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An improved DRBL AlGaN/GaN HEMT with high power added efficiency

Hujun Jia*, Shunwei Zhu, Mei Hu, Yibo Tong, Tao Li, Yintang Yang

Key Laboratory of the Ministry of Education for Wide Band-Gap Semiconductor Materials and Devices, School of Microelectronics, Xidian University, Xi'an 710071, China

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ABSTRACT

An improved DRBL AlGaN/GaN HEMT (IDRBL HEMT) with high power added efficiency is proposed and its mechanism is studied by co-simulation of ADS and TCAD software. The barrier layer on both sides of the gate of the new structure has a recessed layer. The simulation results show that the optimized IDRBL HEMT has a large breakdown voltage, a small gate-source capacitance and a large power added efficiency. The maximum PAE obtained from IDRBL HEMT was 53.30%, while the PAE of DRBL HEMT was 36.02%. Therefore, the HEMT of the IDRBL structure has great application prospects in the microwave and radio frequency fields.

1. Introduction

In recent years, related research on device technology, DC characteristics, RF characteristics and efficiency of AlGaN/GaN HEMTs [1–3] has been a research hotspot in the field of semiconductor devices and microwave and millimeter wave circuits [4]. However, the vast majority of research focus on improving the DC and AC characteristics of devices [5,6]. Based on the urgent need of green efficiency and energy saving, finding a way to ensure that the device has a large enough output power density and a large energy conversion efficiency will become a new research hotspot.

In this paper, an AlGaN/GaN HEMT with IDRBL structure is proposed. Through the modeling and simulation of ADS and ISE TCAD, the DRBL AlGaN/GaN HEMT proposed in the literature [7] is studied and optimized, to obtain a higher PAE, and the device-level theoretical basis and design method are laid for further high-efficiency RF power amplifier design.

2. Device structure

Fig. 1. (a) and (b) shows the schematic of DRBL AlGaN/GaN HEMT and IDRBL AlGaN/GaN HEMT respectively. The conventional DRBL structure has one recessed region on each side of the AlGaN barrier layer on both sides of the gate of the device. The left and right sides of the barrier layer are respectively n^+ doped source and drain. Below are the 3 µm GaN buffer layer, 40 nm AlN nuclear layer and SiC substrate layer. The IDRBL HEMT structure is similar to the DRBL except that the height and length of the two recessed regions are different from those of the DRBL. The structural parameters of the device are defined in Fig. 1. (a) and (b). In the DRBL and IDRBL structures, the fixed values L_{gs} and L_{gd} are 1 µm and 2.5 µm, respectively, the length and height of the left recessed area are L_1 and H_1, respectively, and the length and height of the right recessed area are L_2 and H_2, respectively. The process achieved in the recessed region can be obtained by an additional HBr/Ar-based plasma dry etching technology in the inductively coupled plasma (ICP) system [8].

In TCAD software, the basic Poisson equation, drift diffusion equation, Generation compound model, Schrodinger coupling equation, Mobility Model (Doping Dep Highfields at Enormal), Effective Intrinsic Density Model (Nobandgapnarrowing), Recombination Model (SRH (dopingDep)), Incomplete Inonization Model and Carrier are mainly used [9]. In ADS software, the EE_HEMT [10] model is used to characterize the equivalent circuit of the device under various bias conditions. The simulated bias conditions are as follows: V_{gs} is −3.8 V, V_{ds} is 28 V, RF Frequency is 1.2 GHz, and Pavs_dBm is 28 dBm, the gate is the input and the drain is the output. The remaining structural parameters are derived from calculations, published literature, and default parameters in EE_HEMT.

3. Results and discussion

3.1. Effect of the length of the recessed region on the PAE

Fig. 2. shows the effect of the structure parameters on the PAE of the DRBL HEMT. It can be seen from the figure that for the recessed region on the left side, when L_1 is from 0.1 µm to 0.7 µm, PAE has a tendency to increase with L_1, and when L_1 is equal to 0.7 µm, PAE reaches a maximum value; when L_1 is from 0.7 µm to 1.0 µm, PAE decreases first with L_1 and then tends to be flat. Similarly, for the recessed region on the right side, when L_2 is from 0.1 µm to 0.8 µm, PAE gradually

* Corresponding author.
E-mail address: hjjia@mail.xidian.edu.cn (H. Jia).

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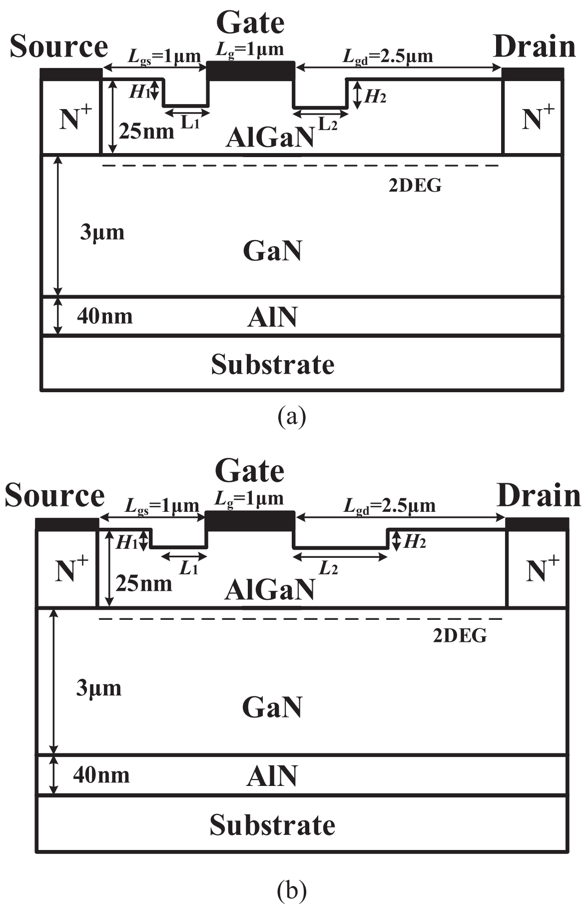

Fig. 1. Schematic cross sections of the (a) DRBL AlGaN/GaN HEMT, (b) IDRBL AlGaN/GaN HEMT.

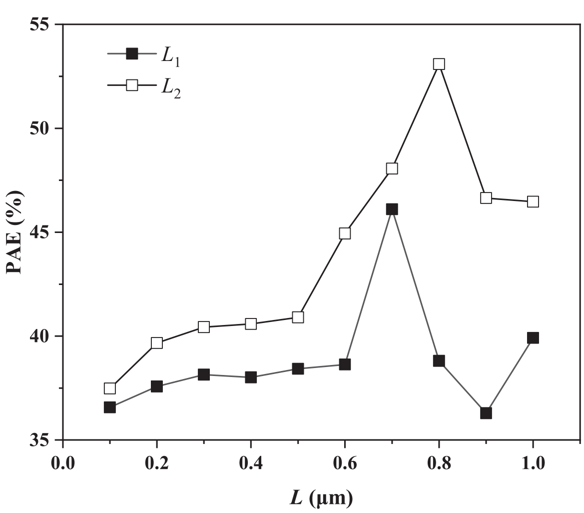

Fig. 2. The effect of the L_1 & L_2 on PAE.

increases with the increase of L_2, and the PAE maximum value when L_2 reaches 0.8. When L_2 is greater than 0.8 μm, PAE decreases with L_2.

3.2. Effect of the height of the recessed region on the PAE

As shown in Fig. 3., it is the curve of the height of the recessed region as a function of PAE. H_1 and H_2 are the recessed region heights of the left and right sides, respectively. It can be seen from the figure that in the recessed region on the left side, when H_1 is between 0 nm and 4 nm, the PAE increases slowly. When the height H_1 reaches 4 nm, the PAE reaches a maximum value. When H_1 is greater than 4 nm, the PAE decreases first and then increases slowly. However, the increase is not large, and the PAE value at H_1 of 10 nm is still smaller than the PAE value at H_2 = 4 nm. Similarly, for the recessed region on the right side, the H_2 is in the range of 0–4 nm, and the PAE is gradually increased. When the H_2 reaches 4 nm, the PAE reaches a maximum value, and when the H_2 is greater than 4 nm, the PAE generally has a wavy downward trend.

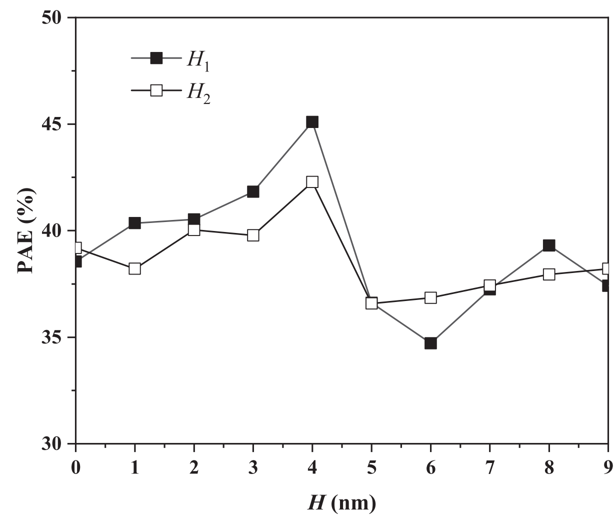

Fig. 3. The effect of the H_1 & H_2 on PAE.

3.3. Optimized results and mechanism discussion

Through further simulation, the results show that the four parameters L_1, L_2, H_1, H_2 have a relatively independent effect on PAE. For example, when taking L_2 = 5 μm, H_1 = 3 nm, H_2 = 3 nm, or L_2 = 7 μm, H_1 = 5 nm, H_2 = 6 nm, the maximum L_1 of PAE is still about 7 μm. This means that when L_2, H_1, and H_2 take different values in their respective ranges, the optimal value of L_1 is still around 7 μm. Similarly, for the parameters of L_2, H_1, and H_2, when other three variables change, the PAE takes the optimal L_2, and the H_1 and H_2 values are 8 μm, 4 nm, and 4 nm, respectively.

According to the discussion in 3.1, 3.2 and further simulation, the lengths and heights of the recessed region are as follows: L_1 = 0.7 μm, L_2 = 0.8 μm, H_1 = 4 nm, H_2 = 4 nm. After ISE TCAD and ADS simulation, the performance parameter pairs of IDRBL and DRBL structures are shown in Table 1. From Table 1, it can be found that the PAE of the IDRBL HEMT is 53.30%, and the PAE of the DRBL HEMT is 36.02%. After optimization, the PAE of the IDRBL structure is 17.28% higher than that of the DRBL. It can also be seen from the table that the PAE improvement also sacrifices some DC parameters and is achieved by discounting the threshold voltage, transconductance, gate-source capacitance C_{gs} and so on.

From Fig. 4. (a) and (d), it can be found that the in the IDRBL HEMT, threshold voltage V_t increases in the reverse direction as the

Table 1
COMPARISON OF PERFORMANCE PARAMETERS OF THE TWO STRUCTURES.

Parameters	DRBL GaN HEMT	IDRBL GaN HEMT
I_{dsat} (mA/mm)	571.00	532.00
V_b (V)	212.00	238.00
g_m (mS/mm)	250.80	267.82
V_t (V)	−3.79	−2.31
C_{gs} (fF/mm)	2830.25	2586.40
PAE (%)	36.02	53.30