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# Effects of combined gate and ohmic recess on GaN HEMTs☆

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**Summary** AlGaN/GaN, because of their superior material properties, are most suitable semiconductor material for High Electron Mobility Transistors (HEMTs). In this work we investigated the hidden physics behind these materials and studied the effect of recess technology in AlGaN/GaN HEMTs. The device under investigation is simulated for different recess depth using Silvaco-Atlas TCAD. Recess technology improves the performance of AlGaN/GaN HEMTs. We considered three kinds of recess technology gate, ohmic and combination of gate and ohmic. Gate recess improves transconductance $g_m$ but it reduces the drain current $I_d$ of the device under investigation. Ohmic recess improves the transconductance $g_m$ but it introduces leakage current $I_g$ in the device. In order to use AlGaN/GaN for high voltage operation, both the transconductance and the drain current should be reasonably high which is obtained by combining both gate and ohmic recess technologies. A good balance in transconductance and drain current is achieved by combining both gate and ohmic recess technologies without any leakage current.


## Introduction

AlGaN/GaN material has a great potential to be used for high power and high frequency communication applications as these material possess large band gap, high electron mobility, high breakdown field, high peak electron velocity and high saturation velocity. In this work, the effects of different recess i.e. gate, ohmic and combination of gate-ohmic are considered which are created by partially etching the top layer of the hetero-structure and forming the recess contacts. These contacts are investigated to find the possible change in the resistance under the contact. It is known that gate recess improves transconductance ($g_m$) but reduces drain current ($I_d$) and in ohmic recess we get the increased drain current but leakage current is introduced ($I_g$) in the device. For most of the application good balance is required for transconductance and drain

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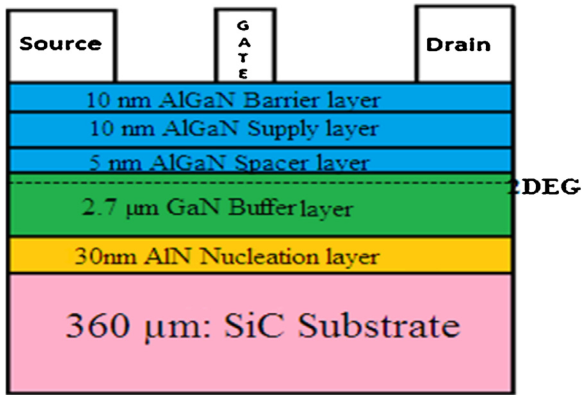


**Figure 1** Schematic cross section of simulated AlGaN/GaN HEMTs.

current without any leakage current; hence by considering the combined effect of gate and ohmic recess we get the reasonable values of drain current and transconductance (Hajlasz et al., 2015; Huang et al., 2013).

## Device structure

The device is fabricated on 3-in. 360 µm thick semi-insulating silicon carbide substrate (SiC) having high thermal conductivity (>330 W/mK) and the device consists of GaN buffer layer (2.7 µm thick), AlGaN layer (25 nm thick), gate length (Lg) = 1 µm, gate width ($W$) of 100 µm and the gate work function is 5.6 eV as shown in Fig. 1.

GaN materials are strongly polar in nature and having the effect of piezoelectric and spontaneous polarization due to which two-dimensional electron gas (2DEG) is formed at the hetrointerface between AlGaN and GaN layer. Spacer layer increases the mobility and density of the carrier in the channel and 30 nm thick AlN nucleation layer is used to reduce the misfit between GaN and SiC substrate (Faraclas and Anwar, 2006).

## Simulation results and discussion

The device under consideration is analyzed by two-dimensional hydrodynamic simulations using Silvaco to achieve good computational efficiency and maximum accuracy (Smith and Brennan, 1998). The simulator self consistently solves a system of four partial differential equations i.e. current continuity equation, poissons equation, energy balance electrons and the lattice heat flow equation. The device is simulated for differnt recess i.e. gate, ohmic and the combined effect of the gate and ohmic recess. Fig. 2 shows the output characteristic between $I_{DS}$ and $V_{DS}$ for gate bias of 2 V and the drain bias is ramped from 0 V to 10 V. The output characteristic shown concludes that maximum drain current 0.73 A/mm is obtained by ohmic recess because ohmic recess reduced the contact resistance and hence increased drain current is obtained. The drain current is only 0.14 A/mm and 0.13 A/mm for gate and gate-ohmic recess respectively (Silvaco International, 2014). Fig. 3 represents the transfer characteristic between gate to source voltage ($V_{GS}$) and drain current ($I_d$) for different gate voltages

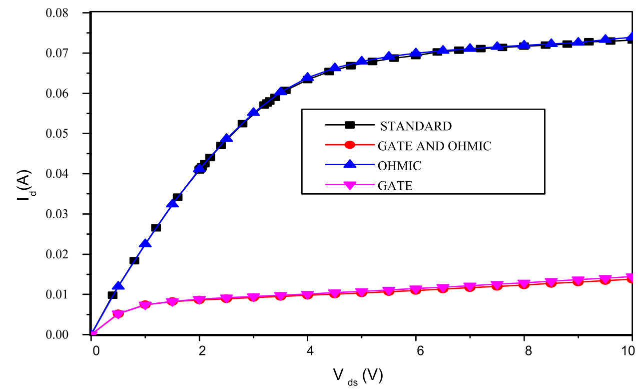


**Figure 2** Output characteristics for gate, ohmic, gate-ohmic recess.

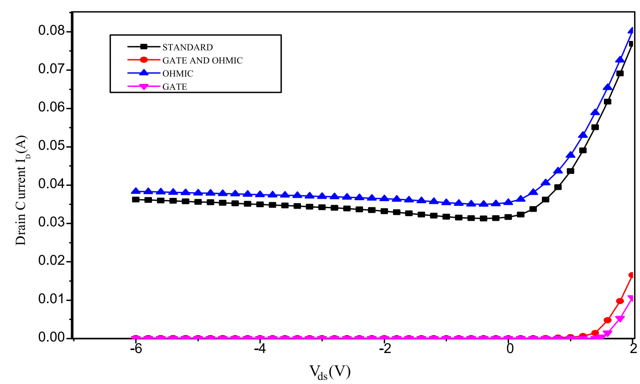


**Figure 3** Transfer characteristics for gate, ohmic, gate-ohmic recess.

ramped from −6 V to 2 V which shows that ohmic recess has a max value of drain current 0.8 A/mm while gate and gate-ohmic have only 0.10 A/mm and 0.14 A/mm, respectively. From the characteristic curve shown in Figs. 2 and 3 it is conluded that drain current is maximum for ohmic recess but the drawback of ohmic recess is that high amount of leakage current is introduced in the device as shown in Fig. 4.

The leakage current characteristic for the different recess shown in Fig. 3 concluded that ohmic recess having highest value of leakage current on the other hand combined gate-ohmic and gate recess have almost zero leakage current. In spite of having highest drain current obtained by ohmic recess it is not suitable because of having highest

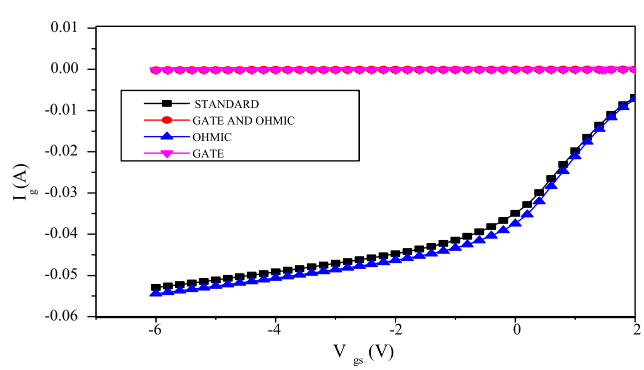


**Figure 4** Leakage current characteristics for gate, ohmic and gate-ohmic recess.

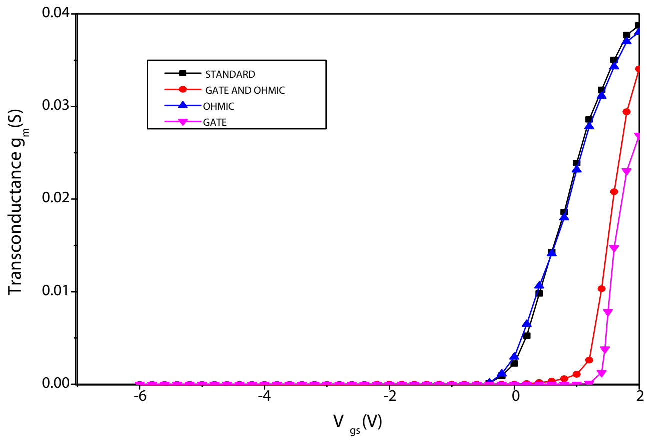


**Figure 5** Transconductance characteristics for gate, ohmic and gate-ohmic recess.

leakage current. So by combining gate and ohmic we get zero leakage current and reasonable drain current ($I_d$) shown in Figs. 3 and 4.

Fig. 5 shows the transconductance characteristic and it is observed that highest value of transconductance obtained for ohmic recess is 380 mS/mm and for gate-ohmic recess it is 340 mS/mm but gate recess shows the lowest value of transconductance which is 268 mS/mm.

The combined effect of gate and ohmic recess has reasonable transconductance as shown in Fig. 5, zero leakage current as shown in Fig. 4 and appropriate drain current as shown in Figs. 2 and 3 due to highest electric field, mobility ($\mu$) and reduced gate channel distance.

## Conclusion

A set of material and model parameters of AlGaN/GaN HEMTs are considered for hydrodynamic simulation and the results obtained after the simulation of the device clearly shows that different recess technology have their own feasibility in terms of drain current, transconductance and leakage current. From Figs. 2—5 it is concluded that a trade off is obtained by combining both gate and ohmic recess which shows balanced value of drain current and transconductance without any leakage current. A special care is to be taken to recess the device because there is the possibility of damage in the barrier layer. The recess depth has a significant effect on the transconductance and threshold voltage.

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