Journal of Materials and Electronic Devices 2 (2024) 25-29

JOURNAL OF MATERIALS AND ELECTRONIC DEVICES
FYTRONIX JMED
http://dergi-fytronix.com/

Investigation of interface state density, series resistance, and diode parameters of Ag/n-InP/In Schottky barrier diodes

Serkan EYMUR[1*], Zeynep KIŞNIŞCI[2]

[1]Department of Energy Systems Engineering, Faculty of Engineering, Giresun University, Giresun, Turkiye
[2]Department of Physics, Faculty of Science, Selçuk University, Campus, 42075 Konya, Turkey

We reported the ideality factor, barrier height, series resistance, and interface state density parameters of the Ag/n-InP/In Schottky diode from current–voltage (I–V) characteristics. We have presented three of many I-V measurements. The conventional thermionic emission (TE) theory is used to study the I-V characteristics. Every produced diode exhibited rectifying characteristics. As an illustration of the computed parameters, the values for ideality factor, barrier height, saturation current, and series resistance are found to be 2.375, 0.486 eV, 1.95x10^{-4} A, and 3.06 Ω, respectively. The values of interfacial state density were found to be approximately 10^{14} eV^{-1} cm^{-2}. As an illustration, consider the energy range where the interfacial state density was 9.50x10^{14} eV^{-1} cm^{-2} in the 0.307-E_{ss} energy range and 3.77x10^{14} eV^{-1} cm^{-2} in the 0.458-E_{ss} energy range.

Keywords: *n-InP, Schottky barrier diode, ideality factor, barrier height, series resistance, interface state density*

Submission Date: 26 March2024
Acceptance Date: 02 June 2024

**Corresponding author: serkan.eymur@giresun.edu.tr*

1. Introduction

Due to its radiation hardness, direct bandgap, and rapid electron mobility, indium phosphide (InP) is one of the most intriguing group III–V semiconductors and has drawn a lot of attention in the past 20 years [1,2]. In light of these electrical characteristics, InP ssemiconductor are especially well-suited for Schottky type devices, which find use in a wide range of technological fields, including solar cells, metal-semiconductor field-effect transistors, infrared detectors, and thermal imaging sensors [3-5]. The InP Schottky contact's low barrier height, which can result in large leakage currents, is a significant disadvantage [6-8].

Schottky barrier diodes (SBDs) have been the focus of much research lately due to their potential applications [9,10]. Metal/semiconductor (M/S) links in electrical circuits enable communication between semiconductor-based devices [11-14]. Many attempts have been made to use alternative metal contacts in InP metal semiconductor (MS) connections in order to alter the barrier height and accomplish its continuous control [15-17]. For example, Reddy [15] has investigated the interface properties and electrical measurements of Au/n-InP Schottky barrier diode (SBD) at room temperature and reported that the barrier height and ideality factor values change to be 0.59 eV and 1.22. The electrical properties of the Au/n-InP Schottky diode were studied by Cimilli et al. [16]. They found that the ideality factor ranges from 1.002 to 1.087 and the barrier height varies from 0.557 to 0.615 eV. The effective barrier heights of the Cu/n-InP and Au/n-InP Schottky diodes are 0.404 eV and 0.480 eV, respectively, as reported by Cetin and Ayyildiz [17].

To evaluate basic diode properties such as ideality factor and barrier height and compare with results of metal/n-InP Schottly diode contacts reported in the literature, we prepared the Ag/n-InP/In Schottky diodes. Based on three different measurement results, we discussed about the diode's current-voltage (I-V) properties. This work used the thermionic emission (TE) and Norde function to obtain the ideality factor (n), barrier height (Φ_b), saturation current

(I_0), series resistance (R_s), and interface state density (N_{ss}) parameters of the Au/n-InP/In type Schottky diode. The objective is to provide reliable and accurate measurements and to compare the results for different ways.

2. Experimental

In this work, the n-InP wafer has Sn doped, fabrication of LEC method, 450 µm thickness, and (1 0 0) surface orientation, and purchased from a University Wafer company. First, the n-InP semiconductor crystal was cleaned chemically to produce the Ag/n-InP/In Schottky diode. Using an ultrasonic titration device, the semiconductor crystal was degreased by washing it in trichlorethylene, acetone, and methanol sequentially for five minutes. To get rid of undesirable contaminants and surface defects, the degreased crystal was shaken in an H_2SO_4:H_2O_2:H_2O (5:1:1) solution for one minute. Indium (In) metal was evaporated and then annealed for three minutes at 300 °C in a N_2 environment to create the ohmic contact on the back side. Schottky contacts were created on the front face of the crystal as points with a diameter of roughly 2 mm by evaporating silver (Ag) metal. Every evaporation step was completed at a pressure of roughly 6×10^{-5} Torr in a vacuum coating equipment. Ag/n-InP/In Schottky diode was thus created (Figure 1). The produced diode's current and voltage were measured between -1 V and +1 V using a Keithley 2400 Sourcemeter,

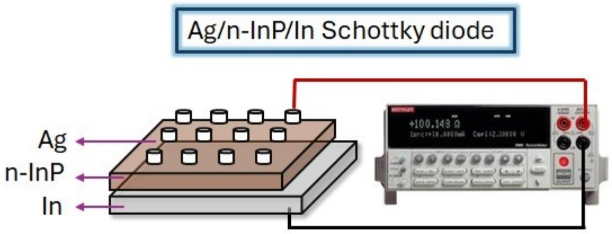

Figure 1: 3D view of Ag/n-InP/In Schottky barrier diode

3. Results

The experimental current-voltage (I–V) characteristics of the three Ag/n-InP/In Schottky barrier diodes are shown in Fig. 2. The three Ag/n-InP/In Schottky barrier diode's experimental semi-logarithmic current-voltage (I-V) characteristics are shown in Fig. 3. The produced diode exhibits rectification behavior, as seen in Figures 2 and 3, and its features can be studied more closely.

Using the relationship between the applied bias voltage V and the current I for thermionic emission, one can determine the Schottky barrier height, ideality factor, and saturation current of the device [10,14, 18]:

$$I = I_0\left[exp\left(\frac{q(V-IR_s)}{nkT}\right)-1\right] \quad (1)$$

where I_0 is the saturation, resistance, k is Boltzmann's constant, q is the electron charge, T is the temperature in K, and R_s is the series resistance.

$$I_0 = AA^*T^2exp\left[\frac{-q\Phi_b}{kT}\right] \quad (2)$$

Where A^* is Richardson constant for n-InP (9.4 Acm^{-2} K^{-2} [19]) and A is the area of diode. The ideality factor (n) and barrier height (Φ_b) values are calculated from the slope and intercept of the ln I-V graph. n and Φ_b are calculated using [10,14]:

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

$$\Phi_b = \frac{kT}{q}ln\left(\frac{AA^*T^2}{I_0}\right) \quad (4)$$

From Fig. 3, in both daylight and dark environments, it exhibits good rectifying behavior with soft reverse features. The series resistance effect causes the features to depart from linearity at increased bias. The determined I_0, Φ_b and n parameters are illustrated in Table 1. The rectification ratio (RR) for dark and daylight from Fig. 2 is calculated as 1098 and 1652, respectively. The fact that Table 1's n is more than 1 indicates that the manufactured diode is of non-ideal. Among the possible causes of this are interfacial states, leakage current, and series resistance [14].

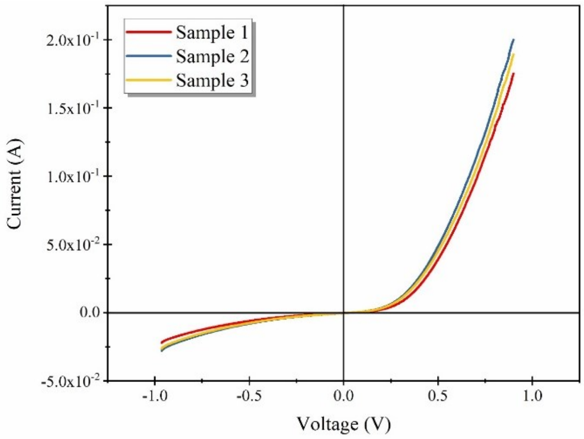

Figure 2: $I-V$ plots of the three Ag/n-InP/In Schottky barrier diodes at room temperature.

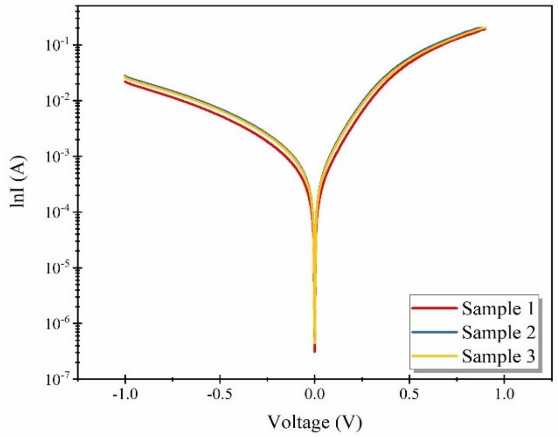

Figure 3: $lnI-V$ plots of the three Ag/n-InP/In Schottky barrier diodes at room temperature.

Table 1. The I_0, Φ_b and n values calculated from $lnI-V$ graphs of Ag/n-InP/In Schottky barrier diode at room temperature.

Sample	n	Φ_b (eV)	I_0 (A)
1	2.375	0.486	$1.35\text{x}10^{-4}$
2	2.373	0.477	$2.77\text{x}10^{-4}$
3	2.390	0.478	$2.61\text{x}10^{-4}$

The ideality factor values range from 2.373 to 2.390, while the obstacle height values computed in the dark at room temperature vary from 0.477 eV to 0.486 eV, as shown in Table 1.

The method employed in this study to compute diode attributes is the Norde method [20]. The following formulas can be used to compute barrier height and series resistance values using this method [20]:

$$F(V) = \frac{V}{\gamma} - \frac{kT}{q} ln(\frac{I(V)}{AA^{*}T^{2}}) \quad (5)$$

$$\Phi_b = F(V_{min}) + \frac{V_{min}}{\gamma} - \frac{kT}{q} \quad (6)$$

$$R_s = \frac{kT(\gamma - n)}{qImin} \quad (7)$$

where V_{min} and I_{min} are the lowest voltage and current, respectively, and $F(V_{min})$ represents the equivalent smallest value of $F(V)$. The Ag/n-InP/In Schottky barrier diode's first integer number larger than n is denoted by γ. Figure 4 shows the $F(V) - V$ graphs of the three Ag/n-InP/In Schottky barrier diodes. Table 3 shows the diode parameters derived from these graphs.

Table 3. Φ_b and R_s values determined from Norde graphs of Ag/n-InP/In Schottky barrier diodes.

Sample	$F(V_{\text{min}})$ (V)	Φ_b (eV)	R_s (Ω)
1	0.485	0.487	3.06
2	0.475	0.475	2.16
3	0.476	0.477	2.35

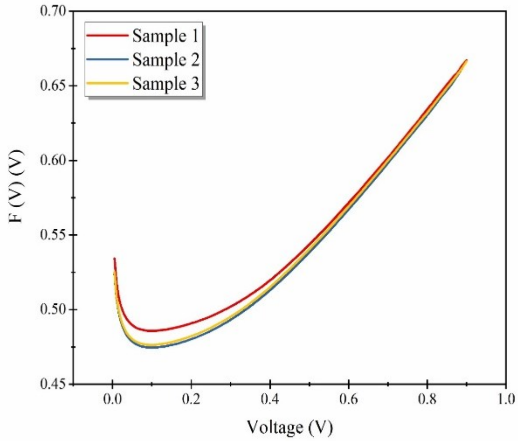

Figure 4: $F(V)-V$ graphs of the three Ag/n-InP/In Schottky barrier diodes.

The interface state density (N_{ss}) at the metal/semiconductor (M/S) interface is frequently caused by semiconductor surface defects such as doping bonds, oxygen vacancies, and structural rearrangements that are maintained by metallization, doping concentration atoms, and native or deposited interfacial layer. $E_c - E_{ss} = q(\Phi_b - V)$ can be used to compute the difference between the energy of the interface state density and the bottom boundary of the conduction band for an n-InP semiconductor (E_{ss}).

Figure 5 shows the energy dispersion of N_{ss}, derived from forward bias I-V measurements, as a function of $E_c - E_{ss}$. Also, Figure 5 and Table 4 show that the interface states density increases exponentially from the mid-gap to the conduction band's bottom. For example, for Sample 1, the density distribution of interface states for the Ag/n-InP/In Schottky diode changes from $9.50\text{x}10^{14}$ eV^{-1} cm^{-2} for $(0.307 - E_{ss})$ to $3.77\text{x}10^{14}$ eV^{-1} cm^{-2} for $(0.458 - E_{ss})$. The electrical properties of the Al/n-InP Schottky diode were studied by Güllü et al. [21]. They found that the density distribution of the interface states for the Al/n-InP Schottky diode changes from $3.67\text{x}10^{12}$ to $1.11\text{x}10^{12}$ eV^{-1} cm^{-2}.

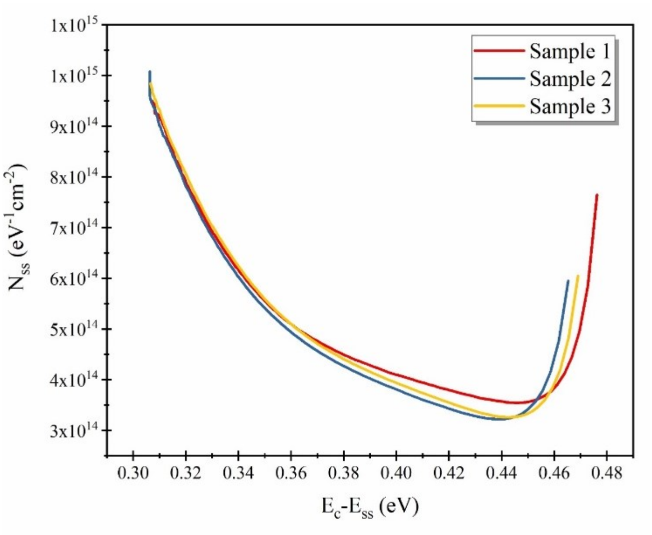

Figure 5: N_{ss}– $(E_c - E_{ss})$ graphs of the three Ag/n-InP/In Schottky barrier diodes.

Table 4. N_{ss}– $(E_c - E_{ss})$ values of Ag/n-InP/In Schottky barrier diodes.

Sample	$E_c - E_{ss}$ (eV)	N_{ss} (eV^{-1}cm^{-2}) x10^{14}
1	0.307 - E_{ss}	9.50
	0.458 - E_{ss}	3.77
2	0.306 - E_{ss}	9.73
	0.458 - E_{ss}	4.15
3	0.306 - E_{ss}	9.84
	0.462 - E_{ss}	4.20

4. Conclusion

In summary, room temperature I–V measurements have been used to examine the electrical characteristics of the Ag/n-InP/In Schottky diode. Some of the basic diode characteristics of the sample, including n, Φ_b, and R_s, were independently determined using thermionic emission (TE) and the Norde function. Three Ag/n-InP/In Schottky contacts have been calculated Schottky barrier height and ideality factor values in the range of 0.477-0.486 eV and 2.373-2.390, respectively. The impact of series resistance was determined to be negligible. A calculation of the interface state density (N_{ss}) for the Ag/n-InP/In Schottky diode was made and the interface states were obtained as 10^{14} eV^{-1} cm^{-2}.

Acknowledgement

The Scientific Research Projects foundation of Giresun University (FEN-BAP-A-090323-21) provided material funding assistance for this work.

References

[1] C.W. Wilmsen, Physics and Chemistry of III–V Compound Semiconductor Interfaces (New York: Plenum, 1985).

[2] P.H. Holloway and G.E. McGuire, Handbook of Compound Semiconductors: Growth, Processing, Characterization, and Devices (New Jersey: Noyes, 1995).

[3] M.S. Pratap Reddy, K. Sreenu, V.R. Reddy, and C. Park, J. Mater. Sci.: Mater. Electron. 28, 4847 (2017).

[4] Pande K P. Characteristics of MOS solar cells built on (n-type) InP substrates. IEEE Trans Electron Devices, ED-27:631 (1980).

[5] R L Van Meirhaeghe, W H Laflere and F Cardon, Influence of defect passivation by hydrogen on the Schottky barrier height of GaAs and InP contacts, J. Appl. Phys. 76 403 (1994).

[6] H. Çetin, E. Ayyıldız, and A. Türüt, “Barrier height enchancement and stability of the Au/n-InP Schottky barrier diodes oxidized by absorbed water vapor,” J. Vac. Sci. Technol. B 23(6), 2436 (2005).

[7] H. Çetin and E. Ayyıldız, “Temperature dependence of electrical parameters of the Au/n-InP Schottky barrier diodes,” Semicond. Sci. Technol. 20, 625–631 (2005).

[8] F. E. Cimilli, M. Sağlam, H. Efeoğlu, and A. Türüt, “Temperature dependent current voltage characteristics of the Au/n-InP diodes with inhomogeneous Shottky barrier height,” Physica B 404, 1558–1562 (2009).

[9] R.T. Tung, Recent advances in Schottky barrier concepts, Mater. Sci. Eng.: R 35, 1–138 (2001).

[10] E.H. Rhoderick, R.H. Williams, Metal-Semiconductor Contacts, 2nd edn. (Clarendon Press, Oxford, 1988), p. 124

[11] K. Ejderha, N. Yildirim, A. Turut, B. Abay, Infuence of interface states on the temperature dependence and current-voltage characteristics of Ni/p-InP schottky diodes. Superlattices Microstruct. 47(2), 241–252 (2010).

[12] İ Taşçıoğlu, U. Aydemir, and Ş Altındal, The explanation of barrier height inhomogeneities in Au/n-Si Schottky barrier diodes with organic thin interfacial layer. J. Appl. Phys. 108, 064506 (2010).

[13] Ö.F. Yüksel, N. Tuğluoğlu, H. Şafak, Z. Nalçacıgil, M. Kuş, and S. Karadeniz, Analysis of temperature dependent electrical properties of Au/perylene-diimide/n-Si Schottky diodes. Thin Solid Films 534, 614 (2013).

[14] S. Sze and K.K. Ng, Physics of Semiconductor Devices, 4th ed., (Wiley, 2006).

[15] V.Rajagopal Reddy, Electrical and interfacial properties of Au/n-InP Schottky contacts with nickel phthalocyanine (NiPc) interlayer, Indian J. Phys. 89(5):463–469 (2015).

[16]F.E. Cimilli, M. Sağlam and A. Türüt, Determination of the lateral barrier height of inhomogeneous Au/n-type InP/In Schottky barrier diodes, Semicond. Sci. Technol. 22 851 (2007).

[17] H. Çetin and E. Ayyildiz, On barrier height inhomogeneities of Au and Cu/n-InP Schottky contacts, Physica B 405 559 (2010).

[18] H.C. Card, E.H. Rhoderick, Studies of Tunnel MOS Diodes I. Interface Effects in Silicon Schottky Diodes. J. Phys. D 4, 1589 (1971).

[19] A.K. Bilgili, R. Çağatay. M.K. Öztürk, M. Özer, General electrical characterisation of Ag/TiO2/n-InP/Au Schottky Diode, Karadeniz Fen Bilimleri Dergisi 11(2), 328–339 (2021).

[20] K.E. Bohlin, Generalized Norde plot including determination of the ideality factor, J. Appl. Phys. 60, 1223 (1986).

[21] O. Güllü, M. Cankaya, V.R. Reddy, Barrier enhancement of Al/n-InP Schottky diodes by graphene oxide thin layer, Indian J. Phys. 93(4):467–474 (2019).