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Comparative study of electrical parameters of Au/GaN and Hg/GaN Schottky diodes

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In this work, we have carried out a comparative study of electrical parameters determined from the current-voltage (I-V) and capacitance-voltage (C-V) characteristics of Au/n-GaN and Hg/n-GaN structures. The analysis of the (I-V) curve for the Au/n-GaN structure showed an ideality factor, barrier height and series resistance of about 1.02, 0.65 eV and 84 Ω, respectively. While for the Hg/n-GaN structure, the values determined are respectively 1.13, 0.65 eV and 670 Ω. The barrier heights and doping concentrations determined from the (C-V) curves are of the order of 1.17 eV and 8.16×1016 cm-3 for the Au/n-GaN Schottky diode and 1.34 eV and 1.87×1016 cm-3 for the Hg/n-GaN Schottky diode. The interfacial state density Nss calculated is equal to 1.09×1012 cm-2 eV-1 for the two diodes.

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1. Introduction

Gallium nitride (GaN) has been considered as a superior material for applications in high-power and high-frequency transistors operating at elevated temperatures [1]. As a wide gap material, GaN exhibits a high breakdown voltage, a high thermal conductivity and a large saturation electron drift velocity. Schottky contacts are used as the key element for the device operation controlling the width of the depletion layer as desired.

In this paper we have investigated the different electrical parameters determined from (I-V) and (C-V) characteristics of the Au/n-GaN and Hg/n-GaN structures. From the forward bias current–voltage (I–V) characteristics, we have determined the saturation current (I_s), the ideality factor (n), the Schottky barrier height (ϕ_b) and the series resistance (R_s). Capacitance–voltage (C–V) measurements also have given detailed information about Schottky contacts. Some parameters of Schottky diode such as barrier height, doping concentration and diffusion potential can be derived from $C^{-2}(V)$ relationship [2,3]. The effects of interface states on the capacitance–voltage characteristic of metal/semiconductor contact have been studied by several authors [4,5].

2. Experimental procedure

The substrate GaN (type n) unintentionally doped is manufactured by Lumilog society, the growth technique used is the HVPE (Hybrid Vapor Phase Epitaxy) method. The GaN substrate is 200 μm thick, freestanding. The contact Schottky used for the first diode is the gold and for the second diode, the mercury contact is used a temporary contact. On the back it's not needed to file an ohmic contact, the face is certainly highly doped and it's just put the structure on the support measures in points.

Thus, the area contact is equal to 1.96×10^{-3} cm^2 for Au/n-GaN and to 7.85×10^{-3} cm^2 for Hg/n-GaN diode.

To characterize our samples electrically, we used the measurements of current with a measuring instrument "HP 4155 B, Semiconductor Parameter Analyzer" and the measurements of capacitance with measuring instrument "Keithley Test System" at high frequency 1 MHz.

3. Results and discussion

3.1. Current–voltage characteristics

The current–voltage characteristics are used widely to study the performance of the Schottky contacts since they offer many important device parameters. Fig. 1 shows the forward and reverse biased curves of Au/n-GaN and Hg/n-GaN Schottky diodes at room temperature. From this figure, we see a better response current of the first diode (Au/n-GaN) compared to the second diode (Hg/n-GaN). So the Schottky contact Au/n-GaN is better quality than the temporary contact Hg/n-GaN.The forward-bias current due to the thermionic emission across the Schottky contacts with the series resistance (R_s) is given as [3]:

$$I = I_0 \, exp\left(\frac{qV - R_s I}{nkT}\right) \qquad (1)$$

Where saturation current I_o is expressed by:

$$I_0 = AA^{**}T^2 \, exp\left(-\frac{q\phi_b}{kT}\right) \qquad (2)$$

Where q is the electronic charge, T the measurement temperature in Kelvin, n the ideality factor, A** the effective Richardson constant (by using an effective mass of 0.22 m_e for n-GaN [6,7], the calculated value of A** is 26.4 A cm^{-2} K^{-2}), k the Boltzmann's constant, R_s the series resistance, ϕ_b the barrier height and A the contact area.

Using a linear curve fit to the forward characteristics of log (I)-V versus V as is shown in Fig. 1, the ideality factor n and the barrier height ϕ_b can be calculated.

The ideality factor is a measure of the conformity of the diode to be pure thermionic emission and is determined from the slope of the forward bias I-V characteristics (see Fig.1) through the relation:

$$n = \frac{q}{kT}\frac{d(V - IR_s)}{d(\ln I)} \qquad (3)$$

The ideality factors of Au/n-GaN and Hg/n-GaN Schottky diodes are found equal to 1.02 and 1.13, respectively.

The apparent or measured barrier height ϕ_b is given by:

$$\phi_b = \frac{kT}{q} ln\left(\frac{AA^{**}T^2}{I_0}\right) \qquad (4)$$

The extrapolation of the log(I)–V curve to zero bias (as showing in Fig. 1) yields the value of saturation current I_0 as 1.98× 10^{-7} A and 2.45× 10^{-7} A for the Au/n-GaN and Hg/n-GaN Schottky diodes, respectively. Then the presence of intentionally grown insulating layer has reduced the value saturation current I_o by two orders of magnitudes. From Eq.(4), the values of the barrier height for the two diodes are found equal to 0.65 (eV) (Au/n-GaN and Hg/n-GaN Schottky diodes).

3.2. Capacitance–voltage characteristics

The capacitance of Schottky diode varies with bias voltage as:

$$\frac{1}{C^2} = \frac{2(V_R + V_d)}{q\varepsilon_s N_D A^2} \qquad (5)$$

Where V_R is the reverse bias voltage, V_d the diffusion potential, ε_s is permittivity of the semiconductor and N_D the doping concentration.

The measurements of the capacitance C of the samples are realized at 1MHz. Fig. 2 shows the C(V) characteristics of the studies structures. The barrier height from C–V measurement is defined by:

$$\phi_b = V_d + \frac{kT}{q} + \phi_n \qquad (6)$$

Where ϕ_n is the Fermi energy measured from the conduction band.

The diffusion potential or built-in potential is usually measured by extrapolating C^{-2} versus V plot to the x-axis (see Fig. 2).

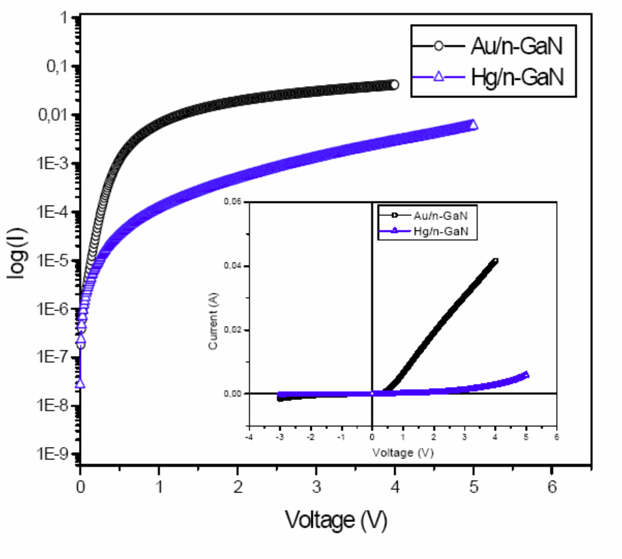

Fig.1. Typical current–voltage characteristics of the Au/n-GaN and Hg/n-GaN diodes at room temperature.

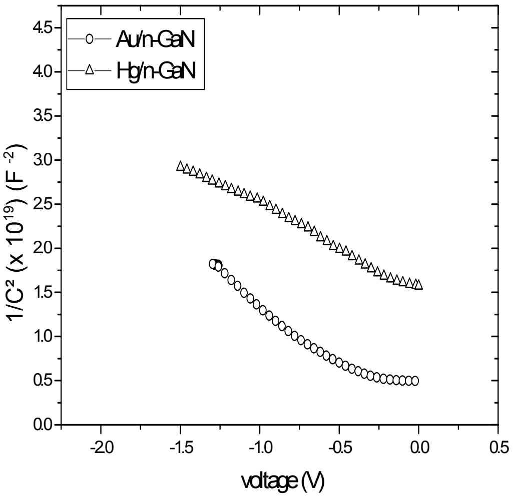

Fig. 2. Capacitance–voltage characteristics of Au/n-GaN and Hg/n-GaN diodes at 1 MHz.

We observe a shift of characteristic C(V) of the Hg/n-GaN structure compared to the Au/n-GaN structure. This is probably due to the presence of a residual capacity due to the contact Hg like it was observed in the Hg/GaN/GaAs structures [8].

For the Au/n-GaN Schottky barrier, the calculated doping concentration and the barrier height are 8.16 $\times 10^{16}$ cm^{-3} and 1.17 eV respectively. The doping concentration and the barrier height of the Hg/n-GaN structure are found equal to 1.87×10^{16} cm^{-3} and 1.34 eV, respectively. However, in the case of Hg/n-GaN Schottky diode, the increase in barrier height with decrease in doping concentration is observed. A reduction of the doping concentration of the Hg/n-GaN diode is obtained compared to the Au/n-GaN diode.

The parameters determined from I–V and C-V characteristics of Au/n-GaN and Hg/n-GaN Schottky diodes are given in Table 1.

Table 1. Calculated parameters of the samples studied.

Parameters	Au/n-GaN	Hg/n-GaN
Thickness of oxide δ (Å)	16	23
The ideality factor n	1.02	1.13
Saturation current I_0 (A)	$1.98 \text{ x}10^{-7}$	$2.45\text{x}10^{-7}$
Schottky barrier height ϕ_b (eV) from I(V)	0.65	0.65
Schottky barrier height ϕ_b (eV) from C(V)	1.17	1.34
Capacity (F) at V=0 V	$1.415\text{x}10^{-10}$	$2.5\text{x}10^{-10}$
Surface of the grid A (cm²)	$1.96\text{x}10^{-3}$	$7.85\text{x}10^{-3}$
Depletion region W (Å) at V=0	1160	2630
Doping concentration N_D (cm^{-3})	$8.16 \text{ x}10^{16}$	$1.87 \text{ x}10^{16}$
Diffusion potential V_d (V)	1.05	1.22
Richardson constant A** (A/K^2cm^{-2})	26.4	26.4

3.3. Determination of interface states density (N_{ss})

The density distribution of the interface states (N_{ss}) can be determined from the forward bias (I-V) data. The quantities of n (V) can be described as in the following equations, respectively [9]:

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

For a diode, the ideality factor n becomes greater than unity as proposed by Card and Rhoderick [9-12]:

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

Where N_{ss} is the density of interface states, ε_s=9.5 ε_0 and ε_i =3.8 ε_0 are the permittivity of the semiconductor and interfacial layer respectively and ε_0= 8.85×10^{-14} F cm^{-1} is the vacuum dielectric constant. The value of W was calculated from reverse bias C^{-2} vs. V plot for each frequency as in the following equations:

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

The interfacial layer thickness δ, generally it is a native oxide layer that is formed when the substrate is in contact with the air before the deposition of the metal and was obtained from the C(V) data in the strong accumulation region using the equation for interfacial layer capacitance ($C_i = \varepsilon_i \varepsilon_0 A/\delta$) at 1 MHz [10-13].

The values of δ and W_D were found to be about 16 Å, 1160 Å, and 23 Å, 2630 Å for Au/n-GaN and Hg/n-GaN, respectively. Furthermore, 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. 3 shows the energy distribution profile of N_{ss} with and without taking R_s into account was obtained from the forward bias I(V) data by using Eq.(8) of the diodes at room temperature. As can be seen in Fig. 3, the exponential growth of the interfacial state density is very apparent. The average interfacial state density N_{ss} calculated is equal to 1.09×10^{12} cm^{-2} eV^{-1} for the two diodes (obtained with two different areas for each contact).

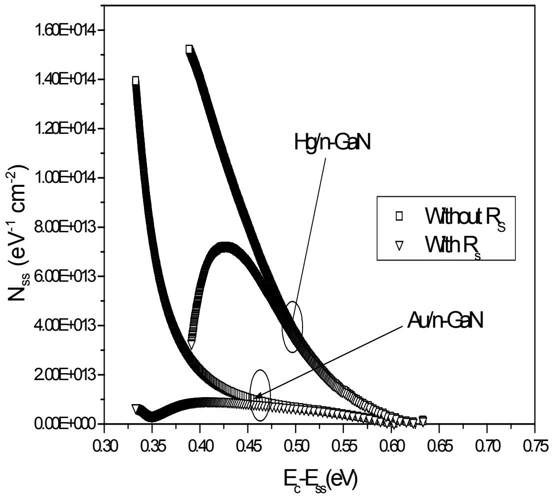

Fig.3. Interface state density distribution profiles as a function of E_c-E_{ss} for Au /n-GaN and Hg/n-GaN diodes.

We note that the density of interface state increases when approaching the conduction band structures for not taking into account the series resistance R_s. By cons when considering this resistance, we observe a high peak located at E_c-E_{ss}= 0.42 eV corresponding to a N_{ss}= 7.19×10^{13} eV^-

^{1}cm^{-2} for the structures Hg/n-GaN and a smaller peak located at E_c-E_{ss}= 0.40 eV corresponding to a N_{ss}= 9.31×10^{12} eV^{-1}cm^{-2} for the structures Au/n-GaN. In addition, the fact to consider this series resistance shows the existence of defect levels within the band gap.

We also note that for a Schottky contact of poor quality (Hg) was the presence of defect levels near the band conduction.

4. Conclusion

In conclusion, the interface properties of Au/n-GaN and Hg/n-GaN Schottky diodes have been investigated by electrical characterization of current–voltage and capacitance–voltage curves.

The Au/n-GaN and Hg/n-GaN exhibit good rectifying behavior. There is good agreement among the Schottky diode parameters obtained from the forward bias I–V characteristics.

This case reveals that the dominant current across Au/n-GaN and Hg/n-GaN Schottky contact is due to thermionic emission. The calculated values of the barrier height for Au/n-GaN and Hg/n-GaN Schottky diodes are found to be 0.65 eV (from I–V curve), 1.17 eV (from C–V curve) and 0.65 eV (from I–V curve), 1.34 eV (from C–V curve), respectively. It is observed that the saturation current (I_o) is reduced in the Au/n-GaN diode as compared to the Hg/n-GaN diode. The energy distribution of the interface states has been determined from the forward-bias I–V data. The density of interface states has been calculated as ~ 10^{12} eV^{-1} cm^{-2}. The R_s is also an important parameter which causes a change in the N_{ss}.

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References

[1] S. J. Pearton, J. C. Zolper, R. J. Shul, F. J. Ren, J. Appl. Phys. **86**, 1 (1999).
[2] E. H. Rhoderick, Metal-S Semiconductor Contacts, University Press, Oxford, 252 p (1988).
[3] S. M. Sze, Physics of Semiconductor Devices, 2nd ed, Wiley, New York, 808 p (1981).
[4] A. M. Goodman, J. Appl. Phys. **34**, 329 (1963).
[5] A. M. Cowley, J. Appl. Phys. **34**, 3024 (1966).
[6] B. B. Kosicki, R. J. Powell, J. E. Burgiel, Phys. Rev. Lett. **24**, 1421 (1970).
[7] X. J. Wang, L. He, Electron. Mater. **27**, 1272 (1998).
[8] K. Ameur, H. Mazari, S. Tizi, R. Khelifi, Z. Benamara, N. Benseddik, A. Chaib, N. Zougagh, M. Mostefaoui, L. Bideux, G. Monier, B. Gruzza, C. Robert Goumet, Sensor Letters, **9**, 2268 (2011).
[9] H. C. Card, E. H. Rhoderick, J. Phys. D: Appl. Phys. **4**, 1589 (1971).
[10] H. S. Altındal, H. Kanbur, I. Yücedag, A. Tataroglu, Microelectron. Eng. **85**, 1495 (2008).
[11] F. Parlaktürk, S. Altındal, A. Tataroglu, M. Parlak, A. Agasiev, Microelectron. Eng. **85**, 81 (2008).
[12] S .Altındal, H. Kanbur, A. Tataroglu, M. Bülbül, Physica, **B 399**, 146 (2007).
[13] E. H. Nicollian, J. R. Brews, MOS Physics and Technology, John Wiley & Sons, New York, p. 307 (1982).

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