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C-V and G-V Characteristics of Nitridated GaAs (100) Structures as Function of Frequency-Effect of Series Resistance

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Abstract: Different works show that the nitridation of the GaAs surface improves the electrical quality of the Schottky diodes based on gallium arsenic. In order to observe this improvement, capacitance/conductance – voltage characteristics were watched at three frequencies (50, 100 and 500 kHz). These characteristics were corrected by eliminating the effect of the series resistance. First, values of the series resistance were determined and plotted at different frequencies. R_s versus voltage curves show significant values of the series resistance. A peak was observed in these curves at about -0.5 V for the 50 and 100 kHz frequencies and at 0.25 V for the 500 kHz. These peaks are caused by the ohmic back contact and the surface states density. Then the real electrical parameters of the fabricated Schottky diode were calculated and the surface states density of the Schottky diode was estimated with and without the effect of series resistance. Surface states density was highly reduced after the elimination of the series resistance effect. Electrical parameters show an improvement of the electrical quality of the fabricated Au/GaN/GaAs Schottky diode.

Keywords: GaN, GaAs, Schottky diode, Series resistance, Interface states

Introduction

Semiconductors containing element N offer interesting opportunities for microelectronic and optoelectronics devices. Gallium nitride is the ideal material for the manufacture of high frequency devices, blue emitters and detectors operating in the UV spectral range. The preparation of the well cleaned surfaces arranged and passivated is of paramount importance for the growth of GaN and development of devices based on this material. Several methods have been developed for the growth of gallium nitride. The characterization of the devices based on this material is extensively studied in recent years, especially the study of the Schottky diodes parameters (Akkal, 2000;Rabehi, 2015). The analysis of the electrical characteristics of the Schottky diode only at one frequency by using (C–V and G–V) measurements cannot give detailed information on the conduction mechanisms and the formation of barrier height at the M/S interface. Therefore, the investigation of these measurements, especially at low frequencies, can supply more information both on conduction mechanism and formation of barrier height at the M/S interface (Demirezen, 2015). The electrical characteristics of the

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Au/GaN/GaAs are dependent on many parameters such as the process of elaboration, the density of interface states, series resistance of the diode and applied bias voltage.

The C-V and G-V characteristics are usually frequency independent at high frequencies, on the other side, at low and moderate frequencies the depletion and accumulation regions depend on the contribution of interface states density, interfacial layer and series resistance of the device. In this work, we investigated the effect of the series resistance on the parameters of the Au/GaN/GaAs diode extracted from C-V and the G-V measurements such as doping concentration N_d, barrier height Φ_b the diffusion potential V_d and the interface states density N_{ss} at three frequencies (50, 100 and 500 kHz) at room temperature.

Experimental Part

The Au/GaN/GaAs Schottky diode (Figure 1) was fabricated by the nitridation of n-GaAs (100) substrate using a glow discharge source (GDS) (Matolin, 2004). Details of the fabrication of the Au/GaN/GaAs Shottky diode have been given in detail in the previous works (Rabehi,2015; Kacha, 2015).

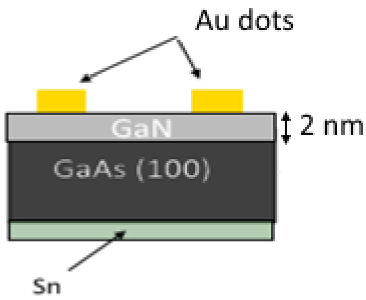


Figure 1. Au/GaN/GaAs Schottky diode

The C-V and G-V measurements were realized in three frequencies (50, 100, 500 kHz) at room temperature using an Impedance Analyzer.

Results and Discussion

C-V curves presented in Figure 2 show an inversion, depletion and accumulation regions such as MIS type Schottky diodes. The C-V plots show a higher capacitance value at low frequencies. This additive capacitance can be explained by the existence of the interface states and traps.

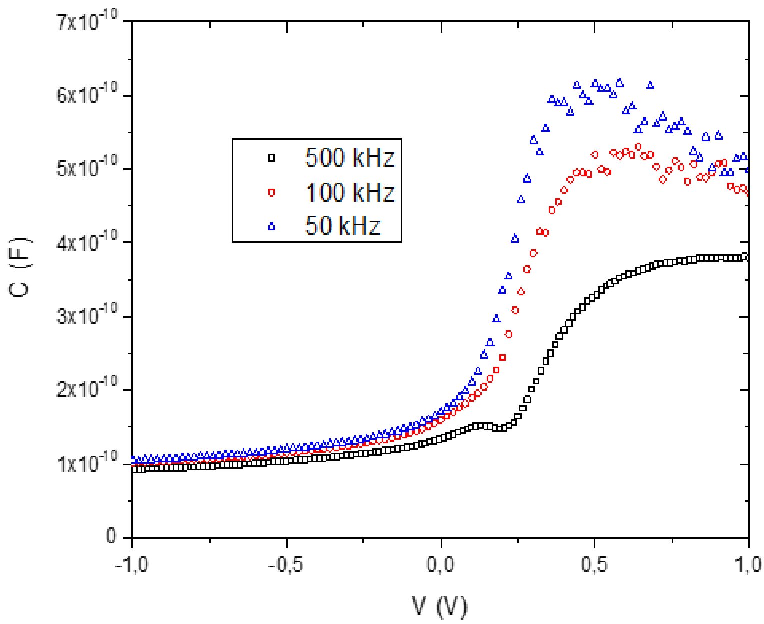


Figure 2. Capacitance – voltage characteristics of the Au/GaN/GaAs Schottky diode at different frequencies.

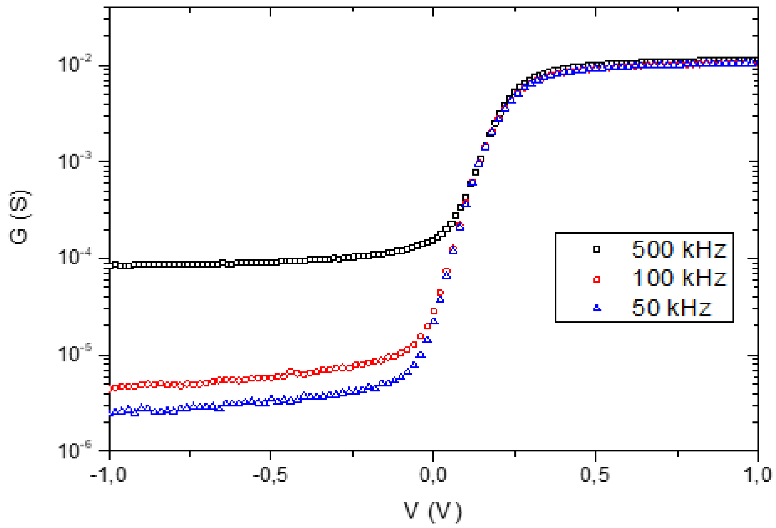


Figure 3. Conductance – voltage characteristics of the Au/GaN/GaAs Schottky diode at different frequencies.

At a high frequency, the N_{ss} cannot follow the ac signal and the contribution of these interface states capacitance to the total capacitance is negligible. In the other side, one can clearly distinct a peak in the accumulation zone especially for low frequencies, this behavior car be explained by the effect of the series resistance of the Schotty diode which causes ohmic back contact S (Demirezen,2012,2014; Tsormpatzoglou, 2005).

G-V curves presented in Figure 3 show a frequency dependence especially at the inverse region. The conductance values increase with decreasing frequency. This can be explained by the distribution of the interface states and traps which follow easily the ac signal. The real value of the series resistance R_s of a Schottky diode can be determined from measured capacitance at accumulation zone C_{ma} and conductance G_{ma} by Nicollian (1982):

$$R_s = \frac{G_{ma}}{G_{ma}^2 + \omega^2 C_{ma}^2} \tag{1}$$

The voltage dependent resistivity R_i of the diode can be also determined using equation (1) for any measured capacitance and conductance for any applied bias voltage. The voltage dependent resistivity calculated from equation (1) for three frequencies (50, 100 and 500 kHz) are plotted in Figure 4.

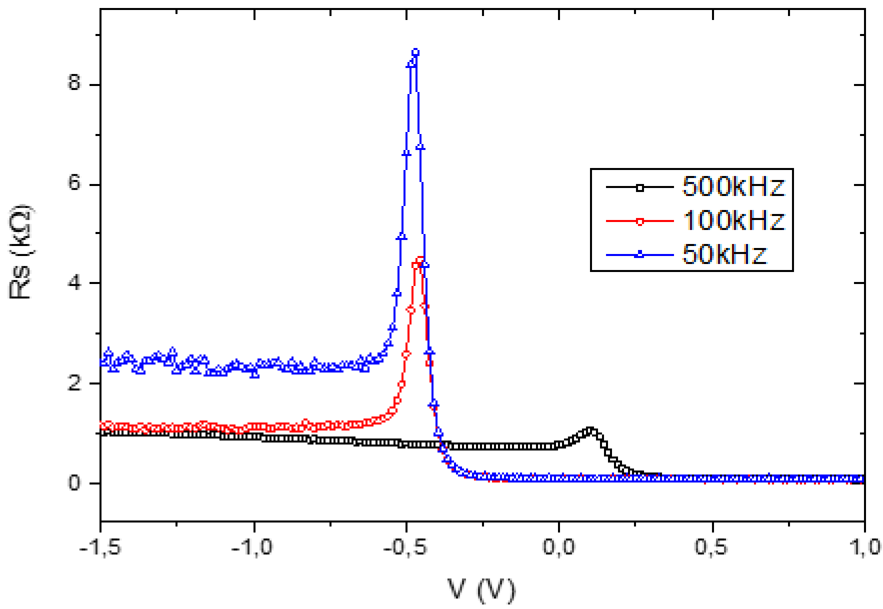


Figure 4. Series resistance vs. applied bias voltage at different frequencies

Rs plots in Figure 4 show a very significant values of the series resistance. These plots give a peak at about -0.5 V for 50 and 100 kHz and a peak at about 0.25 V for 500 kHz. Rs seems to be the most important parameter which causes non-ideality of the C-V and G-V characteristics. Demirezen (2014) have observed two peaks in the R_s plots for an Au/GaAs, they deduced that one of the peaks was caused by the existence of N_{ss} and their particular distribution in semiconductor band gap and the other one was caused by the native interfacial layer.
To obtain the real C-V and G-V characteristics of the Au/GaN/GaAs Schottky diode, the measured capacitance C_m and conductance G_m values were corrected by eliminating the effect of the series resistance R_s using (Nicollian, 1982):

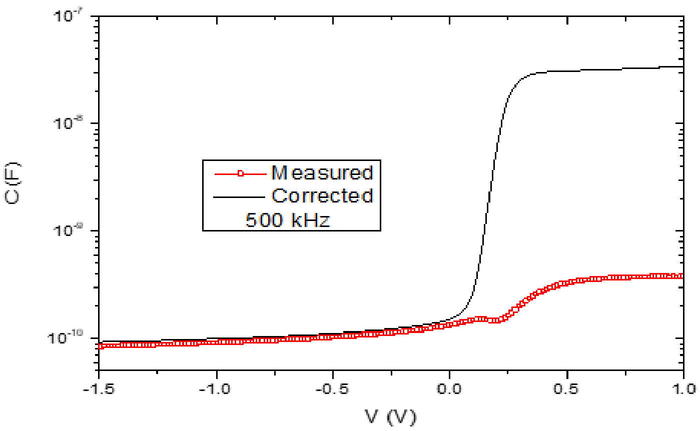
$$C_c = \frac{[G_m^2+(\omega C_m)^2]C_m}{a^2+(\omega C_m)^2} \tag{2}$$

$$G_c = \frac{G_m^2+(\omega C_m)^2 a}{a^2+(\omega C_m)^2} \tag{3}$$

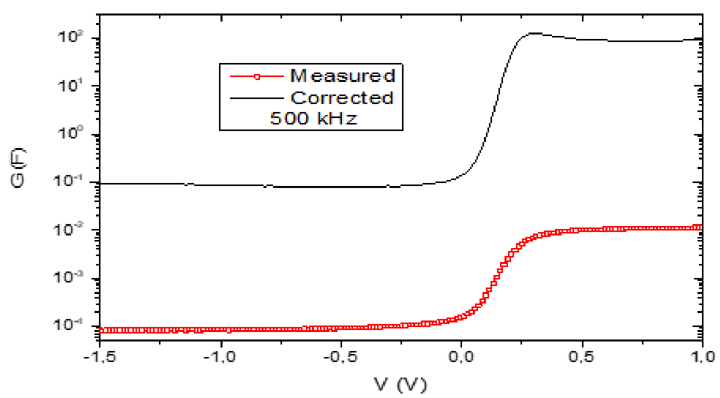
Where:

$$a = C_m - [G_m^2 + (\omega C_m)^2]R_s \tag{4}$$

Capacitance and conductance of the Au/GaN/GaAs Schottky diode for 500 kHz were corrected using equation (2) and (3) and plotted in Figure 5. After correction, values of the C_c and G_c increase in all the range of applied voltage (Figure 5). The corrected C_c shows considerable increase with increasing voltage in the depletion and accumulation zones. It's clearly shown that both change in C-V and G-v characteristics can be affected by R_s especially in accumulation region at high frequencies. So R_s causes errors in the extraction of the electrical parameters. The other more effective parameter on both C and G measurements is the interface states and particular distribution in the semiconductor band gap.



(a)



(b)

Figure 5. Voltage dependent corrected (a) C_c–V and (b) G_c–V plots of the Au/GaN/GaAs Schottky diode for 500 kHz

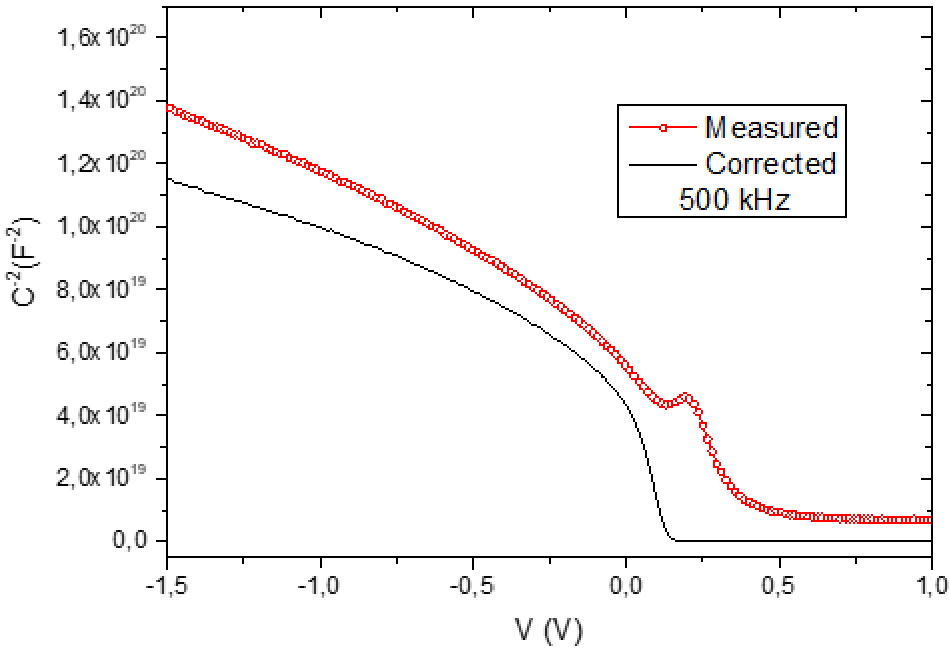


Figure 6. Measured and corrected C^{-2}-V plots of the Au/GaN/GaAs Schottky diode at 500 kHz

The electrical parameters of the Au/GaN/GaAs such as the diffusion potential V_d, the doping concentration N_d and the barrier height Φ_b. The diffusion potential is obtained by the extrapolation of the linear region of the C^{-2}-V characteristic. The doping concentration can be calculated from the slope of the linear region of the C^{-2}-V characteristic using:

$$\frac{dC^{-2}}{dV} = \frac{2}{q\varepsilon_s S^2 N_d} \tag{5}$$

Where ε_s is the substrate permittivity and S the surface of the Schottky contact. The barrier height can be calculated from:

$$\Phi_b = V_d + \frac{kT}{q} ln \frac{N_C}{N_d} \tag{6}$$

The electrical parameters of the Au/GaN/GaAs Schottky diode extracted from the corrected C-V characteristics are regrouped in table 1.

Table 1. Electrical parameters obtained after the elimination of the series resistance effect

V_d (V)	N_d (cm^{-3})	Φ_b (eV)
0.42	5.48×10^{15}	0.54

Electrical parameters shown in table 1 are different than those obtained in our previous works for the same sample (Kacha, 2015). Parameters obtained in this study seem to be the real parameters of the studied Au/GaN/GaAs Schottky diode. The doping concentration obtained with this method is the same concentration of the n-GaAs substrate given by constructor.

The N_{ss} can be extracted from its capacitance contribution to the measured C-V plot by the high-low frequency capacitance method (Nicollian, 1982) with and without the effect of the series resistance. The interface states capacitance C_{ss} can be determined by subtracting the depletion layer capacitance (extracted from the measured high frequency capacitance C_{HF}) from the depletion layer capacitance in parallel with interface states capacitance (extracted from the measured low frequency capacitance C_{LF}). The interface states density is calculated using:

$$qSN_{ss} = C_{ss} = \left[\frac{1}{C_{LF}} - \frac{1}{C_{ox}}\right]^{-1} - \left[\frac{1}{C_{HF}} - \frac{1}{C_{ox}}\right]^{-1} \tag{7}$$

The N_{ss} calculated from equation (7) for the Au/GaN/GaAs Schottky diode before and after correction of the C-V curves are plotted in Figure 7.

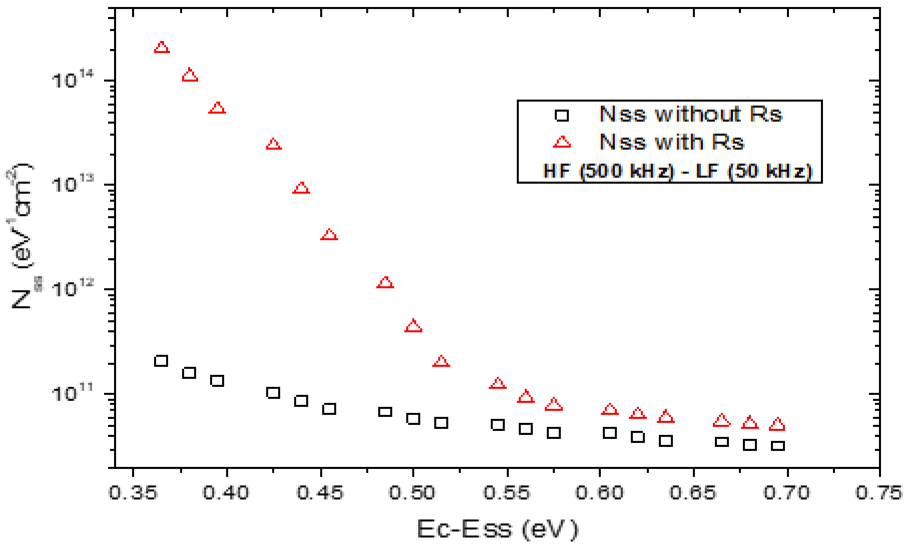


Figure 7. The interface states density distribution in the band gap

The N_{ss} values calculated by elimination of the series resistance R_s are lower than those calculated with R_s. By eliminating R_s effect, the electrical parameters of the Au/GaN/GaAs Schottky diode extracted from C-V measurements are much better than those obtained in our previous study (Kacha, 2015).

Conclusion

The C-V and G-V characteristics of the Au/GaN/GaAs Schottky diode have been investigated for three frequencies (50, 100, 500 kHz). Series resistance influences on the electrical parameters of the Schottky diode. In order to obtain the real parameters, the value of the series resistance was calculated. Then C-V and G-V curves were corrected by eliminating the series resistance which is generally caused by ohmic back contact and surface states. Surface states density was plotted with and within taken in consideration the effect of the series resistance. The surface states density was highly reduced which confirms that the series resistance is a major factor in the fabrication of a Schottky diode. Series resistance can be reduced by improving the ohmic back contact and the conditions of the surface cleaning process and metal deposition on the front side of the diode. Results in this study show an improvement of the electrical quality of the Au/n-GaAs (A. Rabehi, 2015) by the nitridation process. The thin layer of the GaN protects the GaAs surface and improves the quality of the Schottky contact.

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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