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Physical Mechanisms Responsible for Electrical Conduction in Pt/GaN Schottky Diodes

[1] H. MAZARI, [1] K. AMEUR, [1] N. BENSEDDIK, [1] Z. BENAMARA, [1] R. KHELIFI, [1] M. MOSTEFAOUI, [1] N. ZOUGAGH, [1] N. BENYAHYA, [2] R. BECHAREF, [2] G. BASSOU,[3] B. GRUZZA, [4] J. M. BLUET, [4] C. BRU-CHEVALLIER

[1] Laboratoire de Microélectronique Appliquée, Département d'électronique, Université Djillali Liabès de Sidi Bel-Abbes, 22000 Sidi Bel-Abbes, Algérie
[2] Laboratoire d'Elaboration et de Caractérisation des Matériaux, Université Djillali Liabès de Sidi Bel-Abbes, 22000 Sidi Bel-Abbes, Algérie
[3] Laboratoire des Sciences des Matériaux pour l'Electronique et d'Automatique, Université Blaise Pascal, Les Cézeaux, Clermont II, Aubière Cedex, France
[4] Université de Lyon, Institut des Nanotechnologies de Lyon INL-UMR5270, CNRS, INSA de Lyon, Villeurbanne F-69621, France
Tel.: +213 48 55 12 84, fax: +213 48 55 12 84
E-mail: h_mazari2005@yahoo.fr

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Abstract: The current-voltage (I-V) characteristics of Pt/(n.u.d)-GaN and Pt/Si-doped-GaN diodes Schottky are investigated. Based on these measurements, physical mechanisms responsible for electrical conduction have been suggested. The contribution of thermionic-emission current and various other current transport mechanisms were assumed when evaluating the Schottky barrier height. Thus the generation-recombination, tunneling and leakage currents caused by inhomogeneities and defects at metal-semiconductor interface were taken into account. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: GaN, Electrical Characterization, Modeling, Schottky Diode.

1. Introduction

GaN material systems are finding applications, not only in blue emitting lasers and LEDs [1, 2], but also in an electronic devices at high-power/high-frequency/high temperature, UV photodetectors and various gas sensors. Many of these devices use Schottky barriers [3].

However, Schottky diodes formed on GaN suffer from leakage currents; there are many orders of magnitude upper than the prediction of standard thermionic emission (TE) model. Because of this, many papers have tried to explain I-V characteristics [4, 5].

A n-GaN epitaxial structure was grown on sapphire substrate by MOVPE technique. The samples studied GaN is initially grown on a GaN buffer layer (0.02 µm) by MOVPE on sapphire. Then, GaN crystal unintentionally doped (D1 diode) are grown on MOVPE (1.2µm) and Si-doped (D2 diode) are grown on MOVPE (1.2µm). Ohmic contact was created using Ti/Al and a Schottky electrode with Pt. The diameter of a circular Schottky contact is 320 µm. The I-V measurement was investigated using a conventional method.

2. Method of Analysis

The current transport in a Schottky diode can be described, in general, as a contribution of the following mechanisms: thermionic emission (I_{TE}), generation-recombination (I_{GR}), tunneling (I_{TU}) and leakage (I_{LK}) currents. Thus, the total current can be expressed as [6]:

$$I = I_{TE} + I_{GR} + I_{TU} + I_{LK}, \tag{1}$$

and the individual current contributions are:

The thermionic emission component of the current is [7]:

$$I_{TE} = I_{TE0}\left\{\exp\left(\frac{q(V - R_S I)}{nkT}\right) - 1\right\}, \tag{2}$$

where I_{TE0} is the saturation value of the thermionic current component I_{TE}, R_S is the series resistance and I is the total current. R_S depends on the thickness epitaxial layer, the doping concentration and the electron mobility [8].

$$I_{TE0} = SA^*T^2\exp(-\chi^{0.5}\delta)\exp\left(-\frac{q\phi_{bn}}{kT}\right), \tag{3}$$

The semi-Ln(I) curve gives by extrapolation up to zero voltage the current of saturation I_{TE0}.

A^*: Richardson constant; $A^* = 120\frac{m_n^*}{m_0}$

S: diode area; T: temperature; m_n^*: effective mass of the electrons; m_0: free electron mass; δ: interfacial layer thickness; χ: mean barrier height presented by the thin interfacial layer; k: Boltzmann constant; q: electrical charge; n: ideality factor; ϕ_{bn}: barrier height.

The ideality factor n was introduced to include the contributions of other current transport mechanisms.

Note that in writing Eq. (2) it has been assumed that ideality factor n=1. This is necessary because one takes into account the generation-recombination current I_{GR}, the tunneling current I_{TU}, and the leakage current I_{LK}.

The generation-recombination component of the current is:

$$I_{GR} = I_{GR0}\left\{\exp\left(\frac{q(V - R_S I)}{2kT}\right) - 1\right\}, \tag{4}$$

where I_{GR0} is the saturation value of the generation-recombination component I_{GR}.

$$I_{GR0} = \frac{qSWn_i}{2\tau}, \tag{5}$$

where W is the depletion width, n_i is the intrinsic carrier concentration and τ is the carrier lifetime.

The tunneling component of the current is:

$$I_{TU} = I_{TU0}\left\{\exp\left(\frac{q(V - R_S I)}{E_0}\right) - 1\right\}, \tag{6}$$

where I_{TU0} is the saturation value of the tunneling component of the current I_{TU}, and E_0 is the parameter dependent on barrier transparency. As suggested by Padovani and Strattson [9]:

$$E_0 = E_{00}\coth\left(\frac{E_{00}}{kT}\right), \tag{7}$$

With

$$E_{00} = \frac{qh}{4\pi}\sqrt{\frac{N_D}{\varepsilon_S m_n^*}}, \tag{8}$$

ε_S is the dielectric constant.

Finally, the leakage component of the current is

$$I_{LK} = \frac{V - R_S I}{R_t}, \tag{9}$$

R_t is the parasite resistance which represents the inhomogeneities and defects at the metal semiconductor interface.

3. Results and Discussion

The forward I-V curves are illustrated in Fig. 1 at two temperatures 300 K and 110 K.

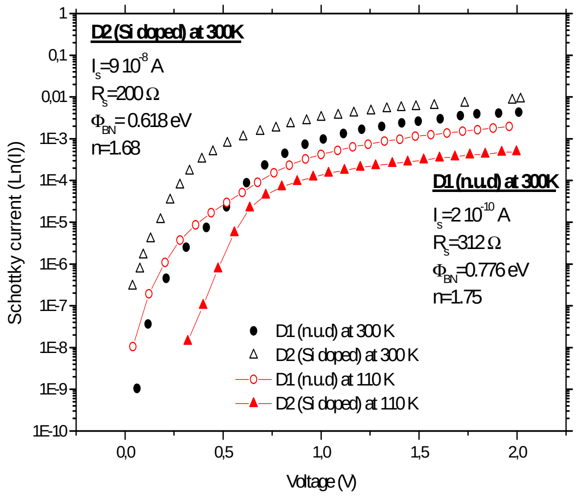

Fig. 1. Characteristics Ln(I) = f(V) of the Pt/n.u.d-GaN (D1) diode and Pt/Si doped-GaN (D2) diode.

The barrier height (Φ_{BN}), ideality factor (n), and series resistance (R_S) are determined from the I-V characteristics are 0.776 eV, 1.75, 312 Ω for diode D1 and 0.618 eV, 1.68, 200 Ω for diode D2 at 300 K and 0.244 eV, 3.2, 566 Ω for diode D1 and 0.302 eV, 3.7, 2.6 kΩ for diode D2 at 110 K respectively.

At 300 K the barrier height is slightly higher than that envisaged by the theory. The ideality factor is high. This indicates that other mechanisms of transport contribute in the total current. In addition to the thermionic current, intervenes the generation-recombination current, the leakage current and especially a tunneling current.

At 110 K the barrier height is lowering already observed in the literature [10] and similar curves were observed in the literature for the GaN [11]. The ideality factor is very high, phenomenon already observed in the literature (SiC, GaN) [12, 13].

The barrier height Φ_{bn} calculated from (2) and (3) tends to go down towards lower temperatures since it dropped from Φ_{bn}= 0.776 eV at 300 K to Φ_{bn} =0.244 eV for diode D1 at 100 K.

While, at the same time, the ideality factor rose from n=1.75 to n=3.2. This shows that other phenomena contribute to the total current.

Most of the material properties of GaN were obtained from literature [14] and are tabulated in Table 1.

Fig. 2. and Fig. 3. show the effect of the generation-recombination current, leakage current and the tunneling current on the final relationship.

The parameters chosen for a data fit at 300 K were:

A^*= 26.4 A/cm^2K^2, I_{TE0}= 1.11x 10^{-26}A, I_{GR0}=10^{-12}A, I_{TU0}= 2×10^{-10} A, E_0=53 meV, $\chi^{0.5}\delta$ = 0.016, R_t= 5 10^6 Ω, and R_S= 312 Ω for D1 diode.

I_{TE0}= 1.77×10^{-21}A, I_{GR0}=10^{-12}A, I_{TU0}=9 10^{-8} A, E_0=44 meV, $\chi^{0.5}\delta$ = 0.01, R_t= 10^5 Ω, and R_S= 200 Ω for D2 diode.

In our structures, the tunneling current has an influence on the total current at 300 K. The introduction of the term $\chi^{0.5}\delta$ decreases the saturation value of the thermionic current component I_{TE} thus increases the barrier height. The existence a low oxide thickness δ to the interface metal/semiconductor can involve an increase height of barrier [15, 16]. It is possible that our structures present a thin oxide layer to the interface.

Table 1. Material properties of GaN with device area and Pt work function.

Parameters	Values
Intrinsic Conc. ni [16]	1.6×10^{-10} cm^{-3}
Band Gap EG	3.51 eV
Electron Affinity χGaN	4.1 eV
Dielectric Constant εGaN	9.5
Electron Mobility µn	1000 cm^2/ V.s
Doping Level: -(n.u.d) (Si –doped)	4.72.1017 cm^{-3} 2.6.1017 cm^{-3}

The values of R_S and R_t depend on the temperature. They decrease when the temperature increases. An abrupt increase of resistivity at low temperatures can be seen which can be due to the lack of free charge carriers as a result of imperfectly ionized impurities at low temperatures. R_t is supposed to be inversely proportional to the free electron concentration [6]. This fact can be used as indirect evidence for our previous assumption about the ohmic character of leakage current, too.

It is a matter of fact that the leakage current characterized by the resistance R_t plays a more important role at lower biases while the thermionic-emission current gets dominant in the resulting relationships at higher biases.

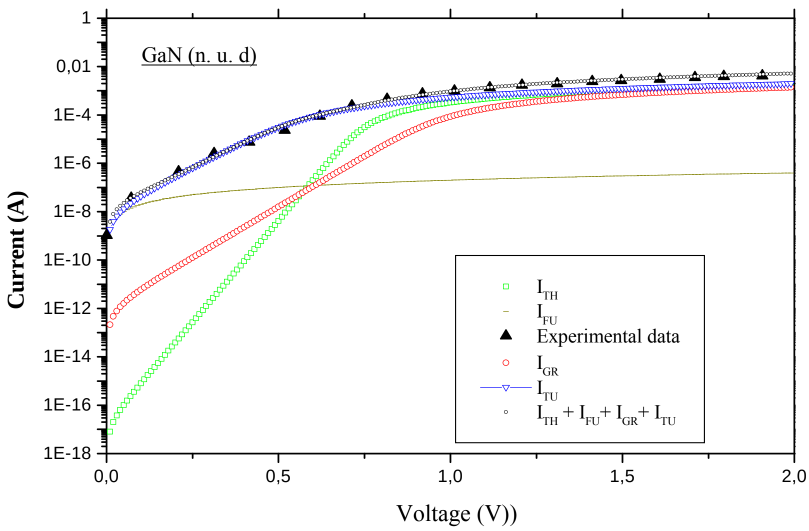

Fig. 2. Variation of the experimental and theoretically fitted plots of the current I of the voltage gate bias V at 300 K with the generation-recombination current, leakage current and the tunneling current (D1 diode).

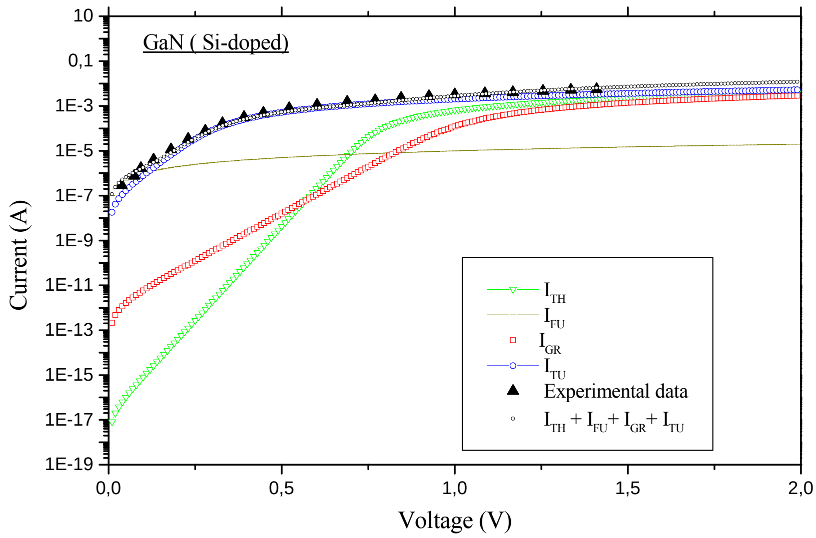

Fig. 3. Variation of the experimental and theoretically fitted plots of the current I of the voltage gate bias V at 300 K with the generation-recombination current, leakage current and the tunneling current (D2 diode).

4. Conclusion

The current-voltage (I-V) characteristics of Pt/(n.u.d)-GaN and Pt/Si-doped-GaN diodes Schottky are investigated. In more for the thermionic emission current add to the recombination current in the surface due for the presence of the interfacial layer and the interface states.

Electrical measurements data, from I–V analysis, indicate, in our model, a contribution of thermionic-emission current and generation-recombination, tunneling and leak currents caused by inhomogeneities and defects at metal-semiconductor interface.

We would like to point to the fact that direct calculations of the barrier height from experimental I-V do not have to be absolutely correct. The leakage current plays a more important role at lower biases while the thermionic-emission current gets dominant in the resulting relationships at higher biases.

In our structures, the tunneling current has an influence on the total current at 300 K. The high value of the ideality factor indicates the presence of the generation-recombination current. A large leakage current or an increased generation-recombination current give evidence of the presence of a considerable amount of defects at the interface and signalize the necessity to revise the technological process. The existence a low oxide thickness δ to the metal/semiconductor interface can involve an increased barrier height.

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