Calculation of Electrical Parameters of The Ag/SnO_2/n-InP/In Schottky Diode

M. Abdolahpour Salari, M. Odabaş, B. Güzeldir, M. Sağlam

Abstract— Tin oxide (SnO_2) belongs to the II - VI semiconductor family with a wide band gap of 3.5 eV. It has been revealed that SnO_2 is n-type direct band semiconductor. In this study, we have investigated the electrical characteristics of Ag/SnO_2/n-InP/In Schottky diode by using current – voltage (*I–V*) and capacitance - voltage (*C–V*) techniques at room temperature. Initially, the ohmic contact has been made on n - InP semiconductor with In metal. After this process the Tin oxide (SnO_2) interface layer was grown with dc magnetic sputter technique on the n - InP semiconductor substrate, and then the contact area is determined by sputtered Ag metal to surface of InP in DC sputtering system at about 10^{-6} Torr. The *I–V* and *C–V* measurements of diode performed by the use of a KEITLEY 487 Picoammeter/ Voltage Source and HP 4192A (50–13 MHz) LF Impedance Analyzer at room temperature and in dark, respectively. The electrical parameters of this diode such as ideality factor and the barrier height values are calculated from I-V measurements and the carrier concentration, Fermi energy and the diffusion potential and barrier height values were extracted from reverse bias C^{-2}–V measurements at various frequencies and room temperature by using thermionic emission theory.

Index Terms— Interface layer, InP, Schottky diode, Tin oxide.

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1 INTRODUCTION

During the last decades, the researchers in physics and electronics are interested by the performance and the microelectronics reliability of metal-insulator semiconductor Schottky diodes particularly depend on the formation of an insulator film, active metal/semiconductor interface, and the interface states distribution at the semiconductor, series resistance, insulator interface and inhomogeneous barrier heights.

Tin oxide has been revealed that SnO_2 is n-type direct band semiconductor and lately became a p-type material especially when it was doped with aluminum, zinc or indium [1,2]. Several applications of SnO_2 such as light emitting diodes and gas sensors have been mentioned [3,4]. In this study, we studied the electronic properties of SnO_2 deposited onto a n-type Indium phosphide substrate by DC magnetron sputtering system. In this work we investigate some electrical characteristics of Ag/SnO_2/n-InP/In Schottky diode by means of I–V and C–V measurements.

2 EXPERIMENTAL

n-InP wafer piece of (100) orientation were used in this study. The InP wafer were chemically cleaned using the cleaning procedure (i.e., 1 min washing in $5H_2SO_4+1H_2O_2+1H_2O$ followed by 1 minutes in $1HCl+10H_2O$) before making contacts. Preceding each cleaning step, the sample was rinsed thoroughly in deionized water of 18.2 MΩ cm resistivity with ultrasonic vibration for 5 min and was finally dried by high purity nitrogen (N_2) atmosphere.

Ohmic contact is made by In metal on the non-polished side of the n- InP wafer piece, and then this diode was immediately inserted into the DC magnetron sputtering system to form the SnO_2 thin film. After this process, the contact area is determined by sputtered Ag metal to surface of SnO_2 in DC sputtering system. Schottky contact was formed when vacuum was decreased by 10^{-6} Torr. In this way, the Ag/SnO_2/n-InP/In Schottky diode was obtained and then the electrical characteristics studies were performed.

3 RESULTS

Figure 1 shows the forward and reverse bias I–V characteristics of the diode. According to thermionic emission theory, forward bias current of a Schottky diode depending on the applied potential that calculated by current equation [5]. The values of ideality factor and barrier height are obtained from the corresponding equations [5]. Effective Richardson constant is 9.8 A/K^2cm^2 for n type InP. The ideality factor (*n*) value, the forward bias is determined from the slope of the linear region of the ln-V characteristic. The value of 1.92 and $5.712X10^{-8}$ For n and I0 for the Ag/SnO_2/n-InP/In, respectively, were obtained from the semi-logarithmic forward bias I vs. The value of barrier height for this diode calculated as 0.66 eV. The high value of n can be attributed to effects of the bias voltage drop across the interfacial native oxide layer and series resistance, therefore, of the bias voltage dependence of the barrier height [6] - [16].

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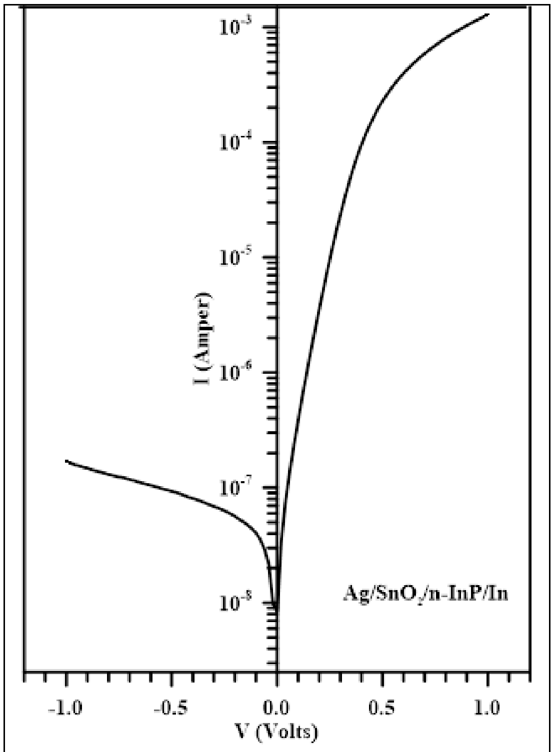

Fig. 1. The forward and reverse bias I–V characteristics of the Ag/SnO$_2$/n-InP/In structure.

The Schottky barrier height can be determined from the reverse-biases capacitance-voltage measurements too. It is determined from the x-axis intercept of the $1/C^2$ versus V. By plotting the $1/C^2$ versus V, one can determine the built-in voltage by a linear extrapolation to the V axis.

Capacity of the depletion region C =|dQ/dV| (per unit area) is given as follows;

$$C= [qN_D\epsilon_s/2(V_{bi}-V_{ex}-(kT/q))]^{1/2}= \epsilon_s/w \qquad (1)$$

Where N_D is the carrier concentration, εs is the dielectric constant of the semiconductor, V_{bi} is the built-in potential, V_{ex} is the extra potential applied in the diode from outside, and w is the width of the depletion region. The concentration of the doping is found by the slope of the $1/C^2$ graph,

$$N_D=2/q\epsilon_s[d(1/C^2)/dV_{ex}]^{-1} \qquad (2)$$

and the built-in voltage Vbi is found by extrapolation of the $1/C^2$ graph to V = 0. From here, the Schottky barrier height can be calculated as;

$$\Phi_b = V_{bi}+ V_n+ kT/q- \Delta\Phi \qquad (3)$$

There is a relationship between V_{bi} and diffusion potential;

$$V_D = V_{bi}+ kT/q \qquad (4)$$

Where kT/q is the thermal energy in eV.

The C-V barrier height of the diodes is given by;

$$\Phi_b = V_D+ E_F \qquad (5)$$

Also the Fermi energy level can be calculated using the following equation;

$$E_F = kT\ln(N_C/N_D) \qquad (6)$$

Fig. 2 show the forward and reverse bias C–V and reverse bias C^{-2}–V characteristics of this diode at various frequencies. The origin of peak that appeared in the forward C-V region in fig. 2 has been ascribed to the series resistance effect by Chattopadhyay [8]. The high-frequency capacitance (C) measured under both forward and reverse bias was corrected for the effect of series resistance to obtain the diode capacitance, C.

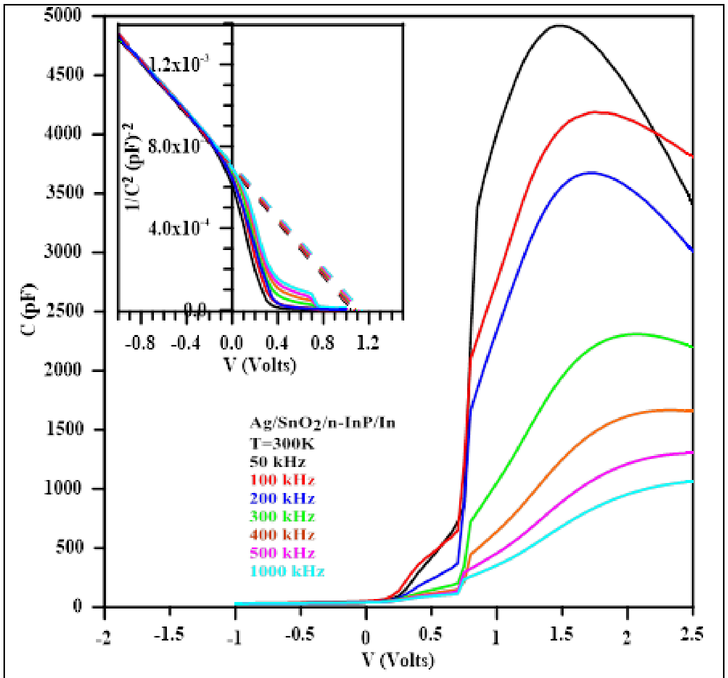

Fig. 2. The forward and reverse bias C–V and reverse bias C^{-2}–V characteristics of the Ag/SnO_2/n-InP/In structure at various frequencies.

As has been seen, the C^{-2}-V characteristics curve have Φ_b value higher than that derived from I-V characteristics as expected. Although this discrepancy could be explained by the existence of excess capacitance at Schottky contacts due to an interfacial layer or to trap states in the semiconductor, the existence of Schottky barrier height (SBH) inhomogeneity offers another explanation [17].

The values of n, I_0, Φ_b, V_D, N_D, E_F and Φ_b calculated are given in Table 1 for Ag/SnO_2/n-InP/In diode.

TABLE 1
THE CHARACTERISTIC PARAMETERS OF THE AG/SNO_2/N-INP/IN STRUCTURE OBTAINED FROM I-V AND C-V CHARACTERISTICS.

I-V			C^{-2}–V				
n	I_0 (A)	Φ_b (eV)	f(kHz)	V_D(eV)	N_D (cm^{-3})X 10^{14}	E_F(eV)	Φ_b(eV)
1.92	5.712X10^{-8}	0.66	50	1.04	2.95	0.1959	1.23
			100	1.06	2.96	0.1958	1.25
			200	1.07	2.99	0.1956	1.26
			300	1.08	2.99	0.1956	1.27
			400	1.09	2.99	0.1956	1.28
			500	1.11	3.03	0.1952	1.30
			1000	1.13	3.07	0.1948	1.32

4 CONCLUSION

The ideality factor, which is an important parameter that determines the quality of the diode, is unitless and it should be 1 for an ideal diode [18]. In this work the value of the ideality factor is greater than unity. High values of n can be attributed to the presence of the interfacial thin native oxide layer at Ag and SnO_2 interface. The reverse bias C^{-2}-V graphs are linear and show the formation of the Schottky junction. As can be seen from the graphs, the slope of the C^{-2}-V curves decreases with increasing frequency. This may be due to the lack of contribution of the interface state loads to the diode capacitance or to the fact that the loads in the interface states cannot follow the alternating current signal. At low frequencies, all interface states affected by the application signal can respond to this signal, while charge at high frequencies may not respond to this signal. The interface state capacitance appears parallel to the depletion capacity, and consequently for Schottky diodes it causes the total value of the capacitance to be higher. At medium frequencies, some interface state charge is incorporated into small signal measurements and the observed values of capacitance can be measured between low and high-frequency values. If the capacitance measurements are made at sufficiently high frequencies, the interface state charge cannot contribute to the diode capacitance.

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