Breakdown Enhancement Voltage of AlGaN/GaN Hemts with Schottky and OHMIC Drain Contacts

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Abstract— In present scenario high voltage AlGaN/GaN High Electron Mobility Transistors (HEMTs) on Si substrate with Schottky drain contacts were simulated to increase the breakdown voltage by replacing the conventional Ohmic drain contacts. A significant increase in breakdown voltage values was achieved for non-annealed Schottky contacts by elimination of metal spikes underneath drain electrodes. The breakdown voltage increase of Schottky drain contacts provides low leakage current at drain source reverse bias. In this paper reports the temperature dependent electrical parameter of Schottky drain contact. The Schottky drain contacts were characterized by better temperature stability of the specific on resistance.

Index Terms—AlGaN/GaN, High Electron Mobility Transistor (HEMT), Schottky drain, Ohmic drain.

I. INTRODUCTION

AlGaN/GaN High Electron Mobility Transistors (HEMTs) are attracting considerable attention for the next generation of power electronics, due to their combination of high electron mobility and high critical electric field [1]. High Electron Mobility Transistors (HEMTs) properties are high breakdown voltage, small losses and large switching speed and also be grown on large diameter, low cost silicon substrates with good thermal conductivity. The main hindrance of commercial AlGaN/GaN on Si power devices is much lower breakdown voltage [2]. In order to increase the breakdown voltage to replace the conventional ohmic drain contacts by the Schottky contacts. As a result, the breakdown voltage of AlGaN/GaN HEMTs has increased above 700 V [3]. It was suggested that the increase of breakdown voltage resulted from the avoidance of the metal spikes underneath alloyed ohmic contacts, which can locally increase the electric field and results in excessive buffer leakage current [4]. In addition to breakdown voltage increase, the Schottky drain contact provides also low leakage current at drain source reverse bias which is necessary in many power electronics applications [5] and eliminates the use of discrete external diodes [6]. Several approaches have been used to improve the device breakdown voltage consisting in the modification of epitaxial structure [7], modification of device design [8]. Recently, a 1.8-kV breakdown voltage has been demonstrated in AlGaN/GaN HEMTs on Si by increasing the buffer thickness to 6 μm [10]. In this paper proving the usefulness of the application of Schottky drain contacts in the design of AlGaN/GaN-on-Si HEMTs [9] and also reports about temperature dependent electrical parameters of the Schottky drain HEMTs. In this paper to improve the breakdown voltage using Schottky drain contact instead of ohmic drain contact with AlGaN/GaN on Si HEMTs. This paper is organized as follows. Section 2 presents the device design and simulation procedure for Schottky and ohmic drain contacts. Section 3 presents the simulation results. Section 4 concludes the paper.

II. DEVICE DESCRIPTION AND SIMULATION

The simulation of both Ohmic and Schottky drain HEMTs are in the same wafer in close proximity to each other. The devices were simulated on an AlGaN/GaN heterostructure grown on 4 nm GaN cap layer, 20 nm Al0.12Ga0.88N barrier layer, 0.8 nm AlN spacer, 1200 nm unintentionally doped GaN layer, 2000 nm AlGaN and n-type Silicon <111> substrate material. The cross sectional vg of AlGaN/GaN HEMTs with both ohmic and Schottky drain electrodes are shown in Fig.1. For, commercial available HEMTs ohmic contacts area was defined by Ti/Al/Mo/Au metal stack was sputtered in source and drain contacts and annealed at 850°C for 30s in nitrogen. Note that for Schottky drain transistors the ohmic electrodes source contact are the same and the drain contact is annealed Ti/Au metal. The device active area was isolated by double implantation of Al+ ions. Next, Ni/Au gate Schottky metal and contact pads were deposited by e-beam evaporation. For Schottky drain devices, the contact pads act as drain electrodes. The contact pads were plasma and dry etched by using BCl3/Ar. The gate length (Lg) and width (Wg) was 2 μm and 50 μm, respectively.
The source-gate distance \( (L_{SG}) \) was 2\( \mu \)m and gate-drain distance \( (L_{GD}) \) varied between 5\( \mu \)m and 20\( \mu \)m. On wafer, temperature dependent electrical measurements were carried out.

III. RESULTS AND DISCUSSION

The results of simulated AlGaN/GaN on Si HEMTs simulations with Ohmic and Schottky drain contacts was performed in Silvaco ATLAS TCAD package [11].

Fig.2 shows the current-voltage characteristic curve of AlGaN/GaN on Si HEMTs with Ohmic and Schottky drain electrodes with 20\( \mu \)m gate to drain distance. Here gate to source voltage was swept from -2V to 4V in steps of 1V. For both type of contacts maximum drain current was about 500mA/mm. For higher drain-source voltage values a negative differential output conductance was appeared due to the self-heating effects. The output characteristics of Schottky drain HEMTs are shifted of about 1.91 V. This shift is called onset voltage \( (V_{on}) \).

The breakdown voltage of 250 V is achieved for relatively small \( L_{GD} = 5 \) \( \mu \)m. For longer \( L_{GD} \) distances (10\( \mu \)m, 15\( \mu \)m and 20 \( \mu \)m) the breakdown voltage is 320, 390 and 505 V, respectively. Large improvement of breakdown voltage is observed in case of Schottky-drain electrodes. For \( L_{GD} = 10 \) \( \mu \)m and \( L_{GD} = 15 \) \( \mu \)m \( V_{BR} = 470 \) V and \( V_{BR} = 740 \) V is observed. This corresponds to 46\% and 89\% enhancement of the \( V_{BR} \) in comparison to conventional HEMT structure. The highest breakdown voltage of 900 V, obtained for \( L_{GD} = 20 \) \( \mu \)m, is 78\% higher than \( V_{BR} \) of conventional HEMT.

Fig.1. Cross sections of AlGaN/GaN HEMTs with (a) Ohmic drain, (b) Schottky drain

Output characteristics (\( V_{GS} = 3 \) V) of ohmic and Schottky drain HEMTs measured within temperature range from \( 25^\circ C \) to \( 200^\circ C \). As expected, on state current substantially depends on temperature and it decreases with increasing temperature. This effect is related to carrier mobility decrease, which is
correlated mainly with polar-optical phonon scattering. The change of 2DEG concentration is low and does not affect on-state current. It is worth to note that the temperature dependence of maximum drain current can be also affected by gate length. For short gate length electric field at gate corner is higher and electron velocity is close to the saturation velocity value.

Fig.3. shows the electron concentration (a) and potential distribution (b) of ohmic and Schottky drain electrodes. There is no depletion region under the gate electrode for ohmic drain design and the potential is uniformly distributed between drain and gate electrodes and there is no barrier for electron flow at the drain side and gate side. In Schottky drain design there is a large potential drop on the edge and under drain contact which acts as a barrier for electrons and two dimensional electron gas is depleted not only under the gate electrode but also under the drain contact for Schottky drain HEMT.

![Electron concentration and potential distribution](image)

Fig 3. Electron concentration (a and c) and potential distribution (b and d) in AlGaN/GaN with Ohmic drain and Schottky drain contacts

IV. CONCLUSION

High voltage AlGaN/GaN on Si HEMTs with ohmic and Schottky drain contacts were successfully simulated and temperature-dependent electrical parameters were evaluated. A significant increase in breakdown voltage values was achieved for non-annealed Schottky drain electrodes. Maximum $V_{BR} = 900$ V was obtained for Schottky drain contacts at gate to drain distance of $L_{GD} = 20 \mu m$ compared to $V_{BR} = 505$ V for ohmic drain contacts. The Schottky drain contacts were characterized by better temperature stability of the specific on-resistance.

REFERENCES


