Physica E 54 (2013) 24–29

Contents lists available at SciVerse ScienceDirect

Physica E

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

A novel AlGaN/GaN HEMT with a p-layer in the barrier

S.M. Razavi [a,*], S.H. Zahiri [a], S.E. Hosseini [b]

[a] Faculty of Engineering, University of Birjand, Birjand, Iran
[b] Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

HIGHLIGHTS

- Simulation results disclose that compared to the conventional and T-gate structures the structure with p-layer in the barrier (PL-HEMT) optimizes the breakdown voltage.
- It reduces the gate–drain capacitance (C_{gd}).
- It decreases the output conductance (g_o).
- It reduces the short channel effect.

ARTICLE INFO

Article history:
Received 25 December 2012
Received in revised form
6 May 2013
Accepted 17 May 2013
Available online 3 June 2013

Keywords:
GaN HEMT
Short channel effect
Gate capacitance
Electric field
DC output conductance
Sub-threshold slope

ABSTRACT

The potential impact of gallium-nitride (GaN) high electron mobility transistor (HEMT) with a p-layer in the barrier is reported. We investigate the device performance focusing on short channel effects, gate–drain capacitance, electric field, breakdown voltage, DC output conductance (g_o), drain current, DC trans-conductance (g_m) and sub-threshold slope using two-dimensional and two-carrier device simulations. Our simulation results reveal that the proposed structure reduces the short channel effects, gate–drain capacitance, sub-threshold slope and g_o compared to the conventional and T-gate structures. Also this new structure reduces the peak electric field at the gate corner near the drain and consequently increases the breakdown voltage significantly. Increasing p-layer length (L_p) and thickness (T_p), improves the breakdown voltage, short channel effects, gate–drain capacitance and g_o.

1. Introduction

In recent decades, due to unique characteristics such as a wide band-gap, superior carrier saturation velocity, a large breakdown field strength and strong spontaneous and piezoelectric polarization, GaN-based high-electron mobility transistors (HEMTs) have attracted considerable attentions and shown excellent performance in high-power and high-frequency electronic applications [1,2]. With their excellent performances in high-power operations at microwave frequencies, wide-band gap AlGaN/GaN HEMTs are emerging as the promising candidates for next generation RF/microwave power amplifiers [3].

In this paper, the potential impact of AlGaN/GaN HEMT with a p-layer in the barrier is studied using a two-dimensional (2-D) device simulator. The unique features of the AlGaN/GaN HEMT with a p-layer in the barrier (PL-HEMT) are explored and compared with those of T-gate [4] and conventional [1] HEMTs in terms of short channel effects, gate–drain capacitance, electric field, breakdown voltage, DC output conductance (g_o), DC trans-conductance (g_m), sub-threshold slope and drain current. In the next section, the proposed structure dimensions and the physical models used in the 2-D simulation are described in detail. In the third section, we first explain how the presence of the p-layer in the barrier will increase breakdown voltage. Also, in this section, the effect of p-layer length and thickness on the short channel effect, gate–drain capacitance, output conductance, drain current and g_m are studied and compared with those in T-gate and conventional structures in details. After that, the sub-threshold slopes of the PL-HEMT as a function of gate length are plotted and compared to those of the conventional and T-gate structures.

2. Device structure

Fig. 1(a), (b) and (c) shows the schematic cross-section of PL-HEMT, conventional [1] and T-gate [4] structures, respectively. The dimensions of the PL-HEMT, T-gate and conventional structures are as follows: gate length $L_g = 0.5\ \mu m$, gate–drain spacing $L_{gd} = 1\ \mu m$, gate–source spacing $L_{gs} = 1\ \mu m$. Barrier layer and channel

* Corresponding author. Tel./fax: +98 571 4411160.
E-mail address: m.136287@gmail.com (S.M. Razavi).

1386-9477/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.physe.2013.05.015

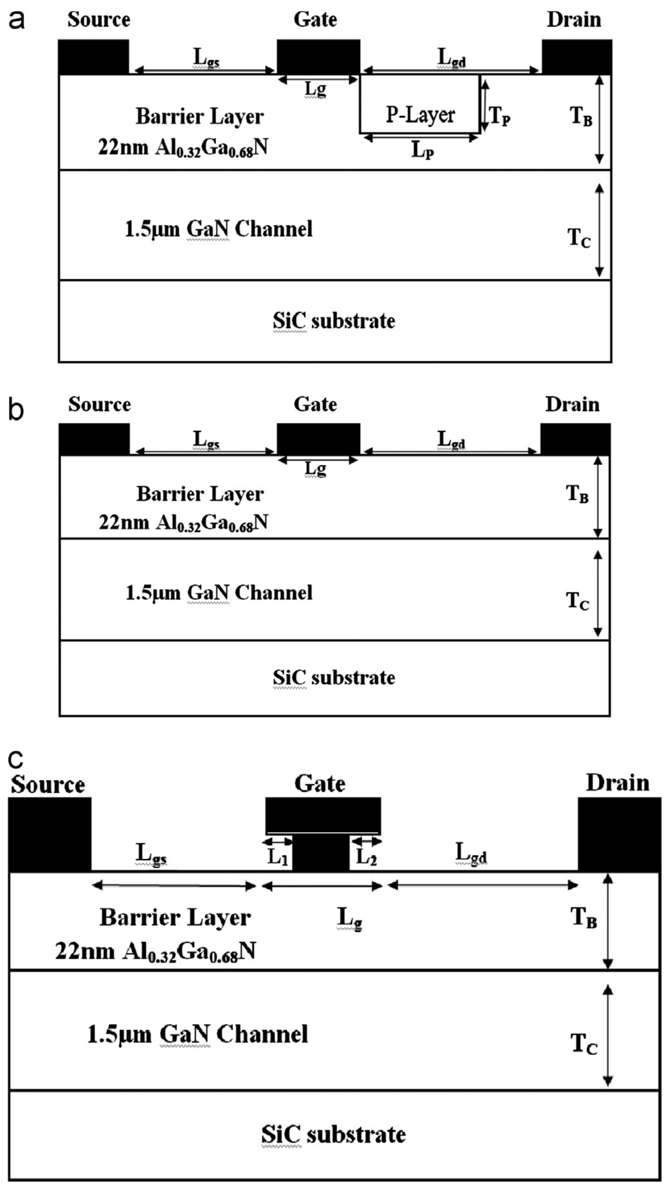

Fig. 1. Cross section of the (a) PL-HEMT, (b) conventional and (c) T-gate structures.

thicknesses are T_B=22 nm and T_C=1.5 μm, respectively. The barrier layer is a n-type heavily doped $Al_{0.32}Ga_{0.68}N$ while the channel layer is an intrinsic GaN. Also, the p-layer in the barrier is a p-type heavily doped $Al_{0.32}Ga_{0.68}N$. The doping concentration of the barrier layer is the same as that of the p-layer. L_1 and L_2 in the T-gate structure have the same lengths of 0.1 μm. Nickel is chosen for the gate Schottky contact with a work function of 5.1 eV. It is worth noting that the PL-HEMT and conventional structures can be fabricated using the same procedure as reported in Ref. [1]. The devices are simulated using two-dimensional ATLAS software [5]. In order to achieve more realistic results, several models are activated in simulations, including the 'SRH' model for Shockley–Read–Hall recombination, the 'Conmob' model for standard concentration dependent mobility, the 'Fldmob' model for parallel electric field-dependent mobility and the 'Fermi Dirac' model for statistics [6,7].

3. Results and discussion

Fig. 2(a) and (b) shows the lateral electric field at the gate corner near the drain at V_{DS}=80 V and V_{GS}=−4 V for different L_P and T_P, respectively. It is obvious from these figures that increasing L_P and T_P in the PL-HEMT reduces the maximum lateral electric field at the gate corner near the drain compared to the conventional and T-gate structures. A further investigation shows that the breakdown happened at gate corner near the drain due to the electric field crowding [8,9]. Hence, it can be deduced that the PL-HEMT with different L_P and T_P have a larger breakdown voltages than those of the conventional and T-gate structures. Also, as can be shown in these two figures, increasing L_P and T_P reduces the maximum electric field and consequently increases the breakdown voltage. In this work, the critical electric field of the GaN (3.5 MV/cm) is used to determine the breakdown voltage. Increasing the drain–source voltage increases the electric field in the channel. The breakdown voltage is nominated the drain–source voltage that maximum electric field in the channel is equal to the critical electric field. It is clear from the simulation results that the breakdown voltage for the PL-HEMT structure with L_P=0.3 μm, 0.6 μm and 0.9 μm at a fixed T_P (15 nm) are about 200 V, 250 V and 270 V, respectively. The breakdown voltage for the PL-HEMT structure with T_P=7 nm and 15 nm at a fixed L_P (0.6 μm) are about 150 V and 220 V, respectively. Also, the breakdown voltage in the conventional and T-gate structures are about 90 V and 150 V, respectively. Because of Field plate in the drain side, the T-gate structure has larger breakdown voltage than that of the conventional structure. The maximum breakdown voltage is obtained in the PL-HEMT with L_P=0.9 μm and T_P=15 nm. Therefore, the breakdown voltage of PL-HEMT (~270 V) is significantly improved compared to that of the conventional (~90 V) and T-gate (~150 V) structures.

The device performance can be greatly improved by reducing the gate length to enhance the trans-conductance and reduce the gate capacitance. On the other hand as the technology is pushing the gate length to the sub-quarter micrometer range, short channel effects are becoming increasingly significant. One of the most pervasive short channel effects is the drain-induced barrier lowering (DIBL). DIBL is an electrostatic effect causing the barrier between the source and the drain of a field effect transistor (FET) in or near the sub-threshold region to be lowered when the drain voltage is increased. This effect causes the channel to return from a pinch-off state to conduct and shifts the threshold voltage. Consequently, the DIBL places a hard limit on the minimum gate size and degrades the trans-conductance and output conductance, which are critical to the gain and power output for a power FET and the noise margin for a digital FET [10–12].

Fig. 3(a) reveals that the negative shift in the threshold voltage with increase in the drain voltage for different L_P at a fixed T_P (15 nm) in the PL-HEMT structure is less than that in the conventional and T-gate structures. As is evident from this figure, a larger L_P can be used to reduce the negative shift in the threshold voltage with increase in the drain voltage. Therefore, increasing L_p reduces the short channel effect such as DIBL. For example, according to this figure, the negative shift values in the threshold voltage with increase in the drain voltage of PL-HEMT (T_P=15 nm and L_p=0.9 μm), conventional and T-gate structures are −8.75 V, −10.5 V and −13 V, respectively. This is because a larger L_P decreases the maximum lateral electric field in Fig. 2(a) and then reduces dependence of the threshold voltage to the drain voltage. As can be shown in Fig. 3(b), increasing T_P at a fixed L_P (0.6 μm) for PL-HEMT reduces the negative shift in the threshold voltage. For instance, it is evident from this figure that the negative shift in the threshold voltage with increase in the drain voltage at PL-HEMT (T_P=15 nm and L_p=0.6 μm), conventional and T-gate structures are −8.5 V, −10.5 V and −13 V, respectively. It can be concluded from Fig. 3(a) and (b) that a larger L_p and T_P can be used to reduce the short channel effect such as DIBL.

Gate–drain capacitance with respect to the frequency for different L_p and T_P in the PL-HEMT at V_{GS}=0 V and V_{DS}=20 V