SERIES RESISTANCE EFFECT ON I-V CHARACTERISTICS OF Au/n-InP SCHOTTKY BARRIER DIODES (SBDs) IN THE TEMPERATURE RANGE OF 80-400K

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Au/p-InP Şotki baryer diodların (ŞBD) düz istiqamətdə gərginlik tətbig etməklə cərəyan-gərginlik-temperatur (I-V-T) xarakteristikaları modifikasiya edilmiş Norde metodu ilə 80-400 K temperatur intervalında ardıcıl müqavimətin təsiri ilə tədqiq edilmişdir. Ardıcıl müqavimətin yüksək olması I-V nəticələrinə mənfi təsir edir. Modifikasiya edilmiş Norde metodu ilə Au/n-InP ŞBD ideallıq faktoru (n), baryer yüksəkliyi (Φ_B) və R_S təyin edildi. Temperaturun artması ilə Φ_B qiymətləri artarkən, I-V-T qiymətlərindən ideallıq faktoru ve ardıcıl müqavimətin azaldığı görünür. Ayrıca, SULA texnologiyası sistemi vasıtəsılə eynı temperatur intervalında şotki diodlarında dərin-səviyyə spektroskopiyası (DLTS) ölçmələri alındı.

В температурном интервале 80-400K модифицированным методом Норде исследовано влияние последовательных сопротивлений при приложении напряжения в прямом направлении тока-напряжения-температуры (I-V-T) на характеристики Au/n-InP Шоттки барьерных диодов (SBD). Высокие значения последовательных сопротивлений отрицательно влияют на результаты вольт-амперных характеристик. В Au/n InP были определены фактор идеальности (**n**) , высота барьера (Φ_B) и последовательных сопротивлений (R_S). При росте значений (Φ_B) с повышением температуры в зависимостях I-V-T происходит уменьшение фактора идеальности и последовательных сопротивлений. Дополнительно, с применением технологической системы SULA в том же температурном интервале были проведены спектроскопические (DLTS) измерении глубоких уровней в диодах Шоттки.

The effect of series resistance (R_s) on forward bias current–voltage-temperature (I–V-T) characteristics of Au/n-InP Schottky barrier diodes (SBDs) have been investigated by modified Norde method in the temperature range of 80-400 K. It is shown that the existence high R_s of diode may cause large errors in I-V characteristics or main electrical parameters of diode. Therefore, this a modified method is proposed which estimates correctly the ideality factor (n), barrier height (Φ_B) and Rs of the Au/n-InP SBDs. Evaluation of the I-V-T data reveals an increase of Φ_B but decrease of n and Rs with increase in temperature. In addition, deep-level transient spectroscopy (DLTS) measurements were made using a SULA Technologies compact system in the same temperature range.

1. INTRODUCTION

InP devices were found to show properties extensively similar with GaAs as optical [1] and microwave sources [2] due to resemblances in band structure. Also, its lower surface recombination velocity, lower compensation in epi layers and bulk crystals are other important advantages. Recently InP and its alloys have received great attention due to to applications in metal-semiconductor (MS), metal-insulator-semiconductor (MIS), metal-insulator-semiconductor field effect transistor (MISFET) devices, light emitting diodes (LEDs) and solar cells [1-5]. The band gap of Si at 1.12 eV and its indirect band gap nature, however, results in solar cells with low conversion efficiency. On the contrary, InP and GaAs 1.35 eV and 1.42 eV, respectively, with a direct band gap of are known as ideal materials for high efficiency solar cells. Only at room temperature, the forward bias I-V characteristics of SBDs can not give us detail information about the current-conduction/transport mechanisms. However, the forward bias I-V characteristics at wide temperature range allow us to understand different aspects of current-conductions mechanism.

According to termionic emission (TE) theory, the value of n is expected to be close to unity. However, the obtained value of n and R_s are greater than unity especially at low temperatures and this behavior of *n* can be attributed to the existence of interfacial insulator layer at M/S interface, particular distribution of interface states at semiconductor band-gap and the image force lowering of the barrier [6-10]. In this study, the forward bias I-V characteristics of the Au/n-InP SBDs have been investigated in the temperature range of 80-400 K. The experimental analysis of the forward bias *I-V* data reveals of an increase of $\Box_B$ but decrease of n and Rs with increase in temperature. In addition, DLTS measurements were made using a Sula Technologies compact system in the same temperature range.

2. EXPERIMENTAL DETAILS

In this study, Si doped n-type InP having thickness of 7000 Å was grown on n-InP(100) substrate using the VG80H solid source molecular beam epitaxy (MBE) system. Before contact process, the n-InP wafer was dipped in 5 H_2SO_4+H_20_2+ H_20 (1:1:300) solution for 1.0 min to remove

surface damage layer and undesirable impurities and then in H_20+HCl solution
and then followed by a rinse in de-ionized water with a resistivity of 18 M.cm. The wafer dried with high purity nitrogen (N_2) and inserted into the vacuum chamber immediately after the etching process then high purity gold (Au) metal (99.999%) with a thickness of 1020 Å was thermally evaporated from the tungsten filament onto the whole back surface of the wafer in the pressure of ~ 10^{-6} Torr. The ohmic contact was formed by sintering the evaporated Au contact at 400 °C for 90 min in flowing dry nitrogen ambient at a rate of ~2 l/min. After finishing this process, temperature was reduced to 300 °C and sample was annealed during 10 minutes. Then the sample was cooled to room temperature. To make Schottky contact on epilayer section, circular dot shaped Au Schottky contacts with a thickness of 1000 Å were formed by evaporating Au in the pressure of ~10^{-6} Torr. After this process Au/n-InP SBDs have been fabricated. Then the sample was removed from system and was soldered with silver pleat and then Schottky contacts were connected with conductor fiber by assistance of silver pleat. After fabricated of the Au/n-InP SBD, The current-voltage (I-V*)* characteristics have been measured in the temperature range of 80-400 K by using a Keithley 2400 Sourcemeter in the Janes VPF-475 cryostat. The sample temperature was controlled a Lake Shore model 321 auto-tuning temperature controllers with sensitivity better than ±0.1 K. For DLTS measurements Sula Technology compact system have been used in the 77-320K temperature range for chosen four rate windows. It is possible to detect low temperature defect (that is located about 77K) using liquid nitrogen during the DLTS measurement.

3. RESULTS AND DISCUSSIONS

When a Au/n-InP Schottky barrier diode (SBD) with series resistance (R_s) is considered, the current through the junction can be given by the thermionic emission (TE) theory for the relationship between the forward bias voltage (V≥3kT/q) and the current (I) of SBD and can be expressed as [11]:

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

where q is the electronic charge, V is the applied voltage across the diode, k is the Boltzmann constant, T is the absolute temperature in K, R_s is the series resistance of diode, IR_s term is the voltage drop across the R_s, n is the ideality factor and I_o is the reverse saturation current derived from the linear region of the intercept of LnI-V at zero bias and can be expressed as

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

where A is the rectifier contact area of the diode, A^* is the effective Richardson constant (n-type InP) [12] and Φ_B is the zero-bias barrier height of the diode. The value of n is calculated from the slope of the linear region of the forward bias LnI-V plot for each temperature and can be written as from Eq.(1)

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

However, this standard approach is difficult to apply if the value of R_s is large. Because, the linear region of LnI-I plot may be small and difficulties will arise due to the voltage drop across the R_s. There are a lot of methods to determine of R_s in the literature [13-18]. Among them Norde [13] has proposed a new method which is considered as a particular case, with n=1, Sato and Yasumura [16] has modified the Norde function for 1<n<2 case and then Bohlin [18] has proposed a new approach as fallowing:

$$F\left(V\right) = \frac{V}{\gamma} - \frac{1}{\beta\left(\ln\left(I / AA^*T^2\right)\right)} \quad (4)$$

where β=q/kT and γ is an arbitrary constant greater than n. In this case, the value of R_s and Φ_B can be obtained from at the minimum point of $F(V_m)$ as:

$$R_S = \frac{\left(\gamma - n\right)}{\beta I_m} \quad \text{and}$$

$$\Phi_B = F(V_m) + \frac{V_m}{\left(\frac{1}{n} - \frac{1}{\gamma}\right)} - \frac{\left(\frac{\gamma}{n} - 1\right)}{\beta} \quad (5)$$

Fig.1. shows of F(V) vs V plots for Au/n-InP SBD (a) at low and (b) high temperature, respectively. As can be seen in Fig.1, the F(V) vs V plots show a minimum $F(V_m)$ for each temperature. The obtained Φ_B and R_s values from Eq(5) are given in Table 1 and Fig.2. It is clear that both the values of n and Φ_B are strong functions of temperature. As shown Fig.2, the value of Φ_B increase but R_s decreases with increase in temperature. Such temperature dependence of Φ_B is an obvious disagreement with reported negative temperature coefficient of InP band gap or BH of diode. At higher temperatures, n is closer to the ideal case (n=1), while at lower temperatures, n increases with decreasing temperature and shows a temperature dependence, which may be described as the "T_o effect or anomaly." Such temperature dependence of n and Φ_B could be attributed to the inhomogeneities in the SBH [19]. When the temperature is lowered, the current is dominated by fewer low-Schottky-SBH regions with lower effective SBHs and larger ideality factors [20].

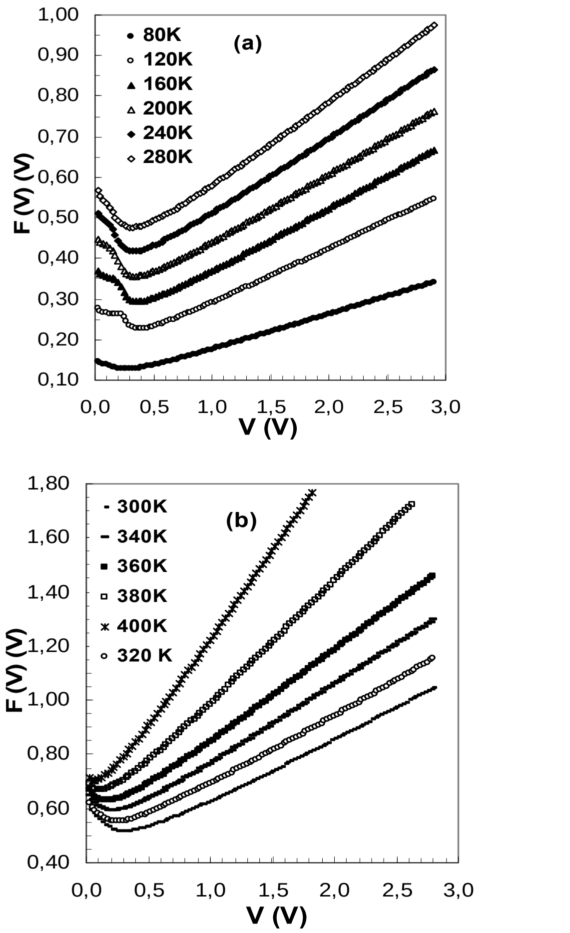

Fig.1. Experimental plots of F(V) vs. V for Au/n-InP SBD (a) at low temperature and (b) at high temperature.

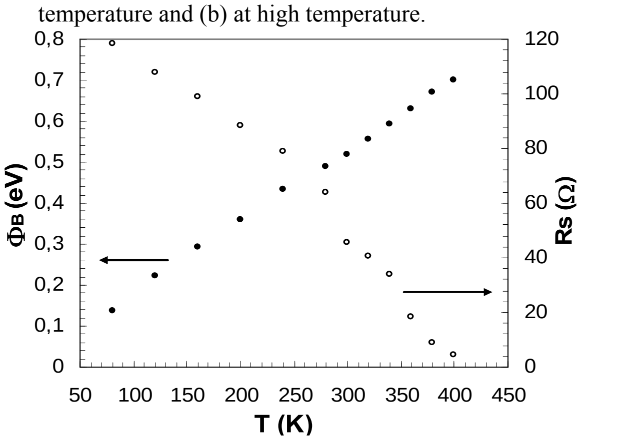

Fig.2. The value of Φ_B and Rs vs T for Au/n-InP SBD.

Fig.3. shows the DLTS spectra of Au/n-InP SBDs. As shown Fig.3. (a), two trap levels with 0.17 eV and 0.70 eV activation energies with 3.1.1014 cm-3 and 1.4.1014 cm-3 trap concentration have been detected form DLTS scans, respectively. For DLTS measurements four rate windows (5, 2, 1, 0.5 ms) were chosen and reverse bias, forward bias were applied as -1 V and 0.5 V, respectively in the 77-320 K temperature range. Activation energy(Ea) lower than 0.2 eV has been calculated. Low activation energy can be attributed to phosphorous vacancies [21] or indium vacancies [22]. This trap can also be attributed to interface On the temperature dependent anomalous peak and negative capacitance in Au/n-InP Schottky barrier diodes 59 defects due to phosphorous vacancies occupied by oxygen after surface treatment of InP [23,24].With regard to the 0.70 eV midgap defect level, its assignment to a phosphorus antisite related defect [25], this defect should be located at the middle of the InP gap[26]. Also experimental studies have reported a midgap defect level related to a phosphorus antisite in InP [27].

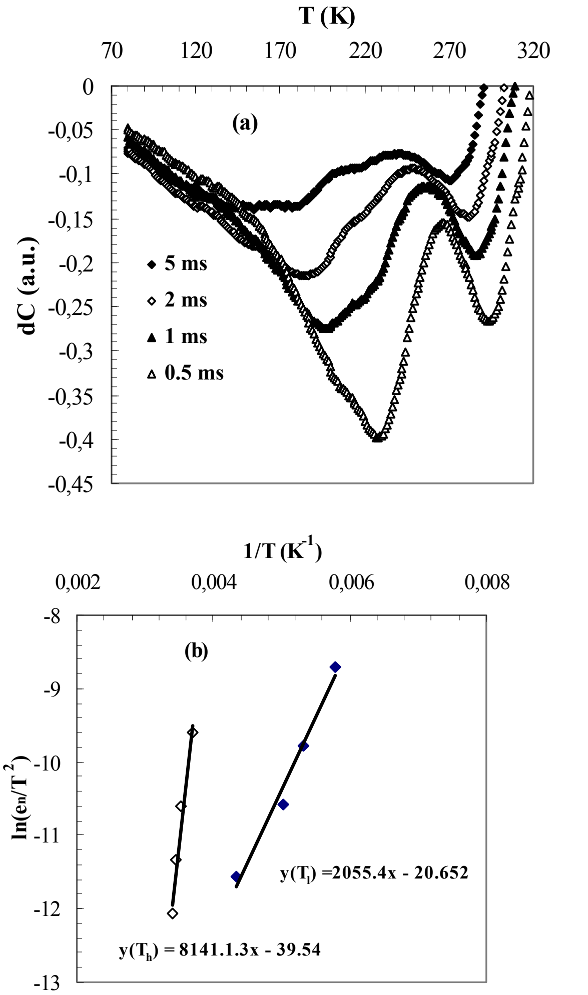

Fig.3. (a) DLTS spectra obtained in Au/n-InP SBDs,
(b) Arrehenius plot for Au/n-InP SBDs obtained from DLTS spectra

Table1.
Temperature dependent values of various parameters determine from forward bias I-V characteristics of the Au/n-InP SBD

T (K)	V_m (V)	I_m (A)	$F(V_m)$ (V)	n	R_s (Ω)	Φ_B (eV)
80	0,32	1,81E-04	0,13	7,90	118,36	0,139
120	0,40	1,06E-04	0,22	7,50	108,00	0,223
160	0,39	1,23E-04	0,29	5,53	99,00	0,294
200	0,37	1,57E-04	0,35	4,70	88,13	0,359
240	0,35	2,13E-04	0,42	4,00	79,00	0,432
280	0,32	3,05E-04	0,48	3,69	64,09	0,490
300	0,30	2,78E-04	0,51	3,51	45,58	0,517
320	0,27	2,53E-04	0,55	3,23	40,42	0,555
340	0,23	1,81E-04	0,59	2,99	33,96	0,593
360	0,20	1,72E-04	0,63	2,90	18,07	0,631
380	0,15	1,33E-04	0,67	2,88	9,00	0,670
400	0,07	7,33E-05	0,70	2,74	4,71	0,700

4. CONCLUSİONS

In this study, the effect of the series resistance (R_s) on I-V characteristics of Au/n-InP SBDs have been investigated as a function of temperature. Experimental measurements and analyses of data show that both the □$_B$ and R_s were quite sensitive to temperature. Experimental results show that the existence high R_s may cause large errors in I-V data. Therefore, this a modified method is propsed which estimates correctly the ideality factor, Φ_B and R_s of the Au/n-InP SBDs. Evaluation of the I-V-T data reveals an increase of Φ_B but decrease of n and Rs with increase in temperature. Such temperature dependence of Φ_B is an obvious disagreement with reported negative temperature coefficient of InP band gap or BH of diode. At higher temperatures, n is closer to the ideal case (n=1), while at lower temperatures, n increases with decreasing temperature and shows a temperature dependence, which may be described as the "T_o effect or anomaly." Such temperature dependence of n and Φ_B could be attributed to the inhomogeneities in the SBH. From DLTS results two peak have been observed in the 77-320 K temperature range. Low activation energy trap can be related to phosphorous vacancies or indium vacancies and a midgap defect is attributed to a phosphorus antisite related defect.

Acknowledgment

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