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Current-Voltage-Temperature (I-V-T) Characteristics of Schottky-Gate of the Structures AlGaN/GaN HEMTs

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

Abstract: In this study, the forward bias current-voltage-temperature (I-V-T) characteristics of (Mo/Au)–AlGaN/GaN high electron mobility transistors (HEMTs) have been investigated over the temperature range of 100-450K. The barrier height (Φ_b), ideality factor (n), series resistance (R_s) and shunt resistance (R_p) of (Mo/Au)–AlGaN/GaN HEMTs have been calculated from their experimental forward bias current–voltage-temperature (I-V-T). The capacitance–voltage (C–V) of (Au/Mo)-AlGaN/GaN HEMTs were investigated at room temperature. The doping concentration (N_d) and the bi-dimensional sheet carrier density (n_s) were evaluated from C–V data. The experimental results show that all forward bias semilogarithmic I-V curves for the different temperatures have a nearly common cross point at a certain bias voltage, even with finite series resistance (R_s). We found that the value of Φ_b and Rs increases by cons n and R_p decreases with increasing temperature. The values of N_{ss} obtained by taking into account the R_s are about one order lower than those obtained without considering the R_s. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: AlGaN/GaN, HEMTs, LPMOCVD, I-V-T Characteristics.

1. Introduction

AlGaN/GaN heterostructure based high electron mobility transistors (HEMTs) are excellent candidates for high-power and high-frequency electronic devices in high-temperature environments [1]. The AlGaN/GaN compound semiconductor material system has been extensively of interest for its large band gap (GaN 3.4 eV, AlN 6.2 eV), high breakdown electric strength (1–3×10^{10} V/cm), high electron saturated drift velocity (2.2×10^{10} cm/s) and good thermal stability [2].

Compared to Silicon Carbide (SiC) FETs, AlGaN/GaN HEMTs have lower specific on-resistance because of the high-density 2D electron gas (2-DEG) (>10^{13}cm^{-2}) and high electron mobility (>1500 cm^2/V s) [3]. AlGaN/GaN power HEMTs fabricated on SiC substrate, take the advantage of high thermal conductivity of SiC to offer high-power, high-frequency device solution at elevated temperatures [4]. The Schottky barrier height of the gate electrode is an important parameter for device performance.

A large barrier height leads to small leakage currents and higher breakdown voltage which results in the improved noise and power performance of HEMTs [5]. Although Schottky diodes formed on GaN and AlGaN materials exhibit excess reverse leakage currents that are many orders of magnitude larger than the prediction of the standard thermionic emission (TE) model [6].

In this study, we investigate the values barrier height (Φ_b), ideality factor (n), series resistance (R_s) and shunt resistance (R_p) were obtained from both forward bias I-V data to understand the different aspects of conduction mechanisms in the temperature range of 100-450 K.

We intend to analyze the C-V characteristics of (Mo/Au)–AlGaN/GaN HEMTs at a frequency of 1 MHz at 300 K.

2. Experimental Details

The layers used in this study were grown by LPMOCVD (Low Pressure Metal Organic Chemical Vapour Depostion) on SiC substrate. The epitaxial structure is composed of a buffer layer, an undoped 1.2 mm GaN layer and an undoped 25 nm AlGaN barrier layer. The Al content of AlGaN layers was maintained as 28 %.

The ohmic contacts are Ti/Al/Ni/Au stacks deposited by evaporation followed by an annealing at 900 °C for 30 s under nitrogen atmosphere. Mushroom-shaped Mo/Au gate contacts with Lg = 30 µm gate-length were fabricated using electron-beam lithography. The drain-source distance is 100 µm. Schematic diagram of AlGaN/GaN HEMTs is shown in Fig. 1. The devices are passivated with SiO_2/SiN (50/100 nm) using plasma enhanced chemical-vapor deposition (PECVD). After passivation opening, the thick interconnection Ti/Pt/Au metallization is evaporated.

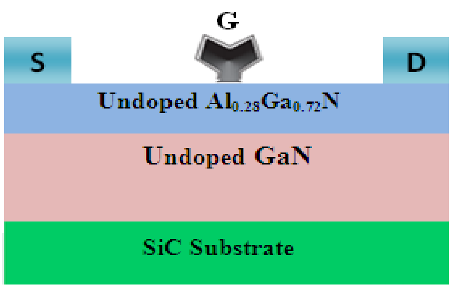

Fig. 1. Schematic of $Al_{028}Ga_{027}N$/GaN HEMTs.

3. Experimental Results and Discussion

3.1. Temperature Dependence of the Forward Bias I –V Characteristics

The current–voltage characteristics as a function of the temperature (I–V–T) were measured using an HP4156. A liquid N_2 cooled cryostat is used for temperature dependent measurement. The results are shown in Fig. 2 and Fig. 3.

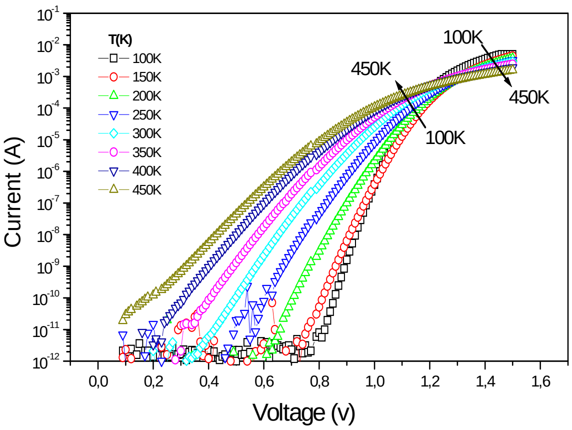

Fig. 2. Forward and reverse bias semilogarithmic I-V characteristics of a (Mo/Au)–AlGaN/GaN HEMTs at various temperatures.

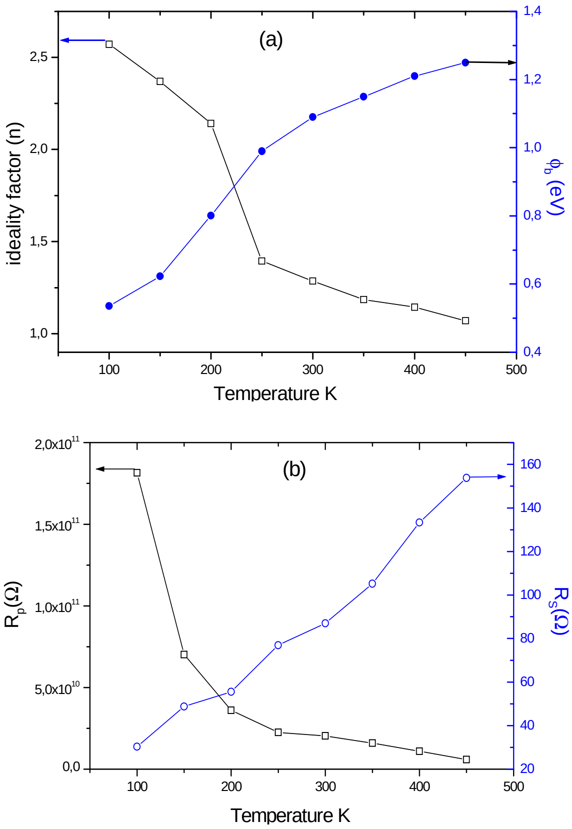

Fig. 3. (a) The values of Φ_b, n and (b) The values of R_S, R_p at various temperatures of a (Mo/Au)–AlGaN/GaN HEMTs.

Fig. 2 shows a forward bias semi-logarithmic I-V characteristics of a (Mo/Au)–AlGaN/GaN HEMTs at various temperatures in the range of 100-450 K. The effective barrier height Φ_b and ideality factor n, were determined using the thermionic current voltage expression [7].

$$I = I_S\left[\exp\left\{\frac{q(V - IR_S)}{nKT}\right\} - 1\right], \quad (1)$$

where I_S is the saturation current derived from the straight line region of the forward-bias current intercept at a zero bias and is given by:

$$I = SA^*T^2 \exp\left(-\frac{q\Phi_b}{KT}\right), \quad (2)$$

where the IR_S term is the voltage drop across the R_S series resistance of structure, S is the device area, q is the electron charge, T is the temperature in Kelvin, $A^* = \frac{4\pi K^2 m^*}{h^3}$ is the effective Richardson constant [5, 6], k is the Boltzmann constant and Φ_b is the barrier height given by:

$$\Phi_b = \frac{kT}{q}\ln\left(\frac{SA^*}{I_S}\right) \quad (3)$$

The ideality factor n is calculated from the slope of the linear region of the forward-bias I–V plot and can be written, from equation (1) as:

$$n = \frac{q}{KT}\ln\left(\frac{dV}{d\ln I}\right) \quad (4)$$

The shunt resistance (R_p) is introduced into equation (1); the total current can be written as [8]:

$$I_T = I + \frac{V - IR_S}{Rp} \quad (5)$$

It is clearly seen from Fig. 2 that the Φ_b linearly decreases and the ideality factor n increases with a decrease in the temperature, respectively, indicating that the current transport departs from the ideal TE model [9].

The values of Φ_b calculated from the I-V characteristics show the unusual behavior of increasing with the increase of temperature. Such temperature dependence is an obvious disagreement with the reported negative temperature coefficient of the barrier height or forbidden band gap of a semiconductor (GaN or AlGaN) [6].

We observed also from this figure that the forward bias I-V characteristics are linear in the intermediate bias regions, but when the applied bias voltage is sufficiently large it started deviate considerably from linearity this is due the R_S effect. The value of this resistance increases with increasing temperature after the intersection point. For the voltages higher than the voltage of the intersection point, the current flowing through the diode is higher at lower temperature [6, 10].

However, the value of the shunt resistance R_p corresponding to a low voltage and temperature region decreases with increasing temperature (Fig. 3(b)).

The experimental values of Φ_b, n, R_S and R_p as a function of temperature are reported in Table 1. As shown in this table the values of Φ_b and n for the (Mo/Au)–AlGaN/GaN HEMTs ranged from 0.536 eV, 2.57 at 100 K to 1.25 eV and 1.07 at 450 K, respectively. The values of R_S and R_p ranged from 30.30 Ω, 1.81×10^{11}Ω at 100 k and 153.8 Ω, 5.92×10^9 Ω at 450 Ω, respectively.

Table 1. Temperature dependent values of various parameters determined from the forward bias I-V characteristics of a (Mo/Au)–AlGaN/GaN HEMTs.

T (K)	Φ_b (eV)	n	R_s (Ω)	R_p (Ω)
100	0.536	2.57	30.30	1.81×10^{11}
150	0.623	2.36	48.78	7.01×10^{10}
200	0.801	2.14	55.55	3.6×10^{10}
250	0.99	1.39	76.92	2.24×10^{10}
300	1.06	1.28	87.00	2.03×10^{10}
350	1.15	1.18	105.2	1.59×10^{10}
400	1.21	1.144	133.3	1.09×10^{10}
450	1.25	1.07	153.8	5.92×10^9

3.2. Capacitance–voltage Characteristics

Fig. 4 shows the C–V characteristics of (Mo/Au)–AlGaN/GaN HEMTs at a frequency of 1 MHz (300 K).

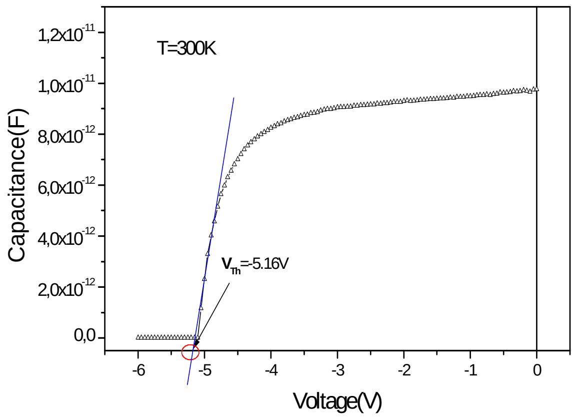

Fig. 4. The C-V characteristics (Mo/Au)–AlGaN/GaN HEMTs of the measured at T = 300 K.

The threshold voltage of (Mo/Au)–AlGaN/GaN HEMTs is -5.16 V. The carrier concentration profile N_{c-v} are determined by C-V measurements performed at room temperature on the (Mo/Au)–AlGaN/GaN HEMTs. We have deduced the carrier concentration profile N_{c-v} versus the space charge depth W in the heterostructure according to the following relation [11]:

$$N_{C-V} = \frac{C^3}{q\varepsilon S^2(dC/dV)} \quad (6)$$

and

$$W = S\frac{\varepsilon_O \varepsilon_r}{C}$$

Fig. 5 shows the distribution of carrier concentration profile, it exhibits a peak at 36 nm below the surface corresponds to the location of the 2DEG channel formed at the AlGaN/GaN heterostructure [12]. The carrier concentration profile is found to be 3.84×10^{18} cm^{-3} and we find the bi-dimensional sheet carrier density of (Mo/Au)–AlGaN/GaN HEMTs is 1×10^{13} cm^{-2}.

In addition, we have determined the net doping concentration N_d and the barrier height Φ_b from the lot of $1/C^2$ as a function of gate voltage (Fig. 6). We found $N_d = 1.2\times10^{18}$ cm^{-3} and Φ_b =1.06 eV.

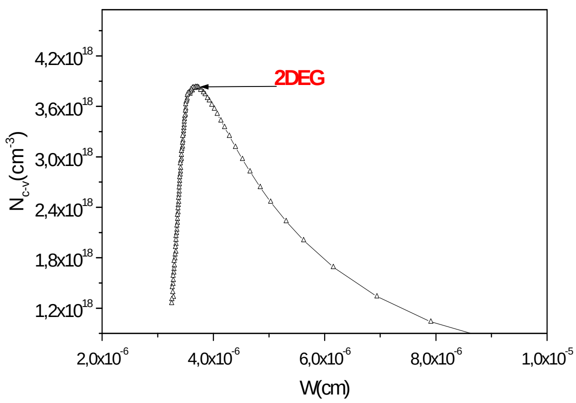

Fig. 5. The concentration $N_{c\text{-}v}$ versus the space charge width W.

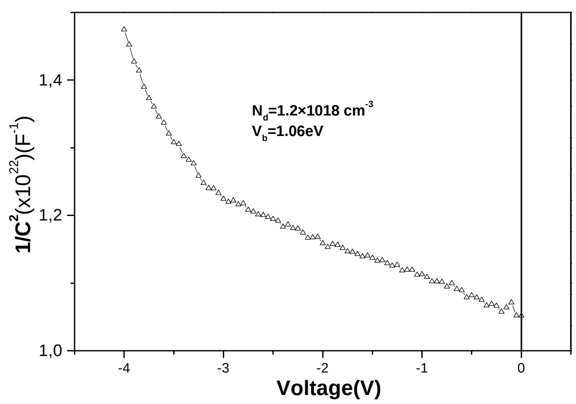

Fig. 6. $1/C^2 - V$ plotted of the (Mo/Au)–AlGaN/GaN HEMTs.

3.3. Determination of the Interface States Density (N_{ss})

The density distribution of the interface states N_{ss} in equilibrium with the semiconductor can be determined from the forward bias (I-V) data by taking the voltage dependent ideality factor n(V) and barrier height Φ_b into account. The quantities of n(V) can be described as in the following equations, respectively [13]:

$$n = \frac{q}{KT}\left[\frac{(V - IR_S)}{\ln(I/I_0)}\right] \tag{7}$$

For a diode, the ideality factor n becomes greater than unity as proposed by Card and Rhoderick [14]:

$$n(V) = 1 + \frac{\delta}{\varepsilon_i}\left[\frac{\varepsilon_s}{W} + qN_{ss}\right], \tag{8}$$

where ε_s and ε_i are the permittivity of semiconductor and the interfacial layer, respectively, δ is the thickness of insulator layer, W the width of the space charge region and N_{ss} the density of the interface states.

The value of W was calculated from reverse bias C^{-2} vs. V plot as in the following equation:

$$W = \sqrt{\left(\frac{2\varepsilon_s V_d}{qN_d}\right)} \tag{9}$$

In addition, in n-type semiconductors, the energy of the interface states with respect to the top of the conduction band at the surface of the semiconductor is given by:

$$E_c - E_{ss} = q(\Phi_b - (V - IR_s)) \tag{10}$$

Fig. 7 shows the energy distribution profile of N_{ss} with and without taking into account R_s obtained from the forward bias I–V characteristics of (Mo/Au)–AlGaN/GaN HEMTs at room temperature.

As can be seen in Fig. 7, the exponential growth of the interfacial state density is very apparent. The energy values of the density distribution of the N_{ss} are in the range of E_c-0.25 to E_c-0.79 eV. The magnitude of N_{ss} with and without R_s in E_c-0.25 eV is 2.36×10^{13} $eV^{-1}cm^{-2}$ and 1.38×10^{13} eV^{-1} cm^{-2}, respectively.

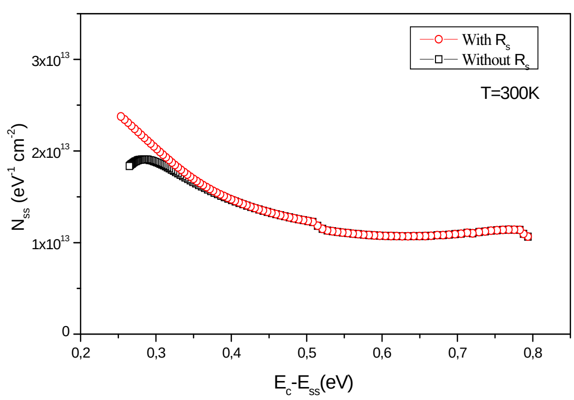

Fig. 7. The energy distribution profiles of N_{ss} as a function of E_c-E_{ss} extracted from the forward bias I-V data of the (Mo/Au)–AlGaN/GaN HEMTs at room temperature.

We observe a peak located at E_c-E_{ss}= 0.28 eV corresponding to an N_{ss}= 1.98×10^{13} $eV^{-1}cm^{-2}$.

So it may indicate the presence of a deep level in this energy [15].The values of N_{ss} obtained by taking into account the R_s are about one order higher than those obtained without considering the R_s near the conduction band. Therefore the effect of R_s must be taken into account in calculations of main electrical parameters such as n, Φ_b, and N_{ss} [10].

4. Conclusion

We have investigated of the (Mo/Au)–AlGaN/GaN HEMTs grown by LPMOCVD.

The forward bias I-V characteristics of the (Mo/Au)–AlGaN/GaN HEMTs were measured in the temperature range of 100–450 K. Using the evaluation of the experimental forward bias *I-V* characteristics reveals an increase of Φ_b and R_s and a decrease of n and R_p with increasing temperature.

The values of R_s show an unusual behavior, in which it increases with an increase of temperature. Moreover, the forward bias I-V curves show this behavior. The values of N_{ss} obtained by taking into account the R_s are about one order lower than those obtained without considering the R_s. Therefore the effect of R_s must be taken into account in calculations of main electrical parameters such as Φ_b, n, and N_{ss}. Therefore, it has been concluded that the temperature dependence of the forward I-V characteristics of (Mo/Au)–AlGaN/GaN HEMTs can be successfully explained based on the thermionic emission mechanism.

References

[1]. T. Lalinský, G. Vanko, M. Vallo, E. Dobročka, I. Rýger and A. Vincze, AlGaN/GaN high electron mobility transistors with nickel oxide based gates formed by high temperature oxidation, *Appl. Phys. Lett,* Vol. 100, 2012, pp. 092105-1.

[2].. W. Luo, X. Wang, H. Xiao, C. Wang, J. Ran, L. J. Li, H. Liu, Y. Chen, F. Yang, J. Li, Growth and fabrication of AlGaN/GaN HEMT based on Si(1 1 1) substrates by MOCVD, *Microelectronics Journal,* Vol. 39, 2008, pp.1109.

[3].. M. A. Huque, S. A. Eliza, T. Rahman, H. F. Huq, S. K. Islama, Temperature dependent analytical model for current–voltage characteristics of AlGaN/GaN power HEMT, *Solid-State Electronics,* Vol. 53, 2009, pp. 342.

[4]. Y. Juan, Z. Xiaoling, L. Changzhi, Study on the Reliability of AlGaN/GaN HEMTs at High Temperature, *IEEE Trans Electron Dev,* Vol. 39, 2011, pp. 774.

[5]. V. Kumar, D. Selvanathan, A. Kuliev, S. Kim, J. Flynn and I. Adesida, Characterisation of iridium Schottky contacts on n-$Al_xGa_{1-x}N$, *Electronics Letters,* Vol. 39, 2003, pp. 747.

[6]. Z. Tekeli, Ş. Altındal, M. Çakmak and S. Özçelik, The behavior of the I-V-T characteristics of inhomogeneous Ni/Au-$Al_{0.3}Ga_{0.7}N$/AlN/GaN heterostructures at high temperatures, *Journal of Applied Physics,* Vol. 102, 2007, pp. 054510-1.

[7]. S. M. Sze. Physics of semiconductor devices, *John Wiley & Sons,* New York, 1981, pp. 248–249.

[8]. B. Abay, G. Çankaya, H. S. Güder, H. Efeoglu and Y. K. Yogurtçu, Barrier characteristics of Cd/p-GaTe Schottky diodes based on I–V–T measurements, *Semicond. Sci. Technol,* Vol. 18, 2003, pp. 76.

[9]. K. Çınar, N. Yıldırım, C. Coşkun, and A. Turut, Temperature dependence of current-voltage characteristics in highly doped Ag/p-GaN/In Schottky diodes, *J. Appl. Phys.,* Vol. 106, 2009, pp. 073717-3.

[10]. İ. Taşçıoğlu, U. Aydemir, Ş. Altındal, B. Kınacı, and S. Özçelik, Analysis of the forward and reverse bias I-V characteristics on Au/PVA:Zn/n-Si Schottky barrier diodes in the wide temperature range, *J. Appl. Phys.,* Vol. 109, 2011, pp. 054502-3.

[11]. M. Charfeddine, M. Gassoumi, H. Mosbahi, C. Gaquiére, M. A. Zaidi, H. Maaref, Electrical Characterization of Traps in AlGaN/GaN FAT-HEMT's on Silicon Substrate by C-V and DLTS Measurements, *Journal of Mod Phys.,* Vol. 2, 2011, pp. 1231.

[12]. M. Gassoumi, S. Saadaoui, M. M. Ben Salem, C. Gaquiere, and H. Maaref, Correlation between hysteresis phenomena and hole-like trap in capacitance-voltage characteristics of AlGaN/GaN of Schottky barrier diode, *Eur. Phys. J. Appl. Phys.,* Vol. 55, 2011, pp. 30101-3.

[13]. H. C. Card, E. H. Rhoderick, Studies of tunnel MOS diodes: Interface effects in silicon Schottky diodes, *J. Phys. D: Appl. Phys.,* Vol. 4, 1971, pp. 1589-1601.

[14]. S. Altındal, H. Kanbur, A. Tataroglu, M. M. Bülbül, The barrier height distribution in identically prepared Al/p-Si Schottky diodes with the native interfacial insulator layer (SiO2), *Physica B: Condensed Matter,* Vol. 399, 2007, pp. 146-154.

[15]. W. Chikhaoui, J.M. Bluet, P. Girard, G. Bremond, C. Bru-Chevallier, C. Dua, R. Aubry, Deep levels investigation of AlGaN/GaN heterostructure transistors, *Physica B: Condensed Matter,* Vol. 404, Issues 23–24, 2009, pp. 4877-4879.