Process Technology study of TiN/AlGaN/GaN Schottky contact on (111) Silicon substrate

Az. Ahaitouf [1,*], J. C. Gerbedoen [2], A. Soltani [3]

[1] *LIMAO, Faculté Polydisciplinaire de Taza BP. 1223, Place de la gare Taza Maroc*
[2] *CRN2-Université de Sherbooke – Canada*
[3] *IEMN-UMR CNRS 8520, USTL, Avenue Poincaré - BP 69, 59652 Villeneuve d'Ascq Cedex – France*

Received in 19 Oct 2010, Revised 15 Nov 2010, Accepted 20 Nov 2010.

*Corresponding author, E-mail: abdelaziz_ahaitouf@yahoo.fr

Abstract

Progress in high electron mobility transistors (HEMTs) based GaN, make them relevant candidates for high power devices with high frequency applications. However there are some issues to be solved for the improvement of this kind of heterostructures. In this paper, we report on a process to realize TiN/Au contacts grown by magnetron sputtering on AlGaN/GaN Si(111) heterostructures-passivated or no. We will present a study on the adequate surface treatment to use before the passivation and thermal annealing. The electrical behavior of rectifier contact was found to be changed by these treatments. The adequate thickness of the TiN layer will also be determined. Reduction of the gate leakage current by as much as six orders of magnitude was recorded by optimization of the thickness of TiN layer associated to a high barrier height.

Keywords: Schottky contact, magnetron sputtering, thermal annealing, leakage current,

1. Introduction:

Schottky contact is a key point in AlGaN/GaN high electron mobility transistors (HEMTs) known candidates for high temperature, high speed and high power operations [1-4]. Indeed major characteristics, like space charge width and power consumption, are affected by the Schottky contact quality. Reduction of the leakage gate current is also one of the key problems to be solved. The excess leakage has been reported to contribute to low frequency noise [5] as well as breakdown voltage [6] of the device.

Different metal contacts were deposited by evaporation and studied earlier to determine the most adequate Schottky contact in our case [7]. Almost all candidates were rejected because of the bad obtained results. The second, studied process was magnetron sputtering and Au/TiN gate contact was the one which presented a Schottky behavior for our heterostructures. The purpose of this paper is to present a study of this contact realized by magnetron sputtering on AlGaN/GaN/(111)Si heterostructures. We will describe the effect of the technological process parameters on the electrical performances. Particularly the effect of the TiN thickness layer, passivation and temperature treatment and finally surface pretreatments will be discussed.

The epilayer of AlGaN/Gan heterostructure were grown by MBE on a silicon substrate. The epilayer consist of 1nm GaN, 25nm of undoped $Al_{0.32}Ga_{0.68}N$ barrier layer. Transistors were fabricated with 1µm and 2µm gate length and four drain-source lengths L_{DS} = 5, 10, 15 and 20 µm, L_{GS} the width was constant W = 100 µm.

2. Effect of the TiN Thickness layer

Six values were used for the thickness layer (2.5, 5, 10, 20, 40 and 60 nm) and the Schottky contacts were first examined using I-V measurements and I_{GS}-V_{GS} were obtained [Fig. 1(a)]. Then, the same diodes were annealed at 500 °C during 40 min in nitrogen ambient and the same I-V measurements were performed [Fig. 1(b)].

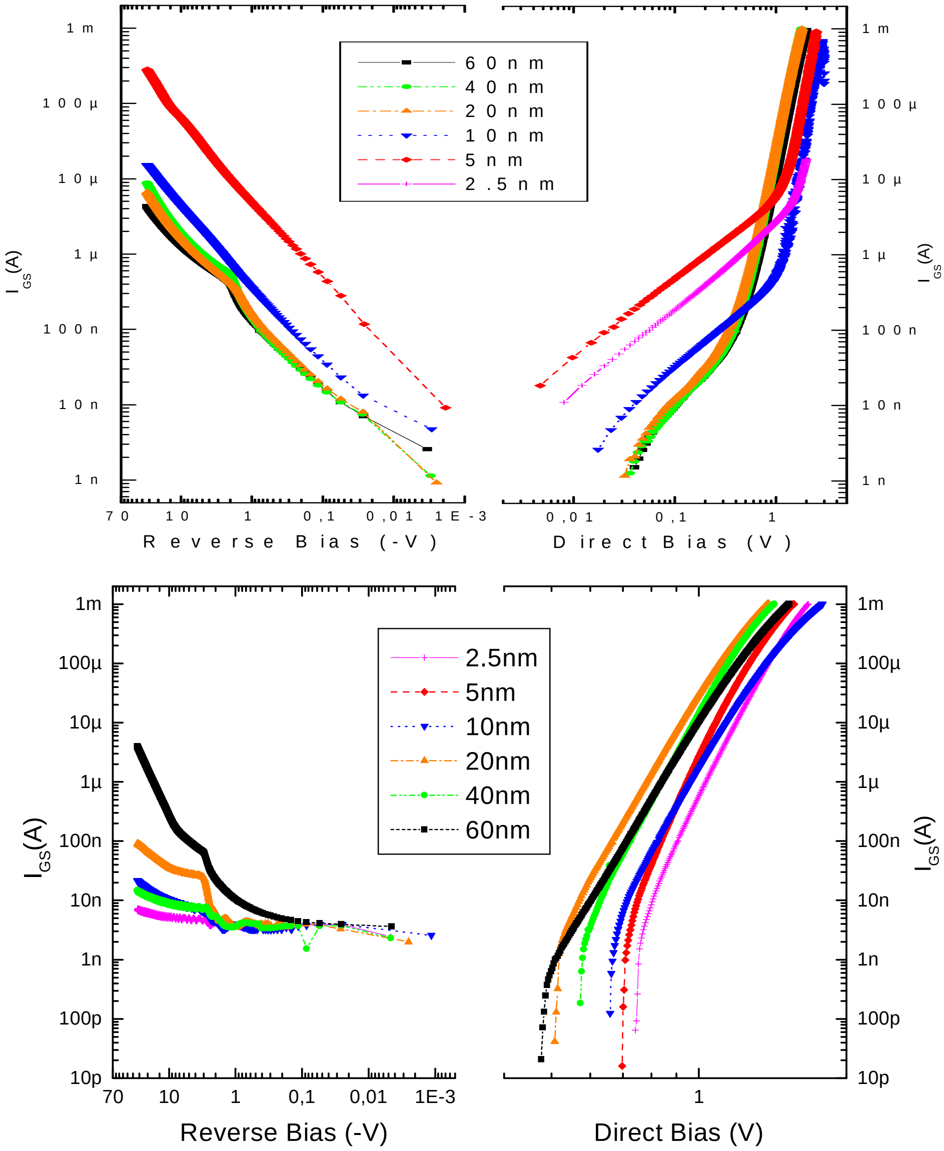

Figure 1: I_{GS}-V_{GS} characteristics of Au/TiN/HEMT Schottky contacts for various thicknesses of TiN metal layers before (a) and after (b) annealing at 500°C in N_2 ambient

Figure 1(a) shows that before annealing, the electric contact is closer than ohmic behavior contact and for reverse bias leakage currents are very high (from some µA to some hundreds of µA at -30V). The I_{GS}-V_{GS} characteristics show also that magnitude of leakage current is 2 orders higher for thick TiN layers. The opposite is observed after annealing (Figure 1 (b)) and leakage currents for reverse bias are drastically reduced. They are similar to a generation-recombination current strongly reduced [8] .We observe also from figure 1(b) that the Schottky contact is better for thin TiN layers (5 nm and 10 nm). Indeed, for these heterostructures leakage currents were reduced from 10µA before annealing to 10nA at -30V after annealing and the higher barrier height increased from 0.507eV before annealing to 1.064eV for the 5nm TiN layer.

3. Passivation and annealing temperature effects

Once the Schottky contacts realized, it was necessary to optimize the annealing temperature and passivation conditions. Different temperatures were chosen (350, 500, and 700°C). Annealing was performed in nitrogen ambient and in vacuum ambient at a pressure of 2×10^{-7} Torr. Heterostructures were passivated with SiO_2/Si_3N_4 (100/50 nm). Surface pretreatments before metallization consist in a desoxidation followed by a dry etching with Ar+ ions. I_{GS}-V_{GS} measurements were performed before and after annealing and Schottky diodes performances such as reverse leakage current, barrier height (ϕ_B) and ideality factor (n) were compared. ϕ_B and n were extracted by fitting I_{GS}-V_{GS} curves of Schottky diodes to the thermionic emission and field-emission tunneling via defects current equations. Study was performed for six (2.5, 5, 10, 20, 40 and 60nm) thickness of TiN thin film. For simplification, we present the result for the 5nm thickness in Table 1.

Table.1: Electrical characteristics (Φ_{Bn}, n and *leakage current* I_{GS} at -30 V) for a TiN (5 nm)/ AlGaN/GaN heterostructure for different conditions of annealing and passivation; L_G = 2 µm, L_{DS} = 10 µm, L_{GS} = 2 µm et W = 100 µm.

	Thickness of TiN 5 nm		
	Φ_{Bn} (V)	n	I (~A)
Before annealing	0,507	9,69	284 µ
Annealing: 500 °C, 40 min, N_2	1,059	1,60	6 n
Passivation SiO_2/Si_3N_4	0,869	1,99	37 n
Annealing : 350 °C 72 h, N_2	**1,064**	**1,46**	**10 n**
Annealing: 350 °C 3 weeks, vacuum	0,905	1,87	13 n
Annealing : 700 °C 40 min, N_2	0,386	15,84	198 µ

These results show that the most successful contact Schottky is the one having a thickness of TiN of 5 nm and subjected to an annealing of 500°C during 40 min. The effect of the passivation was negative in most cases, and degradation of the Schottky contact is observed. Annealing of 3 days under ambient nitrogen becomes necessary to repair passivation induced interface defects and to induce an improving of the electrical characteristics. Other annealing at higher temperature after this last one of 3 days, has no beneficial effects on the Schottky contact, but degrades more its parameters.

4. Surface pretreatments

This section is intended to define the physico-chemical pretreatment conditions of the surface before metallization by sputtering. The pretreatment corresponds to a HCl desoxidation and/or to Ar+ etching. Figure 2 shows the obtained I_{GS}-V_{GS} characteristics for the Schottky optimized by the previous study with a thickness of TiN of 5 nm but all various thicknesses were studied.

Whatever is the studied case, if the annealing is not realized; the Schottky contact is not optimal and shows a leakage current for reverse bias and a surface current for direct polarization. Without surface etching, the contact presents, after annealing, an insulating behavior. On the other hand, the desoxidation shows to have no particular influence on these characteristics. Contrary to deposited gates by evaporation where only a desoxidation or a dry etching allows the obtaining of an acceptable characteristic Schottky [9], it turns out that for gates deposited by sputtering, a dry etching is essential to obtain a behavior Schottky after annealing.

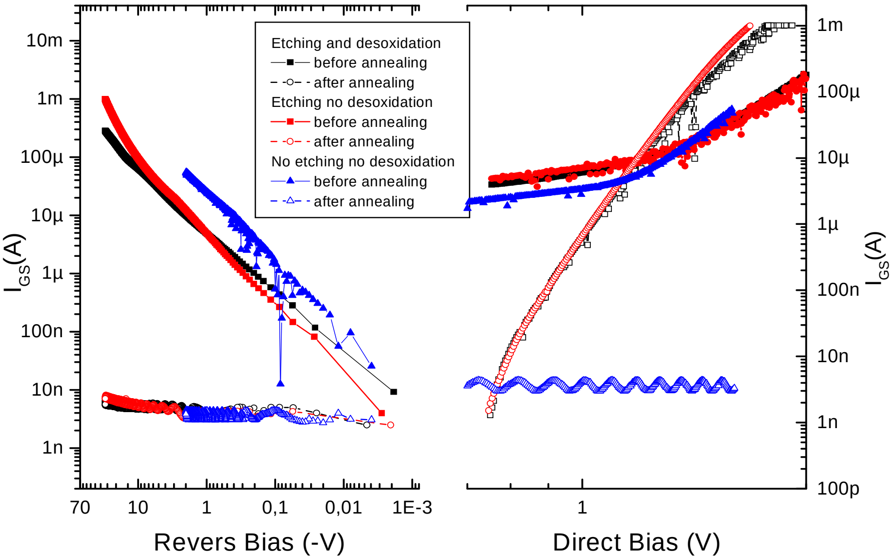

Figure 2 : Surface pretreatments effect on I_{GS}-V_{GS} characteristics of non passivated HEMT (L_G = 2 µm, L_{DS} = 10 µm, L_{GS} = 2 µm and W = 100 µm).

Conclusion

A study on the TiN/AlGaN/GaN Schottky on silicon substrate contacts deposited by magnetron sputtering is presented. Process steps and conditions were fixed and promising results are obtained.

The optimized process contains a pretreatment of surface by Ar etching in - situ, the deposit of TiN layer 5nm thick and an annealing of a 500 °C for 40 min in N_2 ambient.

References

1. Keller, S., Y.F. Wu, G. Parish, N.Ziang, J.J. Xu, B. P. Keller, S.P. Den Baars, and U.K. Mishra, *IEEE Trans. Electron Dev.*, 48 (2001) 552-559.
2. Miura, N., T. Nanjo, M. Suita, T. Oishi, Y. Abe, T. Ozeki, H. Ishikawa, T. Egawa, and T.jimbo, *Sol. St. Elec.*, 48 (2003) 689-695.
3. Osvald, J. *J. Appl. Phys.*, 101 (2007) 103701.
4. Choi, Y.H., J. Lim, I. H. Ji, K. H. Cho, Y. S. Kim, M. K. Han, *ISDRS* (2007) December 12 -14.
5. Rumyantsev, S., M. E. Levinshtein, R. Gaska, M. S. Shur, J. W. Yang, and M. A. Khan, *J. Appl. Phys*,. **87** (2000) 71 – 73.
6. Saito, W., M. Kuraguchi, Y. Takada, K. Tsuda, I. Omura and T. Ogura, *IEEE Trans. Electron. Devices*, 52 (2005) 159-164.
7. Ahaitouf, Az. A. Soltani, Y. Cordier, M. Mattalah, *TELECOM 2007&5èmesJFMMA*, (2007).
8. Tang, Xiao, *Thesis Univ*. Lille 1, (2009).
9. Gerbedoen, J. C., *Thesis Univ*. Lille 1, (2009).