



# Effects of chemical treatment on barrier height and ideality factors of Au/GaN Schottky diodes

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## ABSTRACT

We have studied Au/n-GaN Schottky barrier diodes. GaN surfaces have been prepared by cleaning in HCl and  $(\text{NH}_4)_2\text{S}$  prior to metal deposition. The zero-biased barrier heights and ideality factors obtained from the current–voltage characteristics differ from diode to diode, although all the samples were prepared identically. The statistical analysis for the reverse bias  $C$ – $V$  data yielded mean value of  $(1.35 \pm 0.04)$  eV for Schottky barrier height of HCl treated sample and  $(1.20 \pm 0.03)$  eV for  $(\text{NH}_4)_2\text{S}$  sample, where 9 dots were considered from each cleaning method. It was found that the barrier height values obtained from the  $C^{-2}$ – $V$  (1.43 eV) and  $I$ – $V$  characteristics (0.89 eV) are different from each other by 0.54 eV. The inhomogeneous barrier heights were found to be related to the effect of the high series resistance on diode parameters (Akkiliç et al., 2004) [1].

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## 1. Introduction

Rectifying contacts with low leakage currents and high barrier height are required for the successful fabrication of GaN-based devices. Schottky barrier diodes (SBD) are the choice structure for many semiconductor devices, including microwave diodes, field-effect transistors and photodiodes [2–4]. Their technological importance requires a full understanding of the nature of the electrical characteristics of SBDs. It is well known that SBD has a thin layer of an oxide between the metal and the semiconductor, which cannot be removed by conventional chemical cleaning. Such an oxide converts the diode to metal–insulator–semiconductor (MIS) and usually influences the electrical characteristics of the diode, causing a change in the interfacial charge with bias, giving rise to an electric field at the interfacial layer between the metal and the semiconductor [5,6]. The oxide layer reduces the barrier height and consequently increases the series resistance.

Generally, the forward biased current–voltage ( $I$ – $V$ ) characteristics are linear in the semi-logarithmic scale at low voltages, but deviate considerably from linearity due to the effects of series resistance,  $R_s$ , resulting from the presence of the thin oxide layer and other surface contaminants. The series resistance is only effective in the curvature downward region or non-linear region of the forward  $I$ – $V$  characteristics at sufficiently high voltages. The concavity of the current–voltage characteristics at higher voltages increases with increasing series resistance. Increasing series resistance decreases the barrier height and this result in

non-ideal current–voltage characteristics. Other parameters such as the ideality factor,  $n(V)$  and zero bias barrier height,  $\Phi_{b,0}$  are effective in both the linear and the non-linear regions of the  $I$ – $V$  curve, accompanying the changes in the Schottky barrier height (SBH) [7]. The effect of the series resistance between the depletion region and the ohmic contact of the neutral region of the semiconductor bulk causes the  $I$ – $V$  characteristics of the metal–semiconductor contact to deviate from the expected [8].

The interface states at the metal–semiconductor junction play a vital role in evaluating the Schottky barrier height and the ideality factor. These manifest themselves as deviations from the ideal Schottky barrier formation and are localized within a few atomic layers of the intimate metal–semiconductor contact with energies which fall inside the forbidden gap. Bardeen showed that such charge accumulated at the metal–semiconductor contact reduces the effective potential difference between the semiconductor and the metal contact [9]. Interface states arise from semiconductor surface states due to discontinuity in the lattice potential, metal-induced-gap states due to wave-function tunneling from the metal into the semiconductor, surface states due to contamination and defects; and any new compounds formed as a result of the interaction of the metal and the semiconductor.

A study of the importance of series resistance in calculating the characteristic parameters of Si Schottky contacts was done by Aydin et al. [1], obtaining their estimations from determination of interface states density distribution from the analysis of the current–voltage measurements. Kampen and Monch studied the barrier heights of different metals on GaN using metal-induced gap states (MIGS) and the electronegativity model, concluding that the experimental values of the barrier height are excellently reproduced by the theoretical predictions, which follow from

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physical MIGS and the electronegativity concept [10]. A review of metal-contact technology has revealed the importance of surface preparation prior to metal deposition [11]. In this study, two different surface chemicals were used to treat GaN surface prior to metal deposition. The effects of chemical treatments on Schottky characteristics were investigated using capacitance–voltage ( $C$ – $V$ ) and current–voltage ( $I$ – $V$ ) characteristics. The average barrier height for the diodes was 1.43 and 1.20 eV for  $C$ – $V$ ; and 0.81 and 0.89 for  $I$ – $V$  measurements, respectively.

## 2. Experimental

For this investigation, we have used GaN samples with carrier density of  $1 \times 10^{17} \text{ cm}^{-3}$ , obtained from TDI. Before contact fabrication, samples were cleaned using trichloroethylene (TEC), Isopropanol and HCl:HNO<sub>3</sub> aquaregia. Each of these samples was finally etched in 1:1 HCl:H<sub>2</sub>O (sample 1) and (NH<sub>4</sub>)<sub>2</sub>S (sample 2), respectively. Using patterned surface, Ti/Al/Ni/Au (150/2200/400/500 Å) ohmic contacts were deposited by electron-beam and annealed in ultra pure Ar for 5 min at 500 °C. Thereafter, Au Schottky contacts, 0.25 mm thick, were deposited in the resistive evaporator at room temperature. The values of zero-biased barrier height and ideality factor were determined from  $I$ – $V$  and  $C$ – $V$  measurements at room temperature and corrected afterwards for the effect of series resistance.

## 3. Results and discussion

In Schottky diodes, the depletion layer capacitance can be expressed as [2]

$$C^{-2} = \frac{2(V_{bi} - V_A)}{q\epsilon_s A^2 N_D} \quad (1)$$

where  $A$  is the area of the diode,  $V_{bi}$  the diffusion potential at zero bias and is determined from the extrapolation of the linear  $C^{-2}$  –  $V$  plot to the  $V$  axis and  $V_A$  is the applied voltage. The value of the barrier height can be obtained from the relation:

$$\Phi_{b,0}(C - V) = V_{bi} + V_0 \quad (2)$$

where  $V_0$  is the potential difference between the bottom of the conduction band and the Fermi level; and can be calculated knowing the donor concentration  $N_D$  obtained from the following relation:

$$V_0 = (kT) \ln \left( \frac{N_C}{N_D} \right) \quad (3)$$

where  $N_C = 4.6 \times 10^{16} \text{ cm}^{-3}$  is the effective density of states in the conduction band [3].

Nine dots with the same diameter (0.25 mm) on each sample were evaluated. Fig. 1 shows the reverse bias  $C^{-2}$  –  $V$  characteristics for one diode from sample 1 and sample 2, respectively. For these particular diodes on samples 1 and 2, the  $C$ – $V$  barrier heights are 1.43 and 1.20 eV, respectively. The carrier concentration of  $1.9 \times 10^{16}$  and  $2.4 \times 10^{16} \text{ cm}^{-3}$  from the reverse bias  $C^{-2}$  –  $V$  plots was obtained for samples 1 and 2. The  $C$ – $V$  barrier heights ranged from 1.28 to 1.50 eV for sample 1 and from 1.14 to 1.25 eV for sample 2. The statistical analysis for the  $C$ – $V$  data yielded SBH mean value of  $1.35 \pm 0.04$  eV for sample 1 dots and SBH mean value of  $1.20 \pm 0.03$  eV for sample 2.

In Schottky barrier diodes, the barrier height depends on the voltage and surface conditions prior to metal deposition. The surface condition includes the thickness of the interfacial oxide, which affects the current–transport mechanisms. These include the thermionic emission, which is characterized by ideality factor close to unity and thermionic field emission and field emission. These mechanisms are affected by series resistance, tunneling and generation recombination in the depletion region. Table 1 gives the summary of the electrical characteristics of the diodes.

For a Schottky contact with series resistance, the net current of the device is due to thermionic emission and it is written as [2]

$$I = I_0 \exp \left( -\frac{q(V_A - IR_s)}{nkT} \right) \quad (4)$$

where the saturation current,  $I_0$  is expressed as

$$I_0 = AA^* T^2 \exp \left( -\frac{q\Phi_{b,0}}{kT} \right) \quad (5)$$

where  $q$  is the electron charge,  $A^*$  is the effective Richardson constant and is equal to  $26 \text{ A/cm}^2 \text{ K}^2$  for n-type GaN [12],  $A$  is the

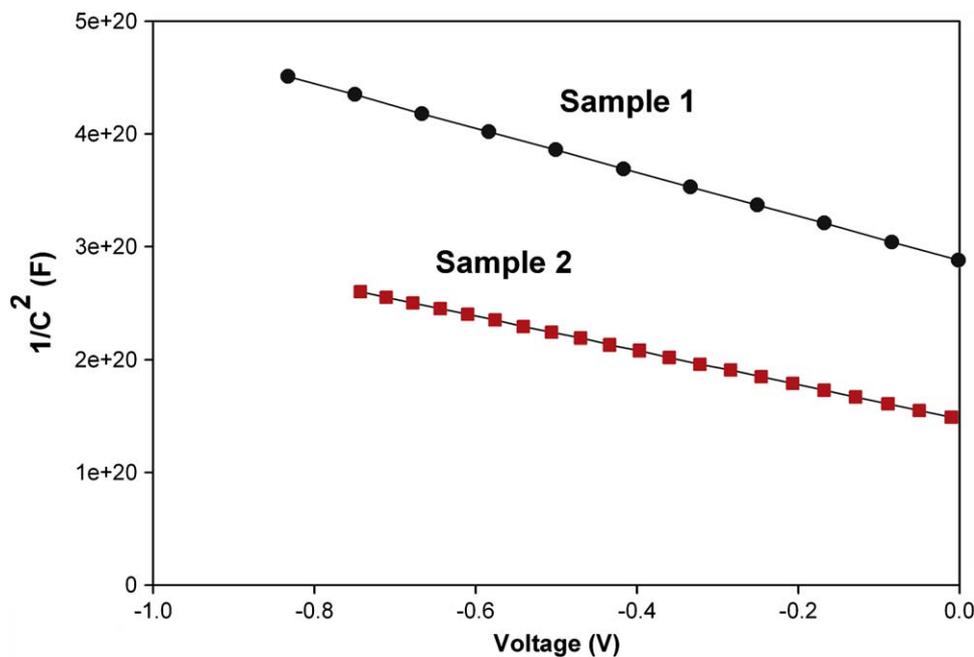


Fig. 1. Reverse bias  $C^{-2}$ – $V$  curves of the HCl and (NH<sub>4</sub>)<sub>2</sub>S samples. For these particular diodes on samples 1 and 2, the  $C$ – $V$  barrier heights are 1.43 and 1.20 eV, respectively.

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