Sensors & Transducers, Vol. 27, Special Issue, May 2014, pp. 277-279

Sensors & Transducers

http://www.sensorsportal.com

Effect of Passivation on Microwave Power Performances of AlGaN/GaN/Si HEMTs

[1] H. MOSBAHI, [1] M. CHARFEDDINE, [1] M. GASSOUMI, [2] H. MEJRI, [3] C. GAQUIÈRE, [3] B. GRIMBERT, [1] M. A. ZAIDI, [1] H. MAAREF

[1] Laboratoire de Micro-optoélectronique et Nanostructures, Département de Physique, Faculté des Sciences de Monastir, 5019 Monastir, Tunisia

[2] Laboratoire d'électronique et de microélectronique, Département de Physique, Faculté des Sciences de Monastir, 5019 Monastir, and Unité de recherche de Mathématiques Appliquées et Physique Mathématique, Ecole Préparatoire aux Académies Militaires Sousse 4029, Tunisia

[3] Institut d'Electronique et de Microélectronique et de Nanotechnologie IEMN, Université des Sciences et Technologies de Lille, Avenue Poincaré, 59652 Villeneuve d'Ascq Cedex, France

[1] E-mail: hanamosbahi@yahoo.fr

Received: 23 November 2013 /Accepted: 12 January 2014 /Published: 26 May 2014

Abstract: This paper reports on the use of plasma assisted molecular beam epitaxy of AlGaN/GaN high electron mobility transistors (HEMTs) grown on silicon substrate. Surface passivation effects on AlGaN/GaN HEMTs were studied using SiO_2/SiN dielectric layers grown by plasma enhanced chemical vapor deposition. The direct current measurement, pulsed characteristics and microwave small-signal characteristics were studied before and after passivation. An improvement of drain-source current density and the extrinsic transconductance was observed on the passivated HEMTs when compared with the unpassivated HEMTs. An enhancement of cut-off frequency (f_t) and maximum power gain (f_{max}) was also observed for the devices with full SiO_2/SiN passivation. A good correlation is found between pulsed and power measurements. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: AlGaN/GaN HEMTs, SiO_2/SiN Passivation, Pulse measurements.

1. Introduction

AlGaN/GaN high electron mobility transistors are promising candidates for high frequency and high-power microwave applications due to their material properties such as wide band gaps, high drain-current density and high saturation velocity [1, 2]. Nevertheless, issues like gate leakage, current collapse and dispersion effects [3] which are mainly induced by the presence of surface traps in the AlGaN layer limit the device reliability and performance. The surface passivation has been found to reduce current collapse and microwave power degradation of AlGaN/GaN HEMTs. Researchers have tried SiO_2 [4], Si_3N_4 or SiN_x [5-7] passivation layer to reduce the current collapse and to increase the drain-current as well as the cut-off frequency and the microwave output power in AlGaN/GaN HEMTs. The present work reports on a study of unpassivated and passivated AlGaN/GaN/Si HEMTs. We have investigated the current-voltage, the radio-frequency and pulsed characteristics. An attempt to correlate all of results has been made in order to explain the origin of the electron transport improvement.

2. Device Structure and Fabrication

The AlGaN/GaN heterostructure pattern is made using molecular beam epitaxy (MBE) techniques on a 625 µm thick silicon substrate. The epitaxial structure consisted of a 23 nm undoped AlGaN (26 % Al) on 1.8 µm thick undoped GaN. Source and drain ohmic contacts were formed by Ti/Al/Ni/Au evaporation with thicknesses of 12/200/40/100 nm and alloyed at 900 °C for 30 sec. The Schottky gate is realized using 100/150 nm Mo/Au layers. The gate length and the gate width were 0.25 µm and 2*150 µm respectively. Following first electrical characterizations, a SiO_2/SiN passivation layers with thickness of 100/50 nm with N_2O pretreatment was deposited.

3. Results and Discussion

3.1. DC Characteristics

Direct current measurements were made with a HP4142A power supply. Fig. 1 shows typical DC characteristics of a 2×150×0.25 μm^2 AlGaN/GaN/Si HEMT device and shows the influence of passivation. From the drain-current as a function of drain-to-source voltage at V_{gs} = 0 V to -5 V. It is found that the maximum of drain-current increases in passivated HEMTs going from 630 to 833 mA/mm. As also shown, passivation gives rise to a more improved electron transport. At large drain-source voltage, the saturation current, nevertheless, exhibits a negative conductance. The latter behavior is due to the self-heating and especially results from a decrease in the electron mobility [8]. In addition, the self-heating occurs in passivated AlGaN/GaN HEMTs. It is worth noticing that the self-heating is not excessively high after passivation. This clearly shows that the use of SiO_2/SiN paasivation layers is more efficient to give rise an improved electron transport.

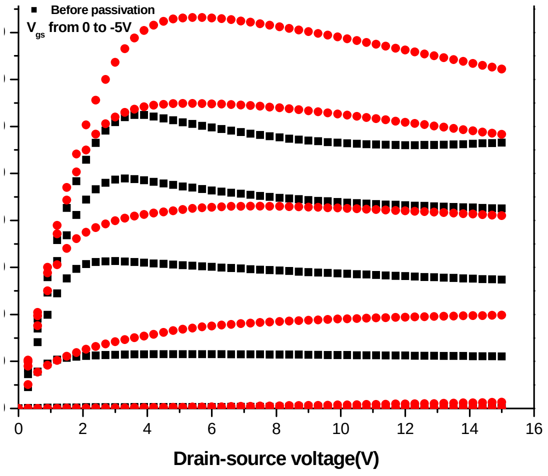

Fig. 1. Direct-current characteristics of the AlGaN/GaN/Si HEMT before and after passivation.

Both the extrinsic transconductance $g_{m,max}$ = 174 mS/mm to 225 mS/mm shown in Fig. 2 of the devices increased after SiO_2/SiN passivation. The enhancement of maximum drain-souce current ($I_{ds,max}$) and the extrinsic transconductance ($g_{m,max}$) is due to the surface controlled effect [6, 9-10]. The improvement of $I_{ds,max}$ and $g_{m,max}$ is in agreement with other reports [5, 9]. Very small threshold voltage shifted from -3.9 V to -4.2 V has been observed after passivation. This shift is shown in Fig. 2 by transfer characteristics of the device. Consequently, we believe that the shift was due to charge redistribution in the structure after passivation process. Also, the transconductance shape of this device could be very interesting for high power.

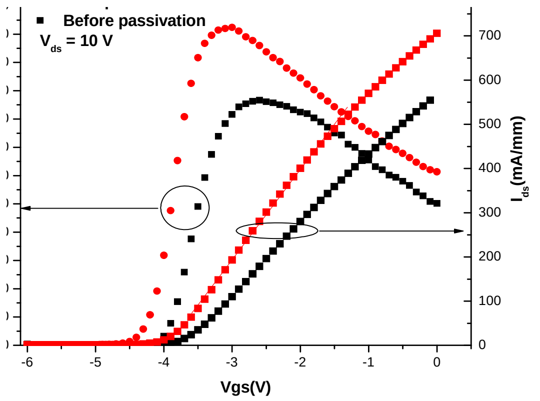

Fig. 2. Transfer characteristics before and after passivation of AlGaN/GaN/Si HEMT.

Small signal characterization was performed with a vector network analyzer HP8510 up to 40 GHz. From the S parameters, we have deduced the current gain and the maximum power gain cutoff frequencies f_t and f_{max}. Table 1 summarizes the small signal characteristics and performance of the same device. The RF parameters of AlGaN/GaN/Si HEMTs are improved after passivation.

Table 1. Small-signal microwave parameters obtained for unpassivated and passivated AlGaN/GaN/Si HEMTs.

	Bias condition	**h_{21} (dB) at 10 GHz**	**F_t (GHz)**	**F_{max} (GHz)**
Unpassivated	V_{ds} = 10V V_{gs} = -3.5V	8	10	28
Passivated	V_{ds} = 10V V_{gs} = -3.5V	16	39	59

3.2. Pulsed I-V Characteristics

To avoid the self-heating in transistors operating at high currents I_{ds} and at high voltages V_{ds}, pulsed measurements are recommended. For the AlGaN/GaN/Si HEMTs under study, a pulse duration of 500 ns has been selected and a period is fixed at 10 µs. the equipment used is described in [11]. Three quiescent bias points are taken in order to reveal the gate-lag and the drain-lag effects: (V_{ds0} = 0V, V_{gs0} = 0 V), (V_{ds0} = 0 V, V_{gs0} = -4 V) and (V_{ds0} = 20 V, V_{gs0} = -4 V). The first quiescent bias point is used as a reference. Fig. 3 shows the pulsed I_{ds}-V_{ds} characteristics determined at different quiescent biases. It should be noted that a decrease of the access resistance and an increase of the maximum drain current. The beneficial effects of the passivation are clearly demonstrated on this figure.

This result indicates that the surface passivation has a strong impact on the power performance of AlGaN/GaN/Si HEMT. This provides an excellent power output. This demonstrated that the surface passivation plays an important part in the device performance of AlGaN/GaN HEMTs.

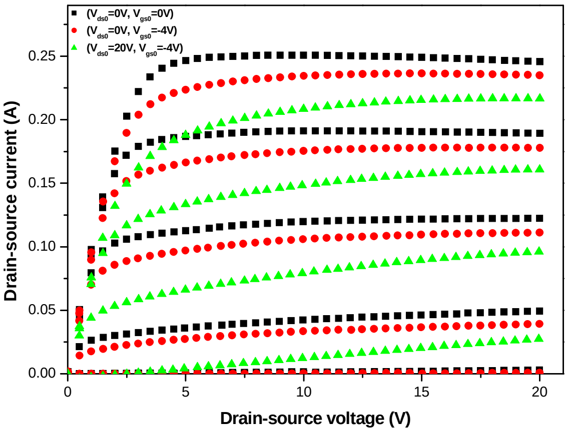

Fig. 3. Pulsed I_{ds}-V_{ds} characteristics of the AlGaN/GaN/Si HEMT transistors after passivation.

4. Conclusions

In this paper, we report the effects of SiO_2/SiN passivation on the transport properties of AlGaN/GaN HEMTs grown on silicon substrate. The electrical behavior of the transistor devices is characterized by using DC, RF and pulsed measurements. As has been shown, passivation improves the electron transport and greatly reduces the gate-lag and the drain-lag as well. SiO_2/SiN is a very promising candidate as a surface passivant for AlGaN/GaN HEMTs.

Acknowledgements

This work has been supported by "Comité Mixte de Coopération Universitaire (CMCU) France-Tunisie" under the project "08G1305" between the IEMN-Lille and the LMON-Monastir University.

References

[1]. M. J. Manfra, N. Weimann, Y. Baeyens, P. Roux, D. M. Tennant, Unpassivated AlGaN/GaN HEMTs with CW power density of 3.2 W/mm at 25 GHz grown by plasma-assisted MBE *Electon Lett.*, Vol. 39, No. 8, 2003, pp. 694-695.

[2]. V. Kumar, A. Kuliev, R. Schwindt, M. Muir, G. Simin, J. Yang, M. A. Khan, I. Adesida, High performance 0.25 µm gate-length AlGaN/GaN on sapphire with power density of over 4.5 W/mm at 20 GHz, *Solid-State Electron*, Vol. 47, 2003, pp. 1577-1580.

[3]. G. Meneghesso, G. Verzellesi, R. Pierobon, F. Rampazzo, A. Chini, U. K. Mishra, C. Canali, E. Zanoni, Surface-related drain current dispersion effects in AlGaN-GaN HEMTs, *IEEE Trans. Elec. Dev.*, Vol. 51, 2004, pp. 1554-1561.

[4]. X. Z. Dang, E. T. Yu, E. J. Piner, B. T. McDermott, Influence of surface processing and passivation on carrier concentrations and transport properties in AlGaN/GaN heterostructures, *J. Appl. Phys.*, Vol. 90, Issue 3, 2001, pp. 1357-1361.

[5]. B. M. Green, K. K. Chu, E. M. Chumbes, J. A. Smart, J. R. Shealy, L. F. Eastman, The Effect of Surface Passivation on the Microwave. Characteristics of Undoped AlGaN/GaN HEMT's, *IEEE Elec. Dev. Lett*,, Vol. 21, 2000, pp. 268-270.

[6]. R. Vetury, N. Q.Z hang, S. Keller, U. K. Mishra, The Impact of Surface States on the DC and RF. Characteristics of AlGaN/GaN HFETs, *IEEE Trans. Elec. Dev.*, Vol. 48, 2001, pp. 560-566.

[7]. Y. Ohno, T. Nakao, S. Kishimoto, K. Maezawa, T. Mizutani, Effects of surface passivation on breakdown of AlGaN/GaN high-electron-mobility transistors, *Appl. Phys. Lett.*, Vol. 84, 2004, pp. 2184-2186.

[8]. M. Gassoumi, C. Gaquiere, H. Maaref, Surface Passivation Effects on AlGaN/GaN High Electron Mobility Transistors with SiO_2, *Sensor Letters.*, Vol. 9, 2011, pp. 2175-.2177.

[9]. S. Arulkumaran, T. Egawa, H. Ishikawa, T. Jimbo, Y. Sano, Surface passivation effects on AlGaN/GaN high-electron-mobility transistors with SiO_2, Si_3N_4, and silicon oxynitride, *Appl. Phys. Lett.*, Vol. 84, 2004, pp. 613-615.

[10]. Y. Ando, Y. Okamoto, H. Miyama, T. Nakayama, K. Kasahara, M. Kuzuhara, *IEDM Tech.Digest.*, 2001, pp. 381.

[11]. C. Gaquiere, J. L. Lafont, Y. Crosnier, Pulsed bias/pulsed RF characterization measurements system of FET at constant intrinsic voltages *Microw. Opt. Tech. Lett.*, Vol. 20, 1999, p. 348-352.