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BARRIER INHOMOGENEITIES OF Al/p-In_2Te_3 THIN FILM SCHOTTKY DIODES

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The current-voltage (I-V) and capacitance-voltage (C-V) characteristics of p-In_2Te_3/Al thin films Schottky diodes papered by Flash Evaporation technique were measured in the temperature range 303-335 K have been interpreted on the basis of the assumption of a Gaussian distribution of barrier heights (φ_{bo}) due to barrier height inhomogeneities that prevail at the interface. It has been found that the occurrence of Gaussian distribution of BHs is responsible for the decrease of the apparent BH (φ_{bo}) and increase of the ideality factor (η). The inhomogeneities are considered to have a Gaussian distribution with a mean barrier height of (φ_{bm}) and standard deviation (σ_s) at zero-bias. Furthermore, the activation energy value (φ_b) at $T = 0$ and Richardson constant (A^{**}) value was obtained as 0.587 eV and 3.09 $Acm^{-2}K^{-1}$ by means of usual Richardson plots. Hence, it has been concluded that the temperature dependence of the I-V characteristics of p-In_2Te_3/Al Schottky Diodes can be successfully explained on the basis of TE mechanism with a Gaussian distribution of the BHs.

Keywords: *p-In_2Te_3 THIN FILM, SCHOTTKY DIODE, CURRENT-VOLTAGE (I-V) CHARACTERISTICS, CAPACITANCE-VOLTAGE (C-V), BARRIER HEIGHT.*

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1. INTRODUCTION

Schottky barriers on semiconductors are of interest not only because of their applications as rectifying contacts but also due to the insight they afford into the nature of bonding and defect levels in solids [9]. Further, the metal-semiconductor (MS) junction has been the subject of intensive study owing to its paramount role in microelectronics [1-3]. In recent years, there has been a growing concern to understand the influence of the MS interface states on the device performance [4-8]. Most modern Schottky diodes fabrication is by planar process using various methods viz. thermal evaporation, chemical decomposition, electron beam evaporation, and sputtering or platting of metals onto chemically etched semiconductor surfaces. Rucelle [10] have reported Schottky diodes using In_2Te_3 single crystals. Growth and structural [11], electrical and optical [12] properties, thermoelectric power [13] of In_2Te_3 thin films and their applications as strain gauge [14], and gas sensor [15] have been reported earlier.

In the present work, we report the fabrication of Schottky diodes using Aluminum on p-In_2Te_3 thin films and determine their barrier height and ideality factor from the temperature dependence of I-V and C-V characteristics. We also discuss the effects of the barrier inhomogeneities in terms of the various models proposed in the literature to understand the variation of the ideality factor with temperature and the peculiar behavior of the barrier height with temperature as obtained from the I-V and the C-V characteristics.

2. EXPERIMENTAL

In_2Te_3 thin films of the thickness 500 nm were deposited on the pre-deposited silver (Ag) thin films using the Flash Evaporation Method. The films, in turn, got deposited on the ultrasonically cleaned glass substrates. During the deposition of In_2Te_3 film, the substrate's temperature was kept constant at 373 K and the vacuum was of the order of 1.33×10^{-4} Pa. The deposition rate of the film was kept at 2 Å sec^{-1}. TEM and EDAX studies revealed hexagonal polycrystalline structure of p-In_2Te_3 films while the composition was nearly stoichiometric. Further, these films have been found to demonstrate p-type conductivity on the basis of Hot-Probe Method as well as Electrical Measurements [11].

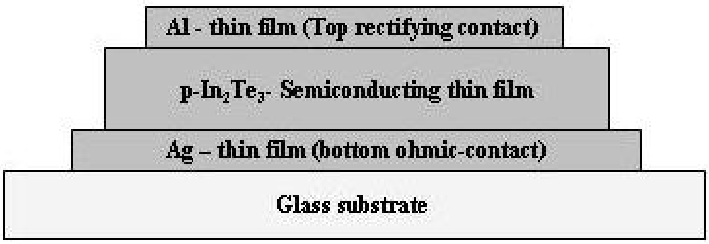

Fig. 1 *– Schematic diagram of Al / p-In_2Te_3 schottky diode Fabricated on a glass substrate*

Fig. 1 shows a schematic diagram of Al / p-In_2Te_3 Schottky Diode fabricated on a glass substrate. It has been observed from a preliminary study of Ag films show good ohmic contact to the p-In_2Te_3 film, and can work as a back-metal electrode, while Al film show good non-ohmic Schottky contact, a thin film of Al, of thickness of about 25 nm was deposited onto the p-In_2Te_3 film. The area of Schottky Diode interface was determined to be 2.5×10^{-3} cm^2. The I-V / C-V characteristics were measured in the temperature range 303-335 K using computer controlled setup consisting Keitheley Make (model 2400) Source Meter and Agilent Make LCR meter (Model no. 4284 A) which were interfaced using NI LabView Software.

3. RESULTS AND DISCUSSIONS

3.1 Current-Voltage (I-V) characteristics

The forward and reverse biased current-voltage (I-V) characteristics of p-In_2Te_3 / Al Schottky Diodes measured at room temperature have been plotted in Fig. 2.

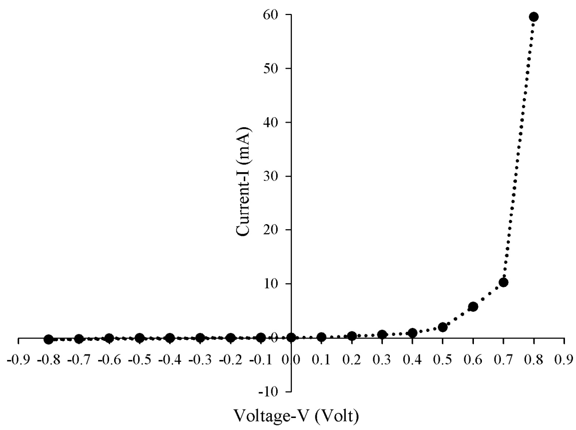

Fig. 2 *– I-V characteristics of* Al-In_2Te_3 *Schottky Diode at room temperature*

It is assumed that the forward bias current of the Schottky Diodes (SDs) is due to thermionic emission mechanism expressed as under [16],

$$J_F = J_S\left[\exp\left(\frac{qV}{\eta kT}\right) - 1\right] \quad (1)$$

where q, k, T, J_s, and η, are, respectively, the electronic charge, the Boltzmann constant, the temperature, the saturation current density and the ideality factor. In the thermionic emission theory [16], the saturation current density, J_S given by,

$$J_S = A^{**}\,T^2\exp\left(\frac{-q\varphi_{b0}}{kT}\right) \quad (2)$$

where A^{**} is the effective Richardson constant and φ_{b0}, the barrier height.

Fig. 3 shows a plot of the forward current density $\ln(J_F)$ versus forward voltage (V_F) of the p-In_2Te_3 / Al Schottky Diodes measured at different temperatures (303, 310, 320 and 335 K). The plots exhibit linear behaviour wherein the intercept of the I-V plot at $V = 0$ provides saturation current densities at different temperatures while the ideality factor η, in Eq. (1) is given by,

$$\eta = \frac{q}{kT}\frac{dV}{d\ln(J/J_o)} \quad (3)$$

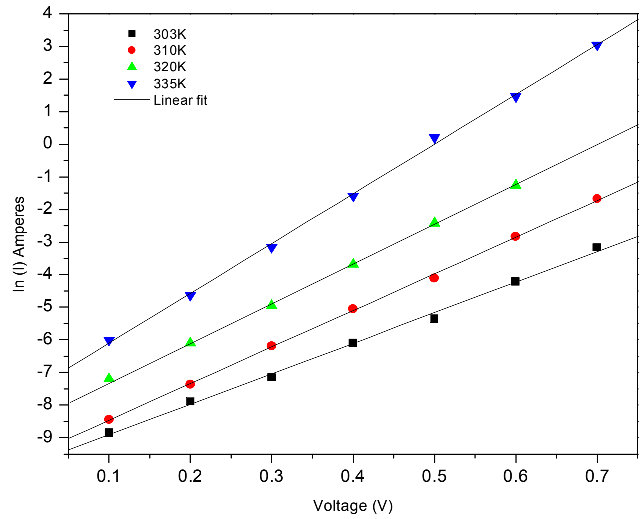

Fig. 3 *– The current density ln(J_F) vs forward bias voltage (V_F) of the p-*In_2Te_3 / Al *Schottky Diode at different temperature. The fitting of the data has been shown by solid lines*

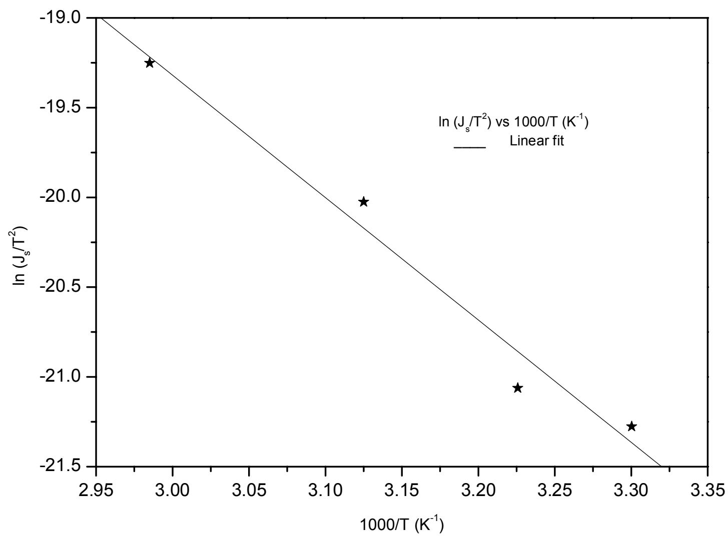

Fig. 4 *– The Richardson plot of* $\ln(J_s/T^2)$ *versus* $1000 / T$ *fields an activation energy value of* 0.587 *eV and an effective Richardson constant value* 3.09 $A\ cm^{-2}\ K^{-2}$*. These values are lower than the corresponding reported values of the activation energy and effective Richardson constants*

and the zero bias barrier height can be computed with the help of Eq. (2). The I-V plots shift towards higher bias side with decrease in temperature. All the extracted parameters have been presented in Table 1.

The Richardson constant was determined from the intercept of the ln (J_s/T^2) vs $1/T$ plot shown in Fig. 6. The dependence of $\ln(J_s/T^2)$ on $1/T$ found to be a straight line in the measured temperature range where intercept provided Richardson constant A^{**} = 3.09 A cm $^{-2}$ K $^{-1}$while the slope yielded an activation energy value of 0.587 eV. The deviations in the Richardson plot values from the reported ones may be due to the spatial inhomogeneous BHs and potential fluctuations at the interface that consist low and high barrier areas [6]. The value of the A** obtained from the temperature dependent I-V characteristics may be effected by the lateral inhomogeneities of the barrier and the fact that it is different from the theoretical value may be connected to the value of real effective mass that is different from the calculated one.

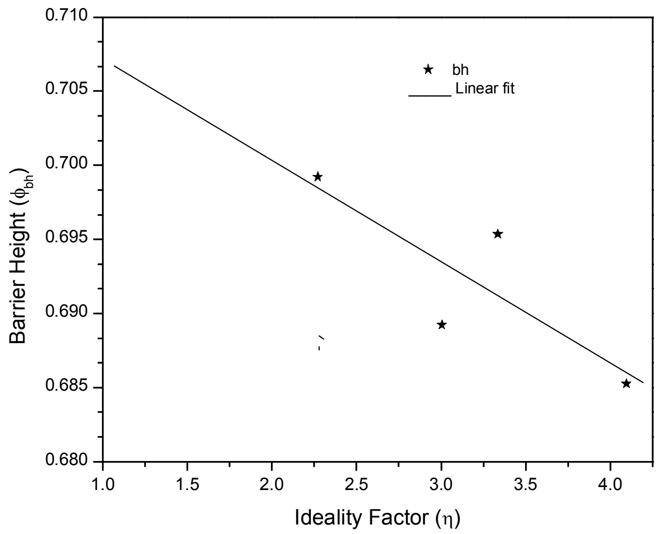

Fig. 5 *– The plot shows correlation between barrier height and ideality factor. The homogenous BH calculated is found to be* 0.707 *eV*

Table 1 *– Parameters calculated from the forward J-V characteristics*

Temperature T(K)	Saturation current density × 10 $^{-5}$ J_S (Amp.cm $^{-2}$)	Diode ideality factor, η	Barrier height (I-V), φ_{bo} (eV)
303	5.28	4.085	0.687
310	6.85	3.455	0.695
320	20.58	2.859	0.689
335	48.91	2.307	0.699

The ideality factor for p-In_2Te_3 / Al Schottky Diodes at room temperature has been found higher than the same reported in the literature [22]. This may be attributed to the formation of thin interfacial layer and or surface effects like, the surface charge and image force effects at the Metal-Semiconductor interface. The ideality factor i.e. determined only by the image force effect should be close to 1.01 or 1.02 [23]. Our data clearly show that the diodes have ideality factors that are considerably larger than the value determined by image force effect only. Therefore, these diodes are patchy [20].

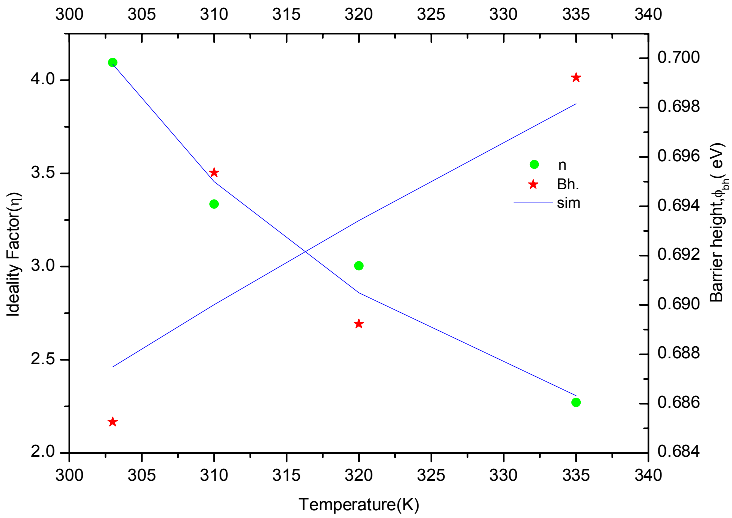

***Fig. 6** – The ideality factors and zero bias barrier heights values at different temperatures; the solid curves have been obtained by simulating the data using equations* 7 *and* 8. *The continuous curves has been used to calculate the values* $\varphi_{bm} = 0.80$ *eV*, $\sigma = 0.076$, $\rho_2 = -1.22$ *and* $\rho_3 = 0.1031$

The ideality factor and the zero bias barrier height have been plotted as a function of temperature in Fig. 6. The plot shows that the ideality factor increases while the barrier height decreases with decreasing temperature. Since current transport across the interface is temperature activated process, electrons are able to overcome the lower barrier; the current transport will be dominated by current flowing through the patches of lower barrier heights and demonstrated large ideality factors. As the temperature increases, more and more electrons may have sufficient energy to overcome the high barriers; as a result, the dominant BH will increase with temperature and bias voltage. An apparent increase in ideality factor and decrease in BH with decreasing temperature are caused possibly by other effects such as inhomogeneities of thickness and non-uniformity of interfacial charges [19]. Both the BH and ideality factors observed temperature dependent I-V characteristics consistent with SBH inhomogeneity and the correlation with experimental BHs and IFs have been approximated by linear relationship monch et. al. [18] has suggested that the extrapolation of the experimental BHs vs. ideality factor at $\eta = 1$ gives laterally homogenous BH values of 0.707 eV obtained for the undertaken Schottky diodes.

3.2 Capacitance-Voltage (C-V) characteristic

In order to access the doping concentration and barrier height, C^2 versus V_R plots (Fig. 7) were obtained from the C-V data. The C-V relationship is applicable to intimate MS Schottky barriers on uniformly doped materials and can be written as [1],

$$\frac{1}{C^2} = 2(V_R + V_o) / q\varepsilon_s N_D \alpha^2 \tag{4}$$

Where V_R is the reverse bias voltage, V_0, is the built-in-potential or diffusion potential, is usually a measured by extrapolating the C^{-2}–V plot to the V-axis. The zero bias barrier height from the C-V measurement is defined by

$$\Phi_{bo} = V_d + V_n \tag{5}$$

Where V_d is the voltage axis intercept of the above plot, $V_n = (kT / q) \cdot \ln(N_c/N_d)$ is the energy difference between the Fermi level and the bottom of the conduction band edge in the present semiconductor and $N_c = 2(2\pi m_e kT / h^2)^{3/2}$ is the effective density of states in the conduction band, where m_e = effective mass, N_a is the donor density, ε_0 = permittivity of the free space is 8.85×10^{-14} F cm^{-1}, a = area of Schottky diode = 2.5×10^{-3} cm^2.

Table 2 shows N_a for different temperatures. By extrapolating the straight-line plot on the x-axis of Fig. 4 (i. e., $C^{-2} = 0$) the values of V_d can be determined. The results obtained from the C-V characteristics at various temperatures, which show that the diffusion potential increases with temperature. The slope of the C^{-2}-V curves at various temperatures, gives the acceptor density of In_2Te_3 thin films, as listed in Table 2. The parameters extracted from the $1/C^2$ vs V_R have been shown in Table 2.

***Table 2** – Parameters from C-V characteristics (Fig. 6)*

Temperature T (K)	Diffusion potential V_d (Volt)	Effective density of states $\times 10^{18}$ N_c (cm^{-3})	Acceptor density $E_F = E_V$ $\times 10^{16}$ N_a (cm^{-3})	Energy difference V_n (eV)	Barrier height(C-V) φ_b (eV)
303	0.480	1.19	2.11	0.10538	0.586
310	0.510	1.26	2.47	0.1051	0.615
320	0.525	1.35	2.96	0.10543	0.650
335	0.590	1.48	3.70	0.1065	0.695

Further, the φ_{cv} values at various temperatures for the SD have been calculated from its experimental reverse bias C^{-2}-V characteristics given in Fig. 7. The experimental values of φ_{cv} as a function of temperaature have been given in Fig. 8, these values increased with decreasing temperature. As can be seen, C^{-2}-V curve gave different BH values than those derived from I-V measurements.

The trend of increasing ϕ_{cv} with decreasing temperature is clear in Fig. 8 which can be understood by the temperature dependance of In_2Te_3 band gap. We can assume a linear dependance of φ^{cv} on T given by,

$$\varphi^{C-V}(T) = \varphi_0^{C-V} + \alpha_\varphi^{C-V} T \tag{6}$$

where $\alpha_\varphi{}^{C\text{-}V}$ is the temperature coefficient of $\varphi^{C\text{-}V}$ and $\varphi_0{}^{C\text{-}V}$ is the SBH extrapolated towards zero temperature. The values of is the $\varphi_0{}^{C\text{-}V} = -0.434$ eV and $\alpha_\varphi{}^{C\text{-}V} = 3.38$ meVK^{-1} are obtained by linear least square fitting of the values of $\varphi^{C\text{-}V}$ measured in the entire temperature range.

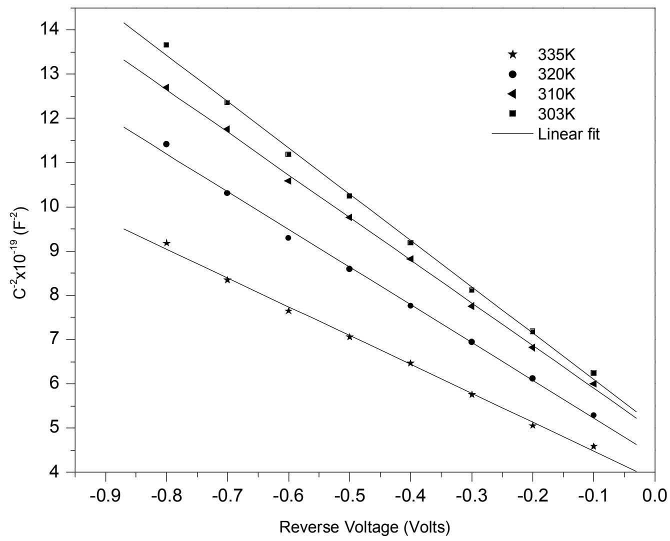

***Fig. 7** – Experimental Capacitance-Voltage characteristics of a typical* p-In_2Te_3/*Al SD in the temperature range* 303-335 *K*

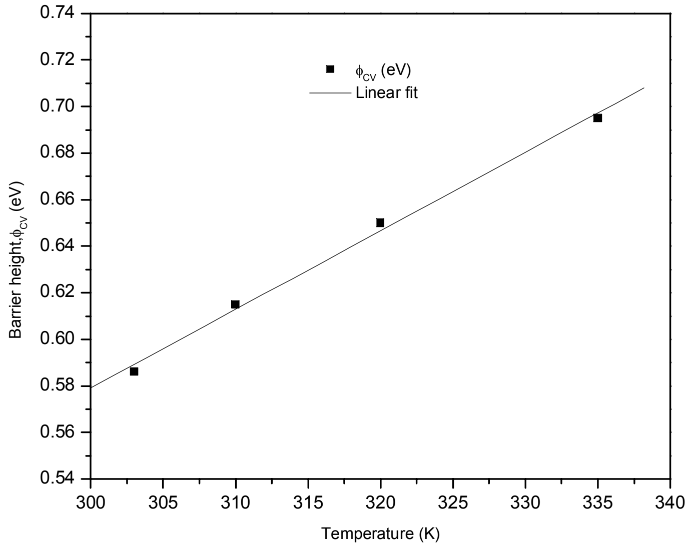

***Fig. 8** – Temperature dependence of the experimental C-V Barrier Height*

Due to the inhomogeneity, charge transport across the interface is no longer due to Thermionic Emission because of the presence of patches of small regions with low barrier heights embedded in higher background uniform barrier [6, 19]. The variations can be explained by the lateral distribution of BH in which it has a Gaussian distribution of the BHs over the Schottky contact area. The Gaussian distribution of the BHs yields the following expression of the BH [6]:

$$\varphi_{bo} = \varphi_{bm} - (\sigma_s^2 q / 2kT) \tag{7}$$

where φ_{bo} is the apparent BH measured experimentally, φ_{bm} , the mean BH and σ_s is ythe standard deviation. The observed variation of ideality factor with temperature in the model is given by [6].The continuous curve of BH fitting as shown in Fig. 4, provides a mean BH (φ_{bm}) = 0.80 eV and standard deviation (σ_s) = 0.076. The standard deviation is a measure of the barrier homogeneities, as we all know that the ideality factors represented direct measure of the interface uniformity. The findings and the assumptions that the patches have smaller BHs than homogenous contact explains the experimentally observed reduction of the BHs with increasing IFs [6, 21].

$$\left(\frac{1}{\eta_{ap}} - 1\right) = -\rho_2 + \frac{q\rho_3}{2KT}, \tag{8}$$

where η_{ap} is the apparent ideality factor and ρ_2 and ρ_3 quantify the voltage deformation of the BH distribution. The continuous curve of Fig. 4 provides ρ_2 and ρ_3 values of − 1.22 and 0.1031 respectively. The continuous curves in Fig. 4 show that the temperature dependant experimental data of the p-In_2Te_3/Al contact are in agreement with the model related to the thermionic emission over a Gaussian distribution [6, 17]. The fitting of the plots demonstrate that the η does indeed express voltage deformation of the Gaussian distribution of the Schottky barrier height. The computed values exactly coincide with the experimental Results in the respective temperature range.

Further, the difference between the I-V and C-V in the Metal-Semiconductor is also evidence for the Schottky barrier inhomogeneity. The reason for the discrepancy between the I-V and C-V measured SBH is clear. The current in the I-V measurement is dominated by the current that flows through the region of low SBHs. The measured I-V BH is significantly different from the weight arithmetic average of the SBHs. On the other hand, the C-V measured BH is influenced by the distribution of charge at the depletion region boundary and this charge distribution follows the weight arithmetic average of the SBH inhomogeneity; hence, the BH determined by C-V is closed to the weighted arithmetic average of the SBHs. Therefore, the SBH determined from the zero-bias intercept assuming thermionic emission as current transport mechanism is different from that of the C-V measured BH and the weighted arithmetic SBHs.

4. CONCLUSIONS

The above results suggest that the forward I-V characteristics of the p-In_2Te_3/Al Schottky contacts are successfully explained on the basis of TED mechanism by incorporating the concept of barrier height inhomogeneities. The temperature dependant I-V / C-V experimental data of the present p-In_2Te_3/Al Schottky Diode have been satisfactorily explained on the basis of Gaussian distribution of the SBHs in the temperature range of 303 − 335 K, suggesting that the contacts are not spatially uniform. Further, the current-voltage characteristics of the undertaken Schottky Diodes were found to be effected by some low SBH patches at the M-S interface.

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