capacitances with respect to Si equipments, with a complete decrease of the power losses. The above advantages of the GaN semiconductor make GaN power transistors attractive for renewable energy domain in particular for use in photovoltaic and wind energy systems[3].

As the functioning demand to microwave equipments, progress to deal the expecting targets of the wireless business, the demand for quick and flexible design tools is ever growing. Empirical HEMT modeling deals with more disputes as Gallium Nitride (GaN) HEMT equipments, which introduce an unexpected function both in terms of power density and wideband function, are established at an industrial stage. In fact, GaN equipments express inbuilt low-frequency (LF) dispersive things that significantly affect their radio-frequency (RF) activities in power amplifiers and RF switches usage [4].

Additionally, there has been enormous improvement concentrated on the development of GaNhigh electron mobility transistor (HEMT) equipment technology together with enhancing the objects quality of epitaxial and passivation layers, choosing the suitable substrate objects, executing the field plates and ultra-short gate lengths and minimizing the GaN barrier breadth [6]. All these technological developments facilitate GaN HEMT technology as a disturbing technology for high-power microwave and mm-wave usage. Moreover, GaN HEMT equipment is proficient of delivering high breakdown potential difference, high switching speed and low on-resistance (RON), which makes it perfect for power switching usage[5].

The latest demands in power utilization decrease and volume decrease in power electronics systems demand the power semiconductor equipments development in power losses and changing frequencies. Eventhough the silicon equipments have been serving the important part in power electronics active equipment till now, the functioning boundary because of silicon object will clearly happen in the upcoming power structure usage[6].

This article proposes a new framework to simulate the semiconductor equipment modelling, HEMT-high electron mobility transistor, equivalent circuit, disadvantages of equipment physics based framework,compact framework,framework equations ,physical method of HEMT.

Merits:

(1) The extraction procedure will run quicker without any optimization technique and the external aspects of framework elements are assured.

(2) It is identical with various device structures.

II. DEVELOPMENT OF A DEVICE

A) Semiconductor Device Modelling

Semiconductor equipment modelling produces models for the behaviour of the electrical equipments depending on primary physics, as like the doping profiles of the methods. It may also comprises the production of miniature models (as like the popular SPICE transistor models), which attempts to save the electrical functionality of such equipments but does not normally draw from the principal physics. Normally it begins from the output of a semiconductor process simulation.

b) HEMT

A high-electron-mobility transistor (HEMT), also referred as heterostructure FET (HFET) or adaptation-doped FET (MODFET), is a field-consequence transistor combining a connection among two objects with various band gaps (i.e. a heterojunction) as the passage way as an alternative of a doped area (which is a normal situation for a MOSFET). A generally utilized object mixture is GaAs with AlGaAs, while there is broad changes, based on the usage of the device. Devices combining more indium normally display good excess-frequency execution, whereas in latest years, gallium nitride HEMTs have become more popular because of their high-power functioning. As like other type of FETs, HEMTs are utilized in integrated circuits as digital on-off switches. FETs can also be utilized as amplifiers for huge quantities of power utilizing a small potential difference as a control signal. Both of these applications are made feasible by the FET’s special power–potential difference features. HEMT transistors are able to function at extreme frequencies than normal transistors, up to millimeter wave frequencies, and are utilised in high-frequency products.

The High Electron Mobility Transistor (HEMT) is a challenger for the popular place as the fastest solid state equipment, even though this claim is being challenged from time to time by MESFET technology. This distinction has initiated a big trade of movement in the area of HEMT modelling. HEMTs are modelled at various levels - from advanced to intermediate, to analytical as well as semi-analytical. These modelsof modifying degrees of sophistication have several usages.

III. HEMTSTRUCTURE

The HEMT is a heterojunction equipment with enhanced functioning to its homojunction matching part, the MESFET. The objective of implementing a HEMT is more or less equivalent to Metal Insulator Semiconductor Field Effect Transistor(MISFET). Conversely, as an alternate of transmitting power in a thick passage way, a HEMT is based on the creation of a two dimensional electron gas at the heterojunction interface. A characteristic cross-sectional schematic of AlGaN/GaN HEMT equipment is shown in Figure 1. The device is usually built on a semi-insulating substrate which has a good thermal stability and close lattice similar with GaN. A buffer layer is grown on top of the substrate to serve as an separation layer among the substrate and passage way. Any lattice not equivalent or crystal faults from the substrate are reduced through this GaN buffer layer. The equipment normally employs a schottky gate connection and ohmic source and drain connection. The passageway in a HEMT is created at the heterojunction interface of the AlGaN barrier and GaN passage way layer. The next part explains about the implementation of HEMT in detail.

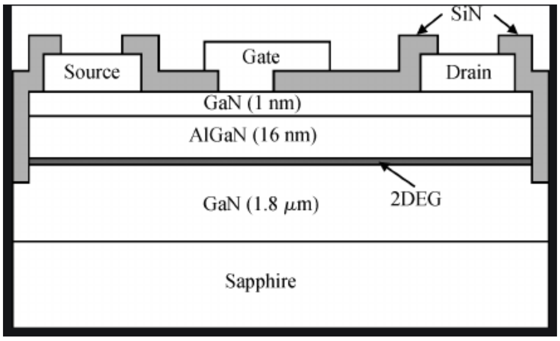

Figure 1. HEMT Structure

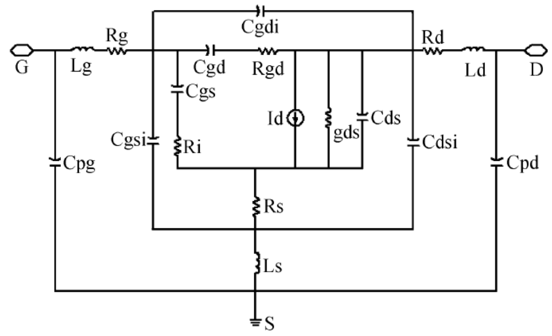

Figure 2. HEMT Equivalent Circuit

An object small-signal framework (shown in Fig.2) gets the extreme frequency consequence into concern. Cpg and Cpd are responsible for pad capacitance which cannot be avoided at excessive frequency and Cgsi, Cgdi and Cdsi denote the inter-electrode and crossover capacitances.

HEMT is observed as a potential device to achieve good-speed microwave and for applications based on RF. The output properties of HEMT transistors can be simulated through various modelling methods: electrical or physics-based frameworks. It is updated regularly to fit as much measured data as possible, nevertheless, the framework is not predictive and as a result presents a challenging task to use it for an array of equipments, which is its major drawback in addition to lacking framework symmetry due to its empirical nature. Gates of GaN HEMT are highly resistive. Therefore,this equipment needs reduced quantity of power to keep it ON. Additionally, it is highly responsive to potential difference. Enhancement type GaN HEMT present in the market, needs applied potential difference of 5V or lesser than that. The HEMT equipments need extremely expert engineers for development and testing. GaN HEMTs needs very good speed drivers. Additionally, they need very fast diodes in parallel to minimize losses.

A ground potential dependent adjustable miniature framework for GaN high electron-mobility transistors (HEMTs) is described. Depending on the unified regional ground potential method(URSP) which assumes subthreshold, Medium- and robust-inversion areas, Fermilevel (Ef) is modified to small extent with related to gate potential difference (Vg). GaN buffer doping has been used for attaining the subthreshold regional solution through conventional charge-potential difference equation

1)**Subthreshold region(Vgo=Vg-Voff< 0)**

As an alternative to the present GaN HEMT models, we follow the asymptotic area layer potential key (in subthreshold area created for bulk nMOS structure as given by

$$\phi_{sub}=\left(-\frac{\Upsilon}{2}+\sqrt{\frac{\Upsilon^2}{4}+\vartheta_f\left(V_{gf};\sigma_f\right)}\right)^2 \quad (1)$$

$$\vartheta_f\left(x;\sigma\right)=0.5\left(x+\sqrt{x^2+4\sigma}\right) \quad (2)$$

where *Vgf=Vg-VFB* denotes the “flat band-shifted” gate potential difference, σf is the smoothing factor and γ is the body factor indicated as

$$\Upsilon=\sqrt{2q\varepsilon_{gan}N_A}\;/\;C_d \quad (3)$$

in which. q indicates the electron charge, $\varepsilon_{\mathrm{gan}}$ is the buffer permittivityand NA is the GaN buffer doping intensity. As our earlier framework was depend on area result of Fermipotential (E_f) and not on ground potential (s), it is essential to change$\emptyset_{\mathrm{sub}}$ to $E_{\mathrm{f,sub}}$ before we continue to obtain the combined Ef framework.

2) Medium inversion area (Ef< E0 and Vgo> 0)

In Medium inversion, local Ef solution is given by

$$E_{f,mod}\models V_{go}-\frac{v_{th}}{1+\lambda_0}\pounds\left\{\theta e^{(1+\lambda_0)V_{go}/v_{th}}\right\} \quad (4)$$

where $\lambda 0$ and θ are equipment-dependent factors.

3) Strong inversion region (Ef< E0 and Vgo> 0)

A unified Ef framework for the strong-inversion area by considering the two sub-bands is mentioned as

$$E_{f,str}=\mathcal{M}\cdot V_{go,act} \quad (5)$$

$$\mathcal{M}=0.5\left(\begin{matrix}\mathcal{M}_1+\mathcal{M}_0+\alpha-\\ \sqrt{(\mathcal{M}_1-\mathcal{M}_0-\alpha)^2+4\alpha\mathcal{M}_1)}\end{matrix}\right) \quad (6)$$

where α is a smoothing factor.

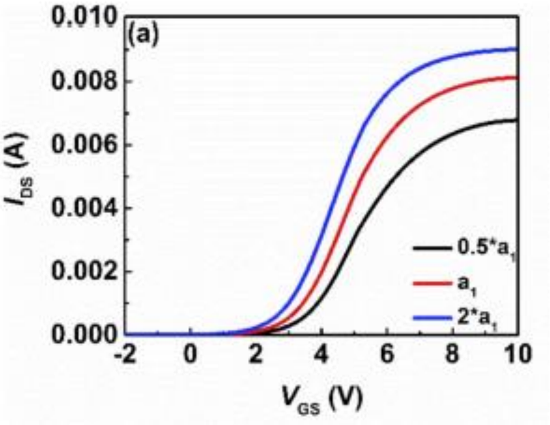

Figure 3 (a).overload power factor

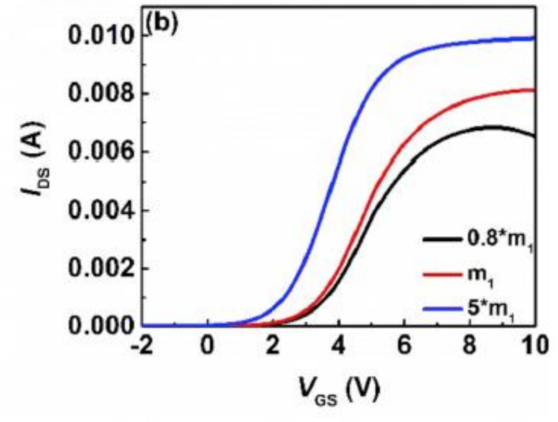

Figure 3(b). overload power adaptation factor

As per the functioning rules, the potential difference-dependent power source IDS predominantly comprises the transfer characteristic equation with the gate-source potential difference VGS as the variable, the output characteristic equation with the drain-source potential difference VDS as the variable.

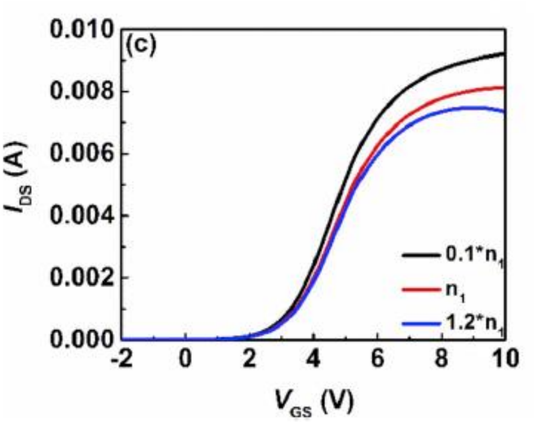

Figure 3(c).overload power adaptation factor

Moreover, the output feature exhibits several plots under various gate-source potential differences VGS, such that the gate-source potential difference should be included as the variable in the output characteristic equation for threshold potential difference and motion which are warmness responsive. It can be observed that at various warmness, the slope of the plots are effectively similar, but the quantity of power are dissimilar.

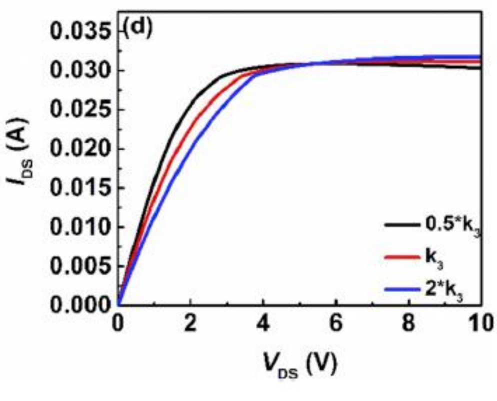

Figure 3(d) overload region transition

Overload power factor, m1 is overload power adaptation parameter, n1 is overload power adaptation factor related with VGS and k3 is overload bend that decides the slope shape of the linear to the overload region transformation. Figure 3a-3dshows that the characteristic changes of the passage way power IDS with different factor quantitys.

IV. CONCLUSION

A large-signal framework of GaNHEMT, that precisely forecasts static and dynamic features was created and established. Additionally, signal simulations after the beginning of the threshold drift function demonstrate that the framework can precisely portrays the functioning of the equipment at various bias potential differences. The framework strength was tested by comparing the simulated and recorded results of the equipment verified at ambient warmness variation of the equipment. The framework is situated in a plain switch test circuit to efficiently validate the junction of the framework.

REFERENCE

[1] Chunyu Liu, Xinhua Wang, Sen Huang, XiaohuaMa et al. "A large-signal Pspicemodeling ofGaN-based MIS-HEMTs", Superlattices and Microstructures, 2019.

[2] BinitSyamal, Siau Ben Chiah, Xing Zhou, ArjunAjaykumar, M. J. Anand, GeokIng Ng, S.Arulkumaran. "GaN HEMT compact framework forcircuit simulation", 2015 IEEE InternationalConference on Electron Devices and Solid-State Circuits (EDSSC), 2015.

[3] Kang Peng, SoheilaEskandari, Enrico Santi."Characterization and Modeling of a

GalliumNitride Power HEMT", IEEE Transactions onIndustry Usage, 2016.

[4] GianPieroGibiino, Alberto Santarelli, FabioFilicori. "Charge-conservative GaNHEMTnonlinear modeling from non-isodynamic multibiasS-parameter measurements", InternationalJournal of Microwave and WirelessTechnologies, 2019.

[5] Changsi Wang, YuehangXu, Xuming Yu,ChunjiangRen, Zhensheng Wang, Haiyan Lu,Tangsheng Chen, Bin Zhang, RuiminXu. "AnElectrothermal Model for Empirical Large- SignalModeling of AlGaN/GaN HEMTs Including Self-Heating and Ambient Warmness Effects",IEEE Transactions on Microwave Theory andTechniques, 2014.

[6] Du Lin, Yang Xiaofeng, Li Yang, ZhangJincheng, HaoYue. "Small-signal switch modelof GaN HEMTs for MMIC usage", TheJournal of China Universities of Posts and Telecommunications, 2016.

[7] Ma Teng. "A new small-signal framework forasymmetrical AlGaN/GaN HEMTs", Journal ofSemiconductors, 06/2010.

[8] Ichiro Omura, Wataru Saito, Tomokazu Domon,KunioTsuda. "Gallium Nitride power HEMT forhigh switching frequency power electronics",
2007 International Workshop on Physics of Semiconductor Devices, 2007.

[9] Michael Shur, Tor A. Fjeldly. "Chapter 3 HEMTModelling", Springer Nature, 1993.

[10] FabrizioRoccaforte, Patrick Fiorenza, GiuseppeGreco, Raffaella Lo Nigro, FilippoGiannazzo,FerdinandoIucolano,
Mario Saggio."Emergingtrends in wide band gap semiconductors (SiCand GaN) technology for power equipments",Microelectronic Engineering, 2018.

[11] Eugeny A. Ryndin, Amgad A. Al-Saman, BorisG. Konoplev. "A Quasi-Two-DimensionalPhysics-Based Model of HEMTs withoutSmoothing Functions for Joining Linear andOverload Regions of I-V Characteristics",Active and Passive Electronic Components,2019.