Microelectronics Journal 46 (2015) 1387–1391

Contents lists available at ScienceDirect

Microelectronics Journal

journal homepage: www.elsevier.com/locate/mejo

The influence of high-k passivation layer on breakdown voltage of Schottky AlGaN/GaN HEMTs

Binola K. Jebalin [a,*], A. Shobha Rekh [a], P. Prajoon [a], N.Mohan Kumar [b], D. Nirmal [a]

[a] Department of Electronics and Communication Engineering, Karunya University, Coimbatore, Tamilnadu, India
[b] SKP Engineering College, Thiruvannamalai, Tamilnadu, India

ARTICLE INFO

Article history:
Received 29 November 2014
Received in revised form
28 April 2015
Accepted 30 April 2015
Available online 28 May 2015

Keywords:
HEMT
Breakdown voltage
AlGaN
GaN
High-k
Relative permittivity
Passivation
Schottky contact

ABSTRACT

In this work, analysis and optimization of different high-k material in the passivation layer is carried out to improve the breakdown voltage in a Schottky based AlGaN/GaN High Electron Mobility Transistor (HEMT). The enhancement in Off-state breakdown voltage is observed for different high-k dielectric in the passivation layer. The device with L_{gd} of 1.5 μm and with high-k passivation layer provides a higher Off-state breakdown voltage. A maximum of 380 V is obtained as the Off-state breakdown for high-k ($\sim HfO_2$) passivation layer and the obtained result is validated using experimental data. The improved drain current and transconductance for the device obtained is 0.51 A/mm and 143 mS/mm respectively. These results show that the Schottky Source Drain contact (SSD) *high-k* passivated AlGaN/GaN device is suitable for high power application.

1. Introduction

GaN based High Electron Mobility Transistor (HEMT) is a promising device for high frequency and high power microwave applications. This is due to higher breakdown voltage (BV) and high sheet carrier density characteristics of HEMT, which allows reduction of the *on-state* loss and switching loss in power electronics applications [1]. There are many techniques available to improve the breakdown voltage of the HEMT device such as (i) introduction of field plate in the gate extending towards the drain end [2,3] (ii) Schottky Source Drain contact technology (SSD) [4–6] and (iii) introduction of passivation layer between gate to drain. The first two techniques enhance the breakdown voltage with a cost of less frequency performance [7]. In the third technique the passivation layer has mainly two functions, one is to protect the top layer of the device from external sources, and another function is to reduce the peak field distribution at the drain end of the gate region [8]. This smooths the drain current flow, which ultimately leads to the improvement in the breakdown voltage. The experimental results show that the passivated device provides a higher breakdown voltage without any degradation in other performance parameters.

In this paper, the Two Dimensional Electron Gas (2DEG) channel current flow with different high-k passivation layer is analyzed to study the breakdown characteristics of the device. The effect of passivation layer as a function of *relative permittivity* (ε_r) is simulated using Synopsys Technology computer Aided Design (TCAD) simulator and found that the increase in ε_r enhances the breakdown voltage.

2. AlGaN/GaN HEMT structure

The proposed AlGaN/GaN HEMT consists of several stacked layers and is mounted on a Silicon Carbide (SiC) semi-insulating substrate. The device's cross sectional schematic and material parameter are shown in Fig. 1 and Table 1 respectively [9].

Here a 3 μm gate length (L_g) device is considered for analysis. An undoped GaN buffer layer is grown over the SiC substrate to decrease the effect of lattice mismatching, associated traps and defects in progressing up the channel layer. After the buffer layer the 2DEG channel is formed at the interface between GaN channel and the undoped AlGaN spacer layer. This is followed by an n-doped AlGaN barrier layer, which is used to supply electron to the quantum well to improve the sheet carrier density in the channel. In AlGaN barrier layer, higher amount of aluminum mole-fraction is required to obtain a wider bandgap and enhanced polarization. However, a higher mole fraction will increase the defect density, so the Al concentration is fixed to 0.26 [9]. Further a cap layer is

* Corresponding author. Tel.: +91 8903219443.
E-mail address: jebalin.binola6@gmail.com (B.K. Jebalin).

http://dx.doi.org/10.1016/j.mejo.2015.04.006
0026-2692/

incorporated between the gate and barrier layer, which has mainly three functions (i) prevent the epitaxial surface from oxidation (ii) reduce the metal semiconductor contact resistance (iii) decrease the overall capacitance. Also, it provides a better gate control over the channel and effectively suppresses the drain field to enable high breakdown voltage. Finally the complete device is passivated with dielectric material of *relative permittivity* (ε_r) and thickness 0.1 µm.

The source and drain Schottky contact consist of a stacked layer of Ni/Au. This stacked Schottky contact terminals further improves the drain current and breakdown voltage of the HEMT device [10].

The energy band profile of the AlGaN/GaN HEMT is shown in Fig. 2 [11]. This band diagram is used to explain the 2DEG channel formation in the AlGaN/GaN HEMT. The discontinuity in the bandgap, between the AlGaN and GaN gives rise to a band bending process at the interface. The band bending is in such a way that the conduction band (E_c) of the GaN falls below the *Fermi level* (E_f) and forms a well at the interface [12,13]. This well is called the quantum well and the electron inside the well obeys the electron wave characteristics. The large band discontinuity associated with strong polarization fields in the GaN and AlGaN allows a large 2DEG concentration to be formed in the device. The electron scattering associated with the impurities is less in this region because of the absence of doping in the GaN channel. Thus the electrons in the 2DEG regions possess a high mobility, resulting in high speed device [14].

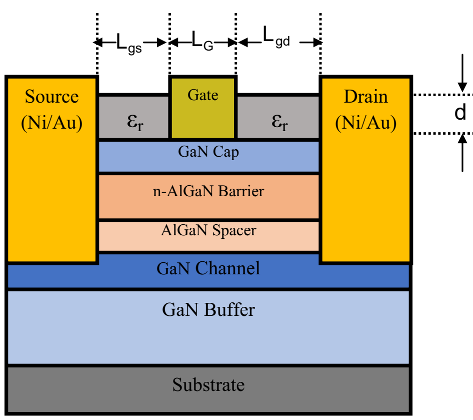

Fig. 1. AlGaN/GaN HEMT device structure.

Table 1
AlGaN/GaN HEMT device dimension.

Layer	Thickness	Al concentration
GaN cap	2 nm	–
AlGaN barrier	16 nm	0.26
AlGaN spacer	2 nm	0.26
GaN channel	5 nm	–
GaN buffer	1.75 µm	–
SiC substrate	0.8 µm	–
Gate length (L_g)	3 µm	–
Gate to drain distance (L_{gd})	1.5 µm	–
Passivation thickness	0.1 µm	–

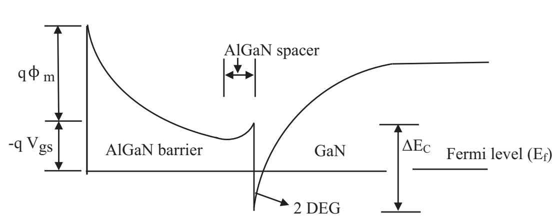

Fig. 2. Energy band profile of AlGaN/GaN HEMT.

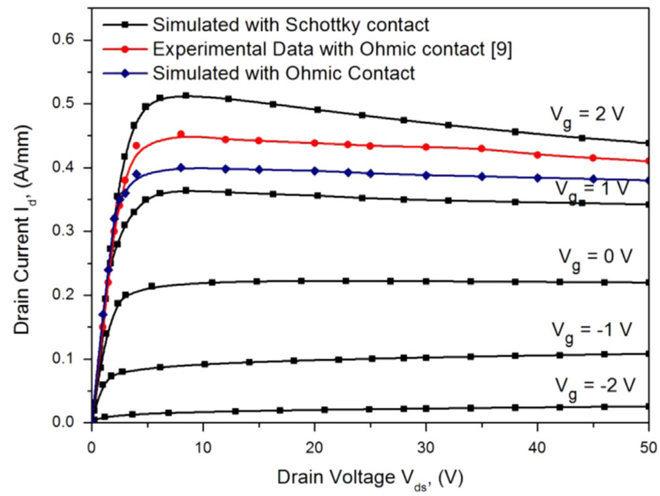

Fig. 3. *I–V* characteristics for an AlGaN/GaN HEMT.

3. Result and discussion

Here SSD AlGaN/GaN HEMT with different passivation layer is simulated and the improvement in drain current, transconductance, frequency and breakdown voltage is analyzed. In Fig. 3, the drain current improvement for Schottky contact HEMT over an ohmic contact HEMT is shown. The result is validated using the experimental data and is in a good agreement with the simulated result for ohmic contact passivated HEMT [9].

The SSD contact technology is used to modulate the Schottky barrier height formed within the nickel (metal source) and the GaN channel by applying the electric field. Due to the band bending process, the on resistance will deteriorate and simultaneously increase the sheet carrier density in the channel. Also, the higher spontaneous and piezoelectric polarization fields associated with GaN and AlGaN leads to form more 2DEG at the AlGaN/GaN heterointerface which effectively increases the sheet carrier density and hence the drain current of the device. For different gate voltage the drain current is measured by sweeping the drain voltage from 0 V to 50 V. The Schottky contact passivation layer device shows drain current of 0.51 A/mm and in the same dimension the experimental data for ohmic contact HEMT shows 0.45 A/mm drain current at a gate voltage of 2 V. This clearly shows that the passivated SSD HEMT has a drain current improvement of 13% compared to experimental passivated ohmic HEMT [9].

The improvement in drain current for different high-k passivation on the SSD HEMT is shown in Fig. 4. From the result, it is clear that the drain current increases from 355 mA/mm for SiO_2 (ε_r=3.9) to 489 mA/mm for high-k passivation (ε_r=60). Drain current shows considerable amount of improvement for different passivation layer HEMT. The improvement in drain current is due to the fact that the high-k passivation reduces the surface effect and smoothens the drain-gate field [15,16]. This will in effect increase the charge density in the channel [17,18]. Also from the simulated result, it is observed that the threshold voltage of the device is not affected and it is fixed to −2 V. This is due to the effect of the GaN cap layer and its better control over the channel under the gate contact. The negative threshold voltage (V_t= −2 V) implies, that the device is working in depletion mode (D-HEMT). The reason for this normally-ON operation of the device is due to