Characterization and Modeling of Schottky Diodes Based on Bulk GaN Unintentionally Doped

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Abstract: In this paper, we have studied Au/n-GaN Schottky diodes. The substrates are realized on bulk GaN. The current-voltage (I-V) and capacitance–voltage (C–V) of Au/n-GaN structures were investigated at room temperature. The electrical parameters such as saturation current $I_0$ ($1.98 \times 10^{-7}$ A), ideality factor $n$ (1.02), barrier height $\phi_{bn}$ (0.65 eV) and series resistance $R_s$ (84 $\Omega$) were evaluated from I–V experimental data. The characteristics in these data structures Schottky Au/n-GaN can help to highlight the main conduction mechanisms observed. In addition to the thermionic current present in our structures, the leakage current intervenes too. The barrier height and doping determined from the (C–V) characteristic are of the order of 1.17 eV and $8.16 \times 10^{16}$ cm$^{-3}$, respectively. The average density of surface states $N_{ss}$ determined set to $1.09 \times 10^{12}$ eV$^{-1}$ cm$^{-2}$. Copyright © 2014 IFSA Publishing, S. L.

Keywords: Au/GaN; I-V; C-V; Schottky Diodes.

1. Introduction

In the last decade GaN rose from a potential material for fabrication of a number of optoelectronic and electronic devices to device realization due to the outstanding progress of growth of GaN on large area foreign substrates [1]. As a wide gap material, GaN exhibits a high breakdown voltage, a high thermal conductivity and a large saturation electron drift velocity.

In this paper we have investigated the different electrical parameters determined from (I-V) and (C-V) characteristics of the Au/n-GaN structure. 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 ($\phi_{bn}$) 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 state on the capacitance–voltage.
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. GaN is 200 µm thick, freestanding. The contact Schottky used is the gold (Au) with area contact equals to 1.96×10⁻³ cm².

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 Schottky diode at room temperature. The forward-bias current due to the thermionic emission across the Schottky contacts with the series resistance (Rs) is given as:

\begin{equation}
I = I_0 \exp \left( \frac{qV - IR_s}{nkT} \right),
\end{equation}

where saturation current \( I_0 \) is expressed by:

\begin{equation}
I_0 = AA^* T^2 \exp \left( -\frac{q \phi_{bn}}{kT} \right),
\end{equation}

where \( q \) is the electronic charge; \( T \) is the measurement temperature in Kelvin; \( n \) is the ideality factor, \( A^* \) is the effective Richardson constant (by using an effective mass of 0.22 me for n-GaN [6, 7], the value of \( A^* \) is calculated to be 26.4 A cm⁻² K⁻²), \( k \) the Boltzmann’s constant, \( R_s \) the series resistance; \( \phi_{bn} \) is 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 \( \phi_{bn} \) 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:

\begin{equation}
n = \frac{q}{kT} \frac{d(V - IR_s)}{d(ln I)},
\end{equation}

The ideality factor of Au/n-GaN diode is found equal to 1.02. The apparent or measured barrier height \( \phi_{bn} \) is given by:

\begin{equation}
\phi_{bn} = \frac{kT}{q} \ln \left( \frac{AA^* T^2}{I_0} \right),
\end{equation}

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. From Eq.(4), the value of the barrier height is found equal to 0.65 eV.

3.2. Capacitance–Voltage Characteristics

The capacitance of Schottky diode varies with bias voltage as:

\begin{equation}
\frac{1}{C^2} = \frac{2(V_R + V_d)}{q \varepsilon_s N_D A^2},
\end{equation}

where \( \varepsilon_s=9.5*\varepsilon_0 \) is the permittivity of the semiconductor, \( \varepsilon_0= 8.85\times10^{-14} \) F cm⁻¹ is the vacuum dielectric constant, \( V_R \) is the reverse bias voltage, \( V_d \) is the diffusion potential, and \( N_D \) is the doping concentration.

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

\begin{equation}
\phi_{bn} = V_d + \frac{kT}{q} + \phi_n,
\end{equation}

where \( \phi_n \) 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). For the Au/n-GaN Schottky diode, the calculated doping concentration \( N_D \) and the barrier height \( \phi_{bn} \) are 8.16 ×10¹⁶ cm⁻³ and 1.17 eV, respectively.

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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Au/n-GaN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of oxide $\delta$ (Å)</td>
<td>16</td>
</tr>
<tr>
<td>The ideality factor $n$</td>
<td>1.02</td>
</tr>
<tr>
<td>Saturation current $I_0$ (A)</td>
<td>1.98 × 10^{-7}</td>
</tr>
<tr>
<td>Schottky barrier height $\phi_{bn}$ (eV) from I (V)</td>
<td>0.65</td>
</tr>
<tr>
<td>Schottky barrier height $\phi_{bn}$ (eV) from C (V)</td>
<td>1.17</td>
</tr>
<tr>
<td>Capacity (F) at V=0 V</td>
<td>1.415 × 10^{-10}</td>
</tr>
<tr>
<td>Surface of the grid A (cm$^2$)</td>
<td>1.96 × 10^{-3}</td>
</tr>
<tr>
<td>Depletion region W (Å) at V=0 V</td>
<td>1160</td>
</tr>
<tr>
<td>Doping concentration $N_o$ (cm$^{-3}$)</td>
<td>8.16 × 10^{16}</td>
</tr>
<tr>
<td>Diffusion potential $V_d$ (V)</td>
<td>1.05</td>
</tr>
<tr>
<td>Richardson constant $A^*$ (A/K$^2$cm$^{-2}$)</td>
<td>26.4</td>
</tr>
<tr>
<td>Thickness of oxide $\delta$ (Å)</td>
<td>16</td>
</tr>
<tr>
<td>The ideality factor $n$</td>
<td>1.02</td>
</tr>
</tbody>
</table>

3.3. Determination of 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 $\phi_{bn}$ into account. The quantities of $n(V)$ can be described as in the following equations, respectively [8]:

$$n = \frac{q}{kT} \left[ \ln\left( \frac{I}{I_0} \right) \right]^{-1}, \quad (7)$$

For a diode, the ideality factor $n$ becomes greater than unity as proposed by Card and Rhoderick [8-11]:

$$n(V) = 1 + \frac{qV}{kT} \ln\left( \frac{I}{I_0} \right) + qN_{ss}, \quad (8)$$

where $N_{ss}$ is the density of interface states, and $\varepsilon_i$ is the permittivity of the interfacial layer.

The value of $W$ was calculated from reverse bias $C^2$ vs. $V$ plot as in the following equations:

$$W = \sqrt{\frac{2e_0V_d}{qN_{ss}}}, \quad (9)$$

The interfacial layer thickness $\delta$ was obtained from the C(V) data in the strong accumulation region using the equation for interfacial layer capacitance ($C_i = \varepsilon_i \varepsilon_0 / \delta$) at 1 MHz [9-12]. The values of $\delta$ and W were found to be about 16 Å, 1160 Å.

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:

$$E_c - E_{ss} = q\left( \phi_{bn} - (V - I_{Rs}) \right), \quad (10)$$

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 $1.09 \times 10^{12}$ cm$^{-2}$ eV$^{-1}$.

![Fig. 3. The energy density distribution profiles of the Au/n-GaN Schottky barrier diode at room temperature.](image)
explanation shows that the series resistance value should be taken into account in determining the interface state density distribution curves.

4. Conclusion

The current-voltage (I-V) and voltage-capacitance (C-V) characteristics of Schottky diodes Au/n-GaN are studied. The electrical parameters calculated as the saturation current $I_0$ ($1.97 \times 10^{-7}$ A), ideality factor $n$ (1.02), the barrier height $\phi_{bn}$ (0.65 eV) and a series resistance $R_s$ (84 $\Omega$), evaluated from (I-V) characteristic. From (C-V) experiment curve, we have determined the doping concentration $N_D$ ($8.16 \times 10^{16}$ cm$^{-3}$), the diffusion potential $V_d$ (1.05 eV) and the barrier height $\phi_{bn}$ (1.17 eV). The distribution of the density of interface states $N_{ss}$ with and without considering $R_s$ in $E_c-0.40$ eV is $9.31 \times 10^{12}$ eV$^{-1}$ cm$^{-2}$ and $4.1 \times 10^{13}$ eV$^{-1}$ cm$^{-2}$, respectively. In general one can say that the Schottky diodes based on GaN represents of good electrical parameters.

References