A Review on Modeling of AlGaN/GaN MODFET based on Artificial Neural Networks

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ABSTRACT: High electron mobility transistors (HEMTs) based on GaN have gained attention mainly due to its high quality performance especially in high-frequency as well as high-power devices. Significant developments have been donein terms of fabrication and performance of HEMT through several modeling techniques. This review article focuses on artificial neural networks for modeling of HEMT devices with enhanced performance.The focus of this article is further extended to the discussion of different models of AlGaN/GaN HEMT devices.

***Keywords**-AlGaN/GaN HEMT, Analytical models, ANN*

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1. INTRODUCTION

In recent years, High electron mobility transistors have attracted much interest in high speed and high power applications. Recently, artificial neural networks have been presented in the microwave area as a fast and flexible means for microwave modeling [1]. HEMTs are hetero-junctions. This property makes this device very special and selective so called selectively doped hetero junction field effect transistor (SDHFET). This means that semiconductors used have dissimilar (wide and narrow) band gaps. The wide band gap element is doped with donor atoms thus it has excess electrons in its conduction band. These electrons will diffuse to the narrow band material's conduction band due to the availability of states with lower energy. The movement of electrons will cause change in potential and thus an electric field between the materials. The electric field will push the electrons back to the wide band element's conduction band. The diffusion process continues until electron diffusion and electron drift balance each other, creating a junction at equilibrium similar to p-n junction. As we can see that un-doped narrow band gap material now has excess majority charge carriers. The fact that the charge carriers are majority carriers yields high switching speeds and the fact that the low band gap material is un-doped means that there are no donor atoms to cause scattering and thus yields high mobility.

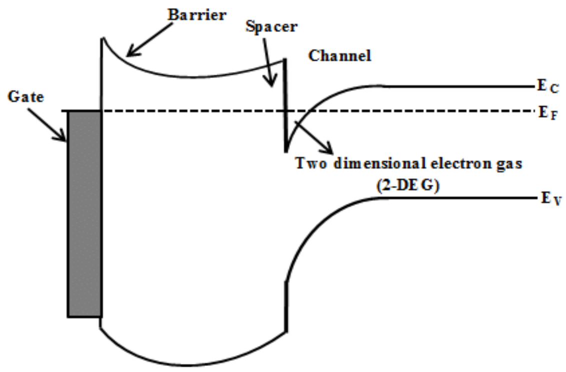

Fig 1: HEMT Conduction Energy Band Diagram

AlGaN/GaN based heterostructures transistors have shown great potential for future very high microwave frequencies and high power applications.This is attributed to their superior physical and electrical properties and ability to operate at high temperature [2]. AlGaN/GaN HEMTs have high electron mobility with values close to 1000 $cm^2/V.s$. It is always desirable to have the highest possible mobility for high frequency and power applications as in table 1.

Material	Mobility μ, $cm^2/V.s$	Dielectric Constant, ε	Bandgap, E_g, eV	Breakdown Field, E_b, 10^6 V/cm	BFOM Ratio	T_{max} (°C)
Si	1300	11.9	1.12	0.3	1.0	300
GaAs	5000	12.5	1.42	0.4	9.6	300
4H-SiC	260	10	3.2	3.5	3.1	600
GaN	1500	9.5	3.4	2	24.6	700

Table1: Material Properties of Microwave Semiconductor [2]

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It is known that interface roughness and alloy scattering are the main limiting factors that degrade mobility in III-heterostructures [4-6].So, to improve the mobility in AlGaN/GaN HEMT, a spacer layer of AlN was inserted between AlGaN/GaN and results were demonstrated by experimentally [6]. In addition, AlN exhibits very high spontaneous polarization due to lattice asymmetry. Pseudomorphic growth of AlN layer on GaN causes a very strong piezoelectric polarization due to the large lattice mismatch between AlGaN and GaN which causes an increase in the effective polarization charge at the interface of AlN/GaN. This thing increases the 2DEG density as well as electron mobility which make GaN as a promising material for high frequency, high power [7-8] and low noise applications [9].

2. Different Models of HEMT using ANN Approach

2.1 Neural Modeling Approach for Trapping and Thermal Effects on AlGaN/GaN HEMT

Elhamadi [10] et al. proposed an ANN model for modeling the trapping and the thermal effect on AlGaN/GaN HEMT devices and characterized by their DC and dynamic I-V characteristics from different static bias points and over a large temperature interval. The simulation results arecompared and close agreement with the experimental data are obtained. Figure 2 shows the modified nonlinear equivalent circuit topology. Figure 3 shows the DC I/V characteristics for two different ambient temperature.

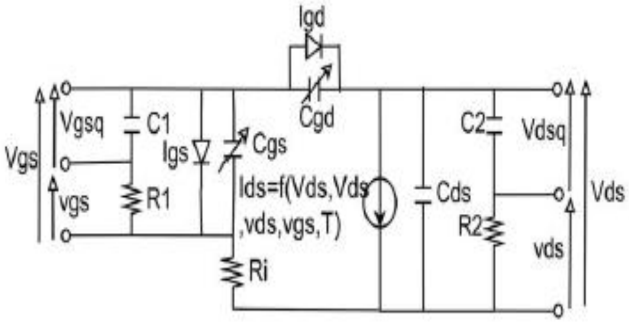

Fig 2: The Modified Nonlinear Equivalent Circuit Topology of FET

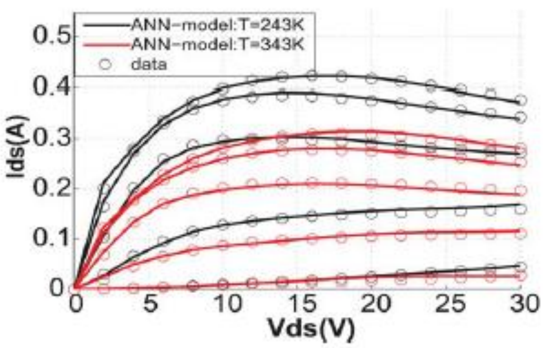

Fig 3: DC Simulation versus DC Measurements (V_{gs} from -4 to 0 V)

2.2 A Novel Approach for the Modeling of AlGaN/GaN HEMT Using ANN

Zhi-Qun [11] etal.presented a modeling approach of AlGaN/GaN HEMT using artificial neural network (ANN) at 300 nm. The authors also studied the neuro-space mapping technique. In this paper, for the first time, ANN modeling based on the EEHEMT model is applied to AlGaN/GaN HEMT.

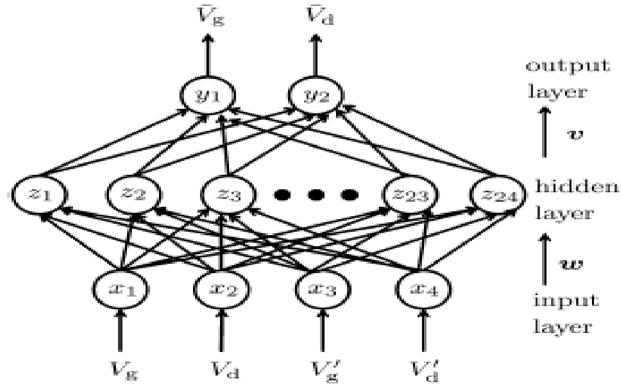

Fig.4: Three Layer Neural Network

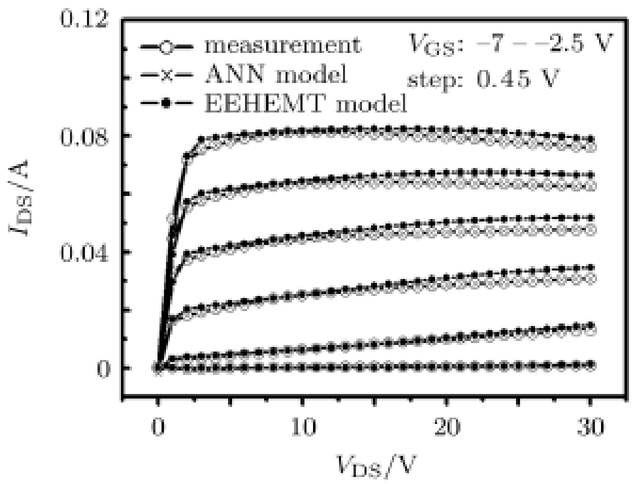

Fig. 5: DC Characteristics of ANN Model.

Fig 4 shows a three layer neural network and fig 5 shows comparison of the DC characteristics of the measured data, ANN model (with mapping) and EEHEMT model (without mapping) with DC drain voltage ranging from 0 to 30 V and gate voltage from -7 to -2.5 V in steps of 0.45 V.

2.3 Millimeter Wave AlGaN/AlN/GaN HEMT using ANN with multi bias

Cheng [12] et al. used an artificial neural network (ANN) for the modeling of millimeter-wave AlGaN/AlN/GaN high electron mobility transistor (HEMT) with multi-biases and designed as well as fabricated millimeter-wave AlGaN/AlN/GaNHEMT with gate width of 2×75 µm and gate length of 0.3 µm using the conjugate training method.

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2nm GaN	Cap layer
18nm AlGaN	Barrier layer
1nm AlN	Spacer layer
2um GaN	Buffer layer
SiC	Substrate

Fig 6: Cross section of AlGaN/AlN/GaN device [19]

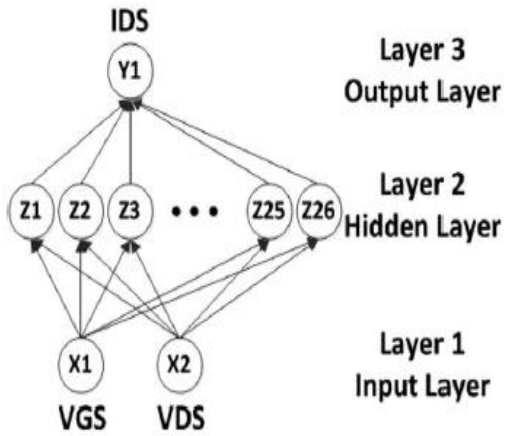

Fig 7: Three layer neural network for DC model

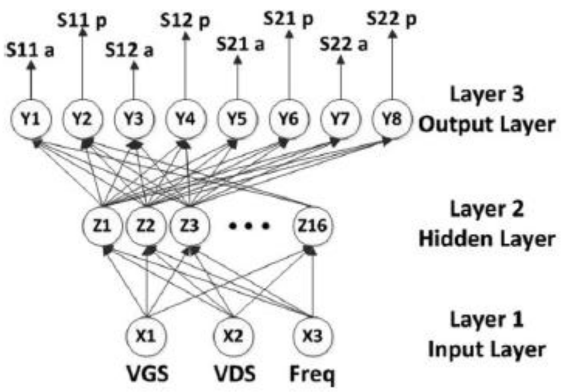

Fig 8: Three layer neural network for AC model

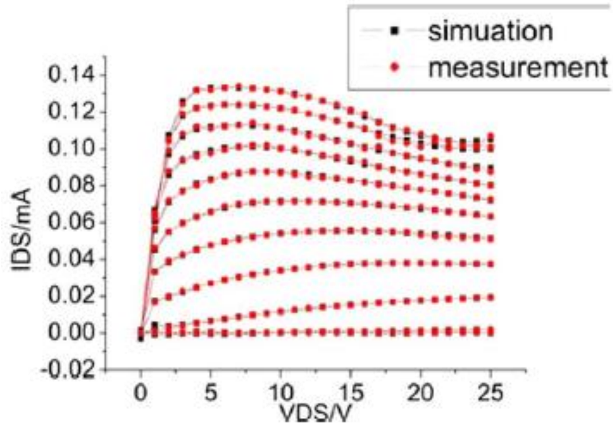

Fig 9: DC output characteristics

The comparison of output characteristics in fig 9 shows the well agreement with the experimental data.

2.3 Drain-Current Model of PHEMT using the Artificial Neural Networks and a Taylor Series Expansion

Elhamadi[13] et al. developed a neural network model for PHEMT using a multi-layer perceptron structure to model the non-linear I-V characteristics. Figure 10 observed the good agreement between model and data measurement.

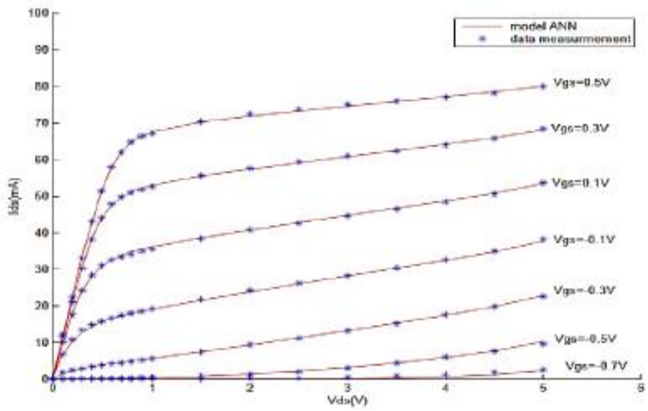

Fig 10: I-V characteristics of ANN Model and Measurement Data

2.4 Microwave Nonlinear Model by Using Artificial Neural Network

Li [14] et al. presented microwave nonlinear device model using artificial neural network approach. By taking the advantage of integration and differential ANN, this approach becomes very useful for the modeling the device. It provides very good agreement between the empirical model and the proposed ANN model.

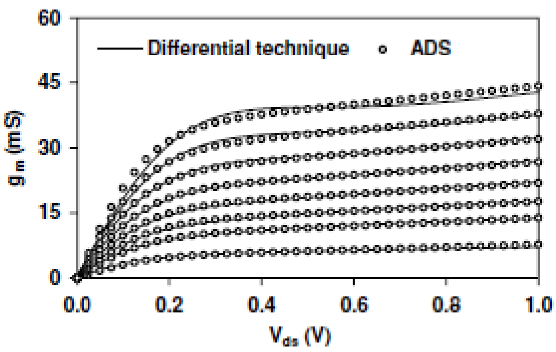

Fig 11: g_m versus V_{ds} between empirical model and ANN model

3. Conclusion

In this paper, a detailed survey of different structures and analytical models of AlGaN/GaN modulation doped field effect transistor using artificial neural network approach is presented. The HEMT 2-D analytical models are analyzed mainly for I-V characteristics. Also, all these models show close agreement with the experimental data.

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