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Direct Carrier Number Measurement Method to Evaluate Current Collapse of GaN HEMT device

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Abstract

In this paper, a new method to evaluate current collapse (C/C) is proposed. We focused on carrier number which has negligible temperature dependence. Capacitance measurement is utilized to calculate carrier number under field plate. It makes possible to identify where the increase of on resistance (Ron) is occurring in the device. Comparing with conventional Ron measurement, proposed method is confirmed to have high accuracy.

1. Introduction

Gallium Nitride (GaN) is a promising candidate for next generation power devices because of its attractive material properties [1]. One of the challenges for GaN device is the suppression of C/C phenomenon known as an increase of Ron by switching test under high drain voltage [2]. Usually Ron is used to characterize C/C [3] but it is affected by heat effect. When the increase of Ron is small, ΔRon caused by self-heating during switching test becomes non-negligible. To overcome this difficulty, a new method to evaluate C/C without temperature dependence is proposed.

2. Measurement Methods and Results

A depletion mode GaN high electron mobility transistor (HEMT) was investigated. Dual field plate (FP) device was fabricated on GaN-on-Si wafer. Fig.1 shows the process flow and schematic cross sectional view of our devices. For evaluating C/C, inductive load switching test was used [4]. The collapse test circuit and example wave form is shown in Fig.2. Although Ron is calculated from measured voltage and current wave form, it is strongly temperature dependent as shown in Fig.3. On the other hand, Vth has almost constant value. These results mean mobility has large temperature dependence while carrier number has small dependence [5]. Fig.4 shows the relationship between temperature and Ron during inductive load switching test of various devices with the blue line calculated from ΔRon in Fig.3. Temperature effect dominates the increase of Ron when its value is small [6]. It is important to distinguish heat effect and carrier decreasing effect because both mobility and carrier number affect Ron. Therefore we focused on not only ΔRon but also carrier number to evaluate C/C.

Direct measurement of carrier number is possible by utilizing capacitance measurement technique [7]. Capacitance change in GaN HEMT devices is related to the depletion of carriers in two dimensional electron gas (2DEG). As drain voltage increases, depletion region expands toward drain direction from the gate edge. Dual-FP structure leads to two step changes in capacitance which are related to the depletion of 2DEG under gate-FP and source-FP respectively [8]. Fig.5 is the comparison of parasitic capacitance before and after inductive load switching test. The large capacitance change of Cds after switching test indicates the decrease of 2DEG under source-FP owing to the relation of Q=CV. Simulation has been carried out as shown in Fig.6. When the number of 2DEG under source-FP is decreased, depletion voltage of Cds becomes smaller. Smaller depletion voltage observed in Cds after switching test means decrease of 2DEG under source-FP which causes the increase of Ron.

3. Discussion

Sheet carrier density (n_s) under FP can be derived by $n_s = \int C(V)dV/(q \times S)$ where S is the area of FP. We are interested in the carrier under source-FP. Therefore the term $\int Cds(V)dV$ should be suitable for characterizing C/C as shown in Fig.7. As an example, 50% decrease of carrier number is estimated for the device shown in Fig.5 by this new method. Fig.8 (a) shows the relation between Ron and the carrier number calculated by $\int Cds(V)dV$ after inductive load switching. Strong correlation observed in Fig.8 verifies our proposed method is appropriate. Fig.8 (b) is the magnified view with theoretical curve based on model $R \propto 1/n\mu(T)$. Temperature effect was taken into account by $\mu(T)$ based on the data in Fig.3. Ron is proportional to $1/n$ when ΔRon is small and increases abruptly when the number of carrier further decreases as highlighted by color in Fig.8 (b). $R \propto 1/n$ implicitly assumes homogeneous carrier distribution but when the carrier decrease is large some part of channel could be totally depleted. As ΔRon increases, additional heating effect will further increase the temperature. These are the reason to explain the deviation from the simple model when ΔRon is large. Heat effect could be ignored when the carrier number is evaluated. In the region Ron(SW)/Ron(ini) < 2, heat effect is the main cause of ΔRon and a small increase of Ron corresponds to a large decrease of carrier number. Thus, carrier number evaluation is more accurate than Ron measurement to evaluate C/C.

4. Conclusions

To exclude the self-heating effect and have an accurate result, direct carrier number measurement method is confirmed. By using this method it becomes possible to evaluate the change of carrier number and mobility independently. Change in capacitance gives direct evidence of carrier decrease and the region it occurs. New method can be used to model and solve the C/C phenomenon.

References

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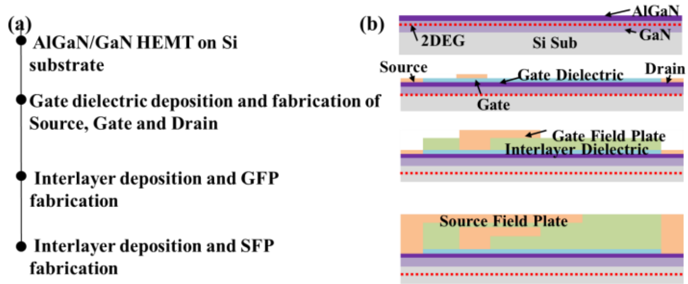

Fig.1 Process flow (a) and schematic cross sectional view (b) of device.

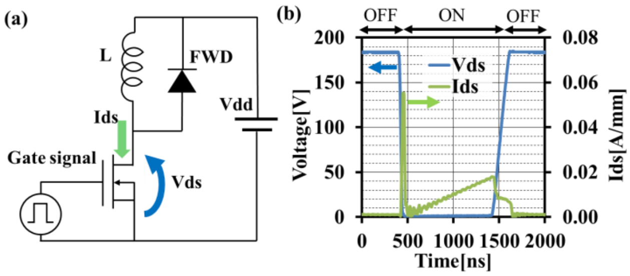

Fig.2 Configuration of inductive load switching test to evaluate current collapse (a) and an example of typical waveform (b). Ron is calculated from measured voltage and current wave form.

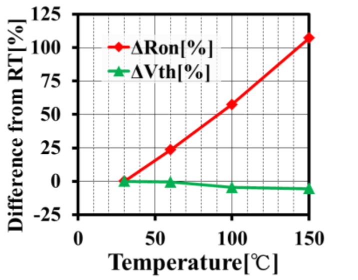

Fig.3 Temperature dependence of Ron and Vth. Mobility has large temperature dependence while carrier number has small dependence.

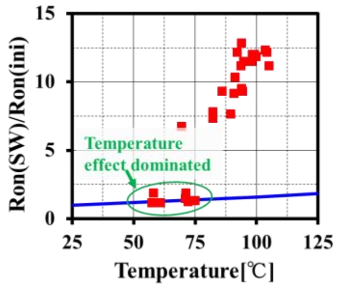

Fig.4 Relationship between temperature and Ron during switching test. Blue line is calculated from ΔRon in Fig.3.

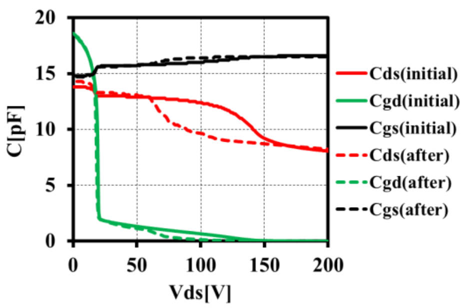

Fig.5 Example of capacitance-voltage measurement result. Dual-FP structure leads to two step changes. The large capacitance change in Cds is observed after switching test.

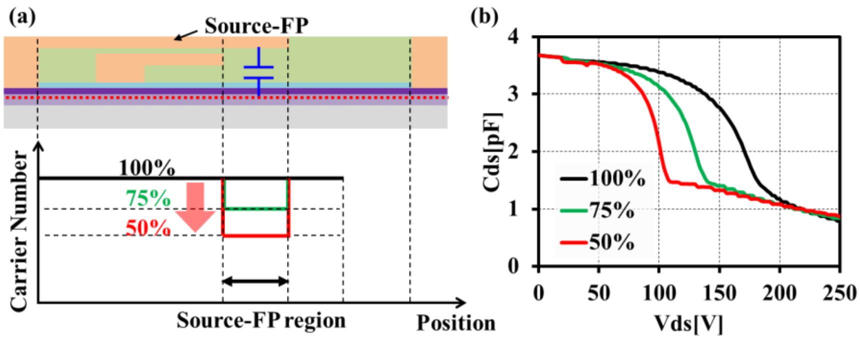

Fig.6 Simulated model (a) and results (b). Carrier under source-FP was decreased as illustrated in (a) and its impact on Cds curve was calculated. The difference appeared in Fig.5 can be explained by the decrease of 2DEG under source-FP during SW test which causes Ron increase.

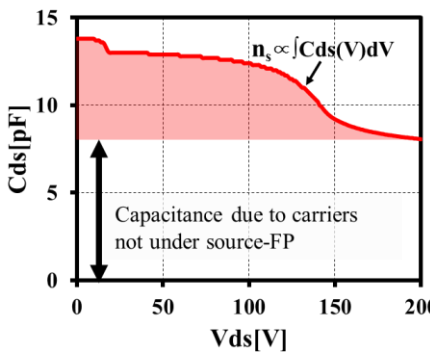

Fig.7 Schematic image of proposed value to evaluate current collapse. To calculate the carrier number source-FP we focused on Cds. Capacitance due to carriers not under source-FP was subtracted as illustrated.

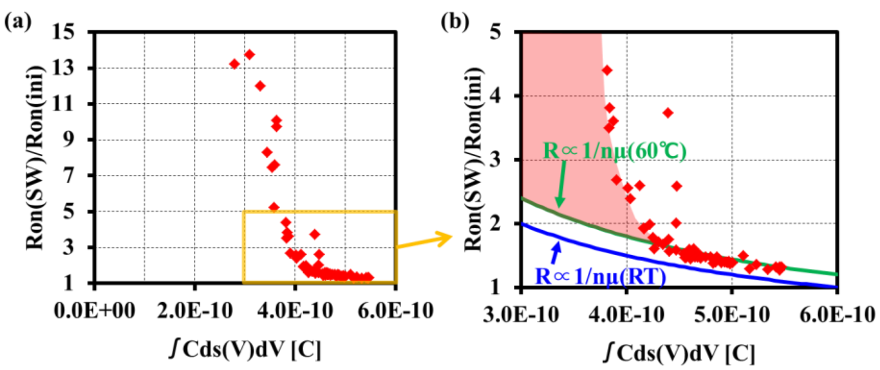

Fig.8 (a): Comparison between conventional Ron ratio (vertical axis) and $\int Cds(V)dV$ (horizontal axis). (b): Magnified view with theoretical curve based on simple model $R \propto 1/n\mu(T)$. Blue line assumes room temperature and green line assumes 60℃. The difference from the model (highlighted) is discussed in the text. Strong correlation observed here verifies the proposed method. Direct carrier number measurement method excludes the heat effect and gives an accurate result.