Effect of Rapid Thermal Anneling on Electrical Properties of Er/P-Inp Schottky Barrier Diode

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The temperature dependence of Current – Voltage (I-V) and Capacitance - Voltage (C-V) characteristics of Er Schottky contact on P-InP Schottky Barrier Diodes (SBD's) have been systematically investigated in the temperature range of 180-420K in the step of 40K. The Schottky Barrier Heights (SBHs) of Er Schottky contact P-InP for as deposited sample in Current - Voltage (I-V) characteristics is 0.71 eV and in Capacitance - Voltage (C-V) characteristics is 0.96 eV. By increasing temperature from 180 - 300 K the schottky barriers height decreases and then increases by increasing the temperature in the range 340-420K.

1. Introduction.

P- type indium phosphide and related compounds, have become important for high speed electronic [1] and optoelectronic devices [2], such as High Electron Mobility Transistors (HEMTs), Photo Diodes (PDs) and Laser Diodes (LDs) [3]. High Power density, high operational speed and reliability are the most important factors determining the materials science issues of the components used in these thin metal based layers [4]. Also, InP is important material for the fabrication of solar cells for space applications due to high conversion efficiency and radiation resistance [5-7].

The device which is used InP as substrate characteristics such as $\phi_{BP} > \phi_{Bn}$ *and* $\rho_{cn} < \rho_{cp}$ interdiffusion between P- InP and contact metal and their electrical chartacteristics is important for improving parameters of the devices and their reliability [8].

Rare - earth element Er has low work function values 3.2 eV and pauling electronegativity 1.2, thus forms low SBs on n-Si (0.3eV) and n- GaAs 0.68 eV [9] but high SBs on P-Si (0.68 eV) and P-GaAs (0.85 eV) [10] in contact to the normal case for Si or GaAs SBs, i.e., the schottky barrier heights (SBHs) for the same metal deposited on n-Si and n-GaAs are obviously larger than those on P-Si and P-GaAs, respectively [11] Chu et at [12] formulated a phenomenological theory based on a linear combination of the thermionic emission transport mechanism and the field emission (tunneling) transport mechanism to explain the temperature dependence of Pt/Ti Ohmic contact to P-InGaAs [13} [14]. The main diode parameters, ideality factor and zero bias barrier height (apparent barrier height) were found to be strongly temperature dependent while zero bias barrier height decreases and ideality factor n increase with decreasing temperature. According to thermionic emission theory (TE), the slope of the conventional Richardson plot should give the barriers height. However, the experimental data obtained do not correlate well with a straight line below 160K. This behaviour has been interpreted on the bias of standard TE theory and the assumption of a Gaussian distribution of barrier heights due to barrier inhomogeneties that persist at the metal-Semiconductor interface. The linearity of the apparent barrier height versus 1/(2kT) plot that yields a mean barrier height of 0.52 eV and standard deviation of 0.06 eV, was interpreted as an evidence to apply the Gaussian distribution of the barrier height [15].

In the current work Er/P-InP Schottky diode was fabricated. The Current-Voltage-Temperature (I-V-T) measurements are used to explain the current transport mechanism and inhomogeneity in barrier and to estimate Schottky Barrier Diode parameters such as the barrier height and ideality factor as 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}. The samples are initially degreased with organic solvents like trichloroethylene, acetone and methanol by means of ultrasonic agitation in sequence for 5 min each to remove contaminants and rinsed in deionised 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. The samples are loaded into electron beam evaporation system and indium ohmic contacts of thickness 500 A^0 are formed on the rough side of the InP wafer under a pressure of 7x10^{-6}m bar. The samples are then annealed at 350^0c for 1 min in N_2 atmosphere. Er (30nm) Schottky contacts are deposited on P-InP using stainless steel circular mask of diameter of 0.7 mm on the polished side using electron beam evaporation system at a pressure of 5x10^{-6}mbar. The Er Schottky contacts are rapid thermal annealed in the temperature range of 180K to 420K for duration of 1 min in N_2 flow. The Current - Voltage (I-V) and Capacitance – Voltage (C-V) characteristics are measured using DLS – 83D spectrometer.

3. Results and discussion:

The typical Current - Voltage (I-V) characteristics of Er Schottky contact of P-InP as a function of annealing temperature are shown in fig (1).

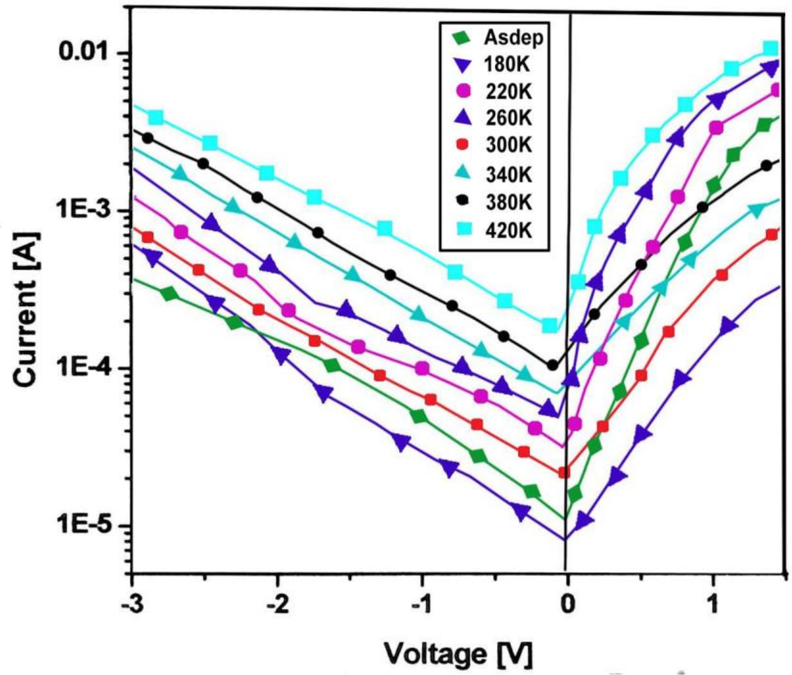

Fig (1) : I-V Characterostics of Er Schottky contacts to P – InP as a function of annealing temperature.

The thermionic emission theory for charge transport in Schottky structures is used to analyze the data. The dependence of current on the applied voltage V according to the thermionic emission theory is given by

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

Where q, n, k and T are respective the electron charge, the ideality factor, the Boltzmann Constant and the absolute temperature. Neglecting the tunneling effects and barriers lowering due to Schottky effect, the barriers height ϕ_b can be determined from the saturation current I_S using equation.

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

Where A the contract area, ϕ_b Is the barriers height A*, the effective Richardson Constant.

The plot of $ln\left[I/(1 - enp\left(-\frac{qv}{kT}\right)\right]$ Versus V as shown in Fig (2) are linear and their intercept is I_o

Equation 2 is rearranged to obtain the barriers height (ϕ_b) is given by

$$\phi_b = \frac{kT}{q}\ln\left[\frac{AA^*T^2}{I_s}\right] \quad .... (3)$$

The barrier, height is increased linearly with increase in temperature from 180-420K as shown in fig (3)

The ideality factor n is given by

$$n = \frac{q}{kT}\left[\frac{dv}{d\,(\ln I)}\right] ....(4)$$

Where q is the electronic charge, V is the applied voltage, I is the corresponding current, K is the Boltzmann Constant, T is the absolute temperature. The ideality factor versus temperature plot as shown in fig. (4) which shows the decrease of ideality factor with increase of temperature barrier height variation with ideality factor.

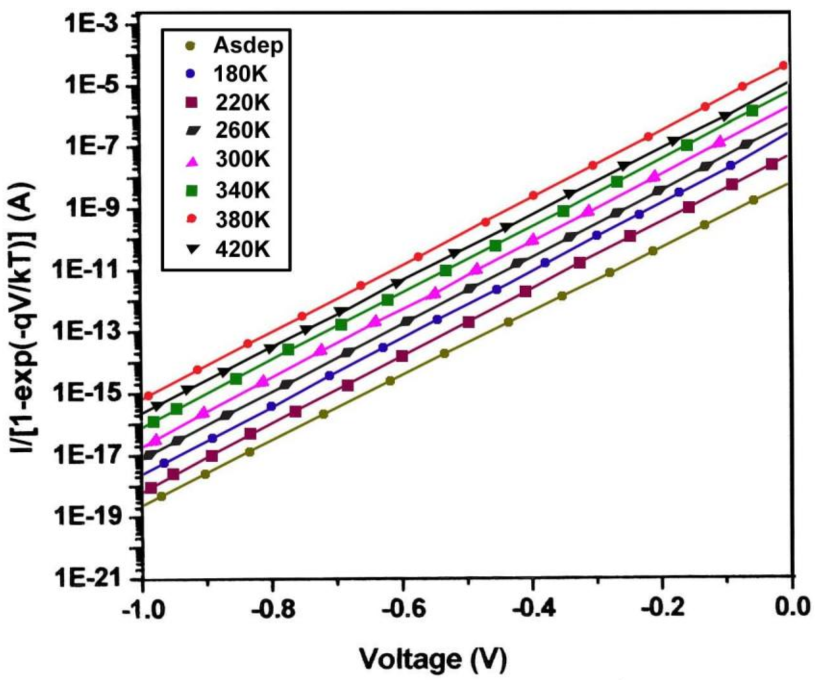

Fig (2) : Plot I/[1-exp (-qV/nkT)] versus V for Er Schottky contacts to P-InP annealed at different temperatures.

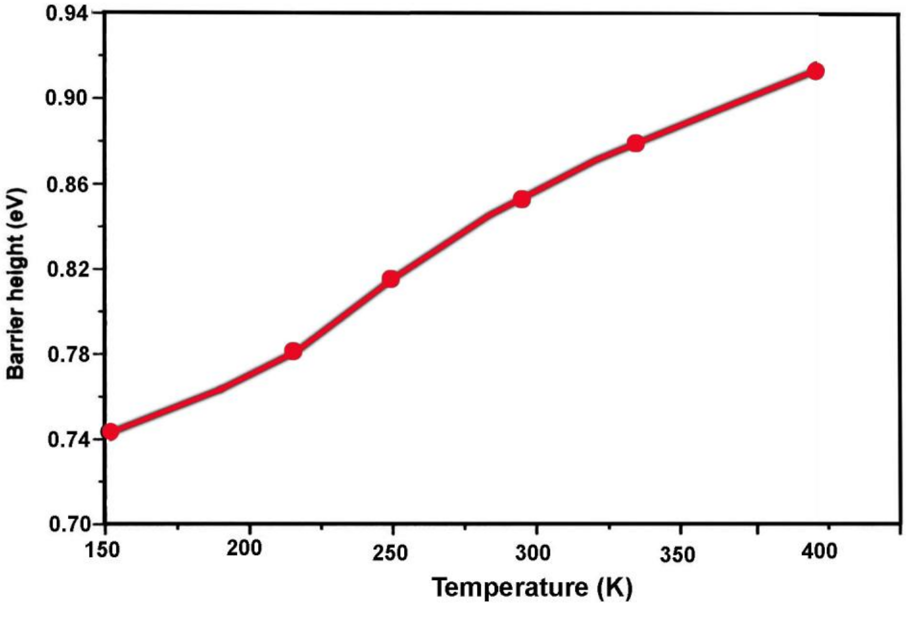

Fig (3) : Plot of Schottky barrier height versus temperature for Er Schottky contact to P – In P.

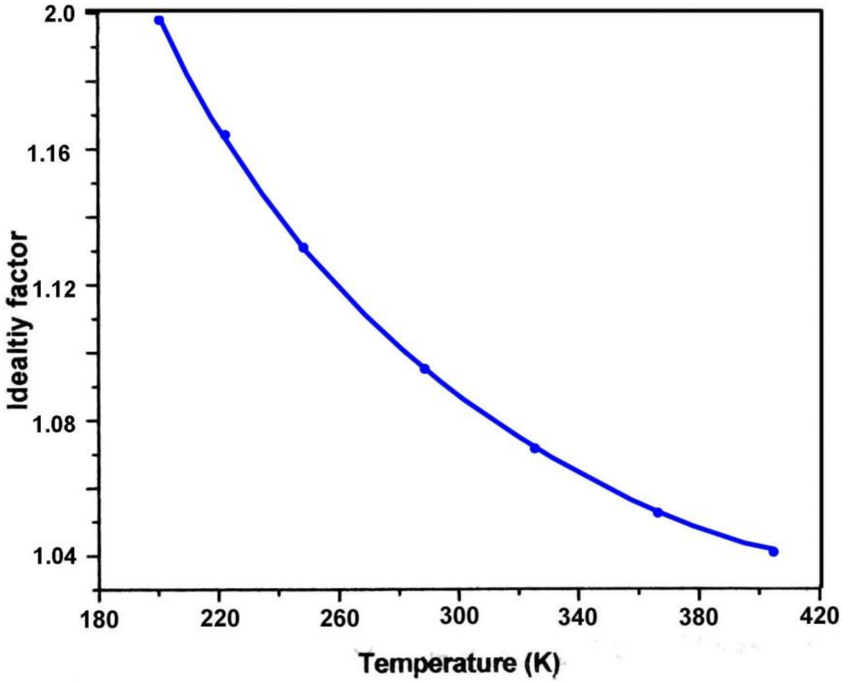

Fig (4) : Plot of ideality factor versus temperature for Er Schottky contact to P - InP.

A decrease in the experimental barrier height ϕ_b and an increase in the ideality factor n with a decrease in temperature have been explained on the basis of thermionic emission mechanism with Gaussian distribution of the barrier heights due to BH inhomogeneities at the mental - semiconductor interface [18]. The barriers height decrease as the ideality factor increases as shown in fig (5).

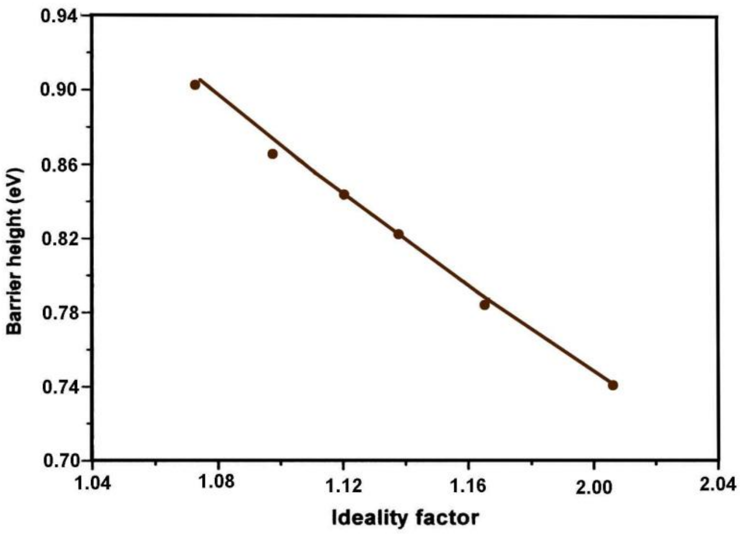

Fig (5) : Zero – bias apparent barrier height versus ideality factor of Er Schottky Contact to P-In P.

In Schottky Diodes, the current transport occurs by thermionic emission over Schottky barrier. The Current-Voltage characteristics of Schottky contacts are described by two fitting parameters such as effective barriers height and the ideality factor [19]. Since current transport across the metal-semiconductor interface is a temperature activated process, electrons at low temperatures are able to surmount the lower barriers and therefore current transport will be dominated by current flowing through patches of the lower schottky barrier height and a large ideality factor [20] [21] [22]. As the temperature increases on one and more electrons have sufficient energy surmount the higher barriers. As a result, the dominant barriers height will increase with the temperature and bias voltage. The high valves of ideality factor n can be attributed to presence of the thin interfacial native oxide layer between the metal and semiconductor [23]. Only the barrier inhomogeneities are very important explanation for the higher values of the ideality factor. The extrapolation of the experimental barrier height versus ideality factor plot n=1 gives a homogeneous barrier height $\left(\phi_b^{\text{hom}}\right)$ of approximately 0.98 eV.

The value of ideality factor for as-deposited sample in case of Er Schottky contact is found to be 1.11. The ideality factor obtained from forward Current-Voltage characteristics are greater than unity suggests that transport mechanisms other than thermionic emission, such as recombination are involved

Plots of I/C^2 versus applied voltage for different annealing temperatures are shown in Fig (6) the C-V relationship for schottky Diode is given by

$$C^2 = \frac{2\left[V_b - \frac{kT}{q} - v\right]}{A^2 q\, N_d\, E_s} \text{ .... (4)}$$

Where E_s is the permittivity of the semiconductor ($E_s=11E_0$) V is the applied voltage, A is the surface area of the diode. The x-intercept of the plot between (I/C^2) versus V is V_0 which is related to the built in potential V_b by the equation $V_b=V_0$ + (kT/q). Where T is the absolute temperature. The barriers height is given by the equation $\phi_b = V_o + V_b + kT/q$

Where $V_0 = (kT/q)\ln(N_c/N_d)$ The density of states in the conduction band is given by $N_C = 2\left(2\pi\, m^*\, kT/h^2\right)^{3/2}$

Where $m^\phi = 0.8 m_0$ and N_c value is 5.7 x 10^{17} cm^{-3} for InP [24]

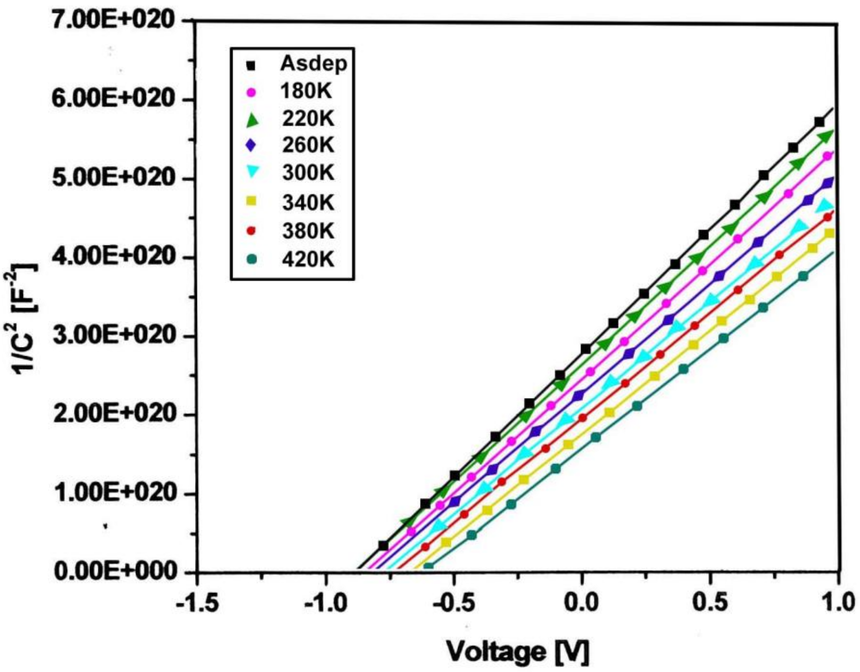

Fig (6) : Plot of I/C2 Versus V for Er Schottky contacts to P – InP annealed at different temperatures.

To compare the effective Schottky barriers height of contacts, the Norde method is also employed [25].

Where F (v) is given by

$$F(V) = \frac{V}{2} - \frac{kT}{q}\ln\left[\frac{I(V)}{AA^\phi T^2}\right] \text{................(5)}$$

The effective Schottky Barriers Height (SBH) is given by $\phi_b = F(V_{\min}) + \frac{V_{\min}}{2} - \frac{kT}{q}$

Where F (V_{min}) is the minimum value of F (V) and V_{min} is the corresponding voltage. The plots of F (V) versus V for the samples annealed at different temperature are shown in fig (7) Table-1 shows the contacts to P-InP as a function of annealing temperatures.

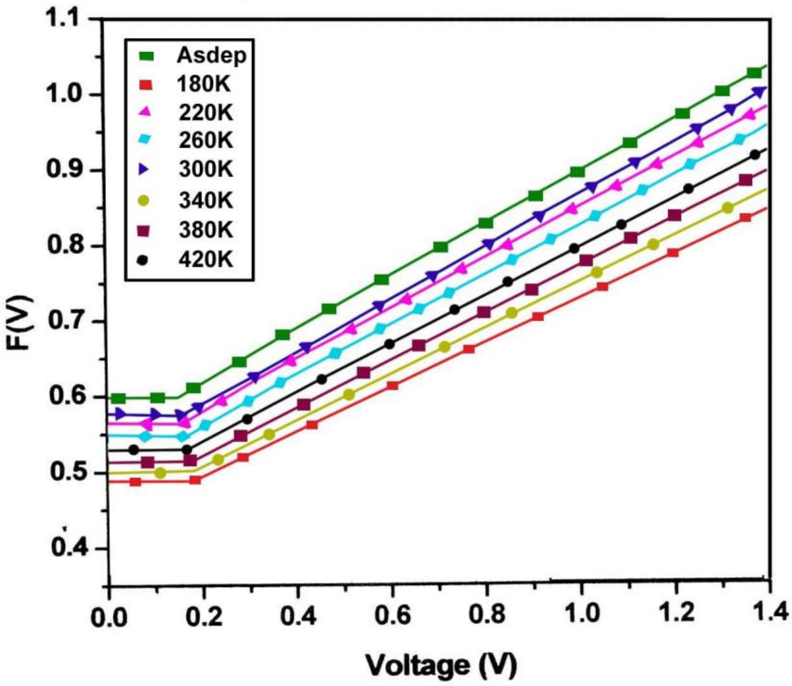

Fig (7) : Plot of F (V) versus V for Er Schottky contacts to P – InP annealed at different temperatures.

Table 1. The schottky barrier height and ideality factor of Er Schottky contact to P.InP as a function of annealing temperature.

Sample	**Schottky Barriers Height ϕ_b eV**			**Ideality factor**
	I-V	**C-V**	**Norde**	
180 K	0.73	0.98	0.75	2.00
220 K	0.75	1.00	0.78	1.18
260 K	0.79	1.02	0.80	1.14
300 K	0.83	1.03	0.84	1.11
340 K	0.84	1.05	0.86	1.07
380 K	0.83	1.04	0.85	1.05
420 K	0.86	1.05	0.88	1.04

The Plot between barriers height of Er Schottky contact and annealing temperature is shown in fig (8). It can be observed that the barriers height ϕ_b obtained from I-V measurements are lower than those obtained from C-V measurements. The spatial inhomogeneities at the interface may play an important role in difference between barrier heights measured from I-V and C-V methods, Further, the transport mechanism in these diodes may not be purely thermionic emission in nature. To these diodes, the ϕ_b obtained from I-V method is voltage or electric field sensitive, unlike the ϕ_b obtained from C-V.

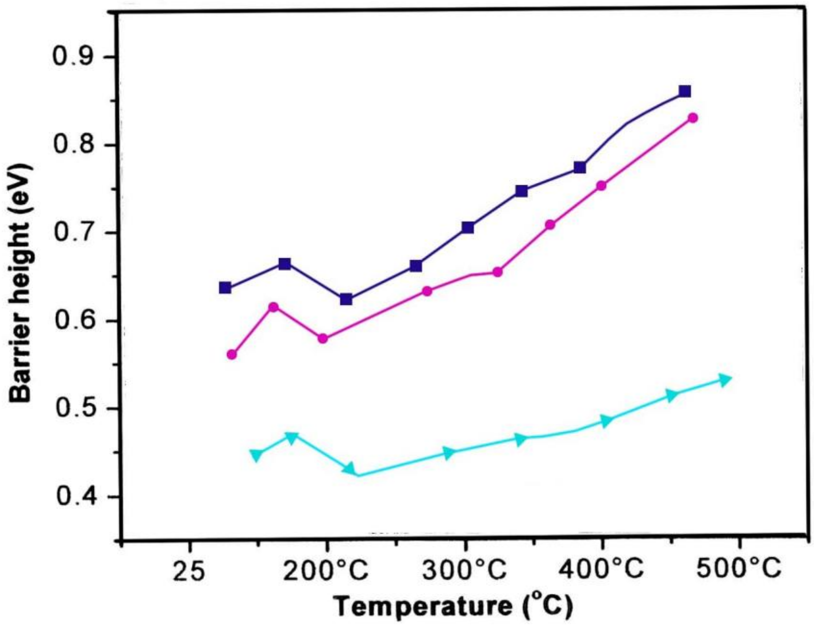

Fig (8) : Plot of barrier heights of Er Schottky contacts to P – InP as a function of annealing temperature.

Conclusion:

The electrical properties of Er shottky diode on P-type InP have been investigated are a function of annealing temperature in the range 180K-420K. The schottky barriers height, are calculated using Current – Voltage (I-V) and Capacitance – Voltage (C-V) characteristics. The SBH for as deposited sample in I-V method is 0.7 eV and C-V method is 0.96 eV. The ideality factor for as - deposited sample is 1.11. The increase in barrier height and decrease in ideality factor from temperature dependent I-V characteristics are consistent with schottky barriers height (SBH) inhomogeneity. The homogeneous barriers height (ϕ_b^{hom}) is 0.98 eV.

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