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STRESS METROLOGY AND RADIO-FREQUENCIES CHARACTERISTIC OF AlGaN/GaN HIGH ELECTRON MOBILITY TRANSISTORS (HEMTs)

S. AYACHI[a], A. GUESMI [b], N.BEN HAMADI[b*], K. KHAIROUNI[a], S. ALTHOYAIB[c], M. GASSOUMI[c]

[a]*Laboratory of Physics of Materials and Nanomaterials Applied at Environment, University of Gabes, Department of Physics, 6079, Gabes, Tunisia.*

[b]*Chemistry Department, College of Sciences, IMSIU (Al Imam Mohammad Ibn Saud Islamic University), Riyadh 11623, kingdom of Saudi Arabia.*

[c]*College of Science, Department of Physics, Qassim University, Buraidah 51452, Saudi Arabia.*

AlGaN/GaN HEMTs have been fabricated and their static and small-signal RF characteristics investigated. Device simulation was also carried on in ADS-Agilent to probe into the operation mechanism of HEMTs. As we used this last simulation, tool to extract the Radio-Frequency (RF) parameter; Cut-off Frequency (F_t), maximum oscillation frequency (F_{mag}), variation maximum stable gain (G_{ms}) and maximum available gain (G_{ma}). Mechanical stress is an important factor influencing the performance and reliability of GaN-based devices. In highly piezoelectric materials like AlGaN/GaN, mechanical stress directly influences the piezoelectric polarization, and hence the charge density of the 2D electron gas.

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1. Introduction

It is well known that the performance of AlGaN/GaN heterostructure field-effect transistors (HFETs) is limited because of the reduced radio-frequency (RF) drain current. Much attention was paid to explain the effect of DC/RF dispersion, also called current collapse, and various models were presented. Mostly, trapping effects caused by surface states are considered. In this connection, existence of a 'virtual gate' due to the existence of slow surface states that cause the depletion of transistor access regions was proposed [1]. Trapping effects in either the GaN buffer or AlGaN barrier layers as a possible source of the current collapse were also considered [2]. However, the finding that surface passivation by a dielectric can reduce the current collapse [3] indicates that the surface properties need to be involved into the current collapse mechanism. Surface passivation based on SiN and SiO2 layers is now widely used to improve the performance of AlGaN/GaN HFETs. Application of various dielectrics, such as AlN, MgO, Al_2O_3,HfO_2 and Sc_2O_3, has also been investigatedfor passivation [4]. The obtained results also have importance in the design and preparation of GaN based metal–insulator–semiconductor HFETs (MISHFETs), which provide a number of advantages over the more conventional Schottky gate transistors [5]. However, published data on HFET performance after passivation show many controversial results ([6] and references therein) and the mechanism of passivation is not fully clear yet. Besides the mostly accepted explanation that the passivation reduces the surface trap density [1,3], it is speculated that passivation causes Si incorporation as a shallow donor at the AlGaN surface. Another explanation is based on the assumption that the bulk traps can be passivated by hydrogen diffusion during the dielectric layer deposition [7].

* Corresponding author: bh_naoufel@yahoo.fr

The influence of passivation-induced stress on properties of AlGaN/GaN heterostructures and HFETs has recently gained interest [6, 8−11]. We reported that changes in the channel conductivity of undoped and doped AlGaN/GaN structures after SiN passivation can be explained as a consequence of the influence of stress-induced polarization charges [6]. Fenget al [8] found that SiN passivation deposited by plasma-enhanced chemical vapour deposition (PECVD) at high and low frequency produces tensile and compressive stress and an increase and decrease of the sheet charge density, respectively. But it was also reported that the low-frequency deposition process induces significant surface damage and consequently a drastic reduction of the sheet charge density [9]. Jeonet al [11] found an increase of the sheet charge density with increased tensile stress by SiN passivation of different thicknesses. However, the passivation mechanism and the proper passivation procedure concerning current collapse reduction are not fully clear yet. However, the stress appears in the film during the hetero-expitaxial growth process influences on crystalline quality of thin film and it can affect optical and electrical properties of AlGaN/GaN HEMT's. Therefore, In this paper we reports on a study of AlGaN/GaN HEMTs on Si substrates passivated, we have investigated the simulation of variation of 2DEG layer, the radio-frequency (RF) characteristics at output, also we show the ability to reveal this biaxial stress distribution in AlGaN/GaN HEMT's on Si substrat passivated SiN.

2. Sample growth

The samples used in the present study consist on AlGaN/GaN/Si HEMT development of 2x150x0.25μm^2. The ohmic and Schottky contacts were made on the top surface. The Schottky contacts have been prepared by the evaporation deposition of Mo/Au (100/150 µm) an argon etching. The ohmic contacts have been prepared by evaporation of the electron channels of Ti/Al/Ni/Au (12/200/40/100 nm) annealed at 900°C for 30s. The structure of the HEMTs composed by a 1nm cap layer GaN, a 23 nm thick of undoped Al0.26Ga0.74N barrier , a 1.8 µm undoped GaN channel and a 50 nm thick of undoped buffer layer AlN/AlGaN in order to compensate the disadvantages of GaN growth on Si substrates. The epilayers were deposited on silicon substrate by using the electron-beam epitaxy. On the other hand, our sample AlGaN/GaN HEMTs have been passivated by 100/50 nm SiO2/SiN.The passivation step is an essential and critical point thanks to its significant impacted performance in frequency and power. Surface passivation study was performed to observe their influence on the electrical and optical characteristics. A layer of SiN/SiO2 (50/100 nm) is deposited by plasma PECVD (Plasma Enhanced Chemical Vapor Deposition) at a temperature of 340 °C.

3. Results and discussion

3.1. C-V characterization:

Capacitance–Voltage(C-V) characteristics were measured at frequency of 1 MHz at temperatures 300K. Little variation with surface passivation by SiO_2/SiN was observed.

Fig.1 shows a comparison of the C-V curves at room temperature before and after passivation by SiO_2/SiN of the Schottky barrier diode an increase in pinch-off voltage from V_{th} = -4.36 V before passivation to V_{th}= -4.92 after passivation .

The difference in the capacitance values observed indicates that the carrier concentration is almost no uniform suffered from traps and/or surface states.

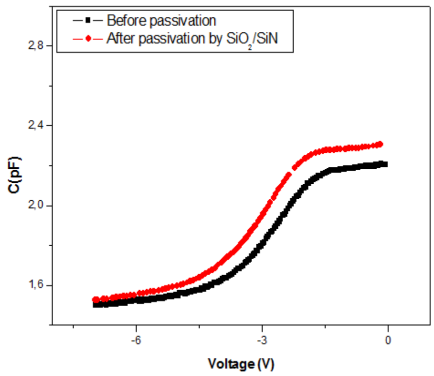

Fig.1.Reverse bias capacitance-voltage (C-V) measurements at T=300K of the Schottky contact before and after passivation [12]

We was extracted the carrier concentration N_d and the barrier height φ_b from the plot of $1/C^2$ as a function of gate voltage and according to Equation.1 we have extract the value of φ_b = 1.02 eV before passivation and φ_b = 0.8 eV after passivation by SiO_2/SiN and the carrier concentration N_d= 3.22 $\times 10^{20}$ cm^{-3} :

$$\frac{1}{C^2} = \frac{2(\varphi_b - V_a)}{\varepsilon q N_d S^2} \tag{1}$$

Where S is the surface of the Schottky contact, ε is the relative dielectric constant of AlGaN barrier and q is the elementary charge. N_d is the carrier concentration and φ_b is the barrier height. Such behavior was attributed to the interface states or dislocations and it is more pronounced for the unpassivated schottky diode compared to that passivated.

3.2. RF characteristics

Generally, the transistor HEMTs is characterized in dynamics by tow important parameters; the cut-off frequency (FT) and the maximum oscillation frequency (Fmax). We determine these parameters from the curves of the current gain and the unilateral power gain as shonw in Fig.2.

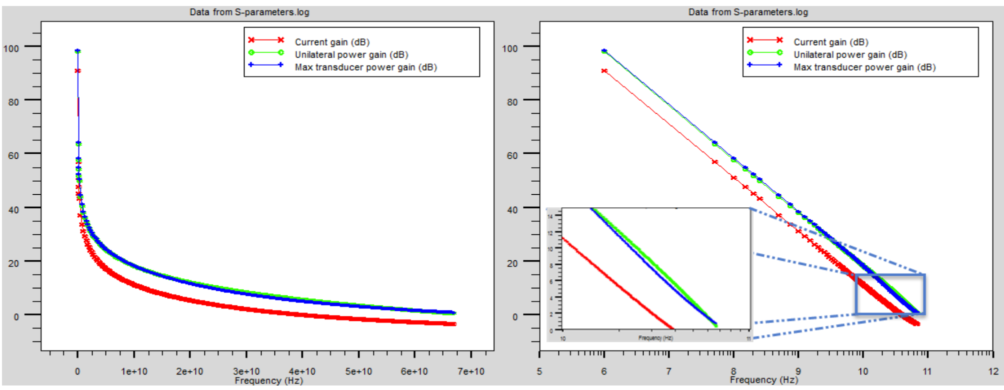

Fig .2. Simulated current gain (H_{21}), Unilateral power gain (UT) and max transducer power gain (MTG) and the typical semilog of AlGaN/GaN HEMT on Si Substrates

The cut-off frequency is defined for the module of the current gain equal to 1, According to the figure, F_T = 20 GHz. The maximum oscillation frequency characterizes the quality of the technology. It corresponds to the maximum frequency of use of the transistor, wherein the power gain is 1, from to the figure, $F_{max} \approx 40$ GHz.

Another very important factor for operation in RF regime is the 'Maximum transducer power gain' which is regarded to be the 'FM' of any RF amplifier design. For a circuit to operate according to the microwave regime, the power gain is considered to be a more important factor than the voltage gain.

A steep decrease in G_{ms} is observed for low frequencies up to about 10 GHz. After that, the variation of G_{ms} with frequency becomes constant until more than 50 GHz. Which indicates a good stability performance of the for microwave and low-noise amplifier applications.

3. The effect of stress on the 2DEG sheet carrier density

The 2DEG region of an HEMT is of a highly complex nature and its physics are defined on the quantum level.

The 2DEG is formed at the heterojunction as a result of the conduction band offset (ΔEC) between the AlGaN/GaN interfaces.

The combination of piezoelectric and spontaneous polarization in the AlGaN/GaN layers induce a 2DEG in the absence of electric field and intentional doping. Benefitting from mechanical strain, AlGaN/GaN HEMTs are capable of achieving this two dimensional electron gas (2DEG) sheet carrier density greater than 10^{13} $cm^{-2.}$

Relating the total polarization at the interface AlGaN/GaN and according to Ambacher et al. [13] gives an increase ranging from 0.064% to 1% for 360 MPa of tensile stress.

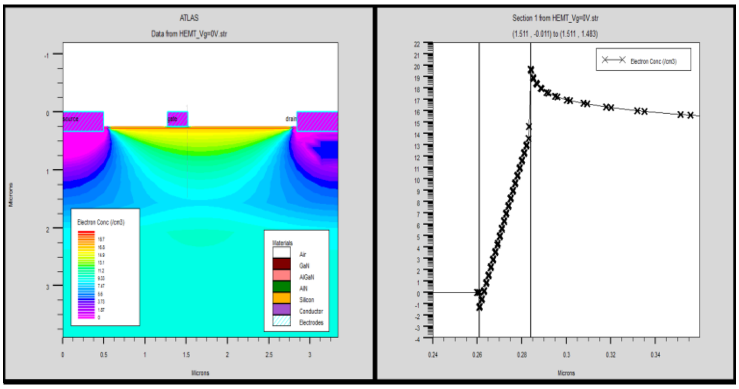

Fig. 3. Electron concentration at the AlGaN/GaN interface with zero gate bias

Fig. 3. is an ATLAS-generated representation of the Electron concentration at the $Al_{0.26}Ga_{0.74}N$/GaN/Si unpassivated (a) and passivated by SiO2/SiN (b) at zero gate bias . As can be seen, the electrons concentration is highest near the AlGaN/GaN interface. The observed peak is a representative of the 2-DEG resulting from polarization.

4. Conclusion

In this paper, we present a study in C-V and RF of passivated and unpassivated $Al_{0.26}Ga_{0.74}N$/GaN/Si HEMTs. For devices with surface passivation; electron trapping by surface states is reduced**.**

We have presented the measured and simulated with silvaco ATLAS results of RF characteristic of HEMT AlGaN/GaN.

Stress is an important step to study in AlGaN/GaN HEMT devices; because the generated stress can impact performance and reliability of these components.

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