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Fabrication Process of Nano and Optoelectronic Devices Based on Nitrided Gaas: XPS Analysis and Electrical Measurements

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Abstract: Nano and optoelectronic devices elaborated with gallium arsenic (GaAs) usually known as have been a topic of several studies. Such structures are widely used in various applications. However, the major obstacle encountered in the elaboration of these structures is the oxidation of the GaAs surface which incur a poor quality of the interfaces between the III-V's and the metallic contacts leading to the degradation of the electronic properties of the device. Thereby the passivation of the GaAs surface appears as a key point to improve the performance of GaAs based devices. Different surface passivation methods have been developed to remove this adverse effect as anodization process, Se treatment and N2 plasma treatment. We focused our attention in this presentation on the improvement of the electrical quality of Schottky barrier diodes (SBDs) based on nitridated n-GaAs(100) using a new fabrication process. We will focus on controlling the elaboration steps using XPS measurements and electrically testing the fabricated structures using I-V and C-V measurements at different conditions. This presentation allows us to analyze the effect of the nitridation process and the impact of the technological steps of fabrication on the electrical quality of realized SBDs.

Keywords: XPS, SBDs, Characterization, GaAs, Nitridation

Introduction

Gallium arsenide (GaAs) is one of the most attractive III–V compound semiconductors for high-speed, high-frequency, and optoelectronic device applications due to its direct bandgap, high electron mobility, and excellent thermal and chemical stability (Jenabi,2017; Kansız, 2025 ;Robertson, 2006).It is widely used in ; Schottky barrier diodes (SBDs), high-electron-mobility transistors (HEMTs), and photonic devices such as photodetectors and light-emitting diodes (Gullu, 2024; Zutter, 2021; Sirkeli, 2025). However, despite its outstanding intrinsic properties, the performance of GaAs-based devices is often limited by the poor quality of the metal–semiconductor interface, primarily caused by the spontaneous formation of native oxides and surface defects (Sirkeli, 2020,2024) .These imperfections lead to a high density of interface states that trap carriers, increasing leakage current and degrading both the barrier height and the rectification efficiency of SBDs (Raman, 2025; Sreelekshmi, 2025; Xiao, 2024).

To mitigate these issues, several surface passivation methods have been developed, including chemical etching, sulfur or selenium treatments, anodization, and plasma-assisted techniques (Egorkin, 2024; Liu (2024), Ravendra (2025)). Among these, plasma nitridation has proven particularly effective in suppressing surface oxidation and reducing interface states through the formation of a stable gallium nitride (GaN) interfacial layer (Hadjouni, 2025; Sirkeli, (2015). This thin GaN film acts as a barrier against metal diffusion and oxide regrowth, thereby improving the thermal and electrical stability of GaAs-based Schottky contacts (Sirkeli, 2017; Pokatilov, 2006; Khales, 2025). Moreover, the incorporation of ultra-thin nitride interlayers has been shown to enhance carrier transport and reduce recombination losses in related III–V structures Kacha (2016, 2021) and Benamara (2022), offering a pathway toward more efficient nano- and optoelectronic devices.

In this work, we investigate the fabrication and characterization of Au/GaN/GaAs Schottky barrier diodes incorporating an ultra-thin GaN interlayer (~17 Å) formed by in-situ electron cyclotron resonance (ECR) nitrogen plasma nitridation. The nitridation process was carefully monitored using X-ray photoelectron spectroscopy (XPS) to assess the chemical composition and structural quality of the interface (Kacha,2021; Helal, 2021). The electrical behavior of the fabricated diodes was then evaluated through current–voltage (I–V) and interface state density analyses to determine the effect of the nitridation process on key parameters such as the barrier height, ideality factor, and leakage current.

The objective of this study is to demonstrate that controlled in-situ nitridation significantly improves the electrical performance of Au/GaN/GaAs Schottky barrier diodes by enhancing the interfacial properties and reducing leakage paths. The results show that the introduction of the GaN layer leads to a lower ideality factor, reduced saturation current, higher barrier height, and a substantial decrease in interface state density. These findings confirm that nitridation is an efficient surface engineering approach for optimizing GaAs-based SBDs, enabling their advanced application in nano- and optoelectronic technologies.

Methods

The studied structure was fabricated on n-type GaAs (001) substrates with a donor concentration of ND = 4.9×10^{15} cm^{-3}. To remove surface contaminants, the fabrication process began with a two-step cleaning procedure. The first step consisted of an ex-situ chemical treatment using an HCl and isopropanol solution for 2 minutes and 30 seconds under dark conditions. The second step involved in-situ thermal cleaning by heating the substrate to 500°C under ultra-high vacuum (UHV) conditions (Kacha, 2021).

The nitridation process, applied only to the studied Schottky barrier diodes, was carried out in situ using an ECR N_2 plasma source oriented normal to the surface at a temperature of 500°C and a pressure of 2.5×10^{-5} mbar. XPS measurements were employed to monitor the nitridation step. The thickness and chemical composition of the formed GaN layer were determined using the XPS models proposed by Mehdi (2018). Subsequently, four circular Au contacts, each 600 µm in diameter and 100 nm thick, were deposited in situ on the front surface of the sample using a Knudsen cell evaporator.

To enhance the Ohmic contact quality of the studied structure, AuGe contacts were fabricated ex situ on the backside of each sample by sequential evaporation of 10 nm of Au, 35 nm of Ge, and 100 nm of Au under a pressure of approximately 10^{-6} Torr. The contacts were subsequently annealed in a H_2–N_2 atmosphere through a three-step heating process: 200°C for 3 minutes, 250°C for 1 minute, and 300°C for 1 minute. This thermal treatment promoted the diffusion of AuGe into the GaAs substrate, ensuring low-resistance Ohmic behavior. Fabrication details of the studied sample are summarized in Table 1.

Table 1. Technological details of the structure.

GaAs	Nitridation	δ-GaN	Metal contacts
(001) $N_D = 4.9\times10^{15}$ cm^{-3}	120min500°C	17 Å	Schottky: Au Ohmic: AuGe

Realized structures were electrically tested by current-voltage measurements in dark and under illumination at room temperature. These measurements were carried out with a Keithly 2636.

Results and Discussion

XPS Measurements

To monitor the nitridation process and identify the surface composition of the Au/GaN/GaAs structure with a 17 Å GaN interlayer, X-ray photoelectron spectroscopy (XPS) measurements were performed. The spectra corresponding to As 3d, Ga 3d, O 1s, and N 1s core levels were recorded and analyzed after applying a Shirley background correction. Figure 1 presents the spectra obtained before and after the nitridation treatment, highlighting the chemical changes induced at the surface.

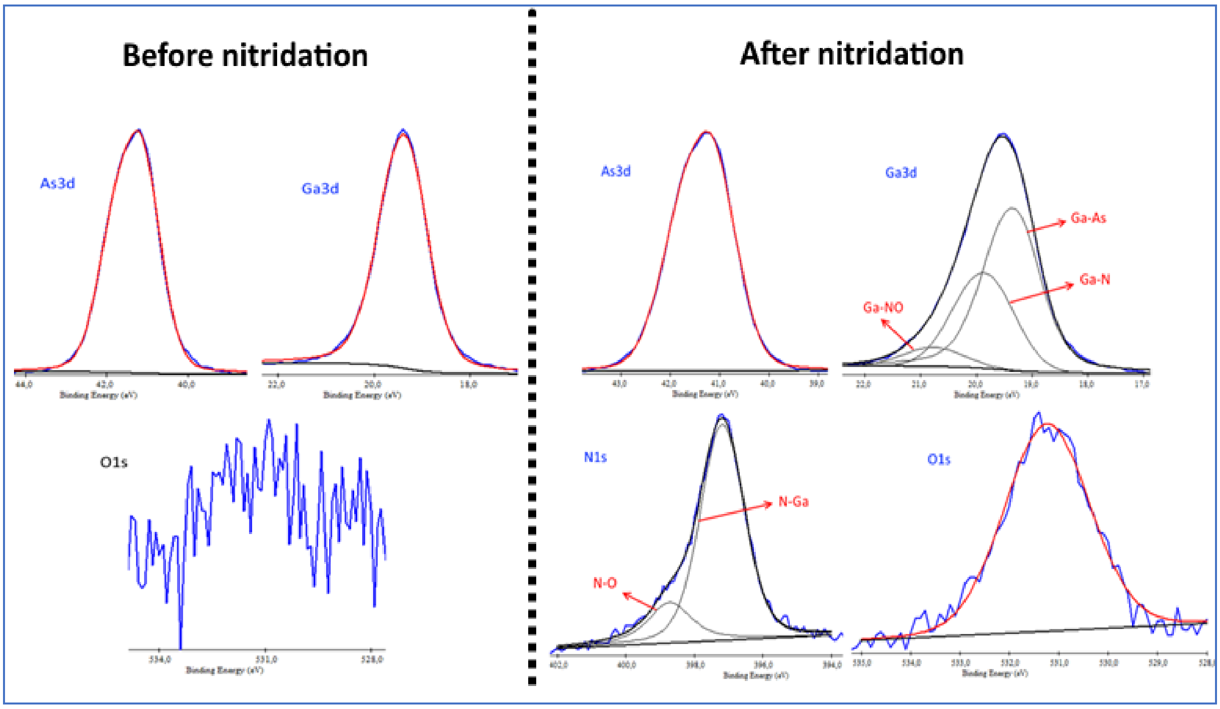

Figure 1. XPS spectra before and after nitridation (Kacha, 2021)

Before nitridation, the O 1s signal at around 531 eV was very weak and noisy, indicating a negligible oxygen contribution on the surface. After nitridation, the As 3d peak at 41 eV retained both its energy position and full width at half maximum (FWHM), suggesting that it originates solely from the As–Ga bonding environment of the GaAs substrate. This observation confirms that arsenic is not incorporated into the thin GaN overlayer. In contrast, the Ga 3d peak at approximately 19 eV exhibited a noticeable broadening after nitridation, consistent with the coexistence of multiple chemical environments. Deconvolution of this peak revealed three components associated with Ga–As, Ga–N, and Ga–NO bonds, as illustrated in Figure 1. A new N 1s signal emerged near 397 eV, composed of two distinct contributions corresponding to N–Ga and N–O bonds. The appearance of Ga–NO and N–O components is further supported by the enhanced O 1s peak intensity at 531 eV following nitridation. Based on the relative XPS peak intensities and the theoretical model proposed by Mehdi (2018), the estimated GaN layer thickness and the associated oxygen content were determined and are reported in Table 2.

Table 2. Estimations of GaN created layers thickness and oxygen rate

δ-GaN	Oxygen rate
17 ± 2 Å	16 ± 1 %

The oxygen content detected after nitridation is within an acceptable range and is attributed to unavoidable surface contamination that typically occurs during the nitridation process. For this structure with a 17 Å GaN layer, the nitride film is extremely thin, allowing it to be regarded as an interfacial layer between the gold contact and the GaAs substrate. This ultrathin GaN interlayer plays a crucial role in influencing the structural and electronic properties of the resulting Schottky barrier diode (SBD).

Electrical Measurements

Figure 2 presents the current–voltage (I–V) characteristics of the Au/GaN/GaAs structure, measured in the dark and at room temperature, using both linear and semi-logarithmic scales.

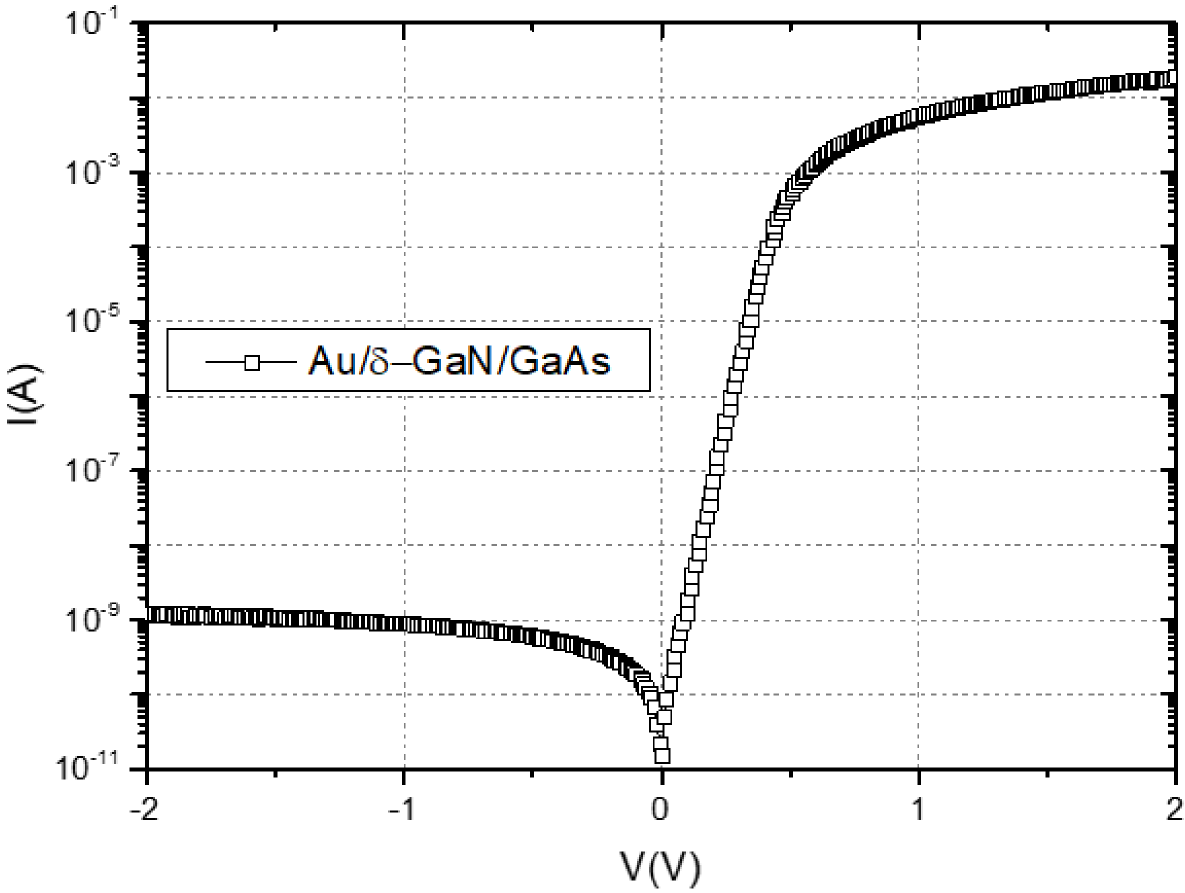

Figure 2. Current-voltage curve.

The thermionic emission current of a real Schottky diode is given by the relation (Kacha, 2021):

$$I_{th} = I_s (e^{\frac{q(V - R_s I_{th})}{nkT}}) \qquad \text{for } V > 3kT/q \tag{1}$$

Where V is the applied voltage drop across the semiconductor surface depletion layer, q is the electron charge, k the Boltzmann constant, n the ideality factor, R_s the series resistance and I_s, the saturation current. The saturation current can be defined by Kacha (2021):

$$I_s = A^* T^2 e^{\frac{-q\phi_{Bno}}{kT}} \tag{2}$$

Where T, φ_{Bno}, A^*, are the temperature in Kelvin, the barrier height at zero bias and the effective Richardson constant which is equal to 8.78 $Acm^{-2}K^{-2}$ respectively (Kacha, 2021).

As shown in Figure 1, the Au/GaN/GaAs structure with a 17 Å GaN interlayer exhibits a significantly lower reverse current indicating a reduction in leakage current after the introduction of the GaN layer. The rectifying ratio (RR), defined as the ratio of the forward current to the reverse current Kacha (2021), was used to evaluate the diode's rectifying performance. The rectification ratio can be estimated using:

$$RR = \frac{I_{Forward}}{I_{reverse}} \tag{3}$$

The rectifying ratio curve of the studied structure is shown in Figure 3.

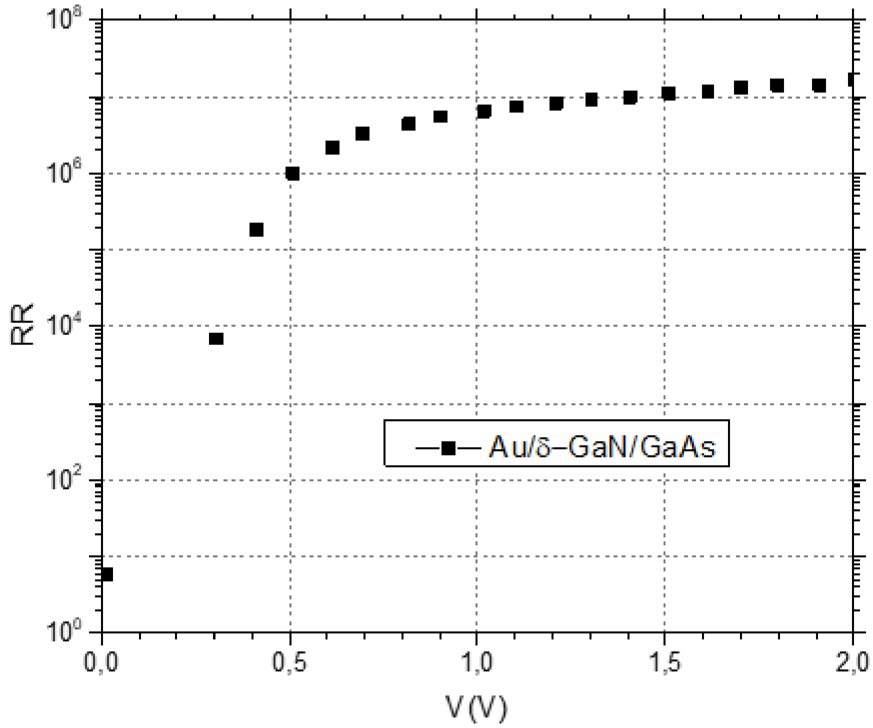

Figure 3. The rectifying ratio curve of the studied structure

The RR parameter of the studied structure show a good rectifier behavior. Indeed, the RR parameter is about 10^7 at 2V bias voltage. The resistance of the junction JR is another parameter that can represent the electrical quality of the studied structure. This parameter is calculated using Ohm's law (Kacha, 2021):

$$JR = \frac{V}{I} \tag{4}$$

JR is plotted in Figure 4.

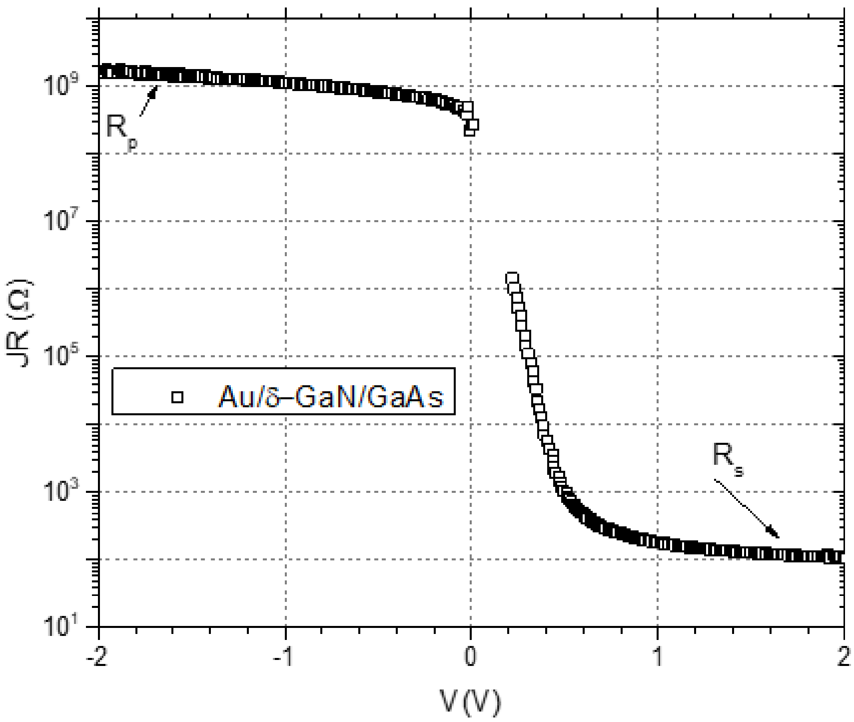

Figure 4. Junction resistance plot of the studied structures

For positive bias values, the JR plot provides an estimate of the series resistance, while for negative bias values it reflects the parallel resistance. As shown in Figure 4, the studied structure exhibits a much higher parallel resistance of approximately 10^9 Ω. This significant increase explains the lower reverse current observed in the I–V characteristics (Figure 1), as the leakage current in a Schottky barrier diode is inversely proportional to the parallel resistance (Kacha, 2021). To extract the main electrical parameters, including the ideality factor (n), the saturation current (Is), the zero-bias barrier height (ϕbn0), and the series resistance (Rs), the ln(I)–V characteristic was plotted, as shown in Figure 5.

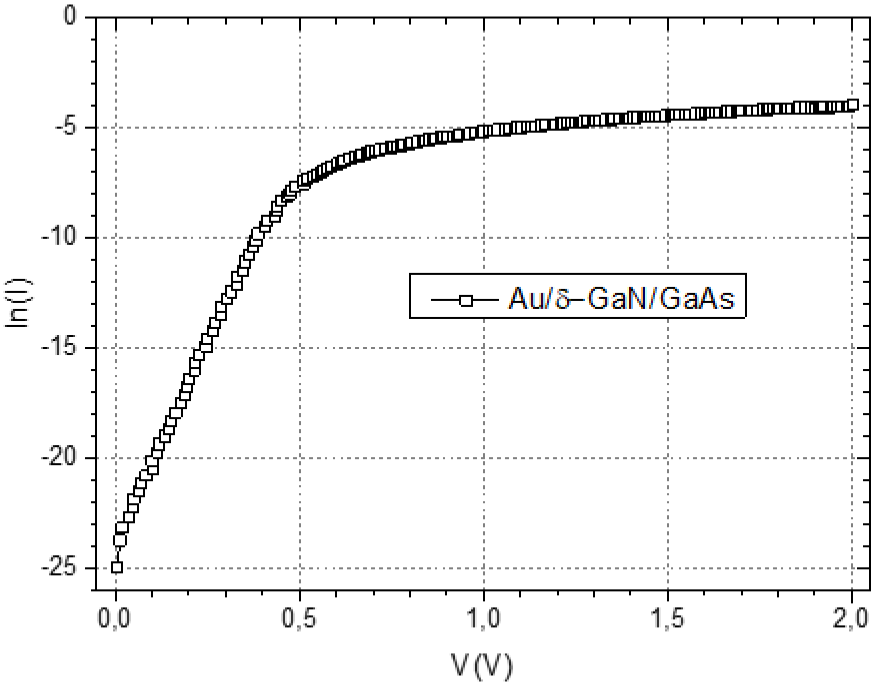

Figure 5. Variation of ln(I) as a function of bias voltage V.

The procedure used to extract the electrical parameters from the ln(I)–V characteristics has been described in detail in our previous work (Kacha, 2021). The parameters determined from ln(I)–V curve are summarized in Table 3.

Table 3. Electrical parameters obtained from ln(I)=f(V)

	n	I_s (A)	ϕ_{Bn0} (V)	R_s (Ω)
Au/GaN/GaAs	1.15	1.07×10^{-10}	0.81	85.34

The electrical parameters extracted from the current–voltage measurements (Table 3) indicate a notable improvement following the nitridation process. Compared to conventional Au/GaAs electrical parameters (Helal (2021)), the ideality factor decreased by approximately 7%, the saturation current by about 31%, and the series resistance by nearly 5%. Meanwhile, the barrier height increased by around 2.5%. These enhancements suggest an improvement in the quality of the metal–semiconductor interface of the studied structure after nitridation (Benamara (2022). To further analyze the interfacial behavior, the interface state density (Nss) was evaluated using the relation given in (Kacha, 2021):

$$n = 1 + \frac{q^2 \delta N_{ss}}{\varepsilon_i} \tag{5}$$

Where ε_i and δ are the permittivity and the thickness of the interfacial layer respectively. In Figure 6, we have plotted the distribution of the interface state density in the band gap using (Kacha (2021)):

$$E_c - E_{ss} = q(\phi_{Bno} - V) \tag{6}$$

Where E_{ss} is the interface state energy compared to the conduction band edge E_c at the surface.

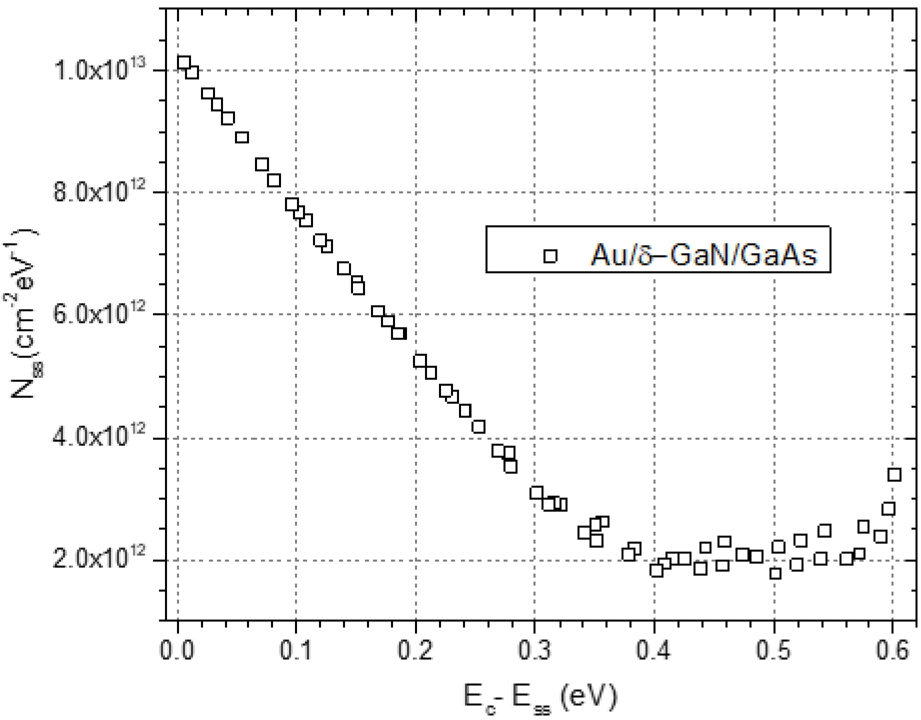

Figure 6. The distribution of the interface state density in the band gap

The calculated values of Nss are considerably low. Following 120 minutes of nitridation, the interface state density was reduced to about 2.0×10^{12} cm^{-2} eV^{-1} at at (Ec − 0.5) eV for the studied structure. This reduction is attributed to a structural reorganization at the metal–semiconductor interface induced by the formation of the thin GaN interfacial layer (Kacha, 2021). To further confirm the improvement of the interface quality after nitridation, the leakage current responsible for the reverse current was estimated. The thermionic emission current (Eq. 1) was simulated using the experimentally determined parameters n, Is, and Rs, and the simulated result was compared with the experimental data, as shown in Figure 7.

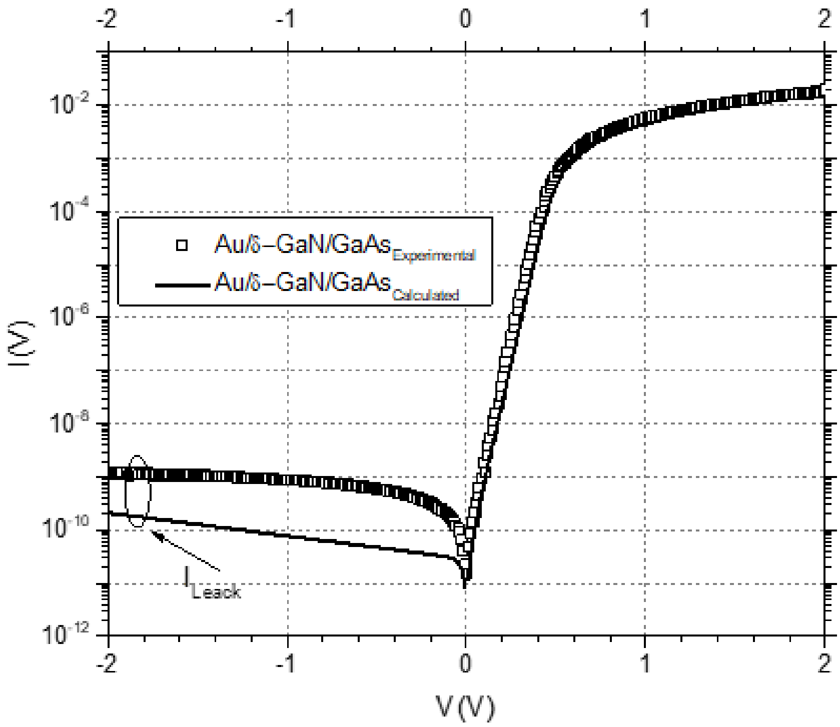

Figure 7. Estimation of the leakage current

The plots in Figure 7 reveal a noticeable deviation between the simulated and experimental I–V curves under reverse bias, with the experimental currents being higher. This discrepancy corresponds to the leakage current (Kacha (2021)). After the nitridation process, a significant reduction in leakage current was observed. At a reverse bias of −2 V, the leakage current is estimated to about 9.36×10^{-10} A in the studied structure, confirming the beneficial effect of the GaN interlayer on reducing reverse leakage.

Conclusion

In this work, the fabrication and characterization of the studied Au/GaN/GaAs Schottky barrier diode confirmed that the in-situ nitridation process significantly improves the structural and electrical properties of the metal–semiconductor interface. XPS analysis verified the successful formation of an ultrathin GaN layer of about 17 ± 2 Å with an oxygen content of approximately 16%, confirming the controlled nitridation and stability of the interface. Electrical characterization revealed clear improvements in the diode's performance after nitridation: the ideality factor decreased to 1.15 (a reduction of nearly 7%), the saturation current dropped to 1.07×10^{-10} A (about 31% lower than in non-nitridated structures), and the series resistance was reduced to 85.34 Ω (around 5% improvement). Simultaneously, the barrier height increased to 0.81 eV, and the parallel resistance rose to nearly 10^9 Ω, indicating enhanced rectifying behavior.

The rectification ratio reached about 10^7 at 2 V, confirming excellent diode performance. The interface state density (Nss) was also significantly reduced to around 2.0×10^{12} cm^{-2} eV^{-1} at (Ec – 0.5 eV), demonstrating improved surface passivation. Furthermore, the leakage current at −2 V decreased from to 9.36×10^{-10} A after nitridation, highlighting the effectiveness of the GaN interlayer in reducing reverse leakage. Overall, these results demonstrate that the controlled nitridation process is a reliable and efficient technique for enhancing the electrical quality of GaAs-based Schottky barrier diodes, paving the way for their optimized use in nano- and optoelectronic device applications.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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