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The theoretical and experimental study on double-Gaussian distribution in inhomogeneous barrier-height Schottky contacts

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ABSTRACT

We have considered multi-Gaussian distribution of barrier-heights for non-interactive barrier inhomogeneities in the inhomogeneous Schottky diodes, and we have shown the presence of the intersecting behavior in the forward-bias current–voltage (*I*–*V*) curves for the double-Gaussian distribution model at low temperatures. We have tried to eliminate this effect by generating *I*–*V* curves at lower temperatures with the bias-dependent barrier-height expression which leads to the ideality factors greater than unity. For this calculation, we have obtained the expressions for the barrier-height change and ideality factor, and for bias-dependency of the BH for the multi-Gaussian model by following the literature. We have shown that the experimental forward-bias *I*–*V* curves coincide with the theoretical ones using the bias-dependent inhomogeneous BH expression at low and high temperatures in the double-Gaussian distribution of BHs.

1. Introduction

The fact that the fundamental physical mechanisms which determine Schottky barrier diode (SBD) parameters such as ideality factor n and barrier-height (BH) are fully understood has vital importance in all electronic and optoelectronics devices [1–7]. The analysis of the temperature dependence of the current–voltage (*I*–*V*) characteristics of the SBDs allows us to understand different aspects of conduction mechanisms because the *I*–*V* characteristics at room temperature only does not give detailed information about their conduction process [1–13]. However, a complete description of the charge carrier transport through a metal semiconductor (MS) contact is still a challenging problem [1–13]. As well-known, the temperature dependence of the BH and the ideality factor is generally observed in SBDs also if the pure thermionic emission is the most probable way of carrier transport. Sometimes, the temperature-dependent behavior of SBDs can only obey the special barrier inhomogeneity present in Schottky contacts which is recently described mainly with a Gaussian distribution function [8–14]. The BH in Schottky contacts is likely a function of the interface atomic structure and the atomic inhomogeneities at the MS interface [8–15].

Some of the authors [15–19] discussed the intersection behavior of the *I*–*V* characteristics of inhomogeneous Schottky contacts. Chand [16,17] has described an interesting effect that the calculations have shown that the current at lower temperature may exceed the current at higher temperatures which should appear in inhomogeneous Schottky contacts. He [16,17] used the apparent BH expression given by Song et al. [8] and Werner and Güttler [9] to simulate the forward-bias *I*–*V* curves of the non-interaction inhomogeneous SBDs. According to Chand [16,17], the intersection of ln(*I*)–*V* curves may occur because of decreasing apparent BH with decreasing temperature, which has been also supported by Osvald [18]. The same effect has also been confirmed by Yıldırım and Türüt [19]. Chand [16,17] has eliminated this affect with an ideality factor greater than unity for lower temperatures modifying the model of conventional Gaussian distribution of BHs. Yıldırım and Türüt [19] have supplied the fact that the experimental forward-bias *I*–*V* curves coincide with the theoretical ones using the bias-dependent BH expression at low and high temperatures.

In the present study, we have shown the presence of the intersecting behavior in the forward-bias *I*–*V* curves for the double-Gaussian distribution, considering multi-Gaussian distribution of BHs of the inhomogeneous SBDs suggested by Jiang et al. [20,21]. Then, we have obtained the expressions of the BH change and ideality factor and bias-dependency of the BH by following Werner and Güttler [9] and Refs. [19–22] for the multi-Gaussian model. The main effort in the manuscript is devoted to the deriving of the apparent barrier-height of inhomogeneous Schottky diode and its temperature dependence. We have supplied the fact that the experimental forward-bias *I*–*V* curves coincide with the theoretical ones

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using the bias-dependent BH expression for low and high temperatures in the double-Gaussian distribution of BHs. The experimental temperature-dependent forward-bias I–V characteristics of a Ni/n-GaAs SBD given by us in Ref. [23] have been used in the calculations.

2. Theoretical considerations

The forward-bias thermionic emission (TE) current expression for Schottky diodes is given as follows [1]:

$$I = AA^{*}T^{2}\,\exp\left(-\frac{q\Phi_b(0,T)}{kT}\right)\left[\exp\left(\frac{q(V_D)}{nkT}\right)-1\right], \tag{1}$$

where

$$I_0 = AA^{*}\,T^{2}\,\exp\left(-\frac{q\Phi_b(0,T)}{kT}\right) \tag{2}$$

is the saturation current, q is the electron charge, $V_D = (V - IR_s)$, V is the forward-bias voltage, A is the effective diode area, k is the Boltzmann constant, T is the absolute temperature, A^{*} is the effective Richardson constant of 8.16 A cm^{-2}K^{-2} for n-type GaAs, R_s is the series resistance of the neutral region of the semiconductor bulk (between the depletion region and ohmic contact), IR_s and V_D are the voltage drop across the series resistance and the depletion region, respectively, $\Phi_b(0,T)$ is the zero bias BH at a given temperature and n is the ideality factor. From Eq. (1), for ($V \geqslant 3\,kT/q$), the ideality factor n can be written as

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

The ideality factor, n, is introduced to take into account the deviation of the experimental I–V data from the ideal thermionic model due to the barrier inhomogeneity and other effects and it should be $n = 1$ for an ideal contact. When the BH is bias-dependent, Eq. (1) is given as

$$I = AA^{*}T^{2}\,\exp\left(-\frac{q\Phi_b(V,T)}{kT}\right)\left[\exp\left(\frac{q(V_D)}{n_0kT}\right)-1\right] \tag{4}$$

where $\Phi_b(V,T)$ is the bias-dependent BH at a given temperature, and n_0 can be regarded as the ideality factor caused by other factors except the inhomogeneity effect. Let us consider the inhomogeneity effect only, then $n_0 = 1$ and the voltage dependence of the BH requires $n > 1$. Therefore, the BH increases with increasing bias voltage. We assume that the BH distribution at inhomogeneous Schottky contacts can be described by the Gaussian distribution. In such a case, the ideality factor n is given by [1,9,10]

$$(n^{-1}(T)-1)V_D = -\Delta\Phi_b(V,T), \tag{5}$$

where $\Delta\Phi_b(V,T)$ is the change of the BH under bias, and it is written as [1,9,10]

$$\Delta\Phi_b(V,T) = \Phi_b(V,T) - \Phi_b(0,T). \tag{6}$$

Eq. (6) demonstrates that voltage-independent ideality factor n requires a linear increase of $\Phi_b(V,T)$ with the bias, i.e.,

$$\Delta\Phi_b(V,T) = \rho_1(T)V_D \tag{7}$$

$$n^{-1}(T) - 1 = -\rho_1(T) \tag{8}$$

where $\rho_1 > 0$ and it is a voltage coefficient which must depend on T for a temperature-dependent $n(T)$. However, the distributions differ for each bias voltage, we postulate therefore that the BHs in Eqs. (1), (4), and (6) hold for all bias voltage including $V = 0$ and we write as [9,10]

$$\Phi_b(0,T) = \bar{\Phi}_b(0,T) - \frac{q\sigma^2(0)}{2kT} \tag{9}$$

$$\Phi_b(V,T) = \bar{\Phi}_b(V,T) - \frac{q\sigma^2(V)}{2kT}, \tag{10}$$

where $\bar{\Phi}_b(0,T)$ and $\bar{\Phi}_b(V,T)$ are mean values of the Gaussian BH distributions. Thus, from Eqs. (6), (9), and (10), the change of the BH under bias is given as [9]

$$\begin{aligned}\Delta\Phi_b(V,T) &= \Phi_b(V,T) - \Phi_b(0,T)\\ &= \bar{\Phi}_b(V,T) - \bar{\Phi}_b(0,T) - \frac{q(\sigma^2(V)-\sigma^2(0))}{2kT}\\ &= \Delta\bar{\Phi}_b(V,T) - \frac{q\Delta\sigma^2(V)}{2kT}\end{aligned} \tag{11}$$

Now, from Eqs. (5) and (11), for single-Gaussian distribution the ideality factor is obtained as

$$(n^{-1}(T)-1)V_D = -\Delta\bar{\Phi}_b(V,T) + \frac{q\Delta\sigma^2(V)}{2kT} \tag{12}$$

or

$$(n^{-1}(T)-1) = -\rho_2 + \frac{q\rho_3}{2kT}, \tag{13}$$

where [9]

$$\Delta\bar{\Phi}_b(V,T) = \bar{\Phi}_b(V,T) - \bar{\Phi}_b(0,T) = \rho_2 V_D, \tag{14}$$

$$\Delta\sigma^2(V) = \sigma^2(V) - \sigma^2(0) = \rho_3 V_D. \tag{15}$$

We restrict ourselves to the special case of voltage-independent ideality factors [9–12]. The ideality factors which are independent of bias voltage are only possible if the mean BH $\bar{\Phi}_b$ as well as the square of the standard deviation σ^2 vary linearly with the bias. In Eqs. (14) and (15), ρ_2 is the voltage coefficient of the mean BH, and ρ_3 is the voltage coefficient of the standard deviation. According to Eq. (13), a plot of $(n^{-1}-1)$ against $1/T$ should give a straight line with the slope and y-axis intercept related to the voltage coefficients ρ_2 and ρ_3, respectively. All plots give negative value for the slope which indicates that $\sigma^2(V) < \sigma^2(0)$ (for $V > 0$) due to the expression $\sigma^2(V) - \sigma^2(0) = \rho_3 V_D$ [9–13]. The value of ρ_3 indicates that the distribution of the BH becomes more homogeneous with voltage increase. Consequently, substituting $\bar{\Phi}_b(V,T)$ and $\sigma^2(V)$ from Eqs. (14) and (15) in Eq. (10), the bias-dependent BH $\Phi_b(V,T)$ for the single-Gaussian distribution at a given temperature is obtained as [19,24]

$$\Phi_b(V,T) = \bar{\Phi}_b(0,T) - \frac{q\sigma^2(0)}{2kT} + \left(\rho_2 - \frac{q\rho_3}{2kT}\right)V_D. \tag{16}$$

Chand [16,17] has reported an unexpected observation in the I–V curves at low temperatures of Schottky contacts containing non-interactive barrier inhomogeneities, using Eq. (1) (for $n = 1$) and Eq. (9) based on a Gaussian distribution model of the BHs. The results [15–19] have shown that the current at low temperatures may exceed the current at high temperatures. The same observation has also been confirmed by the Osvald [18]. Chand [16] tried to eliminate this effect by generating I–V curves for lower temperatures with an ideality factor greater than unity, indicating that the higher ideality factor arises due to the bias dependence of the BHs, and showed that no such crossing is observed in the curves with higher ideality factor at low temperatures. It is well-known that the bias dependence of BHs in the distribution through mean and standard deviations leads to the temperature-dependent ideality factor in the inhomogeneous Schottky contacts. Therefore, Yıldırım and Türüt [19] have reported that, if the bias dependence of the BH is considered in the calculations or Eq. (16) is used in Eq. (4) for $n_0 = 1$, no such a crossing is observed in the I–V curves at low temperatures. Moreover, they [19] have showed that the theoretical I–V curves exactly coincide with experimental I–V curves at low and high temperatures when Eq. (16) is used in Eq. (4) for $n_0 = 1$. As well-known, the BH is known to depend on the applied bias, and the high ideality factor arises due to the bias dependence of the BH [1,16,19]. The bias dependence of BH in the distribution through mean and standard deviations leads to the temperature-dependent ideality factor in inhomogeneous Schottky diodes [16,19].

Now, let us make the same calculations by using double-Gaussian distribution model which holds over whole measurement temperature range suggested by Jiang et al. [20,21]. They [20,21] have assumed that an infinite number of Gaussian distributions with different mean values and standard deviations. $\Phi_b(0,T)$ and $\Phi_b(V,T)$ in a new multi-Gaussian distribution model that they have developed are given by [20–22]

$$\Phi_b(0,T) = -\frac{kT}{q}\ln\sum_{i=1}^{n} A_i \exp\left(-\frac{q\bar{\Phi}_{bi}(0,T)}{kT} + \frac{q^2\sigma_i^2(0)}{2k^2T^2}\right) \tag{17}$$

$$\Phi_b(V,T) = -\frac{kT}{q}\ln\sum_{i=1}^{n} A_i \exp\left(-\frac{q\bar{\Phi}_{bi}(V,T)}{kT} + \frac{q^2\sigma_i^2(V)}{2k^2T^2}\right) \tag{18}$$

where A_i represents the weight of each Gaussian distribution, and the normalization of distribution function requires $\sum_i A_i = 1$. Following Eqs. (14) and (15), for the multi-Gaussian distribution we have

$$\Delta\bar{\Phi}_b(V,T) = \bar{\Phi}_{bi}(V,T) - \bar{\Phi}_{bi}(0,T) = \rho_{2i}V_D, \tag{19}$$

$$\Delta\sigma^2(V) = \sigma_i^2(V) - \sigma_i^2(0) = \rho_{3i}V_D. \tag{20}$$

Substituting $\bar{\Phi}_{bi}(V,T)$ and $\sigma_i^2(V)$ from Eqs. (19) and (20) in Eq. (18), the bias-dependent BH $\Phi_b(V,T)$ at a given temperature is obtained as

$$\Phi_b(V,T) = -\frac{kT}{q}\ln\left[\sum_{i=1}^{n} A_i \exp\left(-\frac{q(\rho_{2i}V_D + \bar{\Phi}_{bi}(0,T))}{kT} + \frac{q^2(\rho_{3i}V_D + \sigma_i^2(0))}{2k^2T^2}\right)\right]. \tag{21}$$

For an inhomogeneous Schottky diode with a double-Gaussian distribution of the BHs, from Eqs. (17) and (21), the $\Phi_b(0,T)$ and $\Phi_b(V,T)$ can be written as

$$\Phi_b(0,T) = -kT\ln\left[A_1\exp\left(-\frac{\bar{\Phi}_{b1}(0,T)}{kT} + \frac{\sigma_1^2(0)}{2(kT)^2}\right) + A_2\exp\left(-\frac{\bar{\Phi}_{b2}(0,T)}{kT} + \frac{\sigma_2^2}{2(kT)^2}\right)\right], \tag{22}$$

$$\begin{aligned}\Phi_b(V,T) = -\frac{kT}{q}\ln\Bigg[&A_1\exp\left(-\frac{q(\rho_{21}V_D + \bar{\Phi}_{b1}(0,T))}{kT} + \frac{q^2(\rho_{31}V_D + \sigma_1^2(0))}{2k^2T^2}\right)\\ &+A_2\exp\left(-\frac{q(\rho_{22}V_D + \bar{\Phi}_{b2}(0,T))}{kT} + \frac{q^2(\rho_{32}V_D + \sigma_2^2(0))}{2k^2T^2}\right)\Bigg]\end{aligned} \tag{23}$$

Considering Eqs. (17)–(21), owing to Eq. (6), that is, $\Delta\Phi_b(V,T) = \Phi_b(V,T) - \Phi_b(0,T)$, the change of the BH under bias can be given by [22]

$$\Delta\Phi_b(V,T) = \frac{kT}{q}\ln\left[\frac{\sum_{i=1}^{n} A_i\exp\left(-\frac{q\bar{\Phi}_{bi}(0,T)}{kT} + \frac{q^2\sigma_i^2(0)}{2k^2T^2}\right)}{\sum_{i=1}^{n} A_i\exp\left(-\frac{q\bar{\Phi}_{bi}(V,T)}{kT} + \frac{q^2\sigma_i^2(V)}{2k^2T^2}\right)}\right]. \tag{24}$$

According to Eqs. (5) and (24), the ideality factor can be written as [22]

$$(n^{-1}(T) - 1) = \frac{kT}{qV_D}\ln\left[\frac{\sum_{i=1}^{n} A_i\exp\left(-\frac{q(\rho_{2i}V_D + \bar{\Phi}_{bi}(0,T))}{kT} + \frac{q^2(\rho_{3i}V_D + \sigma_i^2(0))}{2k^2T^2}\right)}{\sum_{i=1}^{n} A_i\exp\left(-\frac{q\bar{\Phi}_{bi}(0,T)}{kT} + \frac{q^2\sigma_i^2(0)}{2k^2T^2}\right)}\right]. \tag{25}$$

We can also write Eqs. (24) and (25) such as Eqs. (22) and (23) for a double-Gaussian distribution of BH if we want to use in the calculations. Let us write the ideality factor n from Eq. (25) for a double-Gaussian as follows:

$$\begin{aligned}\frac{1}{n} = 1 + \frac{kT}{qV_D}\ln\Bigg[&\exp\left(-\frac{q\rho_{21}V_D}{kT} + \frac{q^2\rho_{31}V_D}{2k^2T^2}\right)\\ &+\exp\left(-\frac{q\rho_{22}V_D}{kT} + \frac{q^2\rho_{32}V_D}{2k^2T^2}\right)\Bigg]\end{aligned} \tag{26}$$

3. Results and discussion

Chand [16,17], Osvald [18] and Yıldırım and Türüt [19] have reported an unexpected observation in the *I–V* curves at low temperatures of Schottky contacts containing non-interactive barrier inhomogeneities using Eq. (1) (n = 1) and Eq. (9) based on a single-Gaussian distribution model of the BHs, indicating a high current through the Schottky diodes at lower temperatures which is inconsistent with the thermionic emission diffusion theory. They [15–19] have made necessary some suggestions for the current at low temperatures not to exceed the current at high temperatures. However, Chand [17] have said by following Osvald [18] that attributing a high ideality factor only to the curves at low temperatures is not justified and appears as a compromising attempt to arise curves consistent with conventional diode behavior observed so far. Osvald [18] have supposed that the change of the BH with the temperature is the expression of the temperature dependence of the different participations of different local barrier patches in the whole current. We will make some calculations by using the double-Gaussian distribution model suggested by Jiang et al. [20,21] which holds over whole measurement temperature range. The double-Gaussian distribution model suggested by Jiang et al. [20,21] contains Eqs. (1) and (22) which are given for the non-interactive barrier inhomogeneities for n = 1.

The *I–V* curves obtained using Eqs. (1) and (22) are shown in Fig. 1. The *I–V* curves in Fig. 1 are obtained using the double-Gaussian distribution model by Jiang et al. [20,21]. The parameters, $A_1 = 5.61 \times 10^{-4}$, $A_2 = 1 - A_1$, $\bar{\Phi}_{b1} = 0.77$ eV, $\bar{\Phi}_{b2} = 0.89$ eV, $\sigma_1 = 68$ mV, $\sigma_2 = 52$ mV used for Fig. 1, have been taken from the experimental $\Phi_b(0,T) = \Phi_{ap}$ versus T (Fig. 2) plot which is drawn by means of the temperature-dependent *I–V* data of a Ni/*n*-GaAs Schottky contact fabricated by us [23]. As can be seen from Fig. 1, the *I–V* curves at low temperatures (below ~120 K) intersect those at high temperatures.

Thus, it has been seen from calculations based on the double-Gaussian distribution model of BHs that the SBDs at very lower temperatures exhibit higher currents than those at higher temperatures. This is an unusual observation for the *I–V* curves obtained using Eqs. (1) and (22) and is inconsistent with the thermionic emission theory. However, the crossing may be eliminated if one generates them taking into account the bias dependence of the BH. Firstly, let us use Eq. (23) in Eq. (4) for n_0 = 1 to eliminate the intersection effect by generating *I–V* curves for lower temperatures. But, the theoretical curves shown in Fig. 3 or Fig. 4 are insensitive to the presence of 2nd distribution of BHs, since by putting A_2 = 0 in Eq. (23) while using it in Eq. (4) for generating theoretical I–*V* data yields same current as one get using $A_2 = (1 - A_1)$. The current contribution from the 2nd distribution is effective only at temperature above about 250 K. Therefore, to eliminate the

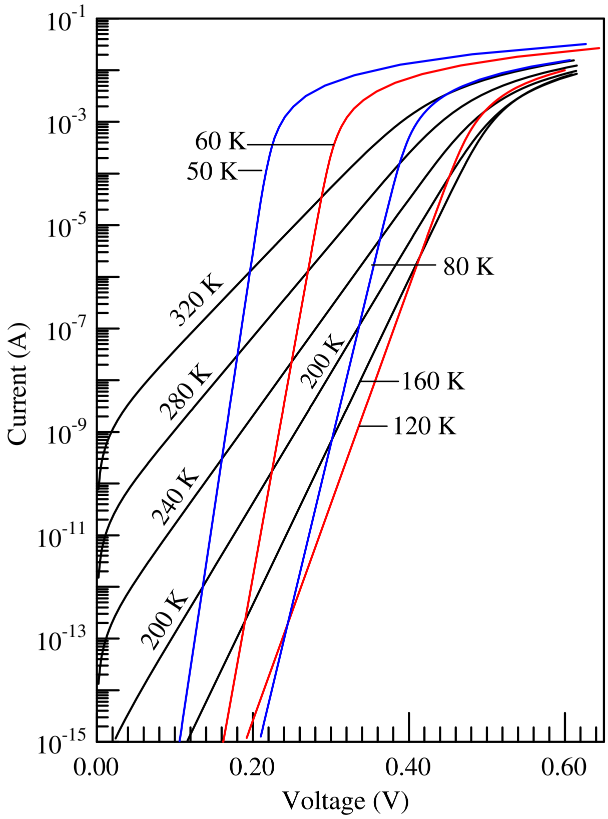

Fig. 1. Theoretical forward-bias current–voltage characteristics of a Schottky contact containing non-interactive barrier inhomogeneities using Eq. (22) in Eq. (1) at various temperatures by taking $A_1 = 5.61 \times 10^{-4}$, $A_2 = 1{-}A_1$, $\bar{\Phi}_{b1} = 0.77$ eV, $\bar{\Phi}_{b2} = 0.89$ eV, $\sigma_1 = 68$ mV, $\sigma_2 = 52$ mV.

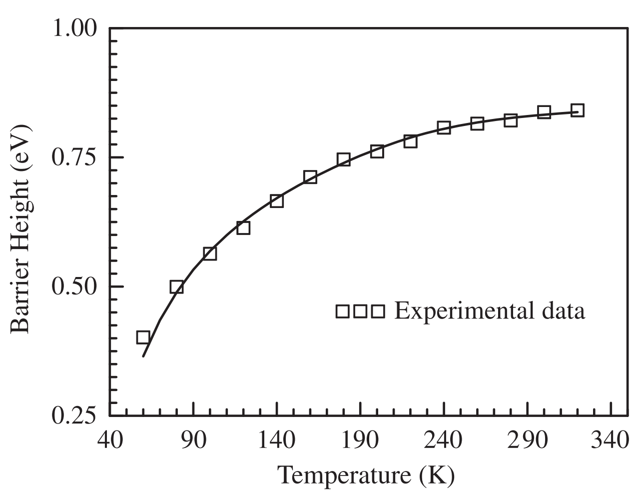

Fig. 2. BH versus temperature plot for the Ni/*n*-GaAs Schottky diode [23]. The continuous curve was obtained using Eq. (22) for double-Gaussian distribution given in Refs. [20,21], where $A_1 = 5.61 \times 10^{-4}$, $\bar{\Phi}_{b1} = 0.77$ eV, $\bar{\Phi}_{b2} = 0.89$ eV, $\sigma_1 = 68$ mV, $\sigma_2 = 52$ mV.

intersection effect, Eq. (22) plus Eq. (24) can be used instead of Eq. (23) in Eq. (4) because $\Phi_b(V,T) = \Phi_b(0,T) + \Delta\Phi_b(V,T)$, or Eqs. (22) and (25) can be used instead of Eq. (23) in Eq. (4) because $(n^{-1}(T) - 1)V_D = -\Delta\Phi_b(V,T)$ or Eqs. (22) and (26) can be used instead of Eq. (23) in Eq. (1). These calculations give the same results. We made the calculations using Eqs. (22) and (26) in Eq. (1).

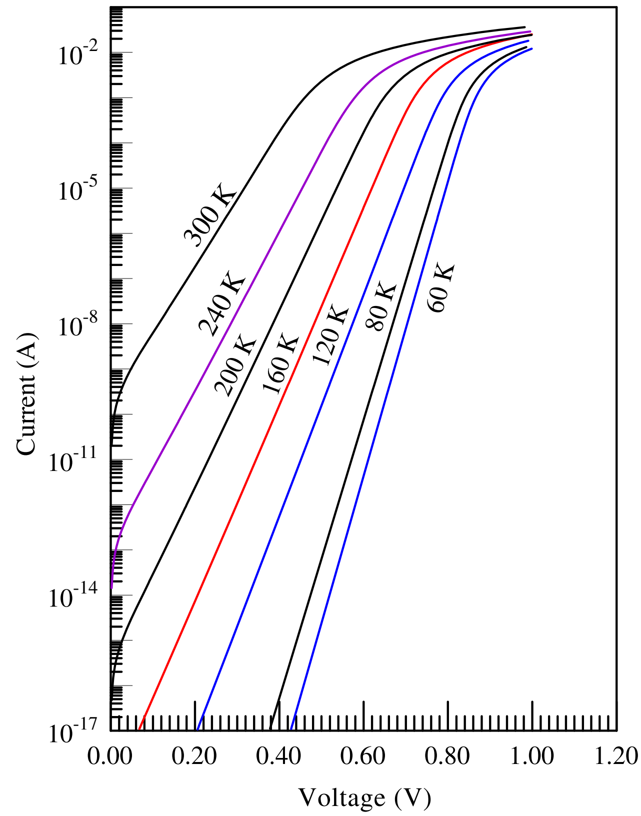

Fig. 3. Theoretical forward-bias current–voltage characteristics of an Schottky contact obtained using Eqs. (22) and (26) in Eq. (1) for various temperatures with $A_1 = 5.61 \times 10^{-4}$, $\bar{\Phi}_{b1} = 0.77$ eV , $\bar{\Phi}_{b2} = 0.89$ eV, $\sigma_1 = 68$ mV, $\sigma_2 = 52$ mV, $\rho_{21} = 0.210$, $\rho_{31} = -0.00416$ V, $\rho_{22} = -0.157$, $\rho_{32} = -0.0126$ V.

Such forward-bias *I–V* curves are given in Fig. 3. The bias and temperature-dependent theoretical forward-bias *I–V* curves were calculated using Eqs. (22) and (26) in Eq. (1) with with $A_1 = 5.61 \times 10^{-4}$, $\bar{\Phi}_{b1} = 0.77$ eV, $\bar{\Phi}_{b2} = 0.89$ eV, $\sigma_1 = 68$ mV, $\sigma_2 = 52$ mV $\rho_{21} = 0.210$, $\rho_{31} = -0.00416$ V, $\rho_{22} = -0.157$, $\rho_{32} = -0.0126$ V. The parameters used for Fig. 3 have been taken from the experimental $\Phi_b(0,T) = \Phi_{ap}$ versus *T* and $n(T) = n_{ap}$ versus $1/T$ plots which are drawn by means of the temperature-dependent *I–V* data of a Ni/*n*-GaAs Schottky contact fabricated by us [23]. The $n(T)$ versus $1/T$ plot of the Ni/*n*-GaAs Schottky contact is given in Ref. [23].

Fig. 4 shows the theoretical and experimental forward-bias current–voltage characteristics of the Ni/*n*-GaAs Schottky contact with non-homogeneous BH. Theoretical curves are obtained using Eqs. (22) and (26) in Eq. (1) for various temperatures with $A_1 = 5.61 \times 10^{-4}$, $\bar{\Phi}_{b1} = 0.77$ eV, $\bar{\Phi}_{b2} 0.89 =$ eV, $\sigma_1 = 68$ mV, $\sigma_2 = 52$ mV, $\rho_{21} = 0.210$, $\rho_{31} = -0.00416$ V, $\rho_{22} = -0.157$, $\rho_{32} = -0.0126$ V. The parameters used for determination of the theoretical calculations in the *I–V* curves in Fig. 4 have been taken from the experimental $\Phi_b(0,T)$ versus *T* plot in Fig. 2 above and from the experimental $n(T)$ versus $1/T$ plot drawn by means of the temperature-dependent *I–V* data of the Ni/*n*-GaAs Schottky contact fabricated by us [23]. As can be seen from Fig. 4, the *I–V* curves computed by considering the bias dependence of the mean and standard deviation values, that is, when using Eqs. (22) and (26) in Eq. (1), exactly coincide with the experimental *I–V* curves of the Ni/*n*-GaAs Schottky contact; but the experimental and computed *I–V* curves do not coincide with each other if Eq. (22) only used instead of Eqs. (22) and (26) in Eq. (1). As stated above, the main effort in the manuscript is devoted to the deriving of the apparent BH of inhomogeneous Schottky diode and its temperature and bias dependence. The bias-dependent BH expression

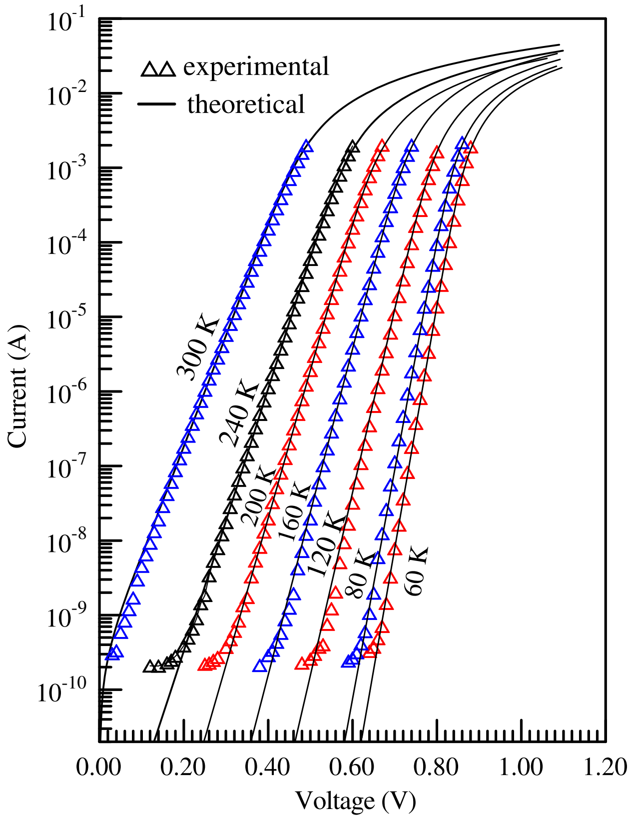

Fig. 4. Theoretical and experimental forward-bias current–voltage characteristics of the Ni/*n*-GaAs Schottky contact with non-homogeneous BH. Theoretical curves are obtained using Eqs. (22) and (26) in Eq. (1) for various temperatures with $A_1 = 5.61 \times 10^{-4}$, $\bar{\Phi}_{b1} = 0.77$eV, $\bar{\Phi}_{b2} = 0.89$ eV, $\sigma_1 = 68$ mV, $\sigma_2 = 52$ mV, $\rho_{21} = 0.210$, $\rho_{31} = -0.00416$ V, $\rho_{22} = -0.157$, $\rho_{32} = -0.0126$ V.

derived for the double-Gaussian distribution of the BH is then used in Eq. (1) for generating *I–V* curves; that is, Eqs. (22) and (26) in Eq. (1). The problem is the fact that the apparent BH is derived for an ideal case without series resistance influence and only then the series resistance is incorporated into the considerations through the Eq. (1). But for inhomogeneous diodes we cannot divide *I–V* curve into the part without and with the series resistance influence. Small barriers are immediately closed, already for very small voltages by the series resistance and are followed continuously by higher and higher barriers [25,26]. Thus, the generation of *I–V* curves is for the case of the continuous barrier-height distribution only possible by numerical procedure [25,26].

In conclusion, we have studied to make some calculations for non-interactive barrier inhomogeneities using the double-Gaussian distribution model suggested by Jiang et al. [20,21] in the SBDs. The forward-bias *I–V* curves have been obtained using Eqs. (1) and (22) for low and high temperatures. The currents at lower temperatures have exceeded the current at high temperatures. We have eliminated this effect by generating *I–V* curves at lower temperatures with the bias-dependent BH values which lead to the ideality factors greater than unity. Consequently, it has been seen that the *I–V* curves computed by considering the bias dependence expression of the BH for the double-Gaussian distribution model, that is, using Eqs. (22) and (26) in Eq. (1), exactly coincide with the experimental *I–V* curves of the Ni/*n*-GaAs Schottky contact.

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