Temperature Dependence of Current-Voltage (I-V) and Capacitance-Voltage (C-V) Characteristics of Zn/Au Schottky Contacts on P-Inp

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The Electrical properties of Zn/Au on P-InP has been measured in the temperature range of 180K-420K. The Current- Voltage (I-V) and Capacitance - Voltage (C-V) characteristics are drawn from the barriers height, ideality factor and series resistance are determined. The barrier height increases from 0.35 eV to 0.50 eV and ideality factor decreases from 2.25 to 1.45 in the temperature range 180K-420K respectively. The value of Richardson constant is 5.64 x 10^{-6} A cm^{-2} K^{-2}, which is much lower than the known value of 9.4 A cm^{-2} K $^{-2}$ explains that the current transport mechanism must be primarily due to thermionic emission. The mean barriers height Φ_{bo} (T=OK) is 0.83 eV and standard deviation □ o is 139 meV indicates that the greater inhomogeneities at the interferace and thus potential fluctuation.

1. Introduction

Indium phosphide (InP) and the other related materials are useful materials for fabrication of Opto-Electronics, Metal-Semiconductor Schottky Barrier Diodes (SBDs) and High-Frequency Microwave Device [1]. In several reviews on InP-based devices and applications, Fast Response Heterojunction Bipolar Transistors, High Electron Mobility Transistors, Advanced Chip Integration and Fabrication Nanoscale Electronic and Opto-Electronics [2]

A self consistent method of analysis is reported to determine the characteristic parameters of MIS diodes, using simultaneously Current-Voltage (I-V) and Capacitance – Voltage (C-V) data as a function of temperature. This computational analysis has been used to examine the current transport mechanism in an Au/P-InP epitaxial MIS diode. The interfacial layer – thermionic emission was clearly the dominant mechanism of the forward current transport in an MIS fabricated on a lightly doped InP-Zn epitaxial layer [3].

The Current - Voltage characteristics Schottky contacts are described by two fitting parameters such as effective barrier height and ideality factor. Due to lateral inhomogeneities of the barrier height, both characteristic diode parameters differ from one diode to another. We have determined the lateral homogeneous barrier height of the SBDs from the linear relationship between experimental barrier heights and ideality factors that can be explained by lateral inhomogeneity of the barrier height. Furthermore the barrier heights of metal-semi conductor contacts have been explained by the continuum of Metal Induced Gap States (MIGS). It has been seen that the laterally homogeneous barrier heights obtained from the experimental data of the metal/P-type InP Schottky contacts quantitatively confirm the predictions of the combination of the physical MIGS and the chemical electronegativity [4].

It is known from standard technical practice that the fabrication of reliable Au-Zn Ohmic contacts to III-V compound semiconductors by the classical method of vaccum evaporation of Au-Zn alloy can be connected with some serious technological problems, such as during the annealing the Zn out diffusion from contacts, the preferential evaporation of Zinc prior to gold, poor adhesion and nonhomogeneiy of Au-Zn deposits [5]. Special techniques have been used to overcome these problems, for example the deposition of a very thin nucleation layer of low vapour pressure metals prior to Au-Zn [6], the application of a diffusion barrier layer [7-11]

In this paper we are designed the Zn/Au P-InP Schottky diode. The Current-Voltage-Temperature (I-V-T) characteristics and Capacitance – Voltage (C-V) Characteristics are drawn. The Schottky Barrier Diode parameters such as barrier height and ideality factor and series resistance are measured as a function of temperature.

2. Experimental Details

Liquid Encapsulated Czokralski (LEC) grown undoped P-InP samples with carrier concentration of ~ 4.5 x $10^{15}cm^{-3}$ are used in the present work. The samples are initially degreased with organic solvents like trichloroethylene, acetone and methanol by means of ultrasonic agitation for 5 Min. in each stage to remove contaminants followed by rinsing in deionized water and then dried in N_2 flow. The samples are then etched with HF (49%) and H_2O (1:10) to remove the native oxides from the substrate indium ohmic contacts of thickness 500A^o are formed on the rough side of the InP wafer prior to Schottky Diode fabrication at a pressure of 7x10^{-}

[6]mbar and are annealed at 350 for 1 min in N_2 atmosphere. For making Schottky contacts, the metals Zn/Au of 500A° each using stainless steel mask of diameter 0.7 mm are deposited on the polished side of InP Wafer. The Current - Voltage (I – V).Characteristics of the as deposited Zn/Au Schottky contact to P-InP are measured in the temperature range of 180-420K by automated DLS-83D spectrometer (Semi Lab, hungary). The Zn/Au Schottky samples are annealed in the temperature range of 180K to 420K for duration of 1 min in N_2 flow using Rapid Thermal Annealing (RTA) system. The Current-Voltage (I-V) and Capacitance-Voltage (C-V) characteristics are measured using automated DLS-83D Spectrometer.

3. Results and discussion

The forward and reverse current voltage characteristics of Zn/Au Schottky contact to P-InP in the temperature range of 180-420K as shown in

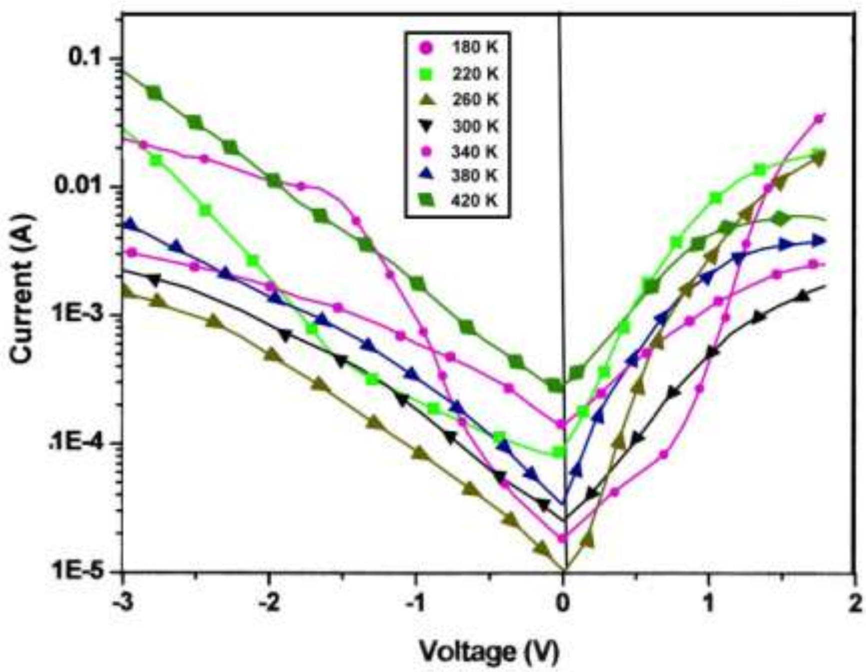

Fig (1) : Temperature dependence of Current – Voltage Characteristics of Zn/Au Schottky contact P-InP in the temperature range of 180 – 420 K.

Fig (1). For Schottky diode, according to thermionic emission theory predicts that the Current – Voltage characteristics is given by [12,13]

$$I = I_s\left[exp\left[\frac{-qv}{nkt} - 1\right]\right] \quad ....1\ (1)$$

Where $$I_s = AA^*T^2 \exp\left(\frac{-q\phi_b}{kT}\right) .... (2)$$

Where I_s is the reverse saturation current, q is the electron charge, V is the applied Voltage, n is the ideality factor, k is the Boltzmann constant, T is the absolute temperature and A is the contact area of the diode. The idelity factor n is given by

$$n = \frac{q}{kT}\left[\frac{dv}{d\ln I}\right] .... (3)$$

A* is the effective Richardson constant and Φ_b is the Schottky barriers height.

The reverse saturation current is determined from the intercept of a plot of $I / \left[1 - \exp\left(-\frac{qv}{kT}\right)\right]$ Versus V measured in the temperature range of 180-420K is shown in Fig(2) and its value is used to determine the barriers height Φ_b for the contacts using the equation.

$$\phi_b = \frac{kT}{q} In\left[\frac{AA^*T^2}{I_S}\right] \qquad (4)$$

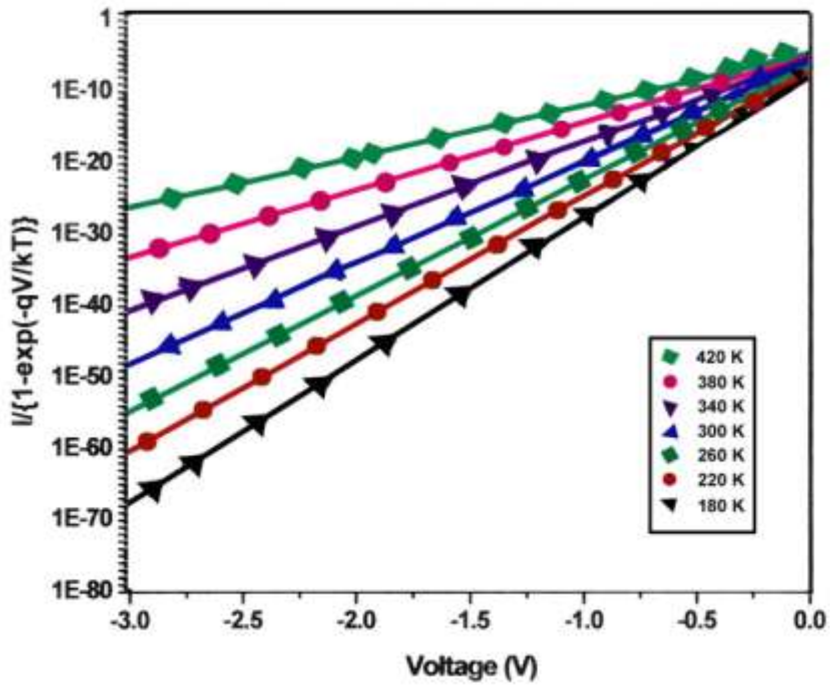

Fig (2) : Plot of In [I/{1-exp(-qV/kT)}] versus V for the Zn/Au Schottky contact to P - InP.

The ideality factor is obtained from the linear portion of the plot between natural log of current and voltage over two orders of magnitudes. The barrier height is increased linearly with increase in temperature and shown in Fig (3). The Ideality factor versus temperature graph is shown in Fig (4) indicates that the increase of ideality factor with decrease of temperature.

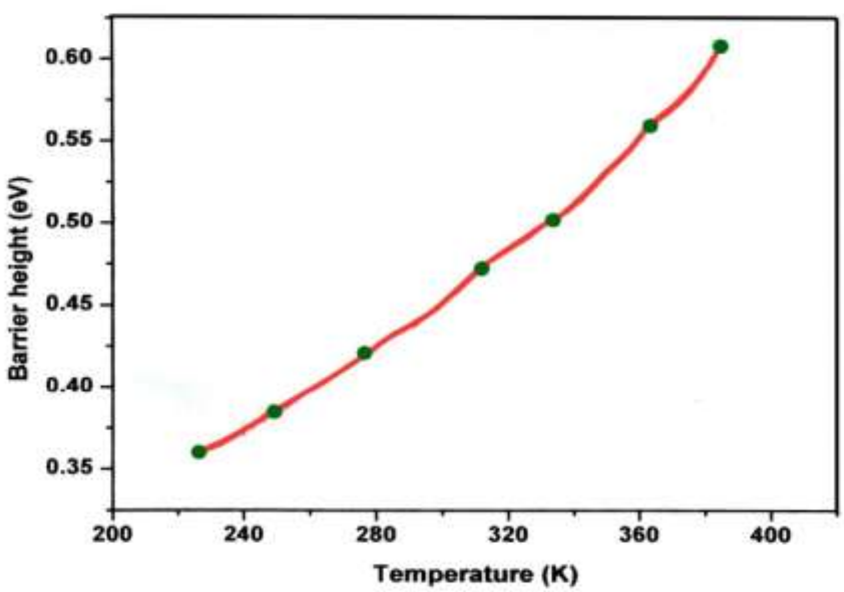

Fig (3) : Plot of Schottky barrier height versus temperature for Zn/Au Schottky contact to P- InP.

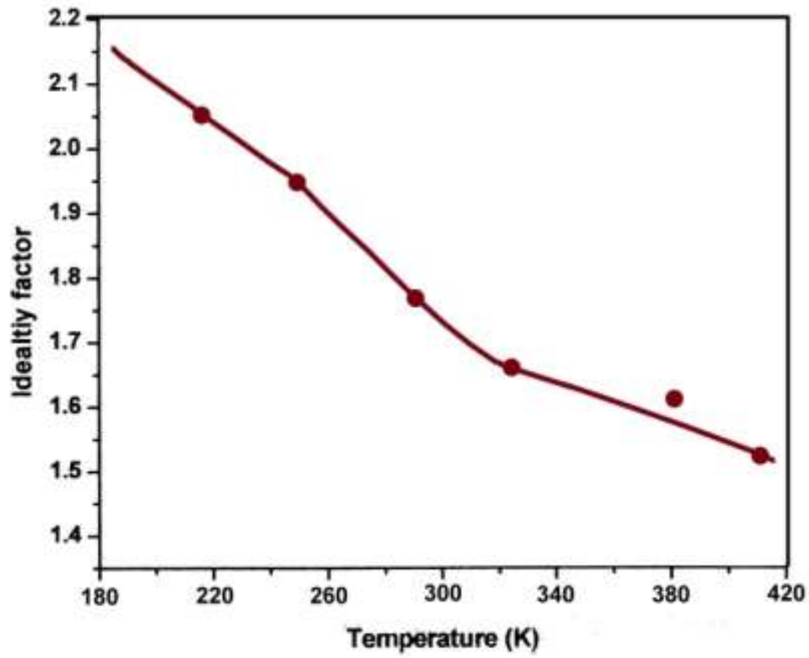

Fig (4) : Plot of ideality factor versus temperature for Zn/Au Schottky contact to P - InP.

The Richardson plot drawn between ln (Io/T^2) and $10^3/T$ used to obtain the zero bias barrier height and Richaradson constant as shown in Fig(5) equation (2) can be rewritten as

$$I_S = AA^* T^2 \exp\left(-\frac{q\phi_b}{kT}\right) \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The plot in ln versus $10^3/T$ is a straight line whose slope can be used to calculate the barrier height at 0K and the intercept (I_s / T^2) gives the Richardson constant (A*). The value of A* obtained from the intercept of the linear portion of the ordinate is 5.64 x 10^{-6}A $cm^{-2}k^{-2}$. Which is much lower than the known value of 9.4 A $cm^{-2}k^{-2}$. Barrier height value of 0.18 eV is obtained from the slope of the straight line.

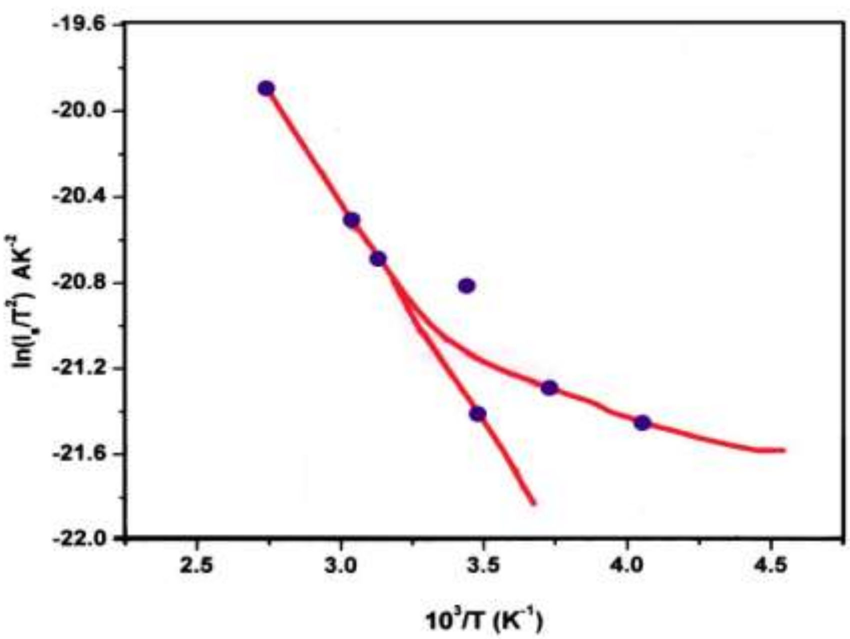

Fig (5) : Richardson plot of In (I_S/T^2) against $10^3/T$ for Zn/Au Schottky contact to P – InP.

The nonlinearity in the Richaradson plot may be due to spatially inhomogeneous barrier height and potential fluctuation at the interface that consists of low and high barrier areas, that is, the current through the diode will be preferentially through the low barriers in the potential distribution [14]. The results obtained are in consistent with the potential fluctuation model.

3.1 Barriers height variation with ideality factor:

The barrier height decreases as the ideality factor increases are shown in Fig (6). An apparent decrease in barrier height and increase in ideality factor at low temperature are possibly caused by some other effects such as inhomogeneities in thickness and composition of the layer, non-uniformity of the inferfacial charges or the presence of a thin insulating layer, between the metal and the semiconductor. At low temperature, the current will be dominated by the current through the patches of low barrier heights because the current transport across the metal-semi conductor interface is a temperature – activated process.

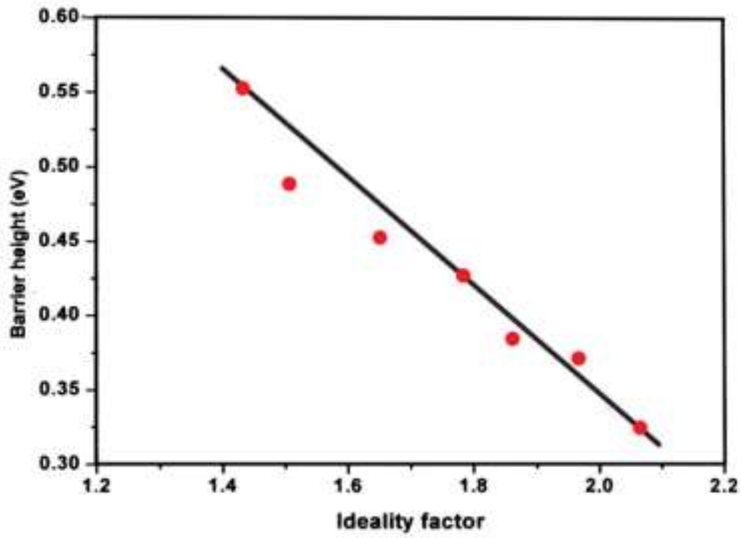

Fig (6) : Zero – bias apparent barrier height versus ideality factor of Zn/Au Schottky Contact to P-InP.

The extrapolation of the experimental barrier height versus ideality factor plot to n=1 gives a homogeneous barrier height (□$_b$ ^{hom}) of approximately 0.98 eV. Thus it is noticed that the significant decrease of the zero-bias barrier height and increase of the ideality factor especially at low temperature may be due to barrier inhomogeneities.

3.2 Variation of flat band barrier height with temperature

The barrier height obtained from equation 3.4 is called as apparent or zero-bias barrier height. The variation of the flat band barrier height of the Zn/Au Schottky contact to p-InP calculated from Current-Voltage barrier height and the corresponding ideality factor at each temperature is shown in Fig (7). The barrier height obtained under flat band condition is considered to be real quantity. Unlike the case of zero-bias barrier height, the electric field to zero under flat band condition. This eliminates the effect of the image force lowering that would affect the current voltage characteristics and removes the influence of lateral inhomogeneity [15].

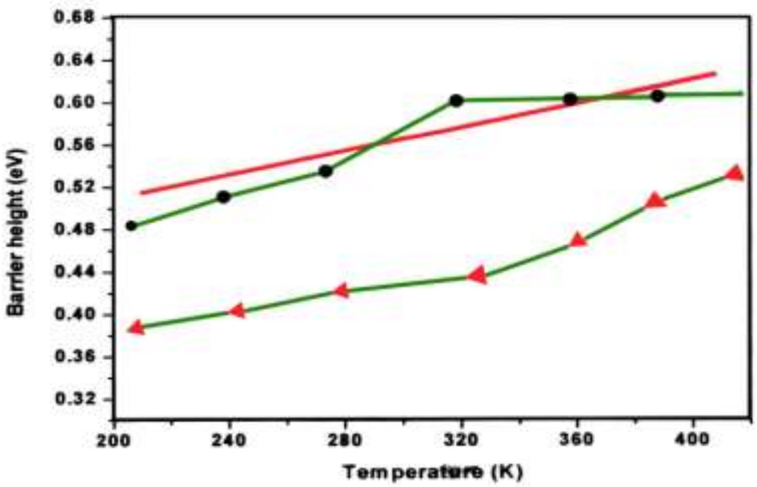

Fig (7) : Plot of variation of the flat – band barrier height and apparent barrier height with temperature for Zn/Au Schottky contact to P-InP.

The Flat band barriers height Φ_{bf} can be calculated using the experimental ideality factor and zero bias barriers height Φ_{bo} is given by [16]

$$\phi_{bf} = n\phi_{b0} - \ n-1 \ \frac{kT}{q}\left[\frac{N_C}{N_D}\right]...........(6)$$

Where N_c is the density of states in the conduction band and N_D is the donor concentration. The temperature dependence of flat-band barrier height can be expressed as

$$\phi_{bf}(T)=\bar{\phi}_{bf}(T=0K)-\alpha T..............(7)$$

Where Φ_{bf} (T=OK) is the flat band barriers height extrapolated to 0K and α is the temperature coefficient. From the slope and intercept of the least square fit of the Φ_{bf}(T) data in the temperature rane 180-420 K gives the values of Φ_{bf} and α. The values obtained are Φ_{bf} (T=0K) is 0.31 eV and α is 8.63291×10^{-4}eV/K.

3.3 Temperature dependent of series Resistance

Temperature dependence of series resistance affect the electrical properties of the Zn/Au Schottky contact to p-InP is measured in the temperature range of 180-420K. The forward bias Current - Voltage characteristics due to thermionic emission of a Schottky contact with the series resistance can be expressed as cheungs function [16] given by

$$\frac{dv}{d\ \ InI} = IR_S + n\left[\frac{kT}{q}\right]....................(8)$$

The plots of experimental dv/d (ln I) versus I for different temperatures are shown in Fig (8) the series resistance value (Rs) is obtained from the slope and nkT/q value from the Y-intercept. The series resistance decreases with increase in temperature. The decrease in series resistance is more at low temperatures than at high temperatures, since the slope of the curve is large at low temperatures Fig (9) the variation of R_s with temperature may be due to the factors responsible for the increase in ideality factor n and lack of free carrier concentration at low temperatures [17].

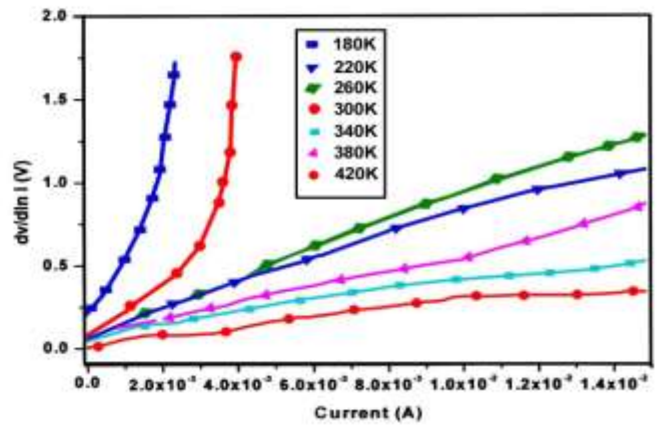

Fig (8) : Plots of d V/dln (I) versus current Zn/Au Schottky contact to P – InP at various temperatures.

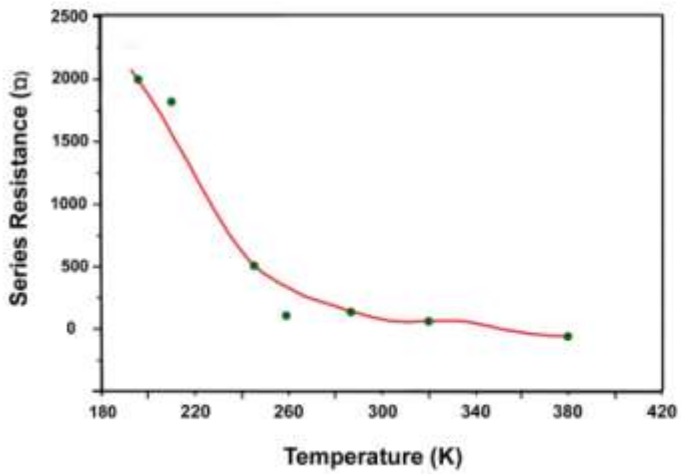

Fig (9) : Temperature dependence of the series resistance for Zn/Au Schottky contact to P-InP.

The barriers height, ideality factor and series resistance of Zn/Au Schottky contact as a function of temperature are shown in the table-1.

Table-1. The values of barrier height, ideality factor and series resistance of Zn/Au Schottky contact to p-InP as function of temperature

Temperature (K)	Barriers height (eV)	Ideality factor (n)	Series Resistance (Ω)
180	0.35	2.25	2405
220	0.37	1.97	2126
260	0.40	1.83	121
300	0.42	1.71	118
340	0.46	1.63	71
380	0.56	1.56	19
420	0.50	1.45	39

3.4 Analysis of inhomogeneous barriers height.

The Gaussian distribution of barrier height over the Schottky contact area can be explained with the mean barrier height Φ_{bo} (T=OK) and standard deviation $\square_o$. The standard deviation is a measure of the barrier inhomogeneity.

According to Gaussian distribution, the expression for the barrier height is given by [18, 19]

$$\phi_b = \phi_b \; T = 0K \; - q\sigma^2 / 2kT \; ....(9)$$

Where Φ_b is the apparent barrier height measured experimentally. The temperature dependence of □$_o$ is usually small and can be neglected. The observed variation of ideality factor in the model is given by [20].

$$1/n_{ap} - 1 \; = -\rho_2 + \; q\rho_3 / 2kT \; ....(10)$$

The n_{ap} is apparent ideality factor (Experimental data) ρ_2 and ρ_3 and quantify the voltage deformation of the barrier height distribution. The experimental Φ_b versus 1/2 kT is a straight line with the intercept on the ordinate determining the zero mean barriers height $\overline{\phi_{bo}}$ (T=OK) and the slope is used to evaluate the zero bias standard deviation □$_o$ The values obtained are 0.83 eV and 139 meV respectively for $\overline{\phi_{bo}}$ (T=OK) and □$_o$ respectively as shown in fig (10) .

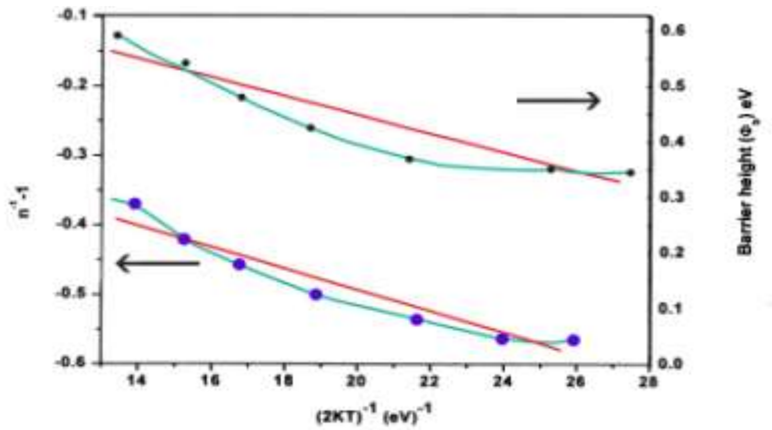

Fig (10): Zero – bias apparent barrier height (the solid circles) and ideality factor (the filled squares) versus $(2kT)^{-1}$ curves of the Zn/Au Schottky contact to P-InP according to the Gaussian barrier height.

Conclusion:

The effect of annealing temperature on the electrical properties of Zn/Au Schottky contacts to P-InP have been investigated by Current-Voltage (I-V) and Capacitance-Voltage (C-V) measurements. The barrier height and ideality factor changes from 0.35 eV and 2.00 at 180K to 0.50 eV and 1.45 at 420K respectively. The homogeneous barriers height (Φ_b^{hom}) of approximately 0.98 eV has been obtained from the linear relationship between experimental barrier height and ideality factor. The Richardson constant from the intercept of the linear portion of the ordinate is 5.64 x 10^{-6}. A $cm^{-2}K^{-2}$. The slope and intercept of the least square fit of Φ_{bf} (T) data in the temperature range 180-420K is the flat band barrier height Φ_{bf} (T=OK) is 0.31 eV and the temperature co-efficient α

is 0.863291 x 10^{-4} eV/K.

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