



The negative capacitance characteristics of in Au/n-GaAs metal-semiconductor contacts at room temperature

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In this study, we investigated negative capacitance effect in Au/n-type GaAs metal semiconductor contacts using capacitance-voltage (C-V) and conductance-voltage (G/ω -V) characteristics at room temperature. The negative capacitance observed only under forward voltages in structures that employ a Schottky contact. Experimental results proved that the negative capacitance behavior is always accompanied bias voltage especially in the accumulation region. Thus, the value of capacitance in the forward bias region reaches to maximum and then becomes negative. The carrier concentration obtained from the C-V characteristics is found to be of the order $10^{17}/\text{cm}^3$. Furthermore, the series resistance-voltage (RS-V) and interface states densities (ESS) characteristics were calculated as dependence to voltage from the capacitance and conductance measurements.

Keywords: Negative capacitance; n-type GaAs; C-V and G/ω -V; Series resistance

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1. Introduction

In recent years, numerous researchers have mentioned a negative capacitance (NC) effect in various electronic devices [1-10]. The search of negative capacitance in metal semiconductor (MS) structures has become an increasingly hot topic due to their fascinating electrical properties and potential in applications [2-6]. Among these metal-semiconductor structures, especially GaAs based structures are widely used as a basic component for high speed electronic, optoelectronic devices, other microwave communication devices and high-speed microelectronic applications due to the technical importance and advantage coming from optimum band gap and a large mobility of GaAs semiconductor [7-10]. This is that the behaviour of negative capacitance is important because it's indicated that increases of forward bias voltage produces a decrease in the carrier charges on the electrodes. For that reason, the metal-semiconductor Au/n-type Schottky contacts in the semiconductor device technology are still investigated and have attracted much attention during recent years. The formation of negative capacitance was observed in various structures and under different conditions. For example, when

the negative capacitance decreases with increasing voltage, it was concluded that it results from internal properties rather than from a parasitic series inductance [7-13]. Furthermore, the negative capacitance of Au/n-GaAs Schottky structures can be explained by polarization and the introduction of more carriers to the structure [2].

In this paper, the C-V, G/ω -V and RS-V characteristics of Au/n-type GaAs metal semiconductor contacts were explored and a detailed analysis is presented based on the results. The forward and reverse bias C-V and G/ω -V characteristics of this GaAs metal semiconductor contacts were investigated at room temperature (300 K) and 500 kHz in the voltage ranges of ± 5.00 V. The experimental results showed that C-V and G/ω -V plots were found to be affected by voltage. The plot of C-V in the forward bias region reached a maximum value and then took negative values in the strong accumulation region.

2. Material and Methods

The Au/n-type GaAs structure have been prepared using cleaned and polished n-GaAs (as received from the

manufactured) with (100) orientation and $4.73 \times 10^{16} \text{ cm}^{-3}$ carrier concentrations (ND). The wafer was cut into small pieces and then cleaned. n-type GaAs wafer was chemically cleaned using the RCA cleaning procedure. For ohmic contacts, Au-Ge (88 and 12 %) alloy was deposited over the entire back surface of the GaAs samples at a pressure about 10^{-6} Torr in a vacuum system. Then, the structure was subjected to a temperature treatment at $450 \text{ }^\circ\text{C}$ for 3 min in N_2 atmosphere. On the other hand, for rectifier contacts, high purity gold (Au) metal with 1.5 mm diameter through a metal shadow masks was deposited over the entire front surface of the GaAs semiconductor. All evaporation processes were carried out in a turbo molecular fitted vacuum coating unit at about 10^{-6} mbar. The capacitance-voltage (C-V) and conductance voltage (G/ω -V) measurements of the Au/n-GaAs metal semiconductor structure was performed in the room temperature 300 K and at 500 kHz frequency by using ST2826/A High Frequency LCR Meter. The cross-section of Au/n-GaAs metal semiconductor structure is shown in Fig. 1.

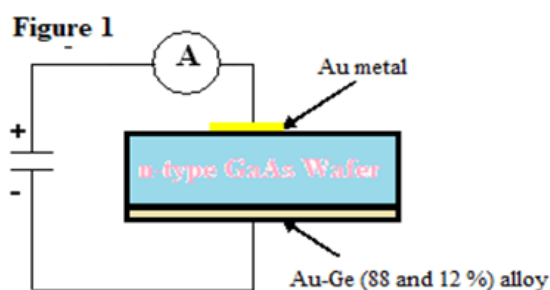


Figure 1. The cross-section of Au/n-type GaAs metal semiconductor structure

4. Results and discussion

The capacitance-voltage (C-V) measurements are important fundamental properties of the metal semiconductor structure. Because, C-V measurements are an important technique to study the junction interface, the density of states and the response function to the alternating current [14, 15]. Figure 2 show the C-V plot measured at 0.5 MHz.

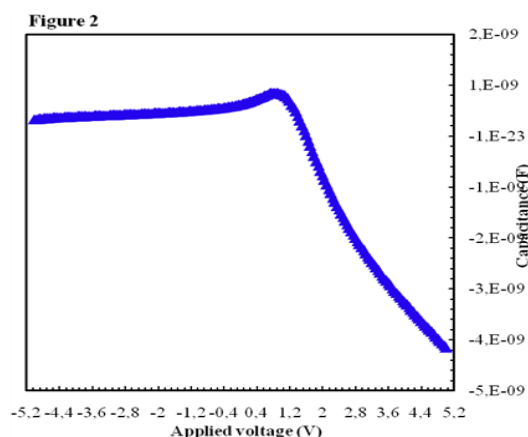


Figure 2. The C-V plot of the Au/n-type GaAs metal semiconductor structure

As can be seen in Fig. 2, the capacitance decreased slowly with decreasing reverse bias voltage, indicating that the width of the depletion layer varied with the applied bias voltage. Later, the C-V curve also revealed an anomalous peak with increasing bias voltage which reach a maximum value at about 0.98 V. However, the C-V plot decreased rapidly with the increasing bias voltage in the forward bias region and take negative values after about 1.62 V. That is, C-V plot shows that negative capacitance was observed under a forward bias. Thus, this behavior of capacitance can be explained by interfacial layer at metal semiconductor interfaces as a function of voltage according to polarization mechanism [4-8]. In the same time, Fig. 3 show the conductance-voltage (G/ω -V) plot measured at 0.5 MHz.

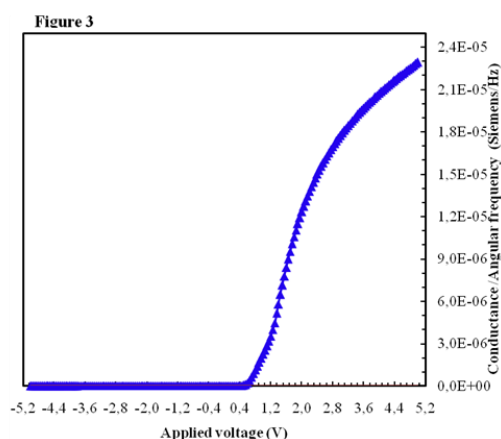


Figure 3. The G/ω -V plots of the Au/n-type GaAs metal semiconductor structure

As can be seen in Fig. 3, contrary to the capacitance, it is clear that, while the capacitance values decrease rapidly, the conductance values increase rapidly in the negative capacitance region in consistency with the predominant reverse electric current. It is clear that the capacitance-voltage (C-V) and conductance voltage (G/ω -V) curves are quite sensitive to frequency at relatively high positive voltages. In these states, series resistance (R_s) is also a very important parameter in metal semiconductor structures and so R_s effects the ideal behavior of C and G/ω versus voltage characteristics.

Series resistance (R_s) is also an important parameter to describe of metal semiconductor structures and it effects the ideal behavior of capacitance and conductance measurements. The real series resistance of metal-semiconductor devices can be subtracted from the measured capacitance (C_{ma}) and conductance (G_{ma}) in strong accumulation region at high frequency. The series resistance values (R_s -V plot) were obtained by using the Nicollian and Brews method [16, 17].

$$R_s = \frac{G_m}{G_m^2 + (\omega C_m)^2} \quad (1)$$

where, R_s is series resistance, G_m is measured conductance, C_m is measured parallel model capacitance, and ω is the

angular frequency ($=2\pi f$). Using Eq. (1), the values of R_s were calculated as a function of voltage at room temperature. Fig. 4 shows the R_s -V curves.

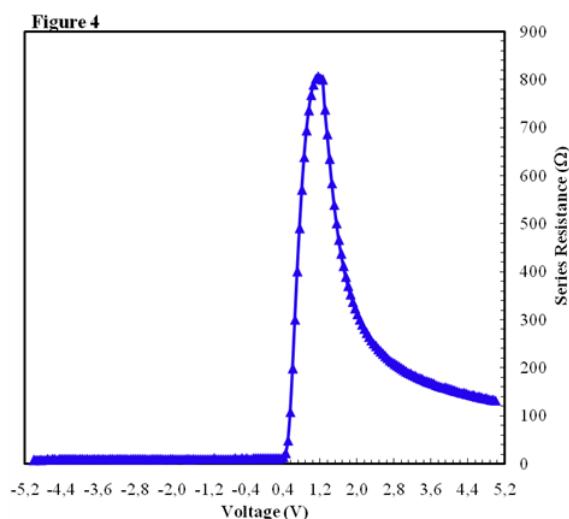


Figure 4. The R_s -V plots of the Au/n-type GaAs metal semiconductor structure

The series resistance was calculated by using values of measured capacitance and conductance. As can be seen in Fig. 4, the series resistance value gives a peak maximum in the voltage range of $0.30 \leq V \leq 2.00$ V. The variation in the peak intensity indicates interface states following the alternating current. The experimental results showed that the series resistance changes depending on the voltage from region to region. Thus, the carriers have enough energy to escape from the traps located between metal and semiconductor interface in the GaAs band gap.

5. Conclusion

In this study, capacitance–voltage (C–V), conductance–voltage (G/ω –V) and series resistance–voltage (RS–V) characteristics of the Au/n-type GaAs metal semiconductor structure were investigated at the room temperature range (300 K). Experimental results showed that capacitance, conductance and series resistance values are quite sensitive to bias voltage. The existence of negative capacitance in diodes made from high resistivity material has been clearly shown by our measurements. Also, negative capacitance behavior can be attributed to the loss of interface charges at occupied states below Fermi level due to impact ionization processes.

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