Investigation of vertical GaN-MOSFET breakdown effects by device simulation

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ABSTRACT

The breakdown mechanisms of a vertical GaN-MOSFET under variation of several structure parameters were investigated. The device simulation results show different breakdown locations and breakdown voltages according to structure parameters. The maximum breakdown voltage reaches 1.6 kV without a field plate. Furthermore the influence of a field plate was simulated. By using an optimized field plate length an increase in breakdown voltage to 2.5 kV was observed. It is limited by impact ionization as a result of the high field strength at p-n junction.

1. INTRODUCTION

GaN-devices are notable for power electronics because of high breakdown field strength and low switching losses [1]. They are suitable for rising power with simultaneous enhancement of energy efficiency [1]. Today vertical devices are in focus of development. They have long drift distances to reach high breakdown voltages [1]. These devices were required for high power applications. Some different vertical GaN-MOSFET structures were already investigated [2-7].

The current work investigates the characteristic parameter breakdown voltage of the transistor shown in Fig. 1. With the aid of device simulations it is possible to evaluate a multitude of different structure variations in a short time and without high costs.

2. DEVICE MODELING

The structure in Fig. 1 was investigated under variation of p- and drift-layer thickness, trench- and mesa-angle, ionization rate of p-doping as well as the existence and length of a field plate. Fig. 1 specifies the layer thicknesses, too. The angles are 90° and 45° respectively. The dopant concentration for p-doping is $1\cdot10^{19}$ cm^{-3}. It is incomplete ionized because of a low energy level of acceptors and partial passivation of them through the formation of MgH complexes by using Mg as dopant [8, 9]. The complex formation can be eliminated by an additional temperature step [10]. P-ionization rates in publications reach from 0.01 % [11] to 10 % [12]. In the simulations typical values of 1 % and 5 % were chosen.

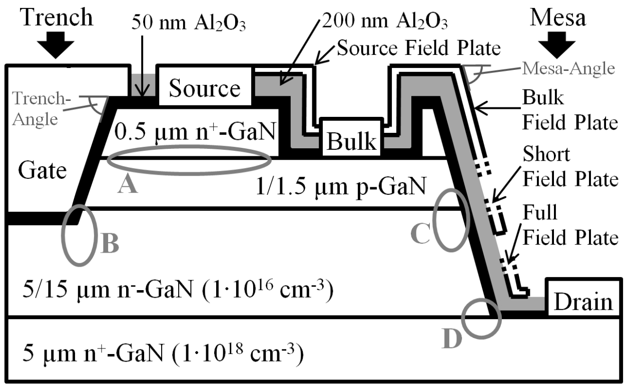

Figure 1: Structure of the investigated GaN-MOSFET with selected breakdown regions

Additionally the influence of a field plate was investigated. Therefore simulations with and without field plate were performed. One variation includes a source and a bulk field plate shown in Fig. 1. In the other case only a bulk field plate was used. For each case a full and a short field plate was simulated. Note that the short field plate only is meaningful with a mesa-angle of 45°.

The device simulations were performed by using drift-diffusion model, doping and field dependence mobility as well as SRH recombination and avalanche generation [13].

3. SIMULATION RESULTS

3.1. Simulation without field plate

First simulations were performed without field plate. With a p-layer thickness of 1 µm and a p-ionization rate of 1 % a punch-through at 670 V for 5 µm drift-layer thickness and at 860 V for 15 µm drift-layer thickness with a mesa-angle of 90° was observed (A in Fig. 1). For 15 µm drift-layer thickness and a mesa-angle of 45° impact ionization at C release the breakdown at 790 V. In order to increase the breakdown voltage a higher p-ionization or thicker p-layer is required. In this case the breakdown voltage is limited by impact ionization at B or C. For example impact ionization occurs at 800 V at position B for p-ionization of 5 %, drift-layer thickness of 5 µm and a mesa-angle of 90°. The maximum breakdown voltage is 1600 V for 1 % p-ionization limited by impact ionization at C. The impact ionization location is also presented in Fig. 2a. For 5 % p-ionization the breakdown voltage maximums are 1600 V (trench-angle 45°) and 1200 V (trench-angle 90°) because of impact ionization at mesa-slope C and trench-corner B (Fig. 2b). These structures consist of a 1.5 µm p- and a 15 µm drift-layer with a mesa-angle of 90°. For a mesa-angle of 45° the breakdown voltages decrease to 1100 V (1 % p-ionization) and 840 V (5 % p-ionization) because of drift distance reduction due to a deflection of space-charge region. The breakdown mechanism is impact ionization located at C also shown in Fig. 2c.

3.2. Simulation with field plate

An improvement in breakdown voltage is expected by using field plates [5]. However, a full field plate at this structure (Fig. 1) reduces the breakdown voltage to about 200 V because of high electric field at mesa-corner D. In consequence of this the impact ionization set in, apparitional in Fig. 2d. A better variant is a short field plate for a mesa-angle of 45°. For 90° a short field plate is not producible. With this field plate and a p-ionization of 1 % the breakdown voltage reaches 1700 V limited by punch-through. Layer thicknesses are 1.5 µm for p-layer and 15 µm for drift-layer. P-ionization of 5 % and a trench-angle of 90° result in a breakdown voltage of 1200 V limited by impact ionization at B. The results of different field plate length at a trench-angle of 45° are shown in Fig. 3. The best variant with a field plate length between 10 % and 35 % of drift-layer thickness has a high breakdown voltage above 2500 V. In this case impact ionization starts because of the high electric field strength at p-n junction. For a longer field plate the electric field strength at the end of field plate is high enough to release impact ionization. For shorter field plates the critical border of p-n junction is not covered enough.

Also the simulation results show that there is no difference in breakdown voltage and mechanism by using source and bulk field plate or only bulk field plate shown in Fig. 1.

4. CONCLUSION

This work investigates the different breakdown mechanisms and voltages for the shown structure of a vertical GaN-MOSFET. The influences of structure parameters were presented. As a result four main locations of breakdown initiation were located. A maximum breakdown voltage of 1600 V was reached without field plate. By using a short field plate and optimizing its length an increase in breakdown voltage to 2500 V was detected. In this case the electric field on p-n junction causes the breakdown. So subsequently options to reduce that field strength, e.g. with a longer drift region, have to be investigated to further increase the breakdown voltage.

5. ACKNOWLEDGMENT

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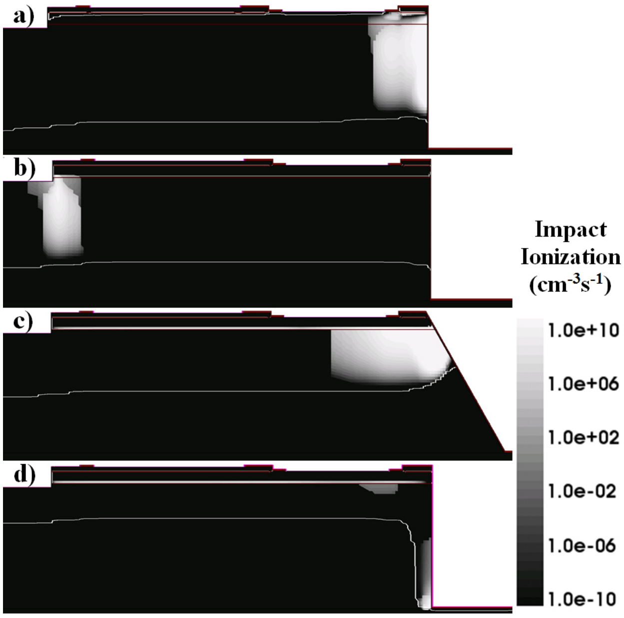

Figure 2: Examples of different impact ionization locations without (a-c) and with (d) field plate at breakdown region (1.5 µm p-layer, 15 µm drift-layer, 1 % (a) and 5 % (b-d) p-ionization)

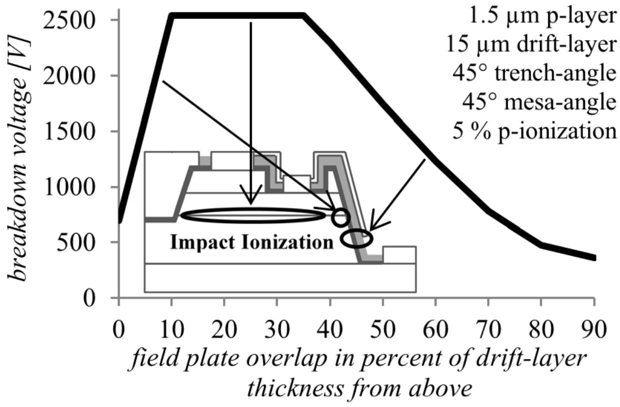

Figure 3: Breakdown voltage according to short field plate length

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