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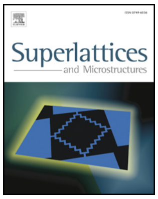

Simulation design of high Baliga's figure of merit normally-off P—GaN gate AlGaN/GaN heterostructure field effect transistors with junction field plates

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ABSTRACT

In this paper, we conducted a numerical analysis on novel Normally-off P—GaN gate AlGaN/GaN heterostructure field effect transistors with junction field plates (JFP-HFET). The breakdown voltage (*BV)* was significantly improved with the introduction of the junction field plate (JFP), which can make a rectangular distribution of the electric field in the GaN channel between the gate and the drain. The highest *BV* of 1340 V of JFP-HFET could be achieved with the gate to the drain distance $L_{gd} = 6\,\mu\text{m}$, the length of the P-type region of the JFP $L_p = 5.8\,\mu\text{m}$, the thickness of the JFP $T_j = 500\,\text{nm}$, the doping concentration of P-type region of the JFP $N_p = 1 \times 10^{17}\,\text{cm}^{-3}$, and the Al fraction of the AlGaN JFP $x_{Al} = 0.25$. The optimum parameters of the JFP-HFET were achieved by considering both the principle of charge balance and the practical fabrication of the III-V devices. The highest Baliga's figure of merit (BFOM) $1.2\,\text{GW/cm}^2$ was obtained under the conditions of $L_{gd} = 6\,\mu\text{m}$, $L_p = 5.8\,\mu\text{m}$, $T_j = 100\,\text{nm}$, $N_p = 6 \times 10^{17}\,\text{cm}^{-3}$, and $x_{Al} = 0.3$. C—V, turn-on and turn-off processes revealed that the JFP-HFET showed better switching characteristics than that of the HFET with metal field plate.

1. Introduction

Gallium nitride (GaN) semiconductor devices have gained considerable attention and broad prospects in high voltage application in recent years because of the high breakdown field of GaN and successful progresses in growth of III-V heterostructure on silicon [1–3]. AlGaN/GaN heterostrurcture field effect transistors (HFETs) with high breakdown voltage (*BV*), low on-resistance thus high Baliga figure of merit (BFOM) are extensively studied and have become one of major interests in the field of the power electronics [4,5]. However, these devices often show normally-on behavior due to the natural 2 dimensional electron gas (2DEG) which is induced by polarization effects of III-V heterojunction. This behavior of AlGaN/GaN HFETs would hinder the design of gate-control circuit, thus exclude them from most power electronics applications.

AlGaN/GaN HFETs with a p-type gate have been reported by many literature. By using a p-type GaN or AlGaN layer under the gate metal, the threshold voltage of HFETs can reach around 1.5 V and can realize normally-off operation with simple and controllable fabrication processes [6–10]. The results show that p-GaN gate AlGaN/GaN HFETs are promising for GaN based power electronics commercialization [11]. However, an electric field (E-field) peak exists at the corner of the gate of lateral kinds of semiconductor devices such as LDMOSFETs [12] and AlGaN/GaN HEMTs [13,14], thus cause a premature breakdown of these kinds

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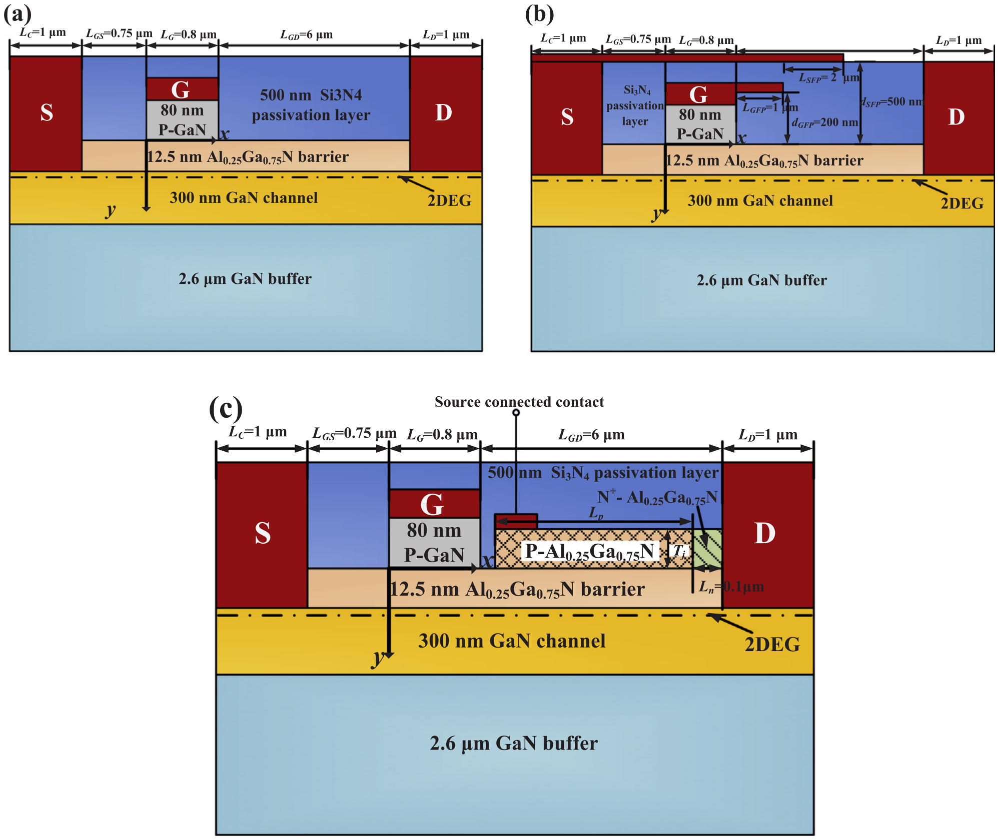

Fig. 1. Schematic structure of the simulated (a) conventional P—GaN gate HFETs, (b) MFP-HFETs and (c) proposed JFP-HFETs.

of semiconductor devices. As one of these kinds of lateral semiconductor device, p-GaN AlGaN/GaN HFETs also suffered from this problem [15]. Although metal field plates (MFP) can modulate the E-field distribution in the channel layer, a new E-field peak is induced at the end MFP, thus hinder the further improvement of the BV [14,16]. So the BFOM of p-GaN gate AlGaN/GaN HFETs is still far from the material limits of GaN. Junction field plates (JFP) have been reported as a new method to improve the *BV* and BFOM of lateral diffusion metal-oxide-semiconductor field effect transistors (LDMOSFETs). Compared to the MFP LDMOSFETs, the JFP LDMOSFETs achieves a superior trade-off between RON, sp and *BV* [12].

In this study, a junction field plate AlGaN/GaN HFETs (JFP-HFETs) was proposed to improve the *BV* of the p-GaN gate devices, because the p-GaN gate GaN HFET have well experimentally studied and have shown great application prospects in power electronics. In the present study, the BV of the AlGaN/GaN HFETs can be significantly enhanced by adding a JFP on the AlGaN barrier between the gate and the drain. The forward characteristics of JFP-HFETs only showed a small degradation when compared to the conventional HFETs. So the proposed JFP-HFETs can achieve a high BFOM. *C—V* simulation was also conducted to determine whether JFP-HFETs had a better switching characteristics than MFP P—GaN gate HFET.

2. Device structure, fabrication and models

The device structure of the conventional P—GaN gate HFETs, MFP-HFETs and proposed JFP-HFETs is shown in Fig. 1. The epitaxial structure of the device consisted of a 2.6 µm thick GaN buffer layer, a 300 nm GaN channel layer, and a 12.5 nm AlGaN barrier layer with a 25% Al content. An 80 nm P—GaN under the gate metal is grown on the AlGaN barrier to realize normally-off operation. The hole density of the P—GaN is set as 1×10^{18}cm^{-3}. A Si_3N_4 passivation layer with a thickness of 500 nm was added to the AlGaN barrier layer. The source length (L_C), drain length (L_D), gate length (L_G), gate-to-source distance (L_{GS}) and gate-to-drain distance (L_{GD}) of the device were 1, 1, 0.8, 0.75, and 6 µm, respectively. All of the parameters used in the simulation were based on the experimental results of Ref. [10]. And were listed in Table 1. High resistive GaN buffer layer can be realized by doping C during the growth of the GaN buffer [17].In the Ref.17, the authors have reported traps energy level of C doped buffer. For low C doping concentration ($N_A = 1 \times 10^{16}$cm^{-3}), there is only one energy level of the C related acceptor-like traps which is 0.59 eV under the conduction band. So here high resistance of GaN buffer layer were simulated as acceptor traps doped GaN with an energy level of E_C-0.59 eV and a density of 1×10^{16} cm^{-3}. In the MFP-HFET in Fig. 1 (b), the gate MFP and the source MFP placed on the passivation layer with a distance to the surface of AlGaN barrier layer were 200 nm and 500 nm, respectively, and both kinds of MFPs are typical in the GaN based high voltage devices [4,18]. In the JFP-HFET in Fig. 1 (c), the JFP consisted of a P-type AlGaN layer and an N^+-type