Superlattices and Microstructures 84 (2015) 54–65

Contents lists available at ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices

Interface DOS dependent analytical model development for DC characteristics of normally-off AlN/GaN MOSHEMT

Raghunandan Swain, Kanjalochan Jena, T.R. Lenka *

Microelectronics and VLSI Design Group, Department of Electronics and Communication Engineering, National Institute of Technology, Silchar, Assam 788010, India

ARTICLE INFO

Article history:
Received 12 December 2014
Received in revised form 21 April 2015
Accepted 28 April 2015
Available online 5 May 2015

Keywords:
2DEG
AlN/GaN
DOS
HEMT
MOSHEMT
Quantum capacitance

ABSTRACT

In this paper a charge controlled analytical model is developed to predict quantum capacitance, threshold voltage and drain current for normally-off AlN/GaN Metal Oxide Semiconductor High Electron Mobility Transistor (MOSHEMT). The oxide/semiconductor interface Density of State (DOS) dependent model for two dimensional electron gas (2DEG) density is obtained by demonstrating necessary energy band diagrams. Quantum capacitance in the channel and threshold voltage is obtained by using different boundary conditions. By using these expressions the drain currents in both linear and saturation mode are derived. It is interesting to note that a positive threshold voltage necessary for normally-off operation can be obtained by decreasing the AlN barrier thickness below a critical value. The predicted DC characteristics are in good agreement with the experimental results, thus it confirms the validity of the proposed model.

1. Introduction

AlN/GaN HEMTs have evolved as among the most promising microwave power devices having high power density and high frequency operations. This is possible due to the excellent materials

---

* Corresponding author.
E-mail address: t.r.lenka@ieee.org (T.R. Lenka).

http://dx.doi.org/10.1016/j.spmi.2015.04.025

properties of III-Nitrides such as GaN and AlN having wide band gap (6.2 eV of AlN and 3.4 eV of GaN), large breakdown electric field strength ($\sim 3 \times 10^6$ V/cm), high 2DEG density (2×10^{13} cm^2), low relative dielectric constant (10.8 for AlN and 9.5 for GaN), high saturation electron drift velocity ($>2 \times 10^7$ cm/s), high mobility ($\sim$1000 cm^2/Vs) [1]. The 2DEG concentration in the conventional AlGaN/GaN structure plays a vital role [2,3] and it has a strong dependence on the Al-content of the AlGaN layer [4]. Maximum 2DEG sheet charge density can be achieved with very thin AlN barrier layer [5]. Moreover, thin AlN can be an ideal candidate for the realization of normally-off (E-mode) HEMT, because in case of thin barrier, due to easy depletion of 2DEG density, a positive gate potential is required to form the 2DEG [6].

The higher gate leakage current in HEMT made to realize the necessity of MOSHEMT technology which incorporates an extra thin dielectric layer such as Al_2O_3 [6] under the gate to minimize the gate leakage current. E-mode AlN/GaN MOSHEMT device with regrown source and drain spacing (L_{SD}) of 0.7 µm shows transconductance (g_m) of 509 mS/mm, maximum drain current (I_d) of 860 mA/mm, gate leakage current less than 1 mA/mm, Ohmic contact resistance 0.153 Ω mm, on-resistance 1.63 Ω mm and I_{on}/I_{off} ratio up to 10^6 [7]. With self-aligned gate-last process cut-off frequency (f_T) of 40 GHz is obtained with a channel length (L_g) of 210 nm [8]. The compact charge based model for current–voltage and capacitance–voltage characteristics in AlGaN/GaN HEMT is presented in Ref. [9]. Similarly, for generic MISHEMTs, a unified 2DEG density based compact model is presented in Ref. [10]. In a scaled MOSHEMT device, oxide capacitance becomes high due to ultra-thin oxide layer. So gate capacitance becomes comparable to quantum capacitance formed due to the channel [11]. But none of the above mentioned models elucidate the effect of oxide interface charges occupied in the interface states and quantum capacitance arising at the heterojunction. Therefore, in this paper the authors have developed a model for predicting 2DEG density, quantum capacitance, threshold voltage and drain current of AlN/GaN MOSHEMT considering oxide/semiconductor interface DOS.

The organization of this paper is as follows. The model development is presented in Section 2 including the model for 2DEG density, quantum capacitance, electric field, threshold voltage, and drain current. The MATLAB based simulation results of the developed model along with the experimental results from the literature for I_d–V_{gs} and I_d–V_{ds} are plotted and compared in Section 3. Finally the conclusion has been drawn in Section 4.

2. Model development

Fig.1 shows a schematic diagram of the AlN/GaN MOSHEMT heterostructure considered in this study. Similar kind of structure (MOS1 in Ref. [7]) is fabricated and characterized in literature, which possesses a threshold voltage of 0.15 V. It consists of a metal gate (Ni) followed by Al_2O_3 (6 nm), AlN barrier layer (1.5 nm), an unintentionally doped GaN channel (875 nm), a GaN semi-insulating buffer layer and substrate layer. The role of n^+-GaN layers re-grown below source and drain regions is to form better Ohmic contacts. The distance between these two regions (L_{SD}) is considered to be 3 µm and gate width (Z) is to be 100 µm.

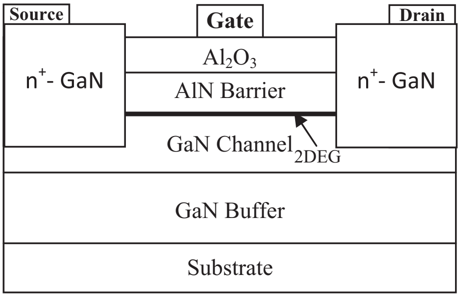

Fig. 1. Proposed MOSHEMT structure.