Fabrication and Improved Performance of AlGaN/GaN HEMTs with Regrown Ohmic Contacts and Passivation-First Process

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***Abstract*—This work reports the fabrication of AlGaN/GaN HEMTs with regrown ohmic contacts using either a passivation-last or a passivation-first process, where the order of surface passivation and gate metallization processes is different. An improved performance is demonstrated using the passivation-first process, achieving a maximum *current/power gain cutoff frequency* (f_T/f_{max}) around 60/127 GHz with an 80-nm gate length. The ohmic contacts were regrown with highly doped n-GaN, resulting in a contact resistance of ~0.2 Ω·mm. The RF performance can be further enhanced by reducing the extrinsic gate capacitance and short channel effects.**

Keywords— High-electron-mobility transistors (HEMTs); Regrowth; Passivation.

I. INTRODUCTION

High-frequency and high-power GaN HEMT based MMICs are required for high-speed and broadband microwave wireless communication systems. A W-band GaN power amplifier delivering an output power of 1.7 W/mm and a power-add-efficiency of 19.1% has been reported [1, 2]. To increase the operation frequency of GaN HEMTs, the transistors need to be scaled down in both lateral and vertical dimensions simultaneously. Conventional Ti based ohmic contacts, exhibiting a very rough contact edge after annealing, is problematic during electron beam lithography for short gate length and short gate-source spacing. However, GaN HEMTs with regrown n^+-GaN [3] or Ta based ohmic contacts [4] can provide a sharp metal boundary. The AlGaN barrier thickness should be reduced to mitigate the short channel effects, which makes surface passivation critical for large-signal performance. This study presents the importance of surface passivation for improving the transistors' performance and demonstrates regrowth technology for the source/drain ohmic contacts.

II. EXPERIMENT AND RESULTS

The heterostructure used in this study consisted of a 2-nm GaN cap layer, a 11-nm $Al_{0.3}Ga_{0.7}N$, and a GaN buffer grown on 6H-SiC substrate, using Aixtron 2400 HT metal organic chemical vapor deposition (MOCVD) system. The GaN HEMTs were fabricated by either a passivation-first or a passivation-last process. In the passivation-first process, the SiN_x passivation layer was deposited before the gate electrode by plasma-enhanced chemical vapor deposition (PECVD). In the passivation-last process, the gate electrode was formed before the passivation layer. To make sure the passivation dielectric completely covers the GaN surface without any voids around the gate foot, the AlN passivation layer was deposited using atomic-layer-deposition. Fig. 1 shows schematic cross sections of two transistors depicting the two processes. As shown in Fig. 2, the transistors without any passivation (Fig. 2(a)) show a large on-state resistance and a very low drain current. The passivation-first GaN HEMTs exhibit the best IV performance (Fig. 2(c)), compared to devices without passivation or with the passivation-last process (Fig. 2 (a-b)). The transistors fabricated using the passivation-first process show the minimal current hysteresis with respect to the V_g sweep directions. This confirms the critical role of the passivation layer for the performance of thin barrier GaN HEMTs. However, a slight current degradation is found in pulsed IV measurements (Fig. 2(d)), indicating the transistors' performance can be further improved by an optimized passivation technique such as Low-Pressure-Chemical-Vapor-Deposition (LPCVD) passivation [5]. The maximum transconductance (g_m) of the passivation-first GaN HEMTs reaches approximately 450 mS/mm (Fig. 3). The short channel effects are clearly found in the transistors with a gate length (L_g) around 80 nm. The maximum f_{max}/f_T extracted from the S-parameters is around 127/60 GHz without pad de-embedding (Fig. 4). Fig. 5 shows the relationship between f_{max}/f_T at different biases. The best RF performance is obtained as the g_m reaches its maximum value. The small-signal parameters (Table. I) are extracted at the bias of the maximum f_T. A higher intrinsic transconductance and lower gate parasitic capacitance and resistance are expected to lead to higher RF performance.

In conclusion, high-performance GaN HEMTs with regrown ohmic contacts are fabricated, achieving a f_{max}/f_T around 127/60 GHz with Lg=80 nm. The passivation-first process is employed in the fabrication process, which shows greater advantage in terms of RF performance compared to the passivation-last process. The transistors' performance can be further boosted if LPCVD passivation is used together with regrowth technology. The coupling capacitance between gate hat and source/drain region can be minimized by separating the gate hat from the passivation surface. As a result, f_{max}/f_T could be further enhanced.

[1] A. Brown, *et al.*, *Microwave Symposium Digest (MTT), 2011 IEEE MTT-S International*, pp. 1-4, 2011.
[2] M. Micovic, *et al.*, *Microwave Symposium Digest (MTT), 2012 IEEE MTT-S International*, pp. 1-3, 2012.
[3] T. Huang, *et al.*, " *Electron Devices, IEEE Transactions on,* vol. 60, pp. 3019-3024, 2013.
[4] J. Bergsten, *et al.*, *Semiconductor Science and Technology,* vol. 30, p. 105034, 2015.
[5] T. Huang, *et al.*, Electron Device Letters, IEEE, vol. 36, pp. 537-539, 2015.

978-1-5090-1964-9/16/$31.00

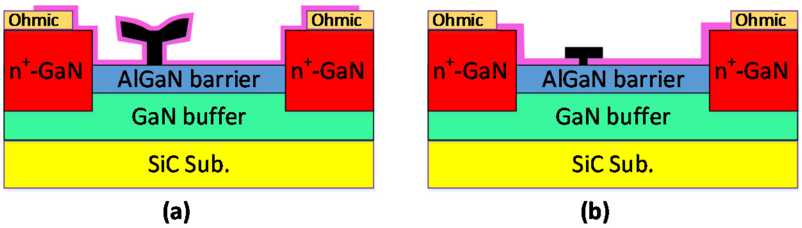
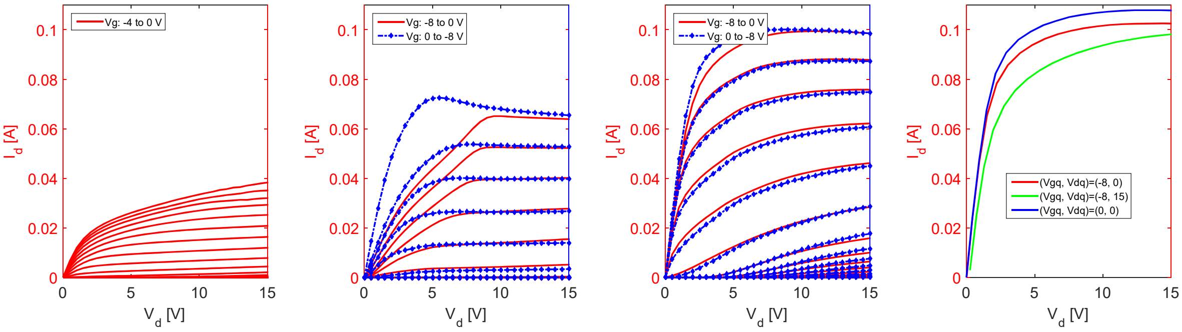


Fig. 1. Schematic cross sections of the (a) passivation-last and (b) passivation-first GaN HEMTs. The dimensions are not drawn to scale.



(a) (b) (c) (d)

Fig. 2. IV curves of GaN HEMTs: (a) without any passivation, (b) by the passivation-last process with double sweep V_g, and (c) by the passivation-first process with double sweep V_g. (d) Pulsed IV of the passivation-first GaN HEMTs at V_g=0.

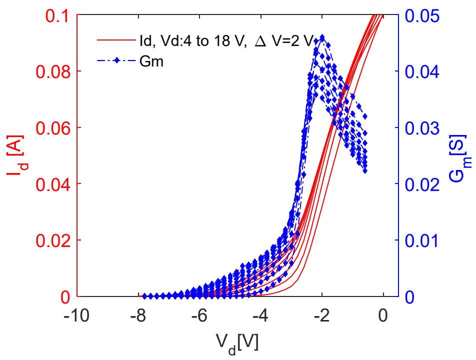


Fig. 3. Transfer curves of the passivation-last HEMTs with L_g=80 nm.

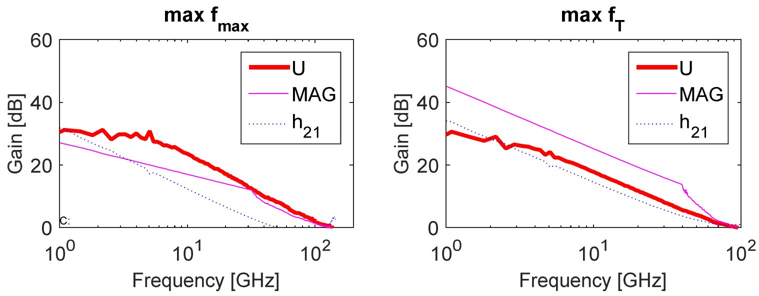
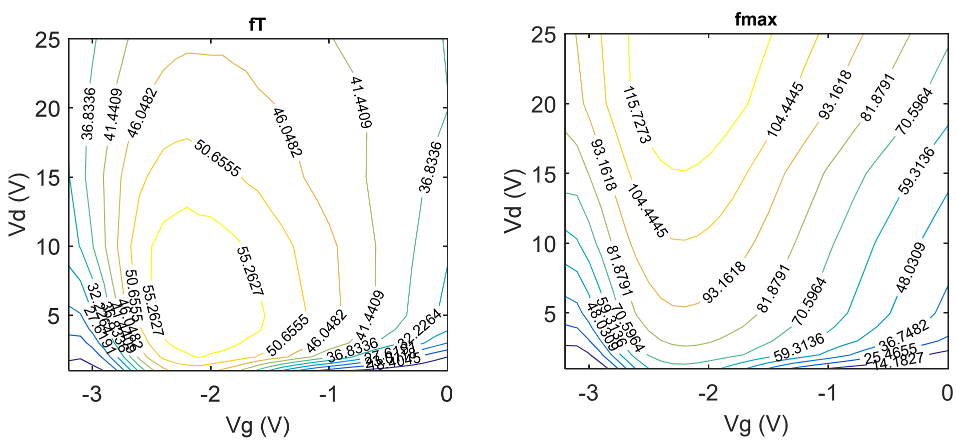


Fig. 4. RF characteristics of the passivation-last HEMTs with L_g=80 nm. (a) the maximum f_{max} under V_g/V_d= -2.1/25 V, (b) the maximum f_T under V_g/V_d= -2.1/5 V.



(a) (b)

Fig. 5. The contour of (a) f_T and (b) f_{max} at various bias points for the passivation-last HEMTs,

TABLE. I. SMALL-SIGNAL EQUIVALENT CIRCUIT MODEL PARAMETERS

Model parameters	
g_{mi}(mS/mm)	620
g_{ds}(mS/mm)	60
C_{gs}(fF/mm)	810
C_{gd}(fF/mm)	361
R_i(Ω·mm)	0.8
R_s(Ω·mm)	0.8
R_d(Ω·mm)	1.0
C_{pg}(fF)	13.4
C_{pd}(fF)	11.0