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Gate-Length Dependence of DC Characteristics in Submicron-Gate AlGaN/GaN HEMTs

Toshihide Ide[1], Mitsuaki Shimizu[1], Shuichi Yagi[1], Masaki Inada[1], Guanxi Piao[1], Yoshiki Yano[2], Nakao Akutsu[2], Hajime Okumura[2], Kazuo Arai[2]

[1]Advanced Industrial Science and Technology (AIST), Power Electronics Research Center
1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan
TEL: +81-29-861-3465, FAX: +81-29-861-5434, e-mail: t-ide@aist.go.jp
[2] Tsukuba Laboratory, TAIYO NIPPON SANSO Corporation
10 Okubo, Tsukuba, Ibaraki 300-2611, Japan

1. Introduction

GaN-based HEMTs are promising for high-power and high-speed switching devices. Since the HEMT characteristics are improved by reducing the gate length, several HEMTs with a gate length of less than 0.1 μm were demonstrated [1-2]. Recently, the shortest gate length of 30 nm was demonstrated in the AlGaN/GaN HEMTs [1]. When the gate length decreases to less than submicron, it is predicted that HEMT characteristics are limited by the short channel effect, saturation of electron drift velocity and so on. Until now, average velocities in the channel were less than 2.0×10^7 cm/s [1-3], which has not reached the predicted value of the saturation drift velocity of 2.88×10^7 cm/s [4]. Therefore, main limiting factor of HEMT characteristics is considered to be not the saturation of the drift velocity but the short channel effect and other effects. In this study, we investigated the gate-length dependence of the submicron-gate AlGaN/GaN HEMTs at room temperature DC measurement. By varying the AlGaN barrier-layer thickness, the relationship between the device scaling and the short channel effect was shown. Moreover, it was found that the gate-length dependence of the transconductance could be explained by considering the additional gate length.

2. Experiment

Two kinds of AlGaN/GaN wafers were grown on c-plane sapphire substrates by the MOCVD system. The main structure consists on a 3-μm-thick i-GaN layer and n-AlGaN barrier layer with a 2-nm-thick i-AlGaN spacer and 5-nm-thick i-AlGaN cap layer. One wafer has a total AlGaN barrier-layer thickness d_{AlGaN} of 20 nm, and the other has 40 nm. The HEMTs were fabricated by the conventional device fabrication process. The mesa isolation was performed by Cl_2-ECR dry etching. The ohmic electrodes were formed by Ti/Al/Ni/Au evaporation and annealed by RTA. The gate electrodes were formed by EB lithography and Ni/Au evaporation. The gate width is 50 μm. The gate length L_G is varied from 0.1 to 1.0 μm and the source-gate spacing L_{SG} is varied from 0.5 to 1.1 μm. Each structural parameter was measured by the SEM images.

3. Results and discussion

The device characteristics were measured at room temperature DC operation. Figure 1(a) and (b) show the current-voltage characteristics of the 0.14-μm-gate HEMTs with the AlGaN barrier thickness of 20 and 40 nm, respectively. The 20-nm device shows good drain-current saturation. The slight current leakage is due to the buffer leakage and does not affect the discussion seriously. On the other hand, the 40-nm device shows higher drain conductance as compared with the 20-nm device. When the L_G was increased to more than 0.2 μm, the drain conductance becomes to be low. Figure 2 and 3 show the gate length dependence of the maximum trance conductance g_{mmax} and threshold voltage V_T, respectively. The 20-nm device shows the increase in g_{mmax} and constant V_T when the L_G is decreased. On the other hand, the 40-nm device shows the slight saturation of g_{mmax} and reduction of V_T at the L_G of less than 0.2 μm. These degradations of the 40-nm device agree with the specific phenomenon due to the short channel effect. Since such degradation is not shown at the 20-nm device, it is considered that the short channel effect becomes to be strong when the aspect ratio of L_G / d_{AlGaN} is less than 5.

Next, we calculated the theoretical g_{mmax} and compared with the experimental data. The theoretical g_{mmax} was calculated by $g_{mmax} = g_{m0}/(1+g_{m0}\cdot R_s)$, which R_s is the source resistance, g_{m0} is the intrinsic transconductance. The g_{m0} was given by $g_{m0} = \varepsilon\cdot\mu\cdot E/d_{AlGaN}$, which ε is the dielectric constant, μ is the electron mobility including the effect of the velocity saturation. The electric field E is calculated by the pinch-off voltage and L_G. Figure 4 shows the gate length dependence of the g_{mmax}. The horizontal axis is the L_G+L_{GS}. The plots show the experimental results. The solid and dashed lines show the theoretical data of the 20 and 40-nm AlGaN deveices, respectively. We considered the additional gate length L_{add} into the L_G+L_{SG}. When the L_{add} is 1.0 μm, the experimental results agree well with the calculation. This L_{add} corresponds to the effective ohmic contact

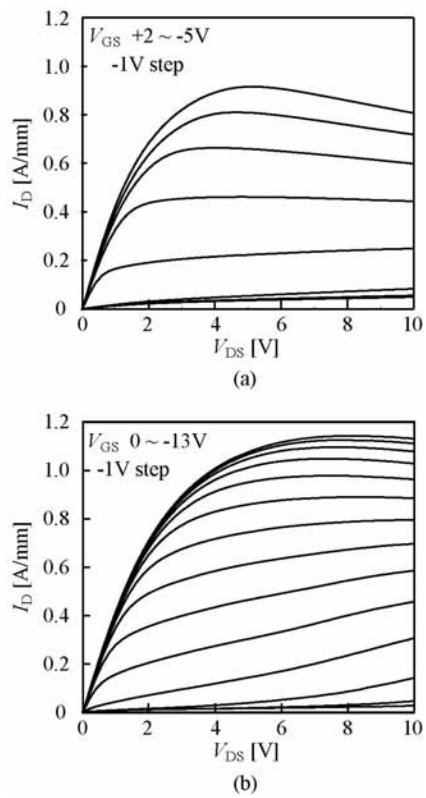

Fig. 1 Current-Voltage characteristics of the 0.14-mm gate HEMTs. (a) 20-nm AlGaN deveice. (b) 40-nm AlGaN devices.

length estimated by the ohmic contact resistivity and the sheet resistance of the channel. These results reveal that the key factor for the g_{mmax} is not only L_G but also L_{SG} and the effective ohmic contact length, and the reduction of these factors will lead to the higher g_{mmax}.

4. Summary

In this study, the gate-length dependence of the submicron-gate AlGaN/GaN HEMTs was investigated at room temperature DC operation. By varying the gate length and AlGaN barrier-layer thickness, the decrease in the threshold voltage due to the short channel effect was shown at L_G / d_{AlGaN} of less than 5. In addition, it was revealed that the gate-length dependence of the transconductance could be explained by considering the gate-source length and effective ohmic contact length.

Reference

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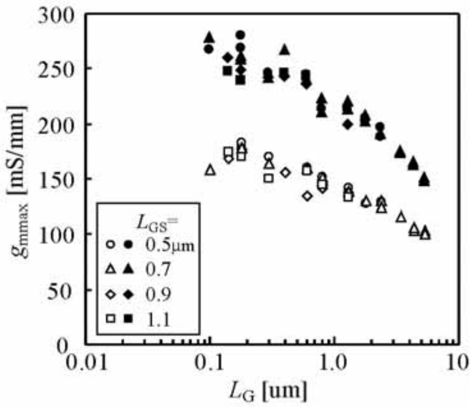

Fig 2 Gate-length dependence of maximum transconductance. Black and white plots are 20nm and 40nm-AlGaN devices,respectively.

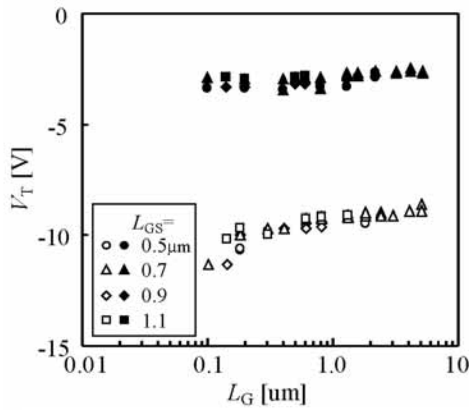

Fig 3 Gate-length dependence of threshold voltage. Black and white plots are 20nm and 40nm-AlGaN devices,respectively.

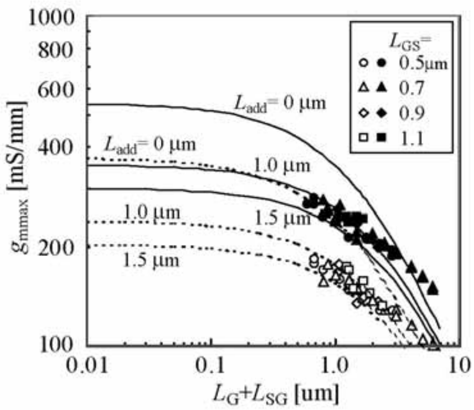

Fig 4 Maximum transconductance versus L_G +L_{SG}. The solid and dashed lines show the theoretical data of the 20 and 40-nm AlGaN deveices, respectively.