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Mechanism study of gate leakage current for AlGaN/GaN HEMT structure under high reverse bias by TSB model and TCAD simulation

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1. Introduction

High electron mobility transistors (HEMTs) used GaN materials are the promising devices for high-power and high-frequency amplifiers due to the high breakdown voltage and high drain current density. Until now, the high performances such as output power density above 40 W/mm and a power added efficiency of 67 % for C-band were reported [1, 2]. However, there is a room for giving full play to their ability of the microwave performance. One of the important issues is a gate leakage current reduction. GaN HEMTs have a larger gate leakage current than that expected from the superior properties as the wide bandgap materials [3]. The large gate leakage current in a reverse bias degraded their high voltage operation and reliability [4-5]. Therefore, the gate leakage current should be reduced in order to keep evolving in the future.

The origin of the gate leakage current is well known to be an electron tunneling through a Schottky gate barrier and there are many papers on the mechanism [6-15]. Almost the papers have dealt with a simple one dimensional structure. However, the GaN HEMTs have a complicated structure. The source and drain electrodes as ohmic electrodes are fabricated on an AlGaN barrier layer, on which the gate electrode also exists. Moreover, a heterojunction to produce a two dimensional electron gas (2DEG) is consisted. This structure is different from one dimensional structure, and a depletion layer from the gate electrode may extend in every direction (both laterally and vertically). Therefore, the gate leakage current analysis taking into account with two dimensional effects is very important under the high drain voltage operation.

In this paper, we have study the gate leakage current mechanism by applying the thin surface barrier (TSB) model to the two dimensional structure with the AlGaN/GaN heterojunction. TSB model explains well the gate leakage current characteristics at the relatively low bias [6, 10]. However, as far as our knowledge, there is no report of TSB model for the two dimensional structure of GaN HEMTs under the high reverse gate bias. From the TCAD simulation results for various surface conditions, the laterally depletion extension from the gate edge plays an important role for the gate leakage current at high reverse bias beyond a pinch off voltage. These phenomena are shown as a model where there are the Schottky diodes under the gate electrode and at the gate edge.

2. Structure for TCAD simulation

Figure 1 shows a schematic cross sectional structure of GaN HEMT used for TCAD simulation. The gate electrode is located on the heterojunction structure of AlGaN barrier/ GaN channel. The drain electrode as the ohmic contact is located at the side of the structure in order to take the two dimensional effect into account. The positive polarity charges for producing the 2DEG are set at the interface of AlGaN/GaN.

As shown in Fig. 1, the structure has the two unintentional surface defect donor thin layers at upper AlGaN barrier layer to take in TSB model. This point is different from the conventional one dimensional TSB model. In simulation, the donor thin layer consists of a donor with shallow activation energy of 0.044 eV and the electron tunneling mechanism is adopted. The simulator of Silvaco ATLAS is used in this study [16].

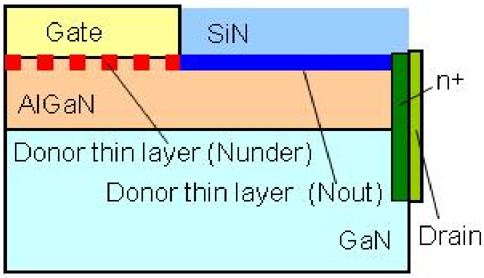

Fig. 1. Schematic cross-sectional GaN HEMT structure for simulation.

3. Simulation results and gate leakage mechanism

The mechanism is studied by simulation for the structures with different doping concentration of two donor thin layers. Figure 2 shows the gate-drain current (-Igd) versus the gate-drain voltage (-Vgd) curves for three types of donor thin layer. One is an uniform doping structure where the doping concentration under the gate electrode (Nunder) is the same as the one between the gate and drain electrode (Nout). The other structures have the only one donor thin layer, whether there is Nunder or Nout. Both Nunder and Nout are 1E18 cm^{-3}. For the low voltage below –Vgd of 3 V, the characteristics for the uniform doping (Nunder =

Nout) is almost the same as one for the doping only under the gate (Nunder). In contract, the curve for the doping only at the gate side (Nout) gets close to one for the uniform doping with increasing –Vgd. –Vgd of 3 V is corresponding to the pinch off voltage, because the depletion layer reaches to the bottom of GaN layer.

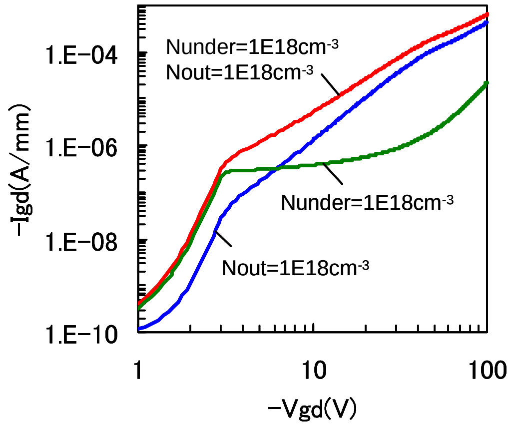

Fig. 2. Igd-Vgd curves for different doping layers.

Figure 3 shows the curves for the different Nunder in the case of only doping at the gate side. The characteristics for the low reverse bias of –Vgd are almost the same for the different Nout. Above –Vgd of 3 V, –Igd increases as –Vgd increases.

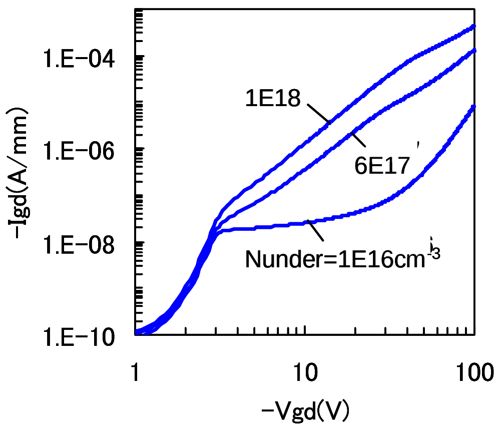

Fig. 3. Igd-Vgd curves for different doping concentration under gate.

The results of Figs. 2 and 3 make the mechanism under the high –Vgd region clear. The depletion layer extends laterally from the gate edge above –Vgd of the pinch off voltage. Therefore, the condition (Nout for the donor thin layer at the gate side) dominates the characteristics under the high reverse gate voltage. Figure 4 (a) shows a gate leakage current model. In the actual GaN HEMTs with the two dimensional structure, a Schottky diode should be considered at the gate side in addition to the Schottky diode under the gate electrode which is considered in the case of conventional one dimensional structure.

4. Summary

The gate leakage current mechanism for the actual GaN HEMTs has studied by using TSB model and TCAD simulation. In the high reverse bias, the lateral extension of the depletion layer dominates the gate leakage, while the vertical extension of the depletion, which deals with the conventional model, dominates at the low reverse bias. We have obtained the excellent agreement with a measurement data for the very wide voltage range [17].

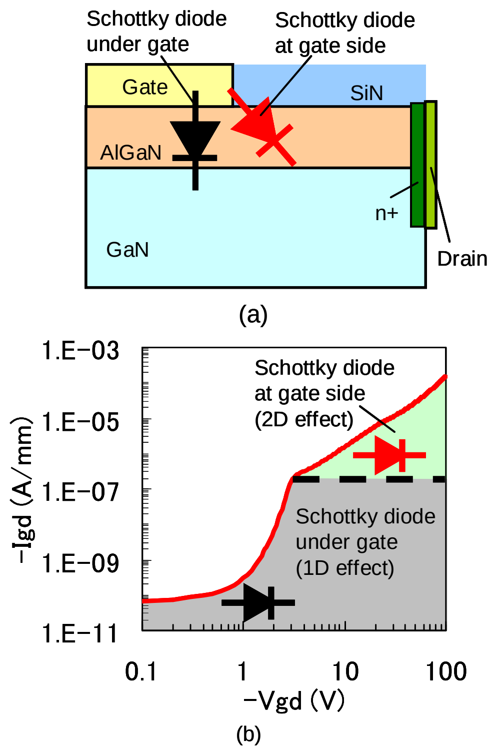

Fig. 4. (a) Gate leakage model.
(b) Igd-Vgd curve for this model.

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