Effect of hydrostatic pressure on series resistance of Au/n-GaAs Schottky diodes

Güven Çankaya\textsuperscript{1} & Nazım Uğur\textsuperscript{2}

\textsuperscript{1}Atatürk University, Faculty of Sciences and Arts, Physics Department, Erzurum, Turkey
\textsuperscript{2}Süleyman Demirel University, Faculty of Sciences and Arts, Physics Department, Isparta, Turkey

Received 4 October 2002; accepted 26 November 2002

Au/n-GaAs Schottky barrier diodes have been fabricated. The series resistance has been measured as a function of hydrostatic pressure using the current-voltage (I-V) technique. It has been found that the series resistance increases with increasing hydrostatic pressure.

1 Introduction

For many years, the metal-semiconductor contact system has been the subject of many investigations because of its presence in electronic circuits. Due to the technological importance of Schottky barrier diodes (SBDs) which are the most simple of the metal-semiconductor (MS) contact devices, full understanding of the nature of the electrical characteristics of these diodes is of great interest but satisfactory understanding, in all details, has still not been achieved\textsuperscript{14}. It is well-known that, the series resistance ($R_s$) of the neutral region of the semiconductor bulk (between the depletion region and ohmic contact) apart from ideality factor ($n$) and barrier height ($\phi$) is an important parameter, which causes the electrical characteristics of SBDs to be non-ideal\textsuperscript{15}. Usually, the forward bias current-voltage (I-V) characteristics are linear in the semi-logarithmic scale at low voltages. But, in the high voltage region, the I-V characteristics deviate from its exponential form due to the presence of a linear or non-linear $R_s$ [Refs 1, 5, 10, 11, 14, 15]. Meanwhile, it has been shown that, in the presence of $R_s$, capacity-voltage (C-V) characteristics exhibit a peak\textsuperscript{12,16,17}. Although, C-f plot in idealized case is frequency-independent, this idealized case is often disturbed due to the presence of $R_s$ of the neutral region of the SBDs [Refs 12,14,18,19]. At the same time, the interface state energy distribution (ISD) values obtained, taking into account, the $R_s$ value have been proved lower than those obtained without considering the $R_s$ [Ref. 20]. Therefore, the non-ideal behaviour observed in the electrical characteristics of SBDs has been attributed to the effect of $R_s$ as well as ISD. For this reason, studies on the $R_s$ especially according to temperature has been made routinely in SBDs. As the $R_s$ occurs in high current region\textsuperscript{20}, the decrease of series resistance with increasing temperature has been modelled by allowing the parasitic resistor of the dominant larger diode, which has a negative linear temperature coefficient. On the other hand, the strong temperature dependence of the $R_s$ has been explained with ionized-cluster beam deposition in Ag/n-Si Schottky diodes\textsuperscript{22} and deep levels due to ion bombardment in Al/n-Si/p-Si Schottky junctions\textsuperscript{23}.

Recently, hydrostatic pressure as well as the temperature has been used to explain the electronic structure of semiconductors by means of the $\phi$, and the $n$ measurements. Corresponding to this, the $\phi$ at the Pt/GaAs interface has been measured as a function of the pressure and has been found to shift to higher energy as the I-V curves shift to the low current values\textsuperscript{28}. Also, an improvement of the diode quality with pressure on the rectifying properties has been shown\textsuperscript{35}. In this work, the effect on the $R_s$ of the hydrostatic pressure has been investigated in Au/n-GaAs Schottky diodes.

2 Experimental Method

The Au/n-GaAs Schottky diodes used in this study were fabricated, using $n$-type LPE (Liquid-phase epitaxy) GaAs wafers (Te-doped) with 100 orientation and 0.01 $\Omega$ cm resistivity. Wafer was rinsed by ultrasonic vibration in de-ionized water and was dried by high purity nitrogen. After this
procedure, an ohmic contact was made by evaporating Au-Ge (12% Ge) and annealing 425 °C for 3 min. The Schottky contacts were formed by evaporating Au dots with diameter of about 1 mm on the front surface of wafer. All evaporation processes were carried out in a turbo-molecular fitted vacuum coating unit, at about 10⁻⁶ mbar. The pressure was created by a piston and cylinder-type chamber apparatus and measured with the resistance changes of manganin wire (an alloy containing 83% copper, 13% manganese, 4% nickel). The I-V measurements were performed in dark in the hydrostatic pressure range of 0-6 kbar at the room temperature. Further experimental details are described elsewhere²⁶.

3 Results and Discussion

The $R_s$ of the neutral region of the semiconductor bulk also plays an important role on the I-V characteristics of SBDs, and causes them to be different from those, which would be expected. Several reports in the last few years have been shown that, the SBD parameters can be calculated from forward I-V characteristics of SBDs. Nordø²⁷ first proposed a method to extract the $R_s$, of ideal SBDs with assumption of $n=1$. In the present work, the $R_s$ has been calculated from the forward bias I-V data, using the method of Cheung & Cheung¹¹. Corresponding to this, the forward bias I-V characteristics due to thermionic emission of Schottky diodes with $R_s$ can be expressed as:\(^{13,25}\):

$$I = A^* T^2 \exp \left( \frac{q\Phi_s}{kT} \right) \exp \left( -\frac{q(V - I R_s)}{n kT} \right)$$

where $q$, $V$, $A$, $k$, and $T$ are the electron charge, applied voltage, effective diode area, the Boltzmann constant and the absolute temperature, respectively. $A^*$ is the effective Richardson constant of 8.16 $Acm^{-2}K^{-2}$ for GaAs and $R_s$ is the series resistance. Now, to determine series resistance, the functions of Cheung are obtained. From the above equation, the following functions can be written as:

$$V = I R_s + n \Phi_s + \frac{kT}{n} \ln \left( \frac{1}{A^* T^2} \right)$$

$$\frac{dV}{d(ln I)} = \frac{n kT}{q} + I R_s$$

The above equation should give a straight line for the data of downward curvature region in the forward bias I-V characteristics. Thus, the slope of a plot of $dV/d(ln I)$ versus $I$ will give $R_s$ of the SBDs.

![Fig. 1 — Experimental forward I-V characteristics taken in hydrostatic pressure range 0 to 6 kbar for Au/n-GaAs Schottky diodes](image-url)

Fig. 1 shows the semilog forward bias dark I-V characteristics of Au/n-GaAs Schottky diode at the hydrostatic pressures from 0 to 6 kbar. As seen from this figure, for the Au/n-GaAs Schottky diodes, the majority of diodes showed good agreement with simple thermionic emission theory, typical $n$ and $\Phi_s$ for these diodes, being 1.061 and 0.80 eV, respectively, at room temperature and 0 kbar. As expected, the I-V characteristics were not perfectly linear and showed a downward curvature at high voltage. The downward concave curvature of the forward bias I-V plots at sufficiently large voltages has been attributed to the presence of the effect of $R_s$, apart from the interface states, which are in equilibrium with the semiconductor. In this region, it can be said that, $n$ is rather controlled by the interface states and $R_s$. Also, there is a hydrostatic pressure effect on the I-V characteristics at the low and high forward voltages. With an increase in pressure, the I-V characteristics move to lower current values. The $R_s$ was calculated using $dV/d(ln I)$ versus $I$ plot which was developed by Cheung & Cheung¹¹ in the higher current range (over which the
$I-V$ characteristics is non-linear). These values have been shown in Fig. 2. It can be said from this figure that, there is a strong pressure dependence of $R$, in these diodes. The $R$ increases with the increasing hydrostatic pressure. The anomalous forward characteristics due to $R$, have been explained in terms of the variation of the $\phi_i$ [Refs 28, 29]. This may be attributed to the existence of material defects across the wafer, which result in the variation of the $\phi_i$ [Ref. 21]. Also, the $R$ increases with thermal treatment due to the formation of a highly resistive layer at the interface$^{30,31,32}$. So, an $R$ value higher than predicted can be explained by the bias dependence of the $\phi_i$ which is caused by highly resistive layer with the thermal treatment. It is suggested that, the pressure-dependence of the $\phi_i$ is responsible for the increasing $R$, with hydrostatic pressure. In a recent work, the authors found that, $\phi_i$ of the Au/n-GaAs contact has a value of 11.21 meV/kbar which suggests that, the Fermi level is pinned to the valence band-edge. Therefore, as a function of externally applied pressure, the $\phi_i$ of Schottky diode increases with the linear pressure coefficient of 11.21 meV/kbar [Ref. 32]. So, the concavity of the $I-V$ curve increases with increasing $\phi_i$ and forward bias. Therefore, a higher $R$ value is obtained. In conclusion, there is a strong pressure-dependence of the $R$, in these diodes at the high forward voltages due to the variation of the $\phi_i$.

References

Fig. 2—Hydrostatic pressure dependence of series resistance for Au/n-GaAs Schottky diodes.


