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AlGaN/GaN HEMTs with inclined-gate-recess structure

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1. Introduction

AlGaN/GaN HEMTs have received much attention for high frequency and high-power applications because of a high electron saturation drift velocity and high breakdown field in the wide-bandgap semiconductor. Even though high-power performance has been realized [1, 2], the current gain cutoff frequency, f_T, and effective saturation velocity in the channel are not so large [3-5] as that expected from the peak saturation velocity [6]. We have recently pointed out that this is due to that the electric field under the gate is much smaller than that for the peak electron velocity, based on the delay time analysis of the device operated at various temperatures [3]. In the case of GaN HEMT, the peak field is about 180 kV/cm, which is difficult to attain in the whole channel under the gate at the normal bias condition even though the field at the gate edge is very high. This results in a small effective saturation velocity, which leads to the small f_T. If this explanation is appropriate, it will be effective to increase the electric field in the channel under the gate to realize high electron velocity, which leads to the high f_T.

In this report, we studied an inclined-gate-recess structure to increase the electric field in the channel under the gate in order to verify the validity of our model. It has been demonstrated that the inclined-gate-recess structure is effective to improve the device performance based on the two-dimensional device simulation and the measurement of the fabricated device.

2. Experiments

Figure 1 shows schematic cross section of the AlGaN/GaN HEMTs with various gate recess structures used in the simulation. The epitaxial layer structure is i-AlGaN (50 nm) / i-GaN (1.5 μm). The gate structures are the well recess (dotted line), stepped recess (broken line), inclined recess (dot-dashed line), and without recess (solid line). The gate length (L_G) is 1 μm.

Figure 2 shows simulation result of electric field along the channel. The potential distribution is shown in the inset. In the case of the devices with well recess and without recess, the potential drop occurs mainly at the drain-side gate edge and the electric field under the gate is small (about 20 kV/cm), this results in a small electron velocity in the channel under the gate, as shown in Fig. 3. In the case of stepped recess and inclined recess, electric field and electron velocity under the gate are larger than those of the device without the gate recess as shown by dotted and dot-dashed lines in Fig. 2 and 3.

Figure 4 shows simulation result of g_m-V_G characteristics. Maximum transconductance g_{mmax} becomes large and threshold voltage shifts toward positive direction in the case of the recess devices. Similar behavior is observed for the gate capacitance C_G. The largest g_{mmax} is obtained for the devices with inclined recess and stepped recess. However C_G increase of those device is not so large as that of the well recess.

f_T calculated using $f_T = g_m / 2\pi C_G$ is shown in Fig. 5. The highest f_T is obtained for the device with inclined-gate-recess structure. This reflects the increase of electron velocity in the channel.

Based on these simulation results, AlGaN/GaN HEMTs with inclined gate recess structure was fabricated using inclined Ar ion milling. Fig. 6 shows the g_m-V_G characteristics of the fabricated HEMTs. Schematic device structure is shown in the inset. Following the gate photolithography, inclined Ar-ion milling (45 degrees) was performed using the gate photoresist pattern as a mask. Then, the gate metal was lifted off. Gate length was 1.5 μm. Etching times were 0 sec (without recess), 90, 120, and 180 sec. g_m increased and threshold voltage shifted toward positive direction as the increase in the etching time. Higher f_T of 7.9 GHz was obtained for the device with inclined gate recess structure (180 sec etching) than that of the device without gate recess (6.4 GHz).

3. Summary

In summary, it has been demonstrated by 2D device simulation that the effective electron velocity in the channel under the gate can be increased by increasing the electric field in the channel by the inclined-gate-recess structure, which leads to the larger g_{mmax} and f_T. Based on the simulation results, AlGaN/GaN HEMTs with the inclined-gate-recess structure were fabricated. The device shows the larger g_{mmax} and f_T than that of HEMTs without gate recess structure.

References

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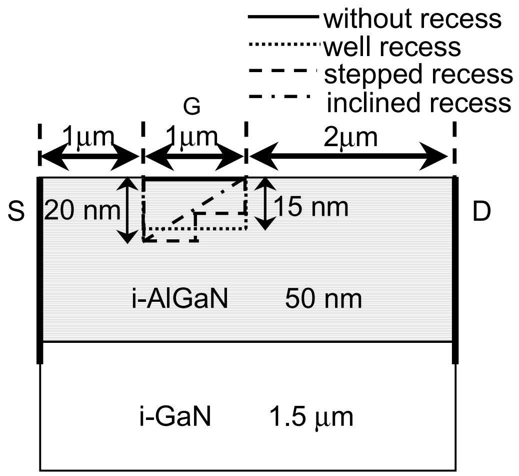

Fig.1 Schematic cross section of the AlGaN/GaN HEMTs with various gate recess structures used for the simulation.

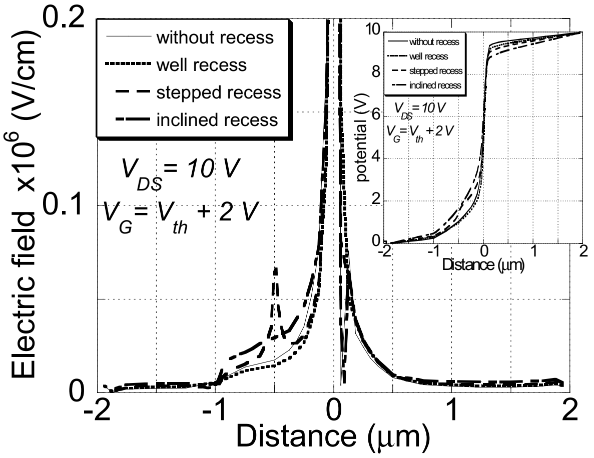

Fig.2 Electric field obtained by the 2D device simulation. Inset is the potential distribution.

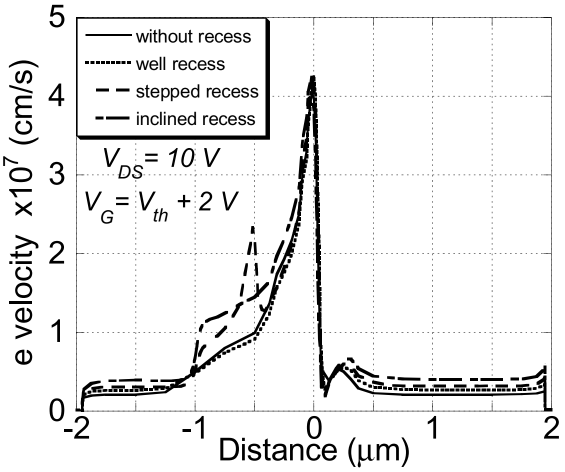

Fig.3 Electron velocity in the channel

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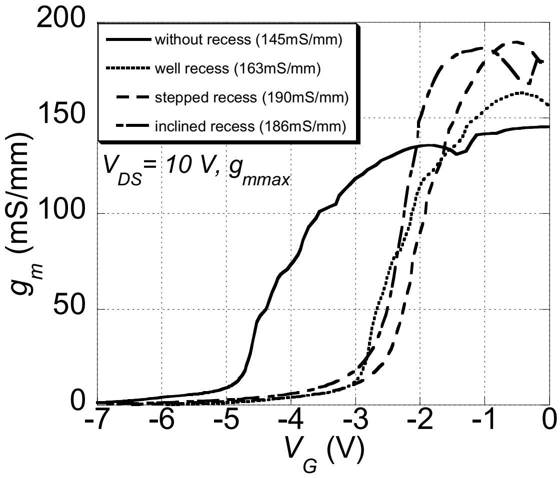

Fig.4 g_m-V_G characteristics of the various recess structures.

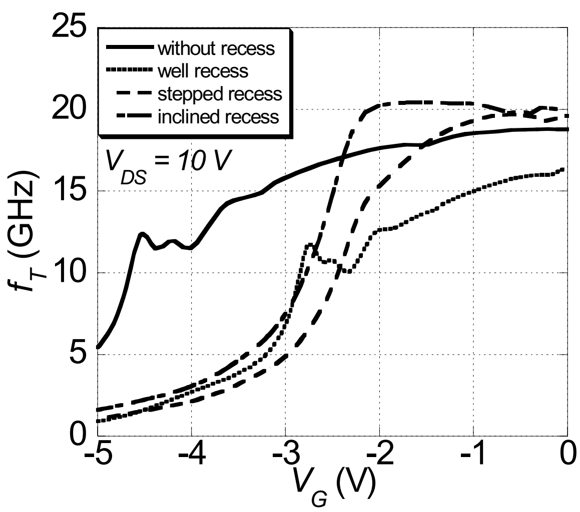

Fig.5 f_T-V_G characteristics of the HEMTs with various recess structures.

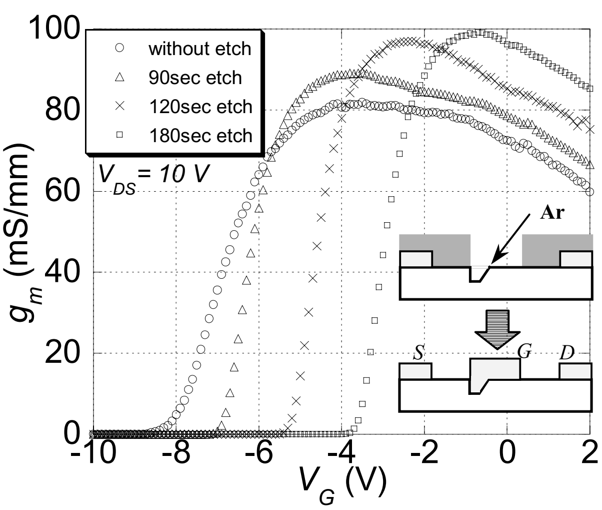

Fig.6 g_m-V_G characteristics of the fabricated AlGaN/GaN HEMTs with the inclined recess structure.