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## Conduction mechanisms in Au/0.8nm-GaN/n-GaAs Schottky contacts in a wide temperature range

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### Abstract

Au/0.8nm-GaN/n-GaAs Schottky diodes were manufactured and electrically characterized over a wide temperature range. As a result, the reverse current  $I_{inv}$  increments from  $1 \times 10^{-7}$  A at 80 K to about  $1 \times 10^{-5}$  A at 420 K. The ideality factor  $n$  shows low values, it decreases from 2 at 80 K to 1.01 at 420 K. The barrier height  $q\phi_b$  grows abnormally from 0.46 eV at 80 K to 0.83 eV at 420 K. The tunnel mechanism TFE effect is the responsible for the  $q\phi_b$  behavior. The series resistance  $R_s$  is very low, it decreases from 13.80  $\Omega$  at 80 K to 4.26  $\Omega$  at 420 K. These good results are due to the good quality of the interface treated by the nitridation process. However, the disadvantage of the nitridation treatment is the fact that the GaN thin layer causes an inhomogeneous barrier height.

**Keywords:** nitridation; GaN/n-GaAs; Schottky diode; I-V-T; conduction mechanisms; barrier height;

## Introduction

Metal-semiconductor (MS) contacts are very important in microelectronics [1-4]. They are used in optoelectronic devices, bipolar integrated circuits, high-temperature, and high-frequency applications [5, 6]. The thermionic emission (TE) theory is the principal theory used to determine the parameters of the Schottky contact.

However, the experimental current-voltage (I-V) characteristics present some anomalies at low temperatures and that both Schottky barrier height and ideality factor are temperature-dependent [5, 7-10].

This deviation of the thermionic emission theory is corrected by introducing other mechanisms, operating at the Schottky barrier such as the thermionic field emission TFE and the emission field FE currents [5, 11].

The origin of these currents is explained by considering several phenomena. First, the Schottky barrier is typically not homogeneous in space [7, 12-15], as measured using ballistic electron emission microscopy [16, 17]. The most widely accepted approach for interpreting experimental data considers that the spatial barrier inhomogeneity can be modeled with a Gaussian distribution function [12, 18-24].

Secondly, the existence of interface states [7, 25], act as recombination centers and generate local electric fields, causing random metallic paths, reducing carrier lifetime, and inducing large leakage current [26-29]. These interface states come from surface dislocations and surface contaminations incorporated during the elaboration process [27, 30, 31]. In addition, the Schottky metallization step can cause interfacial modifications [31-34].

Therefore, the interface quality has an essential impact on device behavior and performance. In this context, surface passivation is the best method to control the defective states [27, 30, 31, 35-39]. Particularly, many studies have carried out to improve the interface properties by nitridation of the GaAs surface [27, 30, 37, 38, 40-43], in order to improve the behavior and the electrical properties of the Schottky contacts such as ideality factor, barrier height, saturation current, series resistance and reverse current. Also, the nitride layers have good stability against the formation of amorphous surface oxides, high electronegativity, and thermal stability [27, 44].

In this work, we measure experimentally the electrical characteristics of Au/0.8 nm-GaN/n-GaAs Schottky contacts fabricated using a glow discharge plasma source (GDS) for nitridation. Moreover, we analyze the current transport mechanisms and several electrical parameters are characterized in a wide range of temperatures (80–420 K).

## Experimental part

The Schottky contacts were elaborated using commercially available Si-doped n-GaAs (100) substrates, of a thickness of 400  $\mu\text{m}$  and electron concentration  $N_d=4.9\times 10^{15}\text{cm}^{-3}$ . The samples were cleaned chemically using  $\text{H}_2\text{SO}_4$ , deionized water, cold and hot methanol sequentially, and dried with  $\text{N}_2$ . Then, the surfaces were bombarded with  $\text{Ar}^+$  ions (ion energy of about 1 keV, sample current equal to 5  $\mu\text{A cm}^{-2}$ , during 1 h) in UHV conditions [30, 40]. After surface cleaning, the substrates were heated at 500  $^\circ\text{C}$  and nitrided using a glow discharge nitrogen plasma source, running at 5 W for 30 min in an UHV chamber. This nitridation process led to the growth of a 0.8 nm-thick of undoped GaN layer. Following the nitridation step, the samples were annealed at 620  $^\circ\text{C}$  for 1 hour in view to crystallize the GaN layer [39, 45, 46].

A XPS system characterized by dual anode Al–Mg X-ray source and hemispherical electron energy analyzer were used for in-situ measurement of the chemical composition and crystal structure. The GaN thickness was calculated by comparing the experimental spectra data to the theoretical XPS peak intensities and positions [38]. The Au dots were deposited with area of  $4.41 \times 10^{-3} \text{ cm}^2$  and thickened up to 100 nm. A Bruker Dimension Icon atomic force microscope (AFM) equipped by ScanAsyst and Nanoscope software 9.7 was used to investigate the film surface roughness. Using the PeakForce tapping mode, the AFM topography measurements were taken in the air. In order to accomplish this, a silicon tip on nitride cantilever (ScanAsyst Air model), with a  $0.4 \text{ N m}^{-1}$  spring constant and a nominal tip radius of 2 nm, were utilized to examine regions of  $1 \times 1 \mu\text{m}^2$  with a resolution of  $256 \text{ pixels} \times 256 \text{ pixels}$ . The current-voltage measurements were investigated under different temperatures (80–420 K), utilizing a current source Keithely 220.

## Results part

Figure 1 presents the PeakForce tapping AFM topography images for (a) GaN surface and (b) Au electrode within a scan size area a  $1 \times 1 \mu\text{m}^2$  represented at the same height scale. The Au texture is formed by interconnected grain channels while that of GaN is almost flat. The obtained root mean square (RMS) surface roughness values indicate a difference of almost one order of magnitude between Au and GaN smoothness, i.e., 0.3 nm for GaN and 4.6 nm for Au. The value of the RMS surface roughness for GaN was calculated neglecting the areas occupied by the contamination features that clearly stand out in the image of Fig. 1(a). This value of roughness (0.3 nm) is less than half the nominal GaN layer thickness (0.8 nm).

The roughness difference is better shown in (c) where the frontier between the Au electrode and the GaN surface is shown as a rendered illuminated 3D AFM image, and the different topographies of Au and GaN are clearly shown. To bring out this difference in roughness more clearly, the height distribution histograms shown in Figure 1(d) were obtained from the topography images. GaN exhibits a narrow peak showing that in comparison to Au, which has a larger peak, the surface layer is more homogeneous. To clarify the difference between the peaks, they have been fitted to a single Gaussian distribution with a peak centered at 2.15, and 21.3 nm, and a full width at half maximum (FWHM) of 1.3 nm, and 9.5 nm for GaN and Au, respectively.

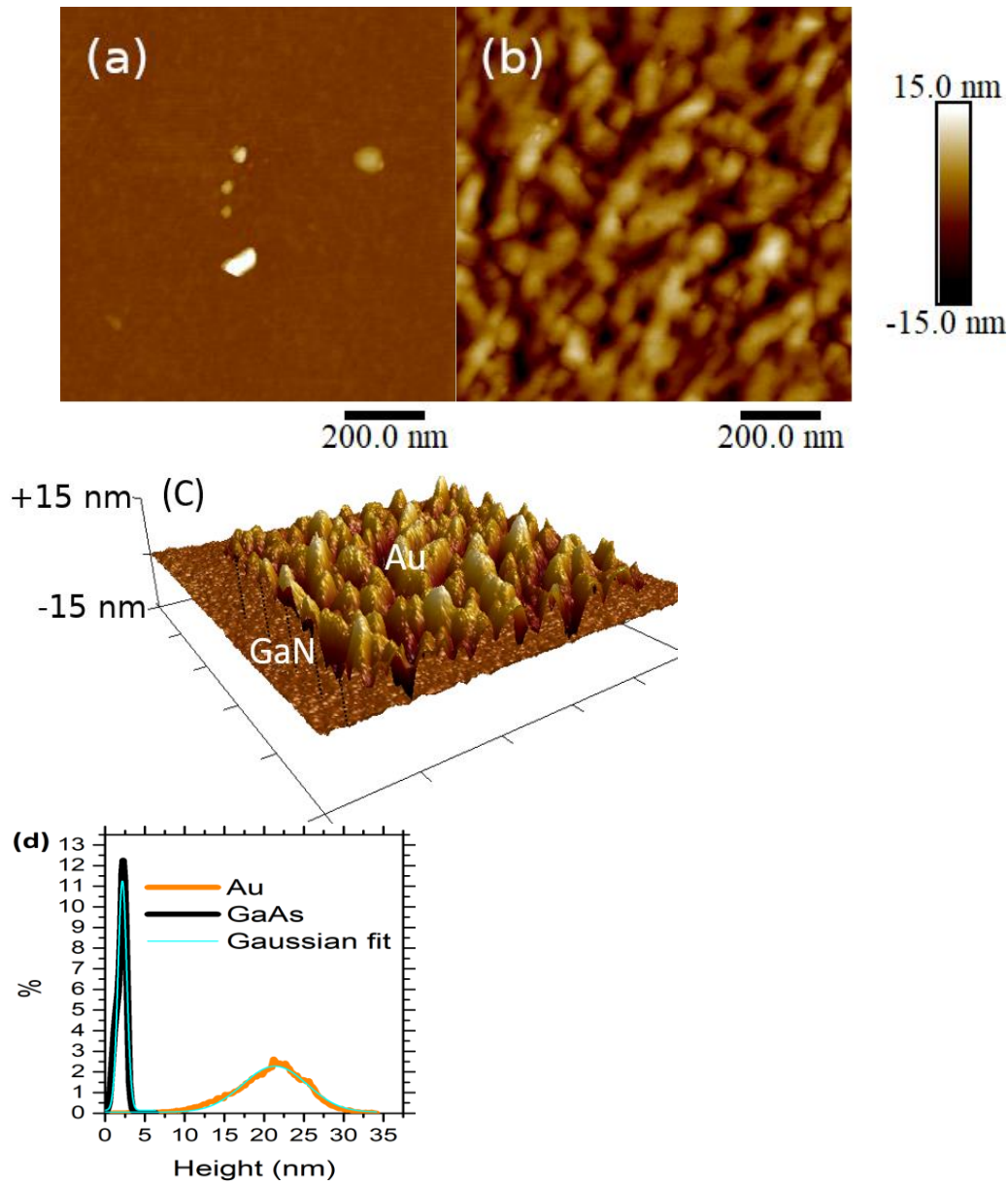


Figure 1: PeakForce tapping AFM topography for (a) GaN, and (b) Au surfaces. (c) Rendered illuminated 3D AFM image of GaN/Au frontier. (d) Height distribution functions obtained from the topography images.

Surface roughness induces a non-uniformity of the thickness, a distribution of interfacial charges, and a local variation of the Fermi level. These phenomena yield to the inhomogeneity of the Schottky barrier height and affect the transport mechanism [47].

Figure 2 depicts the I-V characteristics of the Au/0.8nm-GaN/n-GaAs structure, at temperatures ranging from 80 to 420 K.

The values of the reverse current  $I_{Rev}$  at -1 V and the threshold voltage  $V_{Th}$  are extracted and illustrated in figure 3. Where, with increasing temperature,  $I_{Rev}$  increases exponentially from  $1 \times 10^{-7}$  A at 80 K to  $1 \times 10^{-5}$  A at 420 K, and  $V_{Th}$  decreases from 0.65 V at 80 K to 0.2 V at 420 K.

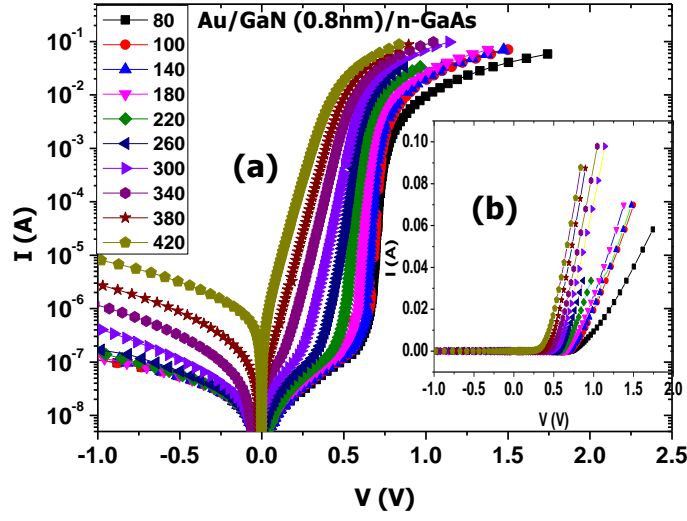


Figure 2: I-V measurements of Au/0.8nm-GaN/n-GaAs structure, (a) semi-logarithmic scale and (b) linear scale.

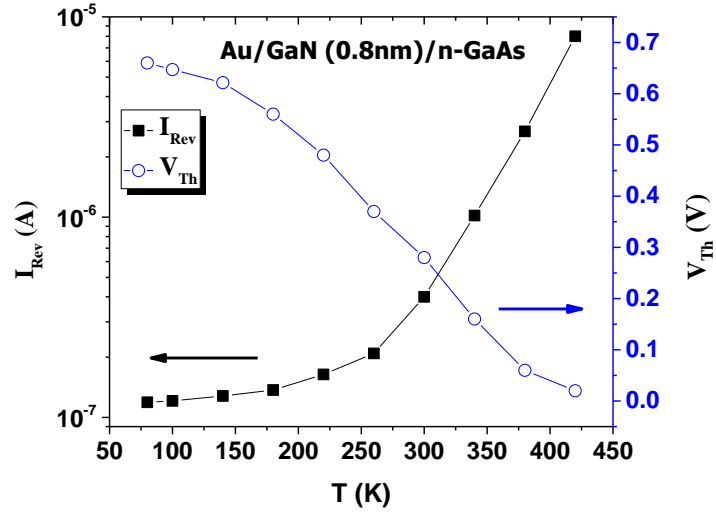


Figure 3: Variation of reverse leakage current and threshold voltage versus temperature.

The expression of the current for non-ideal Schottky diodes is [48]:

$$I = I_s \left( \exp \left( \frac{q(V - IR_s)}{nkT} \right) - 1 \right) \quad (1)$$

and

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

Where,

$I_s$  is the saturation current,

$R_s$  is the series resistance,

$q\phi_b$  is the barrier height,

$n$  is the ideality factor,

$k$  is the Boltzmann constant,

$A$  is the effective diode area,

$A^*$  is the effective Richardson constant equal to  $8.16 Acm^{-2}K^2$  for GaAs,

At the low bias voltage  $V$ , the current  $I$  is low, therefore the term  $IR_s$  is low compared to  $V$ , and (eq.1) becomes as:

$$I = I_s \exp\left(\frac{qV}{nkT}\right) \quad (3)$$

and

$$\ln(I) = \frac{q}{nkT}V + \ln(I_s) \quad (16)$$

$n$  and  $I_s$  values are calculated from the slope and y-axis intercept of  $\ln(I)$ - $V$ , respectively. The  $\phi_b$  value is determined as follows:

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

The  $R_s$  values are extracted using Cheung and Cheung method [48] which is based on:

$$G(I) = \frac{\partial V}{\partial(\ln I)} = R_s I + \frac{nkT}{q} \quad (5)$$

The extracted values of  $n$  and  $q\phi_b$  are plotted in figure 4.

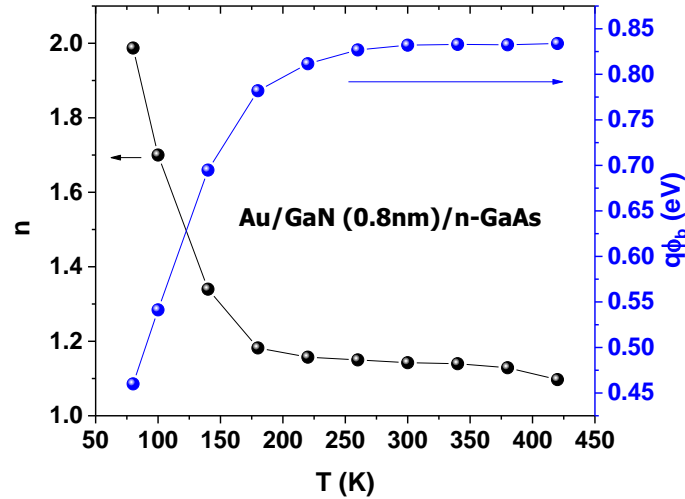


Figure 4:  $n$  and  $\phi_b$  extracted at each temperature.

As can be seen from figure 4, with the rising temperature,  $n$  drops from 2 for 80 K to 1.1 for 420 K. The decrease is very slow from 250 K to 450 K and such behavior is in accordance with the literature [5-7, 11, 26]. The low values of  $n$  may be due to the effect of the nitridation process which improves the quality of the interface.  $q\phi_b$  rises abnormally as temperature rises, from 0.46 eV for 80 K to 0.83 eV for 420 K. These

results are similar to several studies [7, 12, 20, 49-51]. For Schottky contacts, the  $q\phi_b$  value should decrease as the temperature rises, due to the bandgap's temperature variation [1, 2, 7, 48, 50, 52-54]. The  $q\phi_b$  behavior may be explained by the tunnel effect mechanisms, such as thermionic field emission (TFE) [5, 11].

The tunneling current can be expressed as following [1, 12, 55, 56]:

$$I = I_{tun} \left[ \exp\left(\frac{q(V - IR_s)}{E_0}\right) - 1 \right] \quad (6)$$

$$\frac{E_0}{kT} = \frac{E_{00}}{kT} \cot h \left( \frac{E_{00}}{kT} \right) \quad (7)$$

$$E_{00} = \frac{h}{4\pi} \left( \frac{N_D}{m_e^* \epsilon_s} \right)^{\frac{1}{2}} \quad (8)$$

where

$E_{00}$  is the characteristic tunneling energy,

$h$  is the Planck constant,

$m_e^*$  is the effective mass of electron,

$\epsilon_s$  is the dielectric constant of GaAs.

Figure 5 shows the variation of  $(E_0 = nkT/q)$  versus  $kT/q$ .

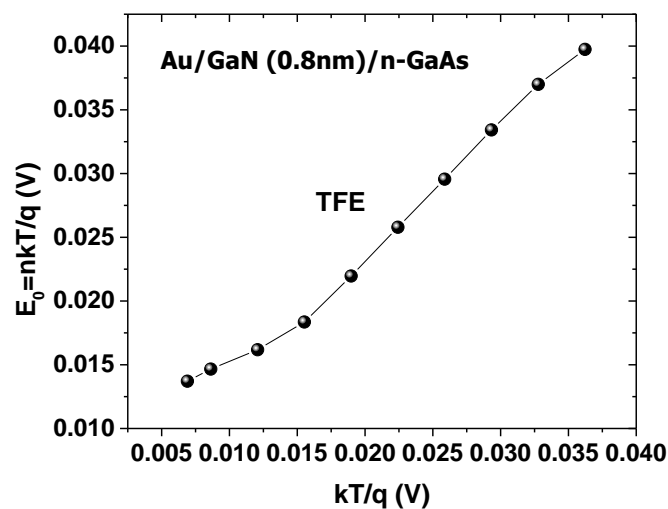


Figure 5: Variation of  $E_0$  ( $nkT/q$ ) versus  $kT/q$ .

From figure 5,  $E_0$  is about  $kT/q$ , this confirms that the TFE mechanism is the dominant one [26], instead of the theoretical mechanism TE of the Schottky contacts, which explains the abnormal behavior of the barrier height and the deviation of the ideality factor from the unity. This is maybe due to the interface states which behave as recombination-generation centers at the interface that affect the conduction mechanism [57].



To further study the abnormal behavior of the barrier height, the Richardson characteristic  $\ln(I_s/T^2)$  versus  $q/kT$  is presented in figure 6 using the equation,

$$\ln\left(\frac{I_s}{T^2}\right) = \ln(AA^*) - q\frac{\phi_{b1}}{kT} \quad (9)$$

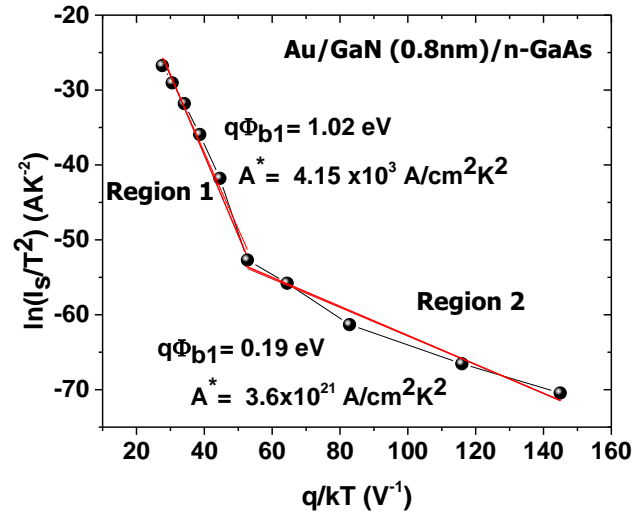


Figure 6: variation of Richardson characteristic  $\ln(I_s/T^2)$  versus  $q/kT$ . Red lines are linear fits of experimental data according to the root mean square method.

Figure 6 gives two linear regions which are due to the inhomogeneity of the barrier height [12].  $q\phi_b$  and  $A^*$  values are  $1.02 eV$  and  $4.15 \times 10^3 Acm^{-2}K^{-2}$  respectively in region 1 and equal to  $0.19 eV$  and  $3.6 \times 10^{21} Acm^{-2}K^{-2}$  respectively in region 2. These values of  $A^*$  are significantly far from the theoretical value  $8.16 Acm^{-2}K^{-2}$  for n-GaAs [52].

Figure 7 presents the variation of  $\phi_b$  versus  $n$ .

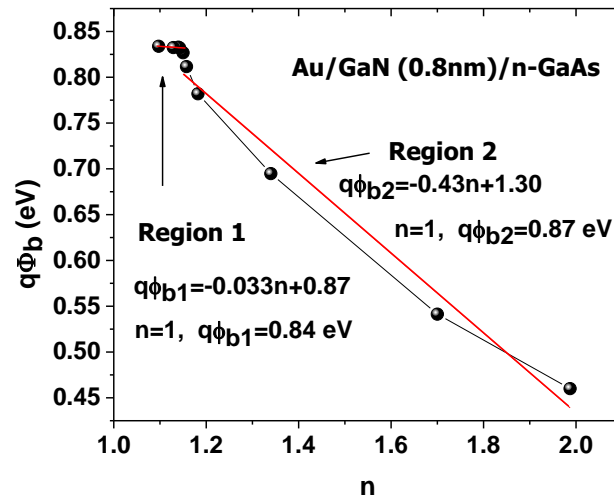
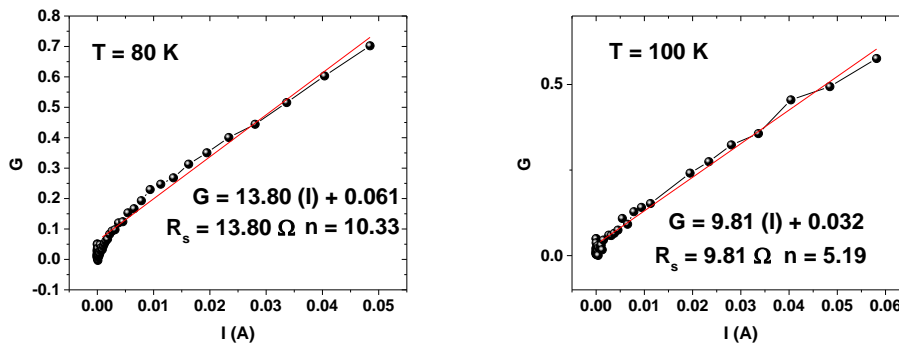


Figure 7:  $\phi_b$  versus  $n$ .

The structure has two linear characteristics, this is due to barrier height inhomogeneity [58, 59]. By extrapolation, the estimated values of  $q\phi_b$  for  $n=1$  are 0.87 eV for region 1, and 0.84 eV for region 2. The obtained values are closer than those extracted from the Richardson characteristics.

The authors of this work [5] have previously performed simulations of Au/n-GaAs Schottky at temperatures ranging from 80 K to 400 K, with and without thin GaN (1 nm) interfacial layer. They found that Au/n-GaAs shows a homogeneous barrier height while Au/1nm-GaN/n-GaAs structure shows an inhomogeneous one. Therefore, the experimental results shown here, that it is the inhomogeneity of the barrier height shown in the Richardson characteristics, and in the plot of  $q\phi_b$  versus  $n$ , are most likely because of 0.8 nm GaN layer.

Figure 8 illustrates  $G(I)$  plots of Cheung and Cheung method at different temperatures (80 K-420 K).



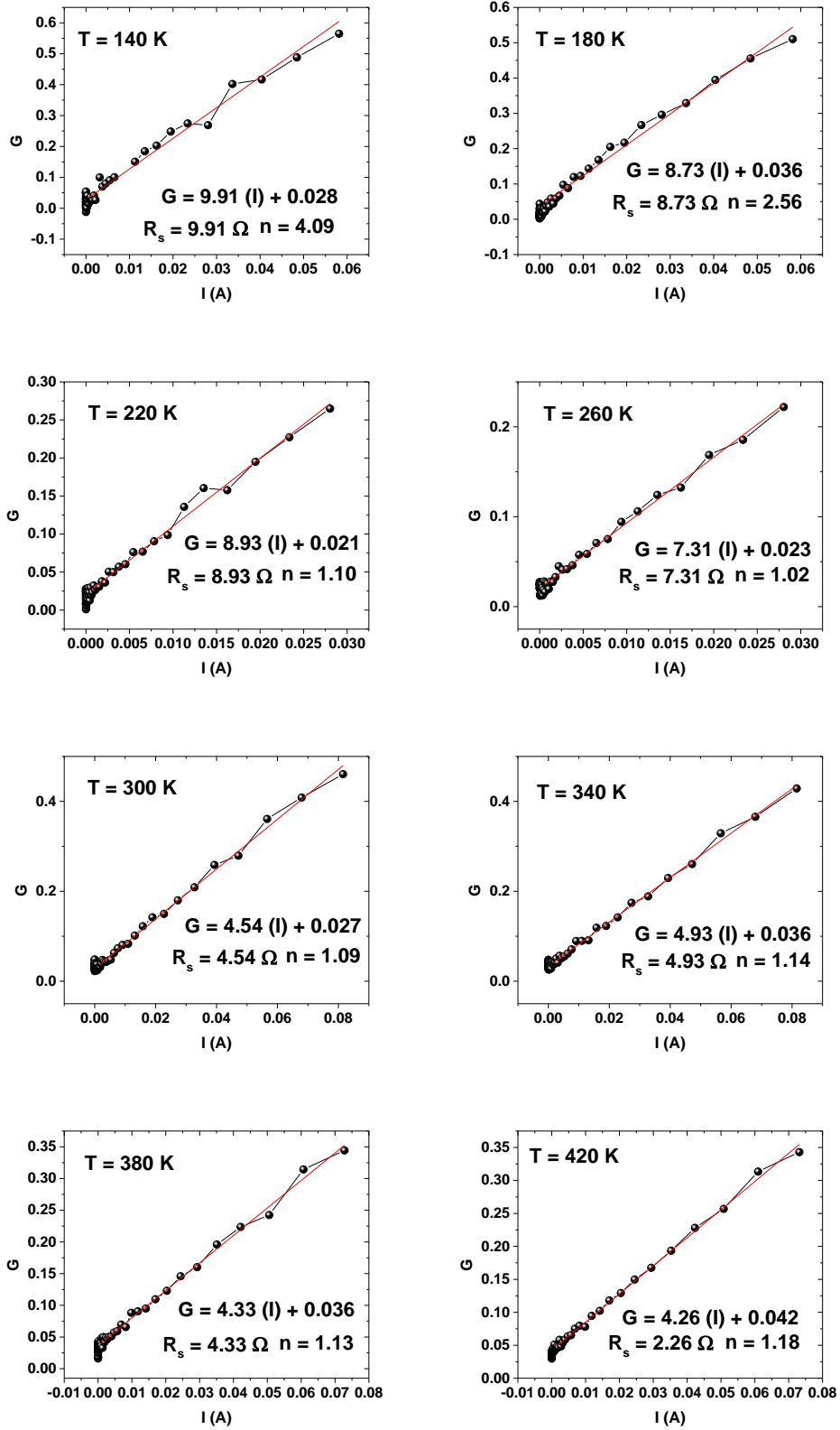


Figure 8:  $dV/d(\ln I)$  plots at different temperatures.

$R_s$  and  $n$  are extracted by Cheung and Cheung method for each temperature and presented in figure 9 and 10, respectively.

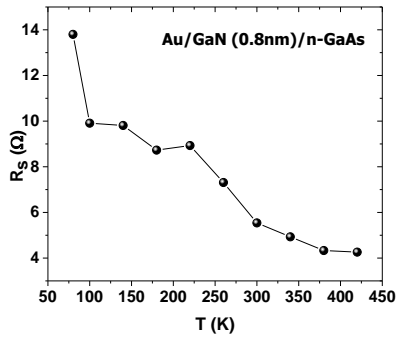


Figure 9:  $R_s$  (Cheung and Cheung method) versus temperature.

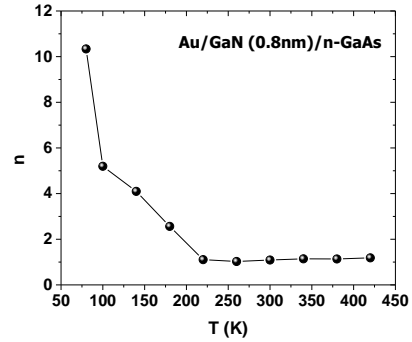


Figure 10: n (Cheung and Cheung method) versus temperature.

As can be seen, the structure gives low resistance series  $R_s$  which decreases from  $13.80 \Omega$  at 80 K to  $4.26 \Omega$  at 420 K, showing the good quality of the interface, improved by the nitridation and the annealing processes [28].

The n values obtained by Cheung and Cheung method are very high at low temperatures compared to those extracted from the first method. This discrepancy is because n values obtained by the first method were extracted from the low bias voltage range, where the series resistance is very low. On the other hand, the n values extracted using Cheung and Cheung method were extracted from all bias voltage range, where the series resistance in high bias voltages affects the calculation of the ideality factor.

Finally, the growth of 0.8 nm of GaN layer on n-GaAs surfaces with an annealing process leads to improving the electrical parameters of the Schottky contacts, such as the series resistance and the ideality factor. However, it can cause the inhomogeneity of the barrier height at the structure.

## Conclusion

Au/0.8nm-GaN/n-GaAs structures were fabricated using a glow discharge plasma source (GDS), and their current-voltage characteristics were investigated for different temperatures. The samples showed good electrical parameters where, n decreases from 2 for 80 K to 1.01 for 420 K. The barrier height  $q\phi_b$  grows abnormally from 0.46 eV at 80 K to 0.83 eV at 420 K, due to the tunnel mechanism TFE effect. Also, the samples show low  $R_s$  which drops from  $13.80 \Omega$  at 80 K to  $4.26 \Omega$  at 420 K. Finally, the results strongly suggest that the GaN thin layer causes an inhomogeneous barrier height that is also in agreement with our previous simulations [5].

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## References

- [1] E. Rhoderick and R. Williams, "Metal–Semiconductor Contacts, Clarendon Press, Oxford 1988."
- [2] S. M. Sze and K. K. Ng, *Physics of semiconductor devices*: John Wiley & sons, 2006.
- [3] Ö. Demircioglu, Ş. Karataş, N. Yıldırım, Ö. Bakkaloglu, and A. Türüt, "Temperature dependent current–voltage and capacitance–voltage characteristics of chromium Schottky contacts formed by electrodeposition technique on n-type Si," *Journal of Alloys and Compounds*, vol. 509, pp. 6433-6439, 2011.
- [4] D. Korucu, A. Turut, and Ş. Altındal, "The origin of negative capacitance in Au/n-GaAs Schottky barrier diodes (SBDs) prepared by photolithography technique in the wide frequency range," *Current Applied Physics*, vol. 13, pp. 1101-1108, 2013.
- [5] H. Helal, Z. Benamara, M. B. Arbia, A. Khetrou, A. Rabehi, A. H. Kacha, and M. Amrani, "A study of current-voltage and capacitance-voltage characteristics of Au/n-GaAs and Au/GaN/n-GaAs Schottky diodes in wide temperature range," *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, p. e2714, 2020.
- [6] S. Zeyrek, M. Bülbül, Ş. Altındal, M. Baykul, and H. Yüzer, "The double gaussian distribution of inhomogeneous barrier heights in Al/GaN/p-GaAs (MIS) schottky diodes in wide temperature range," *Brazilian Journal of Physics*, vol. 38, pp. 591-597, 2008.
- [7] S. Hardikar, M. Hudait, P. Modak, S. Krupanidhi, and N. Padha, "Anomalous current transport in Au/low-doped n-GaAs Schottky barrier diodes at low temperatures," *Applied Physics A*, vol. 68, pp. 49-55, 1999.
- [8] A. Kumar, S. Arafin, M. C. Amann, and R. Singh, "Temperature dependence of electrical characteristics of Pt/GaN Schottky diode fabricated by UHV e-beam evaporation," *Nanoscale research letters*, vol. 8, p. 481, 2013.
- [9] J. Osvald and Z. J. Horvath, "Theoretical study of the temperature dependence of electrical characteristics of Schottky diodes with an inverse near-surface layer," *Applied surface science*, vol. 234, pp. 349-354, 2004.
- [10] S. M. Tunhuma, F. D. Auret, M. J. Legodi, and M. Diale, "The effect of high temperatures on the electrical characteristics of Au/n-GaAs Schottky diodes," *Physica B: Condensed Matter*, vol. 480, pp. 201-205, 2016.
- [11] E. Özavcı, S. Demirezen, U. Aydemir, and Ş. Altındal, "A detailed study on current–voltage characteristics of Au/n-GaAs in wide temperature range," *Sensors and Actuators A: Physical*, vol. 194, pp. 259-268, 2013.
- [12] J. H. Werner and H. H. Güttler, "Barrier inhomogeneities at Schottky contacts," *Journal of applied physics*, vol. 69, pp. 1522-1533, 1991.
- [13] J. Sullivan, R. Tung, M. Pinto, and W. Graham, "Electron transport of inhomogeneous Schottky barriers: A numerical study," *Journal of applied physics*, vol. 70, pp. 7403-7424, 1991.
- [14] R. Tung, "Electron transport at metal-semiconductor interfaces: General theory," *Physical Review B*, vol. 45, p. 13509, 1992.
- [15] R. Schmitsdorf, T. Kampen, and W. Mönch, "Explanation of the linear correlation between barrier heights and ideality factors of real metal-semiconductor contacts by laterally nonuniform Schottky barriers," *Journal of Vacuum Science & Technology B*:

- Microelectronics and Nanometer Structures Processing, Measurement, and Phenomena*, vol. 15, pp. 1221-1226, 1997.
- [16] H. Palm, M. Arbes, and M. Schulz, "Fluctuations of the Au-Si (100) Schottky barrier height," *Physical review letters*, vol. 71, p. 2224, 1993.
- [17] G. Vanalme, L. Goubert, R. Van Meirhaeghe, F. Cardon, and P. Van Daele, "A ballistic electron emission microscopy study of barrier height inhomogeneities introduced in Au/III-V semiconductor Schottky barrier contacts by chemical pretreatments," *Semiconductor science and technology*, vol. 14, p. 871, 1999.
- [18] V. W. Chin, M. Green, and J. W. Storey, "Evidence for multiple barrier heights in P-type PtSi Schottky-barrier diodes from IVT and photoresponse measurements," *Solid-state electronics*, vol. 33, pp. 299-308, 1990.
- [19] A. Singh, K. Reinhardt, and W. Anderson, "Temperature dependence of the electrical characteristics of Yb/p-InP tunnel metal-insulator-semiconductor junctions," *Journal of applied physics*, vol. 68, pp. 3475-3483, 1990.
- [20] S. Chand and J. Kumar, "Current transport in Pd<sub>2</sub>Si/n-Si (100) Schottky barrier diodes at low temperatures," *Applied Physics A*, vol. 63, pp. 171-178, 1996.
- [21] P. McCafferty, A. Sellai, P. Dawson, and H. Elabd, "Barrier characteristics of PtSi-p-Si Schottky diodes as determined from IVT measurements," *Solid-State Electronics*, vol. 39, pp. 583-592, 1996.
- [22] S. Zhu, R. Van Meirhaeghe, C. Detavernier, G.-P. Ru, B.-Z. Li, and F. Cardon, "A BEEM study of the temperature dependence of the barrier height distribution in PtSi/n-Si Schottky diodes," *Solid state communications*, vol. 112, pp. 611-615, 1999.
- [23] S. Zhu, R. Van Meirhaeghe, C. Detavernier, F. Cardon, G.-P. Ru, X.-P. Qu, and B.-Z. Li, "Barrier height inhomogeneities of epitaxial CoSi<sub>2</sub> Schottky contacts on n-Si (100) and (111)," *Solid-State Electronics*, vol. 44, pp. 663-671, 2000.
- [24] D. Korucu, A. Turut, and H. Efeoglu, "Temperature dependent I-V characteristics of an Au/n-GaAs Schottky diode analyzed using Tung's model," *Physica B: Condensed Matter*, vol. 414, pp. 35-41, 2013.
- [25] C. Crowell, "The physical significance of the T<sub>0</sub> anomalies in Schottky barriers," *Solid-State Electronics*, vol. 20, pp. 171-175, 1977.
- [26] M. Hudait, P. Venkateswarlu, and S. Krupanidhi, "Electrical transport characteristics of Au/n-GaAs Schottky diodes on n-Ge at low temperatures," *Solid-State Electronics*, vol. 45, pp. 133-141, 2001.
- [27] H. Helal, Z. Benamara, A. H. Kacha, M. Amrani, A. Rabehi, B. Akkal, G. Monier, and C. Robert-Goumet, "Comparative study of ionic bombardment and heat treatment on the electrical behavior of Au/GaN/n-GaAs Schottky diodes," *Superlattices and Microstructures*, p. 106276, 2019.
- [28] H. Uslu, A. Bengi, S. Çetin, U. Aydemir, Ş. Altındal, S. Aghaliyeva, and S. Özçelik, "Temperature and voltage dependent current-transport mechanisms in GaAs/AlGaAs single-quantum-well lasers," *Journal of alloys and compounds*, vol. 507, pp. 190-195, 2010.
- [29] W. Dawidowski, B. Ściana, K. Bielak, M. Mikolášek, J. Drobný, J. Serafińczuk, I. Lombardero, D. Radziewicz, W. Kijaszek, and A. Kósa, "Analysis of Current Transport Mechanism in AP-MOVPE Grown GaAsN pin Solar Cell," *Energies*, vol. 14, p. 4651, 2021.
- [30] A. Rabehi, M. Amrani, Z. Benamara, B. Akkal, A. Hatem-Kacha, C. Robert-Goumet, G. Monier, and B. Gruzza, "Study of the characteristics current-voltage and capacitance-voltage in nitride GaAs Schottky diode," *The European Physical Journal Applied Physics*, vol. 72, p. 10102, 2015.

- [31] Ö. Güllü, M. Biber, S. Duman, and A. Türüt, "Electrical characteristics of the hydrogen pre-annealed Au/n-GaAs Schottky barrier diodes as a function of temperature," *Applied surface science*, vol. 253, pp. 7246-7253, 2007.
- [32] E. Ayyildiz, H. Cetin, and Z. J. Horvath, "Temperature dependent electrical characteristics of Sn/p-Si Schottky diodes," *Applied surface science*, vol. 252, pp. 1153-1158, 2005.
- [33] Z. J. Horvath, V. Rakovics, B. Szentpali, S. Püspöki, and K. Žd'ánský, "InP Schottky junctions for zero bias detector diodes," *Vacuum*, vol. 71, pp. 113-116, 2003.
- [34] Ş. Altındal, S. Karadeniz, N. Tuğluoğlu, and A. Tataroğlu, "The role of interface states and series resistance on the I–V and C–V characteristics in Al/SnO<sub>2</sub>/p-Si Schottky diodes," *Solid-State Electronics*, vol. 47, pp. 1847-1854, 2003.
- [35] V. Matolin, S. Fabík, J. Glosík, L. Bideux, Y. Ould-Metidji, and B. Gruzza, "Experimental system for GaN thin films growth and in situ characterisation by electron spectroscopic methods," *Vacuum*, vol. 76, pp. 471-476, 2004.
- [36] Y. Ould-Metidji, L. Bideux, D. Baca, B. Gruzza, and V. Matolin, "Nitridation of GaAs (1 0 0) substrates and Ga/GaAs systems studied by XPS spectroscopy," *Applied surface science*, vol. 212, pp. 614-618, 2003.
- [37] Z. Benamara, N. Mecirdi, B. B. Bouiadjra, L. Bideux, B. Gruzza, C. Robert, M. Miczek, and B. Adamowicz, "XPS, electric and photoluminescence-based analysis of the GaAs (1 0 0) nitridation," *Applied surface science*, vol. 252, pp. 7890-7894, 2006.
- [38] A. Kacha, B. Akkal, Z. Benamara, M. Amrani, A. Rabhi, G. Monier, C. Robert-Goumet, L. Bideux, and B. Gruzza, "Effects of the GaN layers and the annealing on the electrical properties in the Schottky diodes based on nitrated GaAs," *Superlattices and Microstructures*, vol. 83, pp. 827-833, 2015.
- [39] H. Mehdi, G. Monier, P. Hoggan, L. Bideux, C. Robert-Goumet, and V. Dubrovskii, "Combined angle-resolved X-ray photoelectron spectroscopy, density functional theory and kinetic study of nitridation of gallium arsenide," *Applied Surface Science*, vol. 427, pp. 662-669, 2018.
- [40] A. Rabehi, M. Amrani, Z. Benamara, B. Akkal, and A. Kacha, "Electrical and photoelectrical characteristics of Au/GaN/GaAs Schottky diode," *Optik*, vol. 127, pp. 6412-6418, 2016.
- [41] M. Ambrico, M. Losurdo, P. Capezzuto, G. Bruno, T. Ligonzo, and H. Haick, "Probing electrical properties of molecule-controlled or plasma-nitrided GaAs surfaces: Two different tools for modifying the electrical characteristics of metal/GaAs diodes," *Applied surface science*, vol. 252, pp. 7636-7641, 2006.
- [42] L. Bideux, G. Monier, V. Matolin, C. Robert-Goumet, and B. Gruzza, "XPS study of the formation of ultrathin GaN film on GaAs (1 0 0)," *Applied Surface Science*, vol. 254, pp. 4150-4153, 2008.
- [43] A. Kacha, B. Akkal, Z. Benamara, C. Robert-Goumet, G. Monier, and B. Gruzza, "Study of the surface state density and potential in MIS diode Schottky using the surface photovoltage method," *Molecular Crystals and Liquid Crystals*, vol. 627, pp. 66-73, 2016.
- [44] V. Berkovits, T. L'vova, and V. Ulin, "Chemical nitridation of GaAs (100) by hydrazine-sulfide water solutions," *Vacuum*, vol. 57, pp. 201-207, 2000.
- [45] G. Monier, L. Bideux, C. Robert-Goumet, B. Gruzza, M. Petit, J. Lábár, and M. Menyhárd, "Passivation of GaAs (001) surface by the growth of high quality c-GaN ultra-thin film using low power glow discharge nitrogen plasma source," *Surface Science*, vol. 606, pp. 1093-1099, 2012.
- [46] H. Mehdi, F. Réveret, C. Bougerol, C. Robert-Goumet, P. Hoggan, L. Bideux, B. Gruzza, J. Leymarie, and G. Monier, "Study of GaN layer crystallization on GaAs (100)

- using electron cyclotron resonance or glow discharge N<sub>2</sub> plasma sources for the nitriding process," *Applied Surface Science*, vol. 495, p. 143586, 2019.
- [47] M. Ozdemir, O. Sevgili, I. Orak, and A. Turut, "Determining the potential barrier presented by the interfacial layer from the temperature induced IV characteristics in Al/p-Si Structure with native oxide layer," *MATERIALS SCIENCE IN SEMICONDUCTOR PROCESSING*, vol. 125, 2021.
- [48] S. Cheung and N. Cheung, "Extraction of Schottky diode parameters from forward current-voltage characteristics," *Applied Physics Letters*, vol. 49, pp. 85-87, 1986.
- [49] Z. J. Horváth, "A New Approach to Temperature Dependent Ideality Factors in Schottky Contacts," *MRS Online Proceedings Library Archive*, vol. 260, 1992.
- [50] R. Hackam and P. Harrop, "Electrical properties of nickel-low-doped n-type gallium arsenide Schottky-barrier diodes," *IEEE Transactions on Electron Devices*, vol. 19, pp. 1231-1238, 1972.
- [51] A. Bhuiyan, A. Martinez, and D. Esteve, "A new Richardson plot for non-ideal schottky diodes," *Thin Solid Films*, vol. 161, pp. 93-100, 1988.
- [52] A. Bengi, S. Altındal, S. Özçelik, and T. Mammadov, "Gaussian distribution of inhomogeneous barrier height in Al<sub>0.24</sub>Ga<sub>0.76</sub>As/GaAs structures," *Physica B: Condensed Matter*, vol. 396, pp. 22-28, 2007.
- [53] J. H. Werner, "Schottky barrier and pn-junction I/V plots—Small signal evaluation," *Applied physics A*, vol. 47, pp. 291-300, 1988.
- [54] M. Panish and H. Casey Jr, "Temperature dependence of the energy gap in GaAs and GaP," *Journal of Applied Physics*, vol. 40, pp. 163-167, 1969.
- [55] F. Padovani and G. Sumner, "Experimental Study of Gold-Gallium Arsenide Schottky Barriers," *Journal of Applied Physics*, vol. 36, pp. 3744-3747, 1965.
- [56] F. Padovani, "Graphical determination of the barrier height and excess temperature of a Schottky barrier," *Journal of Applied Physics*, vol. 37, pp. 921-922, 1966.
- [57] M. A. Ebeoğlu, "Current–voltage characteristics of Au/GaN/GaAs structure," *Physica B: Condensed Matter*, vol. 403, pp. 61-66, 2008.
- [58] R. Schmitsdorf, T. Kampen, and W. Mönch, "Correlation between barrier height and interface structure of AgSi (111) Schottky diodes," *Surface Science*, vol. 324, pp. 249-256, 1995.
- [59] M. Soyulu and F. Yakuphanoglu, "Analysis of barrier height inhomogeneity in Au/n-GaAs Schottky barrier diodes by Tung model," *Journal of Alloys and Compounds*, vol. 506, pp. 418-422, 2010.