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Numerical simulation of local doped barrier layer AlGaN/GaN HEMTs

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ABSTRACT

A GaN HEMT with local doped barrier layer is proposed in this paper. The DC and RF characteristics of the proposed GaN HEMT structure is analyzed by using 2D numerical simulation. The results show that the breakdown voltage is 23% larger than that of the entire doped barrier layer structure due to the extension of depletion layer width between gate and drain electrodes, which reduces the electric field peak value at the right corner of the gate. A theoretical maximum output power density of 16.2 W/mm has been achieved, which is ~34% larger than that of the entire doped barrier layer structure, and 7% larger than that of the unintentionally doped barrier layer structure. And the RF simulation results show that the proposed GaN HEMT also improved the maximum stable gain (MSG) by 0.8 dB up to 25 GHz due to the decrease of the gate–drain capacitance compared to the unintentionally doped and entire doped barrier layer structures.

1. Introduction

Gallium nitride (GaN) high electron mobility transistors (HEMTs) are considered to be excellent candidate for high power, high frequency and high temperature applications in the commercial and military communications [1–3]. This is mainly due to the superior properties of gallium nitride, such as, wide band gap (3.42 eV), high electron saturation velocity (2.5×10^7 cm/s), high critical electric field (3.3 MV/cm), and high thermal conductivity (1.3 W/cm K).

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To utilize GaN materials to their ultimate performance, a large number of GaN HEMT structures and various optimizations have been reported [4–7]. The peculiar transport characteristic of GaN still offers the possibility to enhance the device performances by proper optimization of the device such as doping [8]. In 2001, Chu et al. [9] investigated the influence of the doping level in GaN as well as in the AlGaN layer on the 2DEG distribution, it is found that the two-dimensional electron gas concentration depends much more strongly on the doping level in AlGaN than in GaN. In 2003, Maeda et al. [10] proposed doping based designs that make it possible to obtain high 2DEG densities even for the devices with thin AlGaN barrier layers. In 2011, Abou El-Ela and Mohamed [11] calculated the doping dependencies of the transport properties within GaN and GaAs, the results show that the electron drift velocities decrease much more with increased doping in GaAs than those in GaN.

In this paper, an improved GaN HEMTs with local doped barrier layer is investigated using a 2D device TCAD simulation program, Silvaco ATLAS [12]. The n-type doped barrier layer under the gate electrode can not only improve the saturation drain current, but also enhance device breakdown voltage and high frequency characteristics as compared to the entire doped barrier layer HEMT. In this configuration, the n-type doped barrier layer under the gate terminal is employed to obtain high saturation drain current, while the unintentionally-doped (UID) barrier layer in ungate region is adopted to attain higher breakdown voltage and lower gate–drain capacitance(C_{gd}). The DC and RF performances of the proposed GaN HEMTs have been studied in detail, and the simulation results are compared with those obtained from the entire doped barrier layer and unintentionally doped barrier layer device.

2. Device structure and physical model

2.1. Device structure

Fig. 1a and b shows the schematic cross sections of the entire doped barrier layer structure and the proposed GaN HEMTs, respectively. The entire doped barrier layer structure corresponds to a device described by Shen et al. [13]. To compare the characteristics of the proposed structure with the entire doped barrier layer structure and unintentionally doped barrier layer structure, the basic parameters of the structure, except for the n-type barrier layer configuration, are left unchanged and can be described as follows. These structures consist of semi-insulating SiC substrate, a 1.25 μm semi-insulating GaN layer, a 1 nm AlN interfacial layer, a 5 nm UID $Al_{0.3}Ga_{0.7}N$ barrier layer, a 20 nm Si-doped $Al_{0.3}Ga_{0.7}N$ barrier layer doped at 1×10^{18} cm^{-3}(entire doped barrier layer structure), an unintentionally doped barrier layer(unintentionally doped structure), a local Si-doped (1×10^{18} cm^{-3}) $Al_{0.3}Ga_{0.7}N$ barrier has a 0.9 μm length and 0.7 μm far from the source(proposed structure), and a 100 nm Si_3N_4 passivation layer. All devices have a gate length (L_g) of 0.7 μm, a gate-to-source spacing (L_{gs}) of 0.8 μm and a gate-to-drain spacing (L_{gd}) of 2.0 μm. The gate width was 100 μm, and a temperature of 300 K was employed by default in the simulations. The ohmic contact resistance is 0.7 Ω mm.

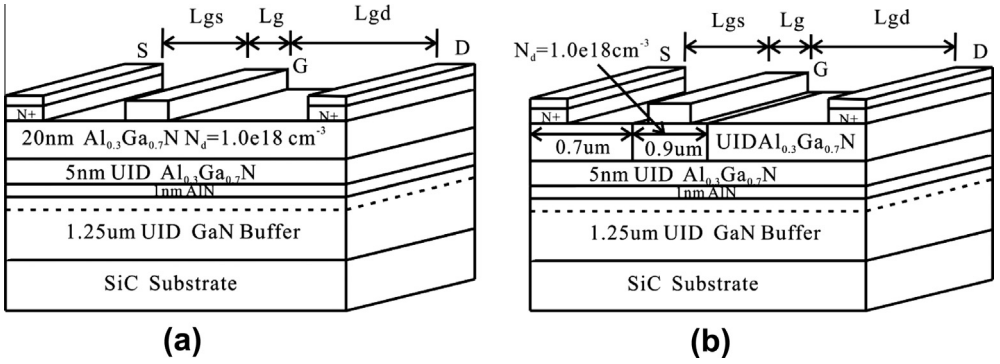

Fig. 1. Schematic cross-sections of GaN HEMTs with (a) entire doped barrier layer and (b) the proposed structure.