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Electrical Study of Au/GaN/GaAs (100) Structures as a Function of Frequency

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Various studies show that the nitridation of the GaAs surface improves the electrical quality of the Schottky diodes based on gallium arsenide. In order to observe this improvement, capacitance/conductance – voltage characteristics were investigated 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 against voltage at different frequencies. The obtained curves show significant values of the series resistance with peaks observed at about – 0.5 V for 50 and 100 kHz frequencies and at 0.25 V for 500 kHz. These peaks are attributed to the ohmic back contact and the surface state density. The electrical properties of the fabricated Schottky diode were then calculated and the surface state density of the Schottky diode was estimated with and without the effect of the series resistance. Surface state density was significantly reduced after the elimination of the series resistance effect. Electrical parameters demonstrate an improvement of the electrical quality of the fabricated Au/GaN/GaAs Schottky diode.

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

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1. INTRODUCTION

Semiconductors containing the element N are employed in the manufacture of various kinds of microelectronic and optoelectronic devices. Gallium nitride is an attractive semiconductor material suited for the development of high frequency device, blue emitters and detectors operating in the UV spectral range. Achieving well cleaned surfaces, arranged and passivated is of paramount importance for the growth of GaN and epy manufacture of devices based on this material. Several methods have been developed for the growth of gallium nitride. The characterization of devices based on this material has been extensively studied in recent years, especially the parameters of Schottky diodes [1-4].

Investigation of the electrical characteristics of the Schottky diode at only one frequency by using *C-V* and *G-V* measurements cannot provide detailed information on the conduction mechanisms and formation of the barrier height at the *M*/*S* interface. Therefore, to obtain more detailed information on these aspects, further study of the electrical characteristics of the Schottky diode especially at low frequencies is required. [5]. The electrical characteristics of Au/GaN/GaAs depend 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; however, at low and moderate frequencies, the depletion and accumulation regions are strongly dependent on the contribution of interface state density, interfacial layer and series resistance of the device.

In this work, we investigate the effect of the series resistance on the parameters of the Au/GaN/GaAs diode extracted from the *C-V* and the *G-V* measurements such as doping concentration N_d, barrier height Φ_b, diffusion potential V_d and the interface states density N_{ss} at three frequencies (50, 100, 500 kHz) at room temperature.

2. EXPERIMENTAL PART

The Au/GaN/GaAs Schottky diode (Fig. 1) was fabricated by nitridation of *n*-GaAs (100) substrate using a glow discharge source (GDS) [6]. Details of the fabrication of the Au/GaN/GaAs Schottky diode are given in detail in the previous works [4, 7].

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

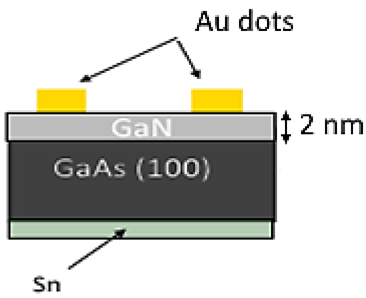

Fig. 1 – Au/GaN/GaAs Schottky diode

3. RESULTS AND DISCUSSION

C-V curves presented in Fig. 2 show the inversion, depletion and accumulation regions such as MIS type Schottky diodes. The *C-V* plots show higher capacitance values at low frequencies. This additive capacitance can be explained by the existence of the interface states and traps. At a high frequency, the N_{ss} cannot follow the ac signal and the contribution of the capacitance of these interface states to the total capacitance is negligible. On the other hand, one can clearly dis-

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tinct a peak in the accumulation zone especially for low frequencies, this behavior can be explained by the effect of the series resistance of the Schottky diode which causes the ohmic back contact [5, 8, 9].

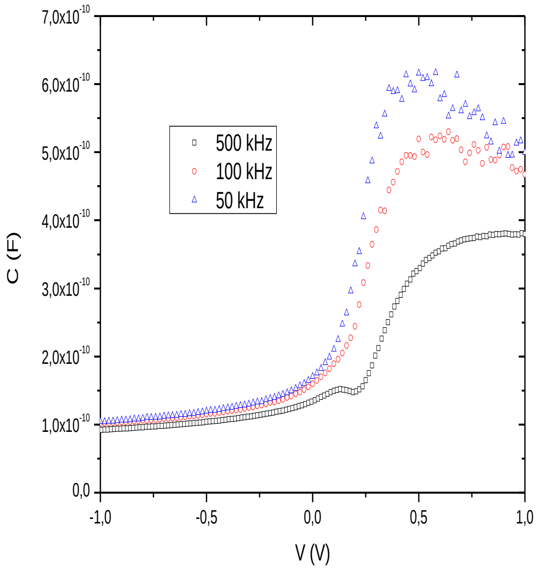

Fig. 2 – Capacitance-voltage characteristics of the Au/GaN/GaAs Schottky diode at different frequencies

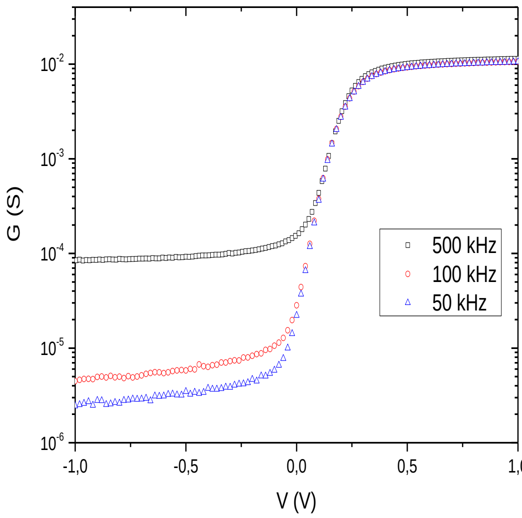

Fig. 3 – Conductance-voltage characteristics of the Au/GaN/GaAs Schottky diode at different frequencies

The *G-V* curves presented in Fig. 3 show the 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 the Schottky diode can be determined from the measured capacitance in the accumulation zone C_{ma} and conductance G_{ma} by [10]:

$$R_s = \frac{G_{ma}}{G_{ma}^2 + \omega^2 C_{ma}^2} . \quad (1)$$

The voltage dependent resistivity R_i of the diode can be also determined using Eq. (1) for any measured capacitance and conductance for any applied bias voltage.

The voltage dependent resistivity calculated from Eq. (1) for three frequencies (50, 100 and 500 kHz) is plotted in Fig. 4.

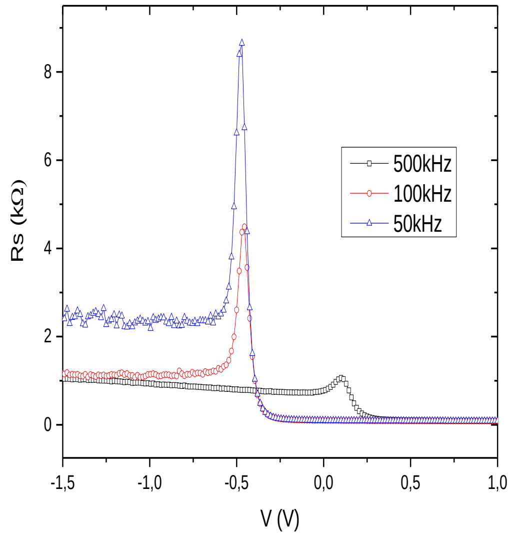

Fig. 4 – Series resistance vs. applied bias voltage at different frequencies

The R_s plots in Fig. 4 show 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. R_s seems to be the most important parameter which causes non-ideality of the *C-V* and *G-V* characteristics. S. Demirezen et al. [5] observed two peaks in the R_s plots for Au/GaAs, they deduced that one of the peaks was caused by the existence of N_{ss} and their particular distribution in the semiconductor band gap and the other was caused by the native interfacial layer.

To obtain 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 [10]:

$$C_c = \frac{\left[G_m^2 + (\omega C_m)^2\right] C_m}{a^2 + (\omega C_m)^2} , \quad (2)$$

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

where

$$a = C_m - \left[G_m^2 + (\omega C_m)^2\right] R_s . \quad (4)$$

Capacitance and conductance of the Au/GaN/GaAs Schottky diode for 500 kHz were corrected using equations (2) and (3) and plotted in Fig. 5.

After correction, the values of C_c and G_c increase in the entire range of applied voltage (Fig. 5). The corrected C_c shows a considerable increase with increasing voltage in the depletion and accumulation zones. It is clearly shown that changes in both *C-V* and *G-V* characteristics can be affected by R_s especially in the accumulation region at high frequencies. So, R_s causes errors in the extraction of the electrical parameters. Another more effective parameter for measurements of both

C and G are the interface states and particular distribution in the semiconductor band gap.

The electrical parameters of Au/GaN/GaAs are 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 is the surface of the Schottky contact.

The barrier height can be calculated from:

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

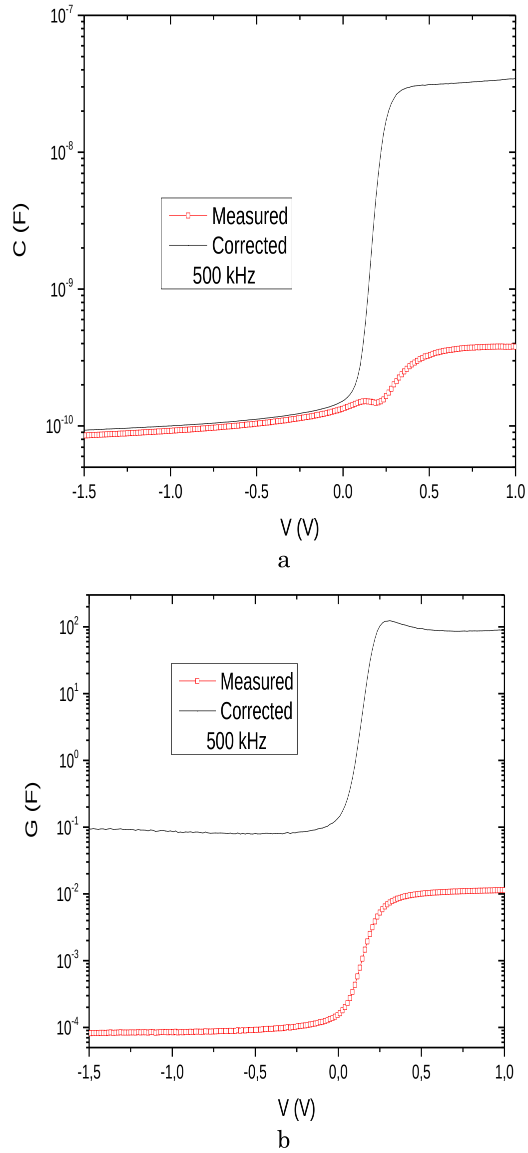

Fig. 5 – Voltage dependent corrected (a) C_c-V and (b) G_c-V plots of the Au/GaN/GaAs Schottky diode for 500 kHz

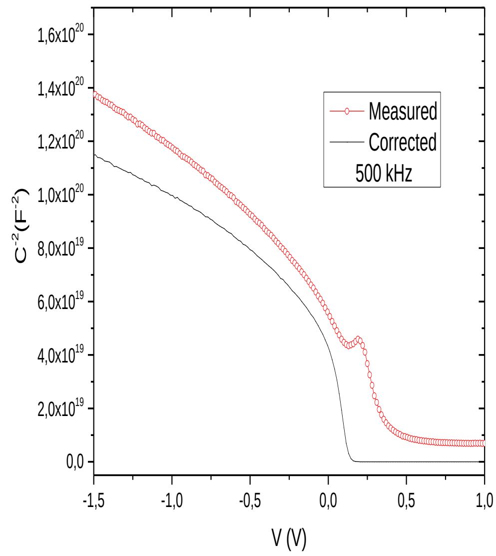

Fig. 6 – Measured and corrected C^{-2}-V plots of the Au/GaN/GaAs Schottky diode at 500 kHz

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

The electrical parameters of the Au/GaN/GaAs Schottky diode extracted from the corrected C-V characteristics are regrouped in Table 1. Electrical parameters shown in Table 1 are different than those obtained in our previous works for the same sample [7]. 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 the constructor.

The N_{ss} can be extracted from its capacitance contribution to the measured C-V plot by the high-low frequency capacitance method [10] with and without the effect of the series resistance. The interface state 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 state capacitance (extracted from the measured low frequency capacitance C_{LF}). The interface state 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 Eq. (7) for the Au/GaN/GaAs Schottky diode before and after correction of the C-V curves is plotted in Fig. 7. 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 [7].

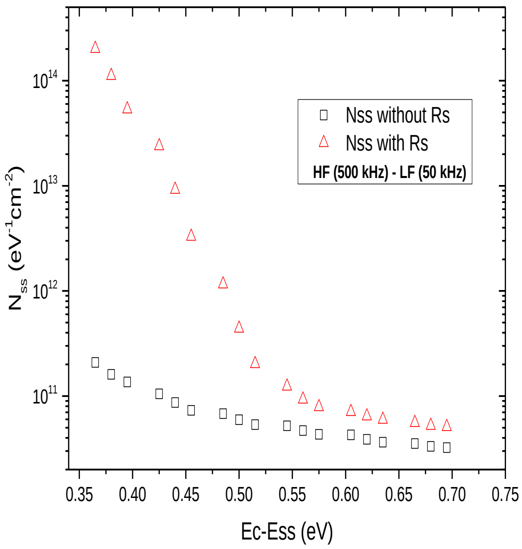

Fig. 7 – The interface state density distribution in the band gap

4. CONCLUSIONS

The *C-V* and *G-V* characteristics of the Au/GaN/GaAs Schottky diode have been investigated for three frequencies (50, 100 and 500 kHz). Series resistance influences the electrical parameters of the Schottky diode. In order to obtain the real parameters, the value of the series resistance was calculated. The *C-V* and *G-V* curves were then corrected by eliminating the series resistance which is generally caused by the ohmic back contact and surface states. Surface state density was plotted with and without taking into consideration the effect of the series resistance. The surface state density was highly reduced, confirming 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 conditions of the surface cleaning process and metal deposition on the front side of the diode. The results of this study show an improvement in the electrical properties of Au/*n*-GaAs [5] by the nitridation process. The thin GaN layer protects the GaAs surface and improves the quality of the Schottky contact.

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Електричне дослідження структур Au/GaN/GaAs (100) як функції частоти

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Різні дослідження показують, що нітрування поверхні GaAs покращує електричну якість діодів Шотткі на основі арсеніду галію. Для того, щоб спостерігати це покращення, були досліджені характеристики ємність/провідність-напруга на трьох частотах (50, 100 та 500 кГц). Ці характеристики були кореговані шляхом усунення ефекту послідовного опору. Спочатку визначали значення послідовного опору та будували графік його залежності від напруги на різних частотах. Отримані криві показують значні значення послідовного опору з піками, які спостерігаються при близько – 0,5 В для частот 50 і 100 кГц і при 0,25 В для 500 кГц. Ці піки пов'язані з омічним зворотним контактом і щільністю поверхневих станів. Потім були розраховані електричні властивості виготовленого діода Шотткі та оцінена щільність поверхневих станів діода Шотткі з ефектом послідовного опору та без нього. Щільність поверхневих станів значно зменшилася після усунення ефекту послідовного опору. Електричні параметри демонструють покращення електричної якості виготовленого діода Шотткі Au/GaN/GaAs.

Ключові слова: GaN, GaAs, Діод Шотткі, Послідовний опір, Стани інтерфейсу.