Transport mechanisms in Schottky diodes realized on GaN

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Abstract.
This work is focused on the conducted transport mechanisms involved on devices based in gallium nitride GaN and its alloys. With considering all conduction mechanisms of current, its possible to understanded these transport phenomena. Thanks to this methodology the current-voltage characteristics of structures with unusual behaviour are further understood and explain. Actually, the barrier height (SBH) is a complex problem since it depends on several parameters like the quality of the metal-semiconductor interface. This study is particularly interesting as solar cells are made on this material and their qualification is closely linked to their transport properties.

1. Introduction

Gallium nitride (GaN) and its ternary and quaternary alloys are attracting more and more interest in the scientific and industrial communities for their potential for devices such as photodetectors, solar cells of new generations, power electronics etc ... Even if the industrial components based on GaN have evolved [1, 2, 3], a number of differences still persist about the physical mechanisms that manage the electronic transport in these components and a wide diversity of interpretations can be found in the literature. The study presented in this work aims to understand and also to control the transport phenomena which are the basis of operation of the performed structures.

This study was conducted through I-V and C-V measurements in function of temperature. After a detailed analysis of different power equations, the important parameters of a Schottky diode such as barrier height, the ideality factor and the doping density are determined. Finally, some physical mechanisms, including the role of deep traps will be presented to explain the different observed behaviours.

2. Experimental procedure

For this study, the BGaN/GaN samples are unintentionally doped, with a 400 nm thick of BGaN. Before metallization, the samples were cleaned with acetone and etched in hydrochloric acid HCl for 5 min to remove the native oxide. For the Ohmic contact, a metallic deposit Au/Ti/Al/Ti of respective thicknesses 200/15/200/15 nm were deposited by thermal evaporation under vacuum to 10^{-6} Torr. To form a Schottky contact layer of Pt (150 nm) was deposited using an electron beam evaporation. All these procedures were performed in a clean room. An example of the produced structures is given in Figure 1.

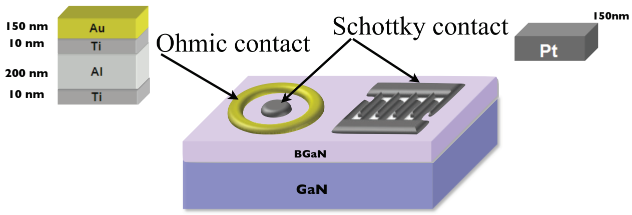

Figure 1. Example of structure showing ohmic and Schottky contacts.

3. Results and discussion

In Schottky diodes, four major mechanisms may contribute to the current in the two directions of polarization. The current thermionic emission I_{te}, the recombination-generation current I_{gr}, tunnel assisted traps current I_{TAT} and direct tunneling I_{TUN}. If the four processes coexist in a structure, the total current can be written:

$$I = I_{te} + I_{gr} + I_{tun} + I_{TAT} \tag{1}$$

In this expression, the thermionic current is given by [4] :

$$I_{te} = I_{te0}[exp(qV/kT) - 1] \tag{2}$$

Where

$$I_{te0} = A^{*}AT^{2}exp((q\phi_b)/kT) \tag{3}$$

Where A^{*} is the Richardson constant modified ($\approx 26.4 \times 10^{4} A/M^{2}K^{2}$) ϕ_b is the effective height of the Schottky barrier, q the electron charge, k and T are the Boltzmann constant and the absolute temperature respectively, and A is the area of the diode. The current generation-recombination is expressed as [4, 5]:

$$I_{gr} = I_{gr0}exp(qV/2kT) \tag{4}$$

With

$$I_{gr0} = \frac{qAW(V)n_i}{(V_{bi} - V)\tau} \tag{5}$$

Where τ is the lifetime of minority carriers taken equal to 7×10^{-9}s and W (V) is the depletion region width, which depends on the bias voltage V, and the barrier potential V_{bi}:

$$W(V) = \sqrt{\frac{2\epsilon_0\epsilon_{sc}|(V - V_{bi})|}{qN_D}} \tag{6}$$

Where n_i is the intrinsic carrier density and N_D is the doping concentration ($N_D = 10^{24}m^{-3}$).

The observed traps in the depletion region associated to the electric field enable the tunnelling electron from the valence band to the traps and the traps to the conduction band using the same way. This is called the tunnel assisted traps current and its expressed by the following equation [3, 6]:

$$I_{TAT} = \frac{\pi^2 q^2 V m_e M^2 N_T}{h^3(E_g - E_T)} \times exp\{-\frac{8\pi(2m_e)^{1/2}(E_g - E_T)^{(3/2)}}{3qE_{max}h}\} \tag{7}$$

With m_e the effective electron mass, h is Planck's constant, E_T is the position of the considered trap level, N_T the concentration of traps, E_{max} is the maximum electric field and M is the matrix element associated to traps ($\approx 10^{-23}eV^2cm^3$) [6]. The fourth type of current is the tunnel current, which depends mainly on the value of the effective masses of the gap and the electric field in the junction. This current results from the crossing of carriers through the formed potential barrier formed [4, 5, 6].

$$I_{tun} = I_{tun0}exp(qV/E_0) \tag{8}$$

$$I_{tun0} = A^*A\frac{T\sqrt{\pi E_{00}q(\phi_b - V - \chi_i)}}{kcoth((qE_{00})/kT)}exp(-\frac{q\chi_i}{kT})exp\{-\frac{q(\phi_b - \chi_i)}{E_0}\} \tag{9}$$

Where χ_i is the Fermi level energy of the semiconductor relative to the minimum of the conduction band. E_{00} is the tunnelling factor given by the following expression:

$$E_{00} = \frac{qh}{4\pi}\sqrt{\frac{N_D}{\epsilon_0\epsilon_{sc}m^*}} \tag{10}$$

and

$$E_0 = E_{00}coth(\frac{qE_{00}}{kT}) \tag{11}$$

Figure 2 shows the curves of the various currents calculated separately. Note that generation-recombination the current is very small compared to others. The tunnel assisted traps current seems dominant between 0 and 0.5V. Above 0.5V we see that the tunnel current and thermionic current dominate.

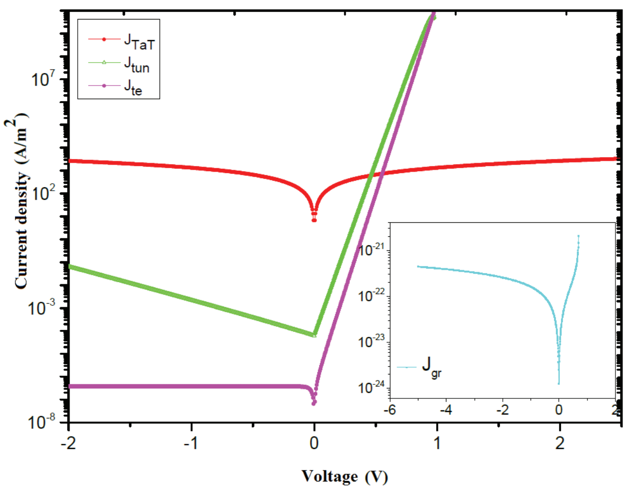

Figure 2. Representation of different currents given in equation (1)

Figure 3 shows an example of comparison between the result of different current calculated and the total current of a Schottky diode at 300K.

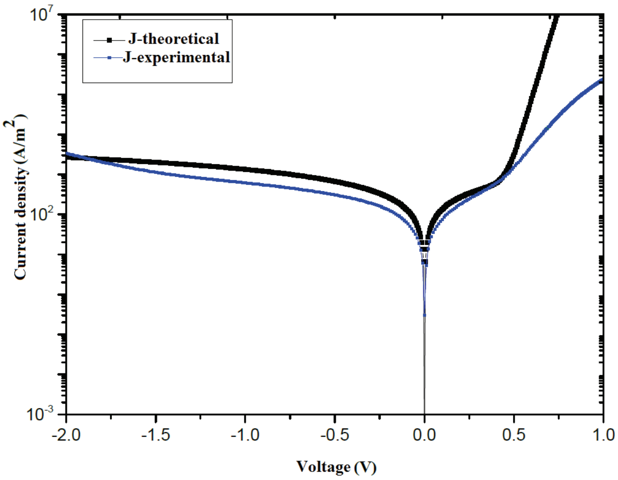

Figure 3. Comparison of theoretical dark current and the measured current in a Schottky diode at 300K

An adjustment between the experimental and the theoretical curve was performed by varying the lifetime of minority carriers τ and the level trapsE_T which are involved respectively the recombination-generation mechanisms and in the conduction mechanism by tunnel assisted trap. The analysis of these curves shows that:

- In the reverse bias the current is dominated by the I_{TAT} component, which confirms the existence of a high density of defects in the bulk of the structure.

- For forward bias, at lower bias voltage $(V < 0.5V)$, the theoretical curve and the experimental measurements fit well, while at high bias $(V > 0.5V)$ the current is dominated by thermionic emission despite a considerable disagreement between experimental measurements and theoretical calculation. This is probably due to a high value of the series resistance in our structures and a large ideality factor which can be, depending on the applied voltage [2, 7].

To verify our assumptions we have tried to determine the values of the series resistance and the ideality factor considering only the thermionic emission, the resulting values are respectively 107.07Ω and 4.06. These rather large values may explain in part the disagreement observed between measurements and theoretical curves.

4. Conclusion

The study was made at room temperature on samples of different concentrations of boron. Analysis of the current-voltage characteristics of Schottky diodes on BGaN allowed us to demonstrate the main conduction mechanisms observed in our samples and the contribution of different mechanisms: thermonic emission, generation-recombination, tunnel and tunnel assisted traps . The work is currently in progress to consider the density of defects, the true value of n and better describe our experimental results.

References

[1] Srour H, Salvestrini J P, Ahaitouf A, Gautier S, Moudakir T, Assouar B, Abarkan M, Hamady S and Ougazzaden A 2011 *Applied Physics Letters* **99** 221101

[2] Ahaitouf A, Srour H, Hamady S O S, Fressengeas N, Ougazzaden A and Salvestrini J 2012 *Thin Solid Films* **522** 345 – 351 ISSN 0040-6090

[3] Gopal V, Plis E, Rodriguez J B, Jones C E, Faraone L and Krishna S 2008 *Journal of Applied Physics* **104** 124506
[4] Sze S and Ng K 2006 *Physics of Semiconductor Devices* (Wiley) ISBN 9780470068304
[5] Mohammad S and Morkoc H 1996 *Progress in Quantum Electronics* **20** 361 – 525 ISSN 0079-6727
[6] Yang Q K, Fuchs F, Schmitz J and Pletschen W 2002 *Applied Physics Letters* **81** 4757–4759
[7] Ahaitouf A, Ahaitouf A, Salvestrini J P and Srour H 2011 *Journal of Semiconductors* **32** 104002