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Review

# Hydrostatic pressure dependence of interface state density of Cd/n-type GaAs Schottky barrier diodes

Savaş Sönmezoğlu [a,*], Fatih Bayansal [b], Güven Çankaya [a]

[a] Gaziosmanpaşa University, Faculty of Arts and Science, Department of Physics, 60250 Tokat, Turkey
[b] Mustafa Kemal University, Faculty of Arts and Science, Department of Physics, 31034, Antakya-Hatay, Turkey

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ABSTRACT

The interface state density obtained from current–voltage (*I–V*) characteristics of Cd/n-type GaAs Schottky barrier diodes (SBDs) at room temperature under hydrostatic pressure was investigated. SBD parameters such as ideality factor ($n$), series resistance ($R_s$), and barrier height ($\phi_b$), were obtained from *I–V* measurements using Cheung's method. The diode parameters, such as ideality factor, series resistance, and barrier heights, were found in the range of 1.464–1.474, 0.995–4.359 kΩ and 0.739–0.777 eV, respectively, with sweeping pressure. The diode shows non-ideal *I–V* behaviors with an ideality factor greater than unity. Additionally, the energy distribution of interface state density was determined from the forward bias *I–V* characteristics by taking into account the bias dependence of the effective barrier height. The results have shown that the presence of the interfacial native oxide layer between the metal and the semiconductor seriously affects interface state density under hydrostatic pressure.



**Contents**



## 1. Introduction

The investigation of metal–semiconductor (MS) contacts, commonly known as Schottky barrier diodes (SBDs), is a very important focus from both a practical and a theoretical part of view. Material gallium arsenide is one of the most popular semiconductors that has intrinsic electric properties superior to silicon, such as a direct energy gap, higher electron mobility, a high breakdown voltage, chemical inertness, mechanical stability, and lower power dissipation. These advantages of gallium arsenide make it attractive for optoelectronic devices, discrete microwave devices and/or large-scale integrated electronic devices. Due to the technological importance of MS GaAs SBDs, a full understanding of the nature of the electrical characteristics of SBDs in the system is of great interest.

However, electrical characteristics of these devices are often influenced by various non-idealities such as interface state, interfacial oxide layer, interface fixed charges, interface traps, and series resistance [1–5]. Therefore, the interface states and series resistance play an important role in determining the Schottky barrier height and other characteristic parameters. Hence, these can affect device performance, stability, and reliability [2,6,7]. Accordingly, it has been concluded that the barrier height determined from the *I–V* characteristics are controlled by the interface states energy distribution in equilibrium with the semiconductor and the applied voltage under forward bias condition.

The study of the characteristics of semiconductor devices under the effect of external agencies is of great importance, both for the practical development of transducers for pressure, temperature, radiation, etc., and for research on the physics of

* Corresponding author.
*E-mail address:* svssonmezoglu@gop.edu.tr (S. Sönmezoğlu).

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the processes in these devices. In view of this, the effect of hydrostatic pressure is of interest in the study of the fundamental properties of semiconductor structures. In particular, hydrostatic pressure and temperature have been employed for understanding the electronic structure of SBD characteristics in recent years [8–13]. Corresponding to this, Çankaya et al. [14] showed that the barrier height increases with increasing hydrostatic pressure. In addition, the same author showed an improvement of diode quality with pressure on the rectifying properties.

Although an immense amount of information on MS Schottky diodes has been gained, little is known about the effect of pressure on the SBD parameters. The present work is to investigate the hydrostatic pressure dependence of Schottky diode parameters, such as ideality factor, barrier height, and series resistance, affecting the performance of the device, by using the forward bias current–voltage (*I–V*) measurements and the interface state density, $N_{ss}$, from the *I–V* characteristics of SBDs, taking into account the bias dependence of the effective barrier height under hydrostatic pressure.

## 2. Experimental procedure

The Cd/n-GaAs Schottky diode used in this study was fabricated using n-type liquid-phase epitaxial (LPE) GaAs wafers (Te doped) with orientation [1 0 0] and 1.5–7.3 mΩ cm resistivities. A wafer was rinsed by ultrasonic vibration in deionized water and was dried with high purity nitrogen. After this procedure, an ohmic contact on the back surface of the wafer was made by evaporating Au–Ge (12% Ge) and annealing at 425 °C for 3 min. The Schottky contacts were formed by evaporating Cd as dots with diameter of about 1 mm on the front surface of the wafer. All evaporation processes were carried out in a turbo molecular vacuum coating unit at about $10^{-6}$ mbar.

The pressure was created by a piston and cylinder-type chamber apparatus [15] and special transformer oil was used to transmit the pressure. The Cd/n-GaAs Schottky diode was located in a pressure cell with a specially designed sample holder and the *I–V* measurements in the hydrostatic pressure range of 1.00–7.00 kbar were made by electrical connections from cell to the diode. The value of hydrostatic pressure in the pressure cell was measured by means of resistance changes of the manganin wire. *I–V* characteristics of Schottky diodes under the pressure were performed using a Keithley 487 picoammeter/voltage source at room temperature.

## 3. Results and discussion

When a Schottky contact with series resistance is considered, it is assumed that the net current of the device is due to the thermionic emission [3], and it can be expressed as

$$I = I_0 \exp\left(\frac{qV}{nkT}\right)\left[1 - \exp\left(-\frac{qV}{kT}\right)\right] \quad (1)$$

where $V$ is the applied voltage and the saturation current $I_0$ is expressed as

$$I_0 = A \cdot A^* T^2 \exp\left(-\frac{q \cdot \phi_{b,0}}{kT}\right) \quad (2)$$

where $q$ is the electron charge, $A^*$ is the effective Richardson's constant and equals 8.16 A cm$^{-2}$ K$^2$ for n-type GaAs [15], $A$ is the effective the diode area, $T$ is the absolute temperature, $k$ is the Boltzmann's constant, $n$ is the ideality factor, and $\phi_{b,0}$ is the effective barrier height at zero bias defined by Eq. (2). For values

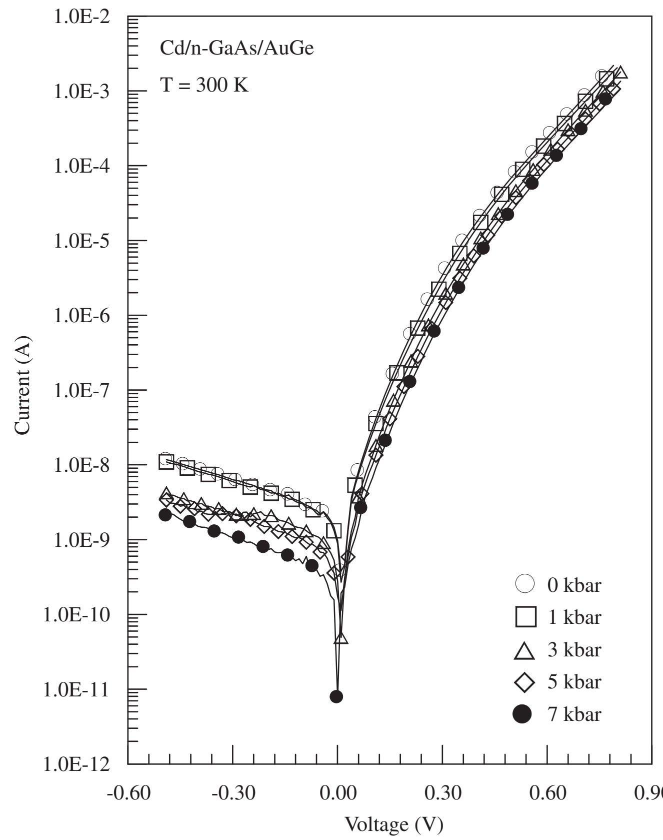


**Fig. 1.** The experimental current–voltage characteristics of the Cd/n-GaAs Schottky barrier diode under hydrostatic pressure.

of $V > 3kT/q$, the ideality factor from Eq. (1) can be written as

$$n = \frac{q}{kT}\frac{dV}{d(\ln I)} \quad (3)$$

Fig. 1 shows a set of experimental semilog-forward bias *I–V* characteristics of Cd/n-GaAs Schottky diodes in the pressure range 0.00–7.00 kbar. The currents of Cd/n-GaAs Schottky diodes decreased under pressure due to an increase of the Schottky barrier. The values of the barrier height and ideality factor of Cd/n-GaAs Schottky diodes were calculated with the help of Eqs. (2) and (3) from the *y*-axis intercepts of the experimental semilog-forward bias *I–V* characteristics indicating that the effect of series resistance in this region was not important [16]. These values are given in Table 1. As seen in Table 1 and Fig. 1, the value of the barrier height and ideality factor of the Cd/n-GaAs Schottky diode was found to be 0.739 eV and 1.464, at $P$=0.00 kbar, to 0.777 eV and 1.474, at $P$=7.00 kbar, respectively. It has seen that increasing pressure to 7.00 kbar slightly increased the ideality factor $n$ and barrier height $\phi_{b,0}$. For an ideal SBD $n$=1. Our data clearly show that the Cd/n-GaAs Schottky diode has an ideality factor that is considerably larger. The underlying cause can be barrier height inhomogeneity, recombination-generation, tunneling and image-force lowering, which is voltage dependent and/or an interfacial oxide layer [7,17,18]. Since the front surface of n-GaAs is exposed to air before the formation of Cd at n-GaAs interface, the presented *I–V* data demonstrate a behavior deviating from pure thermionic emission with $n$ values greater than unity, although the structures performed like a rectifier contact.

The Schottky diode parameters, the barrier height $\phi_{b,0}$, the ideality factor $n$, and the series resistance $R_s$ were also achieved using a method developed by Cheung and Cheung [19]. Cheung's