Numerical study of barrier height of Schottky diode at high temperature

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Abstract

A numerical perspective through MATLAB is implemented in this research to discuss the high temperature effect on the electrical parameters of Schottky diode. Temperature dependent height of barrier and series resistance were obtained by using Norde function along with thermionic emission model. Capacitance-Voltage aspects of Schottky diode have also been discussed in a wide temperature range 700K-1000K and the values of height of barrier were computed. The discrepancy between the outcomes of height of barrier acquired from Norde function and capacitance-voltage aspect have been investigated. A rapid decline was observed in the values of series resistance with increase in temperature.

Key Words: Norde function, Capacitance-Voltage aspects, Barrier height, Temperature effect

Introduction

In the history of semiconductor industry, Metal-Semiconductor (MS) junctions are known as the simplest electronic devices because of their simple process of manufacturing, cost-effective and remarkable application. These MS junctions have fascinated diverse interests due to their wide variety applications and remarkable physical properties in nanoelectronics and optoelectronics. The basic components of electronic technology are MS rectifying circuits, and all semiconductor devices are particularly based on structures of MS either Ohmic contact or Schottky contact [1-2]. Many authors have been studied electrical and photoelectric characteristics of MS as photoelectric cells, photodiode and Schottky diode. Beside the fact that Schottky diodes have very simple structure, they have uncounted advantages and are the core constituent of a wide range of electrical circuit of electronic devices because of their cost-effective fabrication, small resistance, low forward voltage drop and high speed of switching with the comparison of p-n diodes. The procedure of Schottky barrier diode depend upon the properties of devices of MS junction therefore it is essential for device application to have understanding about the electrical aspects of the surface between semiconductor and metal [3-4]. The properties of junction can be affected due to the insulating layer and interface states among metal and semiconductor, Schottky barrier formation and series resistance.

Research of the MS junction has an influence in device application which is based on Zinc Oxide (ZnO). It is a material with 3.37eV direct band gap energy and 60meV exciton binding energy which make it an excellent material for electronic devices. it is a cost-effective semiconductor material which is favorable in various applications like light emitting diode, laser diode and UV photo detectors etc. To prepare high quality electronic devices it is essential to fabricate Schottky or Ohmic contact among metal and ZnO [5]. Several authors have been published their reports about ZnO based Schottky diode. Silver (Ag) was used as Schottky contact by Sheng et al on ZnO [6]. Platinum (pt) Schottky contact with n-type ZnO was reported by IP et el. [7]. Oxygen plasma treatment was used by two scientists

Mosbacker et al and Angadi et al on ZnO films and it was observed that non rectifying behavior of gold (Au) contact on ZnO has changed in to rectifying behavior [8-9]. Aydo˘gan et al prepared Au/n-ZnO Schottky diodes on n-type silicon substrate to discuss its electrical properties [10]. MS structures have technological importance and due to this reason sufficient understanding about the electrical properties of Schottky diode is essential [11]. To obtain the height of barrier and other parameters of Schottky diode, interface states is very important and device performance, strength and creditability can be affected by it [12].

A clear understanding about basic physical mechanism which is used to describe the parameters of Schottky diode is very essential for electronic devices. Barrier height and ideality factor is two important factors which are used to describe electrical properties of Schottky diode [13]. Barrier height is used to describe electrical aspect of MS structures while ideality factor is used to measure consistency of the diode to the ideal diode. Another important parameter is series resistance due to which electrical aspect of Schottky diode to be non-ideal. To operate electronic devices at different temperature it is necessary to form such Schottky diode which are more reliable and thermally stable therefore, it is essential to discuss the behavior of Schottky diode at different temperature [14].

Devices which are based on ZnO Schottky contact are used in practical application. To discuss the transport properties of Schottky diode current-voltage (I-V) and capacitance-voltage(C-V) aspects are extensively used. Several researchers discussed temperature dependent current-voltage and capacitance-voltage aspects experimentally to understand clear picture about the process of charge transportation, nature of barrier across MS contact and mechanism of conduction which could not be explained at room temperature .I-V aspects of Au/ZnO/Si diode have been discussed by M Asghar et al in temperature range 150K -400K [15]. Current-voltage and capacitance-voltage properties of Schottky diode (Au/V2O5/n-Si) in a wide range of temperature i.e.150K-300K have been studied by Somnath Mahato et al [16].

It is a proven fact that numerical methods are always cost and time effective. To fabricate electronic devices numerical methods are extensively used [17]. Temperature dependent I-V aspect of Ni/n-GaAs based Schottky diode have been studied by Durmuş Ali Aldemir et al. and he used thermionic emission model, Cheung method, Norde function and generalized Norde methods [18]. I-V aspect of ZnO based Schottky diode at highly sensitive temperature i.e., 300K-1000K and comparison between the electrical parameters obtained by thermionic emission model and Cheung function have also been investigated [19].

In this study, electrical parameters that control the performance of the device such as height of barrier and series resistance were measured by using I-V and C-V aspects at high temperature 700K-1000K. Series resistance was obtained by using Norde function and height of barrier was obtained by using Norde function and C-V aspects both. MATLAB software was used to explore all parameters. Influence of high temperature on parameters of Schottky diode was discussed and obtained results of height of barrierby using Norde function and C-V aspects were compared.

Norde Function

Based on thermionic emission model the well -known equation of this model which describe the relation between current and voltage is defined by

$$I = AR^{*}T^{2}e^{-\frac{q\phi_b}{KT}}\left(e^{\frac{qV}{nKT}} - 1\right) \qquad (1)$$

Where V represents applied voltage, ideality factor is represented by n, k is constant of Boltzmann, charge of an electron is defined by q , temperature is T and it is measured in Kelvin, Schottky contact area is A , R is constant of Richardson (32 A/cm^{2}K^2 for ZnO) and $\emptyset_b$is the height of barrier of the Schottky diode which can be calculated by

$$\emptyset_b = \frac{KT}{q} ln\left(\frac{AR^*T^2}{I_s}\right) \quad (2)$$

Where I_s represents the saturated current whose values have been extracted from the intercept of semi-logarithmic plot of forward bias I-V properties of Schottky diode at V=0 between the temperature 700K -1000K as presented in Fig. 1 and it was found to be 3.74×10^{-6} mA at 700 K and 1.21×10^{-3} mA at 1000K [20]. These extracted values of saturated current have been utilized in Eq. 2 for the calculation of height of barrier.

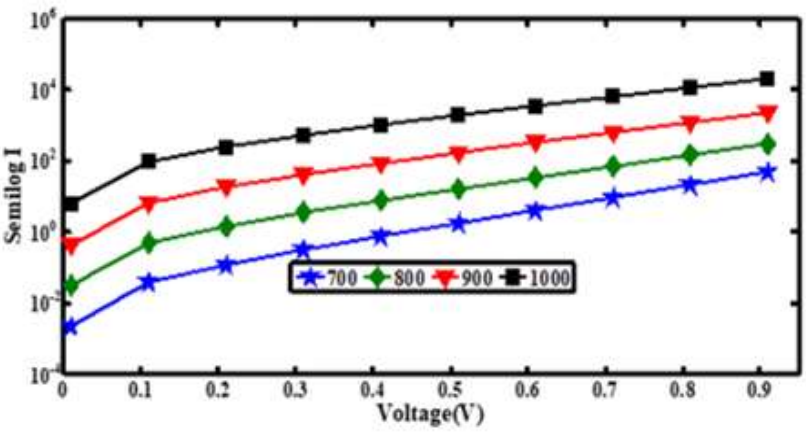

Fig. 1 *Temperature dependent Semilog I-V aspects*

In current-voltage aspect one more obstruction is come up because of the presence of series resistance [21]. I-V aspect of Schottky diode in the presence of series resistance can be defined by

$$I = AR^*T^2e^{-\frac{q\emptyset_b}{KT}}\left(e^{\frac{q(V-IR)}{nKT}} - 1\right) \quad (3)$$

To measure the impact of height of barrier and series resistance on the behavior of Schottky diode another method was suggested by Norde [22] which is defined by the equation

$$F(V) = \frac{V}{\gamma} - \frac{KT}{q}\ln\left(\frac{I(V)}{AR^*T^2}\right) \quad (4)$$

Where I(V) are the values of current extracted from Fig. 1 and γ=2 (ideality factor must be less than γ)[20]. For an ideal condition series resistance of diode is zero and F(V) plot against V must be represented by straight line with gradient less than zero as shown in Fig. 2

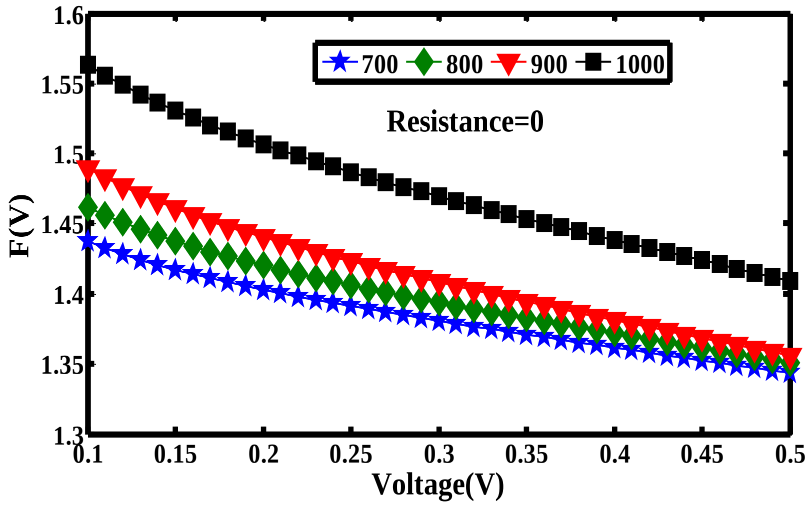

Fig. 2 *Temperature dependent Norde function plot*

For non-ideal case there must be a series resistance [22] and F(V) will be defined as

$$F(V) = \frac{V}{\gamma} - \frac{KT}{q}\ln\left(\frac{V}{AR^{*}RT^{2}}\right) \quad (5)$$

Eq. 5 will come close to a straight line with gradient $(1/\gamma)$, as shown in Fig. 3. The height of barrier and series resistance were obtained by using formula given in Eq. 6 and 7 respectively

$$\emptyset_b = F(V_o) + \frac{V_o}{2} - \frac{KT}{q} \quad (6)$$

$$R_s = \frac{(\gamma-n)}{I_o}\frac{KT}{q} \quad (7)$$

Where $F(V_o)$ and V_o are minimum values of F(V) and V respectively which were extracted from Fig. 3 and I_o is the least value of current which was obtained against the value of V_o[1].

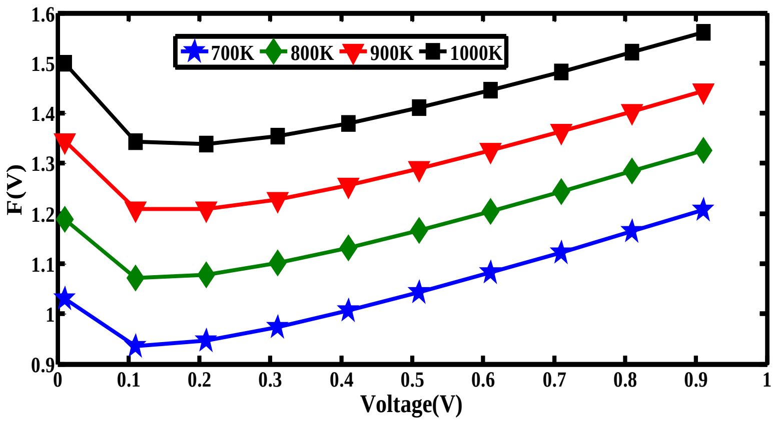

Fig. 3 *Temperature dependent F(V) versus V plot*

Capacitance-voltage aspect

Capacitance-voltage aspect is another approach to investigate the characteristics of Schottky diode. Temperature dependent C-V characteristics were discussed in a wide range of temperature 700K-1000K as shown in Fig. 4 by utilizing the expression

$$\frac{1}{C^2} = \frac{2\left(V_{bi} - \frac{kT}{q} - V\right)}{qA^2 \in N_d} \quad (8)$$

Where built in potential is represented by V_{bi}, donor concentration is shown by N_d, k is constant of Boltzmann, ZnO permittivity is represented by $\epsilon = 7.5 \times 10^{-13} F/cm$ and charge of an electron is q.

Temperature dependent N_d was obtained from the gradient of $1/C^2$ versus V plot by using Eq. 9

$$N_d = -\frac{2}{qA^2 \in \frac{d\left(\frac{1}{C^2}\right)}{dV}} \quad (9)$$

and V_{bi} was calculated by substituting the values of V_n extracted from x-intercept of Fig. 4 in Eq. 10

$$V_{bi} = V_n + \frac{kT}{q} \quad (10)$$

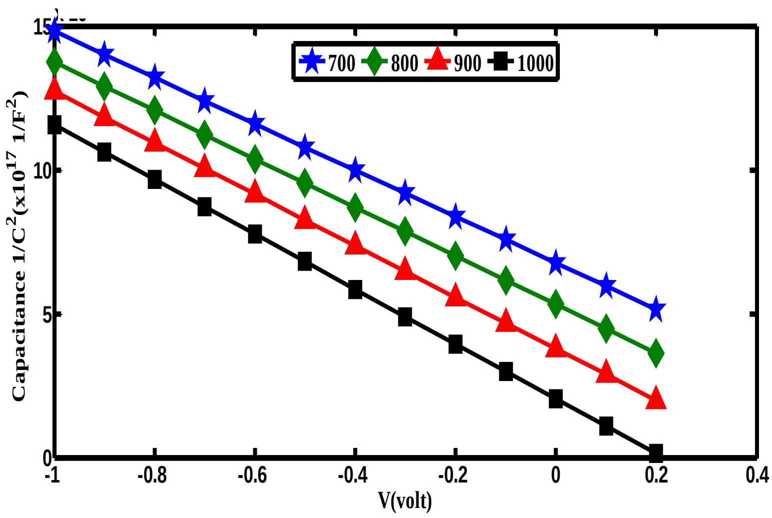

Fig. 4 *Temperature dependent C-V aspects*

By employing these extracted results in Eq. 11 height of barrier can be calculated.

$$\emptyset_b = V_{bi} + \frac{kT}{q} ln\left(\frac{N_c}{N_d}\right) \quad (11)$$

Where effective carrier density N_c is defined by (12)

$$N_c = 2\left\{2\pi m^* \left(\frac{kT}{h^2}\right)\right\}^{\frac{3}{2}} \quad (12)$$

Result and discussion

Table 1 is representing the values of series resistance and comparison among the values of height of barrier obtained by using Norde function and C-V characteristics.

Temperature(K)	Capacitance-Voltage	Norde Function	
	$\emptyset_b$ (eV)	$\emptyset_b$ (eV)	Rs(KΩ)
700	**1.05**	**0.94**	**1.24**
800	**0.88**	**1.08**	**1.04**
900	**0.69**	**1.29**	**0.70**
1000	**0.51**	**0.47**	**0.34**

Table 1*. Acquired results of* height of barrier *and series resistance by using Norde and C-V aspects.*

Fig. 5 illustrates the comparison between the obtained results of height of barrier from Norde function and C-V aspects. It is clearly shown from Fig. 5 that height of barrier shows significantly correlated behavior against temperature when it was calculated from Norde function and through C-V aspect it shows negatively correlated behavior. These results of height of barrier have good compatibility with previous published report [23]. The reason behind this dissimilarity between Norde function and C-V aspect is biasing mode as in forward bias I-V height of barrier increases while in C-V aspect height of barrier decreases because of reverse bias [24].

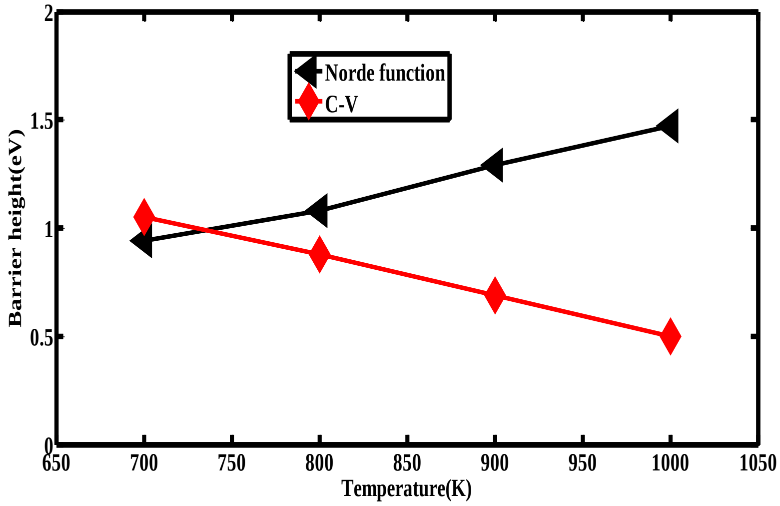

Fig. 5 *Dependency of* height of barrier *on different values of temperature*

Change in the results of series resistance obtained by employing Norde function with respect to temperature is depicted in Fig. 6. These values of series resistance are greater than those which were obtained from Cheung function in previously published report [25]. The reason of this discrepancy is because in the calculation Norde used overall forward bias I-V region whereas non-linear region of I-V characteristics in forward bias was used by Cheung [18].

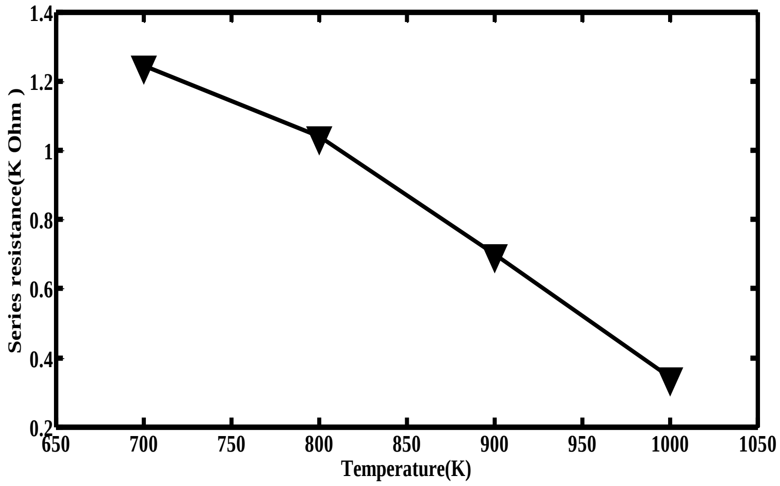

Fig. 6 *Dependency Of resistance on temperature*

Conclusion

Influence of Temperature changing from 700K-1000K on electrical parameters of Schottky diode based on ZnO has been explored by using C-V characteristics and Norde function. Parameters of diode like series resistance and height of barrier were achieved from I-V characteristics through Norde function. The height of barrier was also calculated from C-V characteristics. All parameters were obtained by using MATLAB software. Obtained results of series resistance showed inverse relation with temperature. It was noted that results of height of barrier are in direct relation with temperature when calculated by Norde function and showed inverse relation when calculated by C-V aspects.

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