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Abstract

On-state gate leakage current behavior of AlGaN/GaN high electron mobility transistors (HEMTs) has been studied by using Technology Computer Aided Design (TCAD) simulation. We found the gate leakage current increases above the pinch-off voltage, which is different from the case of a two-terminal operation. This gate leakage current increase is due to self-heating effect at the gate edge of the drain side where the gate leakage occurs.

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Simulation study of gate leakage current under three-terminal operation for AlGaN/GaN HEMTs

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Abstract

On-state gate leakage current behavior of AlGaN/GaN high electron mobility transistors (HEMTs) has been studied by using Technology Computer Aided Design (TCAD) simulation. We found the gate leakage current increases above the pinch-off voltage, which is different from the case of a two-terminal operation. This gate leakage current increase is due to self-heating effect at the gate edge of the drain side where the gate leakage occurs.

Introduction

HEMTs using GaN and related compounds are very promising devices for RF high-power amplifiers due to their superior material properties. Although to date, many high RF performances have been reported, there is still a lot of room for their full potential to be played out [1, 2]. One of the important issues is the gate leakage current reduction. The gate leakage mechanism has been widely studied and the origin of the gate leakage current is the electron tunneling through the Schottky gate barrier [3-5]. However, gate leakage current behavior for three-terminal operation under on-state condition is not clearly understood, because most papers deal with behavior for two-terminal operation under off-state condition where large drain current is absent in a channel. In this paper, we have studied the unique characteristics of the gate leakage current of AlGaN/GaN HEMTs under the on-state condition by using TCAD simulation. The gate leakage current increases above the pinch-off voltage, when the self-heating effect introduces to rise of lattice temperature at the gate edge of the drain side.

Structure for TCAD Simulation

Figure 1 shows the schematic of a cross sectional structure of AlGaN/GaN HEMT which is used in our TCAD simulation. The positive polarity charges are set at the interface between the AlGaN barrier and the GaN channel in order to produce the 2DEG channel. A thin surface barrier model with a donor thin layer at the AlGaN surface is adopted for simulation of the gate leakage current [3, 5]. The self-heating effect is taken into account in this study using Silvaco ATLAS as the simulator [6].

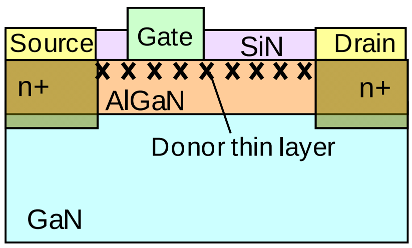

Fig. 1 Schematic cross sectional AlGaN/GaN HEMT structure.

TCAD Simulation results

We have simulated gate current (Ig) and drain current (Id) as dependents of gate voltage (Vg) in order to study the impact of the self-heating effect. Figure 2 shows Id increases monotonically as Vg increases whether with or without self-heating effect. On the other hand, Ig has very different characteristics between with and without self-heating effect. Ig decreases monotonically in the case of no self-heating, while Ig's trend changes at about Vg of -3 V from decreasing to increasing in the case of the self-heating. The increase of Ig above Vg of -3 V cannot be observed by only using the gate leakage mechanism of a two-terminal operation. This should be considered as the effect of the increase of lattice temperature (Tl) due to the stronger self-heating generated by the larger Id above the pinch-off voltage (-3.5 V).

In order to investigate the relationship between Tl and Ig, we simulated the Ig at various Tl without the self-heating. Figure 3 shows Ig and maximum Tl graphs at ambient temperature of 300 K. Figure 3 also shows Ig for the various Tl without self-heating effect. Ig with self-heating effect is almost the same as Ig without the self-heating, when maximum Tl is the same as Tl without self-heating effect (The case of Tl at 400 K is shown using the arrows in Fig. 3). Therefore, Ig increases with Vg at about Vg greater than -3 V is due to the increase of Tl as electron current in the channel increases.

Figure 4 shows Tl and electric field (E) profiles at Vg=-2V where HEMT operates under the on-state condition. Tl has a maximum value near the gate edge of the drain side according to the product of Id and E. From Fig. 5 (a) and (b), the maximum value of Tl exists near the peak value of E at the gate edge where the gate leakage arises. This is a reason why Ig with self-heating increases with Vg as opposed to decreasing Ig with increased Vg without the self-heating.

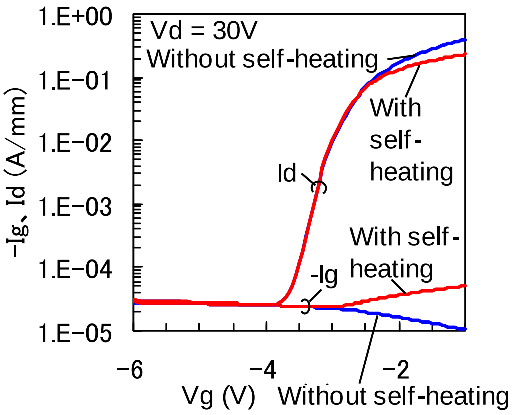

Fig. 2 Drain current and gate current depending on gate voltage at high drain voltage of 30 V with and without self-heating.

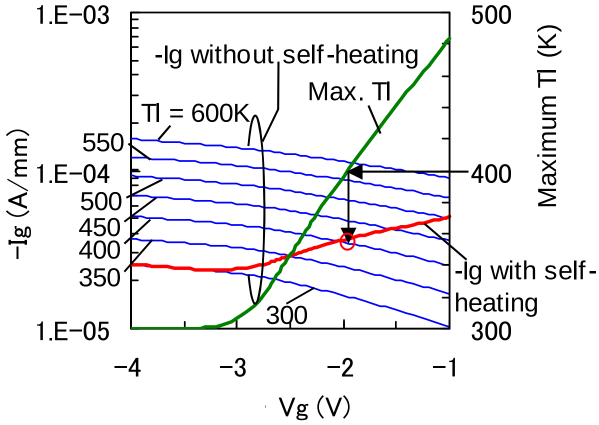

Fig. 3 Gate current for ambient temperature of 300K over-drown by current for various lattice temperatures. Maximum values of Lattice temperature for self-heating are also shown.

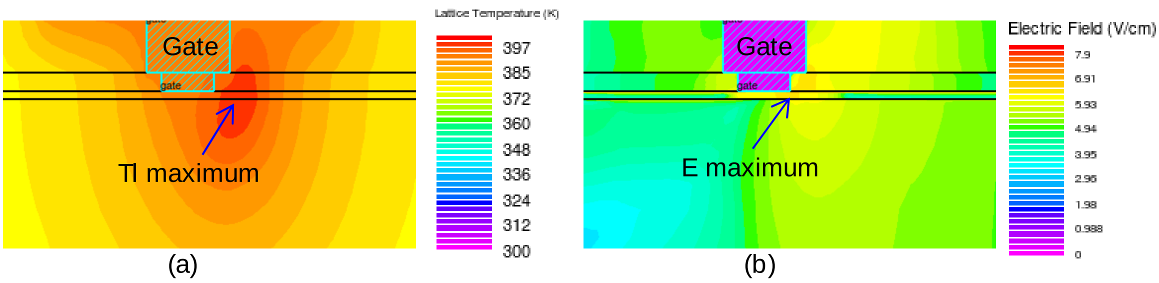

Fig. 4 (a) Lattice temperature and (b) electric field profiles at Vg=-2V and Vd=30V with self-heating effect.

Comparison with experimental data

We confirm the above described Ig behavior in a real AlGaN/GaN HEMT device experiment. Figure 5 shows the comparison between model and measurement data of Ig and Id as function of Vg. The model data have very good agreement with the measurement data for both Id and Ig characteristics. Therefore, the impact on the gate leakage current in the on-state condition due to the increase in the lattice temperature induced by seld-heating should be considered.

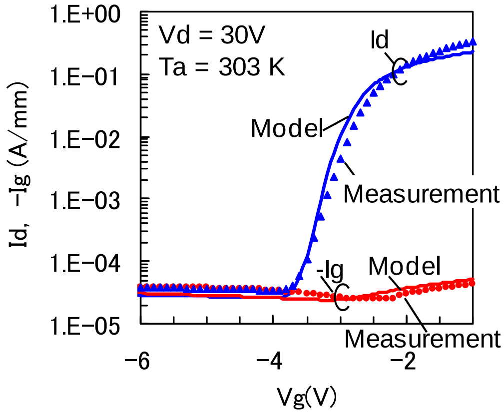

Fig. 5 Comparison between model and measurement for drain and gate current depending on gate voltage.

Summary

Self-heating at the on-state condition in AlGaN/GaN HEMTs has strong impact on the gate leakage current behavior. Above the pinch-off voltage, Ig increases with Vg due to the self-heating of large Id, whereas below pinch-off voltage, Ig follows the expected behavior, decreases as Vg increases.

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