Non Ideal Schottky Barrier Diode’s Parameters Extraction and Materials Identification from Dark I-V-T Characteristics

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Abstract

Several parameters of a commercial Si-based Schottky barrier diode (SBD) with unknown metal material and semiconductor-type have been investigated in this work from dark forward and reverse I-V characteristics in the temperature (T) range of [274.5 K - 366.5 K]. Those parameters include the reverse saturation current (I_s), the ideality factor (n), the series and the shunt resistances (R_s and R_sh), the effective and the zero bias barrier heights (\Phi_s and \Phi_{B0}), the product of the electrical active area (A) and the effective Richardson constant (A’), the built-in potential (V_{bi}), together with the semiconductor doping concentration (N_A or N_D). Some of them have been extracted by using two or three different methods. The main features of each approach have been clearly stated. From one parameter to another, results have been discussed in terms of structure performance, comparison on one another when extracted from different methods, accordance or discordance with data from other works, and parameter’s temperature or voltage dependence. A comparison of results on \Phi_s, \Phi_{B0}, n and N_A or N_D parameters with some available data in literature for the same parameters, has especially led to clear propositions on the identity of the analyzed SBD’s metal and semiconductor-type.

Keywords

SBD, Dark Forward and Reverse I-V-T Characteristics, Different Parameters Extraction Methods, Identification of the Structure’s Metal and Semiconductor-Type

1. Introduction

Rectifying metal-semiconductor (MS) contacts, also known as Schottky barrier diodes (SBDs), have received an increasing attention due to their applications in
photovoltaic solar cells [1] [2] [3] [4], field effect transistors (FETs) [5], infrared high-speed detectors, electronic switching and other high-frequency devices [6] [7] [8] [9]. Many reports on SBDs physical properties have been proposed in order to better understand the performance of those structures and related devices. The four SBD’s key parameters are the reverse saturation current ($I_s$), the ideality factor ($n$), the series resistance ($R_s$) and the effective Schottky barrier height (SBH, $\Phi_B$) [10]. Together with the SBH at zero bias (or the asymptotic SBH) ($\Phi_{0}$), the electrical active area ($A$), the effective Richardson constant ($A^*$) and the semiconductor doping concentration ($N_A$ or $N_D$), those parameters can be extracted by using different methods based on current-voltage ($I$-$V$) characteristics [11]-[28]. Besides this first group of methods, capacitance-voltage ($C$-$V$) techniques are used to extract majority carrier concentration ($N_A$ or $N_D$), activation energy ($E_A$), densities ($n_i$) and energy levels ($E_{is}$) of interface states. In addition, photo-response measurements, which involve various spectroscopic techniques, are implemented in order to extract parameters such as band-gap, impurity and doping concentration, layer thickness, surface roughness and texture [29] [30]. Methods from those three groups are combined in some reports [4] [31]-[37].

While several methods from those groups are analytical ones, numerical techniques are also used [1] [2] [9] [38] [39] [40] [41] [42]. Moreover, as shown in some review reports [43] [44] [45] [46], from one method to another, two or several parameters can be simultaneously extracted; dc or ac, static or dynamic, fixed or varying frequency and temperature operation’s conditions can be applied; different current transport mechanisms may be taken into account; results can be temperature or voltage dependent; and they may be compared one another when different methods are combined.

The SBD analyzed in this work is a commercial Si-based one from ST Microelectronics, for which neither the metal nor the semiconductor-type (p- or n-) were specified in the relevant catalog. By using dark forward and reverse current-voltage ($I$-$V$) characteristics at different temperatures, together with different approaches, our objective was three-fold: firstly to extract different parameters of that structure, secondly to discuss our results, and thirdly to especially come to identify the SBD’s metal and semiconductor-type.

2. Experimental Details

The SBD sample of this analysis is shown magnified in Figure 1 and has the following actual specifications: blue color, BAT 48 as trade mark, diameter and length of the central part equal to 0.15 cm and 0.3 cm, respectively, diameter and length of each of the two terminal’s wires equal to 0.7 mm and 3.0 cm, respectively.

Reverse and forward $I$-$V$-$T$ characteristics of the diode were measured in dark conditions over bias voltage and temperature ranges of $[-2.5; +0.5]$ V and $[274.5; 336.5]$ K, respectively. A common experimental arrangement of simple equipments
Figure 1. Magnified view of the SBD of this study.

has been used for that purpose. These include notably a power supply with d.c. emf fixed to a maximum value $E_0 = 2.5$ V; a rheostat mounted with the power supply in such a way to vary the emf, an ammeter and a voltmeter for $I$-$V$ measurements; an ice bath and an electrical heater to change thermal conditions of the sample, and a thermometer for temperature measurements.

3. Extracted Parameters, Used Methods, Results and Discussion

3.1. $R_{sh}$ from Reverse $I$-$V$ Plots

The complete representation of a real diode’s $I$-$V$ characteristic is given by Equation (1) [47]:

$$I = I_s \left\{ \exp \left[ \frac{q(V - R_s I)}{n k_B T} \right] - 1 \right\} + \frac{V - R_s I}{R_{sh}}$$

(1)

where $I_s$, $n$, $R_s$ and $R_{sh}$ are the diode’s reverse saturation current, ideality factor, series resistance and shunt resistance, respectively, while $q$ is the absolute value of the electronic charge and $k_B$ is the Boltzmann’s constant. The first term of the sum in Equation (1) represents the diode current and the second term describes the current through the shunt resistance ($I_p$). The simplest way to extract $R_{sh}$ or the related shunt conductance ($G_p$) consists in determining the slope of the straight line representing the reverse $I$-$V$ characteristic. That slope is given by Equation (2) [48]:

$$G_p = \frac{\Delta I_p}{\Delta V} = \frac{1}{R_{sh}}$$

(2)

For the considered temperature range, the obtained SBD’s reverse $I$-$V$ lines (Figure 2 is the plot of such a line at $T = 286.5$ K) were so merged that they have led to an almost constant shunt resistance: $R_{sh} = (4.93 \pm 0.07) \times 10^4 \Omega$. This has been a proof of the scarcity of crystal irregularities or defects in the bulk and at the edges of our SBD, through which current losses could occur.

3.2. $I_s$, $R_s$ and $n$ from Forward $\ln I$-$\alpha$-$V$ Plots

With the assumption of thermoionic emission (TE) as the prevailing charge transport mechanism in the SBD, the forward diode’s $I$-$V$ characteristic is given by [19] [47] [49]
In Equation (3), the reverse saturation current \( I_s \) is expressed as

\[
I_s = A A'' \left( -\frac{\Phi_B}{K_B T} \right)
\]  

(4)

where \( T \) is the diode’s absolute temperature, \( A \) is the junction’s electrically active area, \( A'' \) is the effective Richardson constant and \( \Phi_B \) is the effective Schottky barrier height (SBH). When the forward bias \( V > \frac{3K_B T}{q} \), Equation (3) is given by \[50\]

\[
I_d = I_s \exp \left( -\frac{qV}{nK_B T} \right)
\]  

(5)

According to Equation (5), \( n \) and \( I_s \) parameters can be, respectively, extracted from the slope and the intercept of the linear region (diffusion line) in the plot of the experimental \( \ln I_d - V \) data. Nevertheless, the presence of a parasitic series resistance affects the \( I-V \) characteristic mostly at high voltages. To account for this, Equation (5) is re-arranged to become

\[
I_d = I_s \exp \left[ \frac{q(V - R_s I)}{nK_B T} \right]
\]  

(6)

Using Equation (6) and following the Cowley and Sze method (ref. no. 2 in \[43\]), one extracts \( R_s \) from the gap \( \Delta V \) (on the \( V \)-axis) between the actual \( \ln I_d \) vs \( V \) curve and the diffusion line. Figure 3 is the plot of that curve for our SBD at one fixed temperature. On that plot, as different \( R_s \) are obtained at different \( I_d \) in the related region, a mean \( R_s \)-value is extracted.

Values of \( n \), \( I_s \) and \( R_s \) determined according to the previous methodology are summarized in Figure 4.

\( n(T) \) data from Figure 4 exhibit a somehow wavy trend, while results from other works state a slight decrease of the ideality factor with increasing temperature \([19] [22] [36] [51]\). Nevertheless, values of \( n \) for our SBD are higher than those commonly observed for c-Si solar cells \[44\]. Moreover, the ideality factor of our sample has values in good agreement with those of other investigated Si-based SBDs, e.g.: \( 1.2 < n < 2.7 \) for Pt/p-Si \[16\].
The average series resistance \( (R_s) \) of our SBD is much higher than \( R_s \)-values commonly observed for c-Si solar cells [43]. This is likely due to high resistivity (\( \rho \)) of Si-based SBDs (e.g.: \( \rho \) is equal to 15 \( \Omega \) cm for Tb/p-Si; 8 \( \Omega \) cm for Ru/n-Si and 1 \( \Omega \) cm for Pt/n-Si) [52], compared to resistivity of p-Si and n-Si materials (and thus of p-n Si junctions). As examples, \( \rho \) lies in the ranges \([4 \times 10^{-4}; 3 \times 10^{-2}\] \( \Omega \) cm and \([10^{-4}; 6 \times 10^{-2}\] \( \Omega \) cm for n-Si and p-Si, respectively, when the doping concentration decreases from \(10^{21}\) cm\(^{-3}\) to \(10^{18}\) cm\(^{-3}\) [6].

At its side, the reverse saturation current (\( I_s \)) may increase with increasing temperature according to Equation (4). That theoretical trend is not well evidenced by results of Figure 4. Nevertheless, those results do not depart too much from \( I_s \)-values observed elsewhere for some Si-based SBDs in the same temperature and voltage ranges. As examples, \( I_s \) is equal to \(7 \times 10^{-5}\) A for a Cr Si\(_2\)/n-Si junction at 300 K and for \( V \epsilon [0.12; 0.35] \) V [53], and to \(4 \times 10^{-4}\) A for an epitaxial CoSi\(_2\)/n-Si diode with an area of 0.61 mm\(^2\), at 292 K and \( V \in [0.2; 0.5] \) V [51].

### 3.3. \( \Phi_B \) and \( AA^{**} \) from the Activation Energy Method

From Equations (4) and (5), assuming \( n = 1 \), the SBD’s forward \( I-V \) characteristic is expressed as

\[
I = AA^{**} T^2 \exp \left[ -\left( \frac{\Phi_B - qV}{K_B T} \right) \right]
\]

and thus...
The activation energy method is based on the plot of experimental \( \ln(I/T^2) \) vs. \( 1/T \) data at a given voltage bias \( V > \frac{3K_B T}{q} \). From such an Arrhenius (or Richardson) plot, the effective Schottky barrier height (\( \Phi_B \)) and the \( AA^\ast \) product (of the contact’s electrically active area and the effective Richardson constant) can be derived from the negative slope and the intercept of the expected resulting straight line, respectively. Based on experimental forward \( I-V \cdot T \) data on the SBD of this analysis, results of such a determination are shown in Figure 5.

The SBHs in Figure 5 are estimates of actual \( \Phi_B \) since too many approximations are used in the present method. Moreover, experimental data points have been found scattered in each \( \ln(I/T^2) \) vs. \( 1/T \) plot. Nevertheless, a clear increase of the SBH with increasing bias voltage is noticed in agreement with theory (e.g. in Section 3.4).

The \( AA^\ast \) mean product is equal to \( 2.35 \times 10^{-6} \) A/K\(^2\). Using that result and the effective Richardson constants of 12 and 32 \( \times 10^4 \) A·m\(^{-2}\)·K\(^{-2}\) for n-Si and p-Si, respectively [6] [52], one finds the contact’s electrically active area \( A \) of the SBD equal to 2.23 \( \mu \)m\(^2\) and 7.81 \( \mu \)m\(^2\) for n-Si and p-Si, respectively. Those values correspond to diameters of 1.69 \( \mu \)m and 3.15 \( \mu \)m, respectively, which are clearly lower than the measured diameter (=0.7 mm) of each terminal’s wire.

### 3.4. \( \Phi_B \) from the SBH’s Bias Dependence Behavior

The basic equation used to estimate the SBH within the TE theory is obtained by combining Equations (3) and (4):

\[
I_s = AA^\ast T^2 \exp \left( \frac{-\Phi_B}{K_B T} \right) \left[ \exp \left( \frac{qV}{K_B T} \right) - 1 \right]
\]

\[
\ln \left( \frac{I}{T^2} \right) = \ln \left( AA^\ast \right) - \left( \frac{\Phi_B - qV}{K_B} \right) \frac{1}{T}
\]

Figure 5. Results of \( \Phi_B \) and \( AA^\ast \) obtained from Richardson’s plots.
As the SBH is strongly dependent on the electrical field in the depletion region and thus on the applied bias, \( \Phi_B \) is commonly expressed as \cite{16} \cite{19}

\[ \Phi_B = \Phi_{B0} + \beta V \]  

(10)

where \( \Phi_{B0} \) is the barrier height at zero bias (or the asymptotic barrier height) and \( \beta \) is assumed to be a positive constant over the region of measurement. That means an increase of the SBH with increasing bias voltage. This trend is experimentally observed from results in Figure 5. If the ideality factor is defined as in Equation (11)

\[ \frac{1}{n} = 1 - \beta \]  

(11)

then the forward I-\( V \) characteristic of Equation (9) becomes:

\[ I_d = I_0 \exp\left( \frac{qV}{nK_BT} \right) \left[ 1 - \exp\left( -\frac{qV}{K_BT} \right) \right] \]  

(12)

where

\[ I_d = AA''T^2 \exp\left( -\frac{\Phi_{B0}}{K_BT} \right) \]  

(13)

For bias voltage \( V > \frac{3K_BT}{q} \), Equation (12) reduces in the following simple form

\[ I_d \approx I_0 \exp\left( \frac{qV}{nK_BT} \right) \]  

(14)

From Equation (13), the SBH at zero bias is expressed as:

\[ \Phi_{B0} = K_BT \ln\left( \frac{AA''T^2}{I_0} \right) \]  

(15)

where \( I_0 \) is the reverse saturation current extrapolated at zero bias. Equation (15) offers a way to determine \( \Phi_{B0} \) using \( AA'' \) data from Figure 5 and \( I_s \)-values from Figure 4 (\( I_0 \approx I_s \) since extrapolated at zero bias). The results of such a determination are shown in Figure 6.

In accordance with Equation (10), values of \( \Phi_{B0} \) are lower than those of \( \Phi_B \) from Figure 5. Nevertheless, \( \Phi_{B0} - T \) data exhibit a wavy trend whereas results from other works state that the SBH and its value at zero bias slightly increase with increasing temperature \cite{19} \cite{54}.

3.5. \( n, R_s \) and \( \Phi_B \) from the Auxiliary Cheung’s Functions

In this method, firstly Equation (6) (with \( I_d = I \)) is re-arranged as

\[ \ln I = \ln I_s + \frac{qV}{nK_BT} - \frac{qR_s I}{nK_BT} \]  

(16)

and thus

\[ V = \frac{nK_BT}{q} \ln I + R_s I - \frac{nK_BT}{q} \ln I_s \]  

(17)

Differentiating Equation (17) provides:
Figure 6. Results of $\Phi_B$ vs $T$ data for the SBD of this study.

\[ dV = \frac{nK_BT}{q} d(\ln I) + R_s dI \]  

(18)

and thus

\[ \frac{dV}{d(\ln I)} = \frac{nK_BT}{q} R_s I \]  

(19)

Equation (19) shows that, from experimental forward $I$-$V$ data at a given temperature, the curve $[dV/d(\ln I)]$-$I$ is a straight line from which $R_s$ and $nK_BT/q$ can be extracted as the slope and the intercept, respectively.

Secondly, combining Equations (4) and (6) (with $I_d = I$) yields

\[ \Phi \approx 2 \ln \left( \frac{I}{A A'' T^2} \right) + \frac{\Phi_B}{K_BT} = -\frac{q}{K_BT nT} V - \frac{q}{K_BT} R_s I \]  

(20)

Equation (20) is re-arranged to become

\[ H(I) = R_s I + n\Phi_B \]  

(21)

where

\[ H(I) = V - \frac{nK_BT}{q} \ln \left( \frac{I}{A A'' T^2} \right) \]  

(22)

Equations (19), (21) and (22) are the three auxiliary Cheung’s functions [14]. Using the $AA''$ mean value of Figure 5 and experimental forward $I$-$V$ data at a given temperature, allows one to get $H(I)$ data from Equation (22). The plot of those $H(I)$ data (Equation (21)) leads to a straight line from which $R_s$ and $n\Phi_B$ can be extracted as the slope and the intercept, respectively. Figure 7 shows a curve of $[dV/d(\ln I)]$-$I$ data at a fixed temperature. Its points are quite scattered, whereas $H(I)$ data present a good linear behaviour at bias voltages $V > \frac{3K_BT}{q}$ as illustrated in Figure 8.

The values of $n$, $R_s$ and $\Phi_B$ derived by using the previous procedure are presented in Figure 9.

It is shown that values of the ideality factor obtained from $[dV/d(\ln I)]$-$I$ plots (average $n = 1.65$) are quite lower than those extracted from $\ln I$-$V$ plots (in
Figure 7. Plot of $[dV/d(lnI)]$-I data for the SBD of this study at $T = 295$ K.

Figure 8. Plot of $H(I)$ data for the SBD of this analysis at $T = 299.5$ K.

Figure 9. Results of $n$, $R_s$, and $\Phi_B$ extracted from the auxiliary Cheung’s functions.

Figure 4, average $n = 2.04$). Moreover, while $n(T)$ data from Figure 4 show a wavy trend, $n(T)$ results of the present method ($[dV/d(lnI)]$-I plots) seem to increase with increasing temperature.

A comparison of $R_s$-results of Figure 4 and Figure 5 shows that $[dV/d(lnI)]$-I plots yield higher values (mean $R_s = 0.56 \ \Omega$), followed by data from $H$-$I$ plots (mean $R_s = 0.45 \ \Omega$), $\ln I$-$V$ plots leading to lower results (mean $R_s = 0.30 \ \Omega$).
The auxiliary Cheung’s functions method leads also to lower SBHs (mean $\Phi_B = 0.198$ eV) than the activation energy method (in Figure 5, mean $\Phi_B = 0.325$ eV). Moreover, a mean trend of SBH data from the Cheung’s method is a decrease with increasing temperature and with increasing ideality factor. This is in accordance with statements from other works [14] [16] [49] [51].

3.6. $V_{bi}$ from the Maximum Forward Current Method

At a given temperature, the SBD’s maximum forward current ($I_d = I_{max}$) is recorded at bias voltage $V$ equal to the junction’s built-in potential ($V_{bi}$), for which Equation (14) becomes [19]

$$I_{max} \approx I_0 \exp\left(\frac{qV_{bi}}{nK_BT}\right)$$

or

$$\ln I_{max} \approx \ln I_0 + \frac{qV_{bi}}{nK_BT}$$

Therefore, in the experimental $I-V$ characteristics at different temperatures, accounting only for data corresponding to $I_{max}$, one gets a plot of $\ln I_{max}$ vs $\frac{1}{T}$. On the expected resulting straight line, the $V_{bi}$ and $I_0$ parameters are extracted from the slope and intercept, respectively. Estimates obtained by using that procedure and $n$-values of Figure 9, for the SBD and temperature range of this analysis, have been: $V_{bi} = 0.496$ V and $I_0 = 0.34 \times 10^{-4}$ A, respectively.

3.7. $N_A$ or $N_D$ from Reverse $I-V-T$ Data

In forward bias conditions, the SBH increases with increasing bias voltage as shown in Figure 5 (Section 3.3) and Section 3.4. At the opposite, in reverse bias case, the main effect is the lowering of the SBH with the applied bias voltage $|V|$. In that case, the reverse current is expressed as [19]

$$I_R = I_0 \exp\left(\frac{qE}{K_BT}\right)^{1/2}$$

where $I_0$ is the reverse current at zero bias and the $E$ quantity is given by

$$E = \frac{2qN}{\varepsilon_s} \left(|V| + V_{bi} - \frac{K_BT}{q}\right)^{1/2}$$

with $\varepsilon_s$ the semiconductor’s dielectric constant. If $V_{eff} = |V| + V_{bi} \gg \frac{K_BT}{q}$, then Equation (25) becomes

$$I_R \approx I_0 \exp\left(\alpha V_{eff}^{1/4}\right)$$

where the $\alpha$ parameter is expressed as

$$\alpha = \frac{q}{K_BT} \left(\frac{q}{4\pi\varepsilon_s}\right)^{1/2} \left(\frac{2qN}{\varepsilon_s}\right)^{1/4}$$
Equation (27) may be also written as

$$\ln I_R \approx \ln I_0 + \alpha V_{eff}^{1/4}$$  \hspace{1cm} (29)$$

According to Equation (29), by using experimental reverse \(I-V\) data at a given temperature, together with the \(V_{bi}\)-value stated in section 3.6, \(\epsilon_s = 11.9 \epsilon_0\) for Si [19], and \(\epsilon_0 = 8.854 \times 10^{-12} \text{ F} \cdot \text{m}^{-1}\) [55], one gets a plot of \(\ln I_R - V_{eff}^{1/4}\) data, which is expected to yield a straight line, and of which \(I_0 \approx I_s\) and \(\alpha\) (thus \(N = N_A\) or \(N_D\)) parameters can be extracted from the intercept and the slope, respectively. An example of such a plot is shown in Figure 10. The \(N\) and \(I_0 \approx I_s\) results obtained by following that procedure are given in Figure 11.

A comparison of our SBD reverse saturation current’s results shows that the reverse \(I-V-T\) data method leads to slightly lower values (Figure 11, mean \(I_s = 1.31 \times 10^{-4} \text{ A}\)) than those from the forward.

\(\ln I_s-V\) plots (Figure 4, mean \(I_s = 1.7 \times 10^{-4} \text{ A}\)). Moreover, the reverse \(I-V-T\) data method appears to be better than the \(\ln I_s-V\) one for \(I_s\)-parameter extraction, since its results clearly exhibit an increase of reverse saturation current with increasing temperature, in accordance with theory.

Furthermore, for the SBD and the temperature range of this analysis, the semiconductor (Si)’s average doping concentration is found equal to \(6.06 \times 10^{18}\)
Table 1. Synthesis of the obtained results and the used methods for SBD’s parameters extraction in this analysis.

<table>
<thead>
<tr>
<th>N’</th>
<th>Parameter</th>
<th>mean value</th>
<th>Extraction method</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>$R_{sh}$</td>
<td>$(4.93 \pm 0.07) \times 10^4 \Omega$</td>
<td>Slope of reverse $I$-$V$ plots</td>
<td>Not temperature dependent</td>
</tr>
<tr>
<td>2</td>
<td>$n$</td>
<td>2.04</td>
<td>$\ln I$-$V$ plots</td>
<td>Temperature ($T$) dependent</td>
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<tr>
<td></td>
<td></td>
<td>1.65</td>
<td>$[dV/d(lnI)]$-$I$ plots</td>
<td>Increases with increasing $T$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.30 $\Omega$</td>
<td>$\ln I$-$V$ plots</td>
<td>Increases with increasing $T$</td>
</tr>
<tr>
<td>3</td>
<td>$R_s$</td>
<td>0.56 $\Omega$</td>
<td>$[dV/d(lnI)]$-$I$ plots</td>
<td>Temperature dependent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.45 $\Omega$</td>
<td>Cheung’s $H$-$I$ plots</td>
<td>Temperature dependent</td>
</tr>
<tr>
<td>4</td>
<td>$I_s$</td>
<td>$1.7 \times 10^{-4} A$</td>
<td>$\ln I$-$V$ plots</td>
<td>Increases with increasing $T$</td>
</tr>
<tr>
<td>5</td>
<td>$\Phi_B$</td>
<td>0.325 eV</td>
<td>Arrhenius plots</td>
<td>Increases with increasing $V$</td>
</tr>
<tr>
<td>6</td>
<td>$AA'$</td>
<td>$2.35 \times 10^{-6}$ A·K$^{-2}$</td>
<td>Arrhenius plots</td>
<td>Increases with increasing $V$</td>
</tr>
<tr>
<td>7</td>
<td>$V_{bi}$</td>
<td>0.191 V</td>
<td>$V$ dependence of $\Phi_B$</td>
<td>Temperature dependent</td>
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<td>8</td>
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<td>0.496 V</td>
<td>$I_{sat}$-$(1/T)$ plots</td>
<td></td>
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<tr>
<td>9</td>
<td>$N_A$ or $N_D$</td>
<td>$6.06 \times 10^{18}$ cm$^{-3}$</td>
<td>Reverse $I$-$V$-$T$ data</td>
<td>Decreases with increasing $T$</td>
</tr>
</tbody>
</table>

This indicates that, either n- or p-type, the actual Si material has a resistivity $\rho$ of about $10^{-2}$ $\Omega$ cm [6].

3.8. Results Summary

For the SBD and the temperature range of this analysis, Table 1 shows in synthesis the obtained parameters’ mean values and the extraction methods implemented so far.

3.9. Device Materials Identification

On one hand, the following data on some SBDs are reported amongst others in literature: 1) $\Phi_B = (0.272 \pm 0.005)$ eV and $\Phi_B = (0.196 \pm 0.008)$ eV for a typical PtSi/p-Si structure, whereas $\Phi_B \in [0.847;0.868]$ eV for a Pt Si/n-Si diode at room temperature [16]; 2) $\Phi_B = 0.25$ eV for an Au/p-Si (chem.) contact, and $\Phi_B = 0.20$ eV for a PtSi/p-Si (back sputtering) diode from $I$-$V$ data [6]; 3) $n \in [1.2;2.7]$ for Pt/p-Si [16]; 4) with a doping concentration of $10^{18}$ cm$^{-3}$, the resistivity, $\rho = 3 \times 10^{-2}$ $\Omega$ cm and $6 \times 10^{-2}$ $\Omega$ cm for n-Si and p-Si materials, respectively [6]. On the other hand, the parameters’ results obtained for the SBD and the temperature range of this study are presented in Table 1. A comparison of results on the same parameters in those two sets of data, allows one to certify that the SBD of this analysis is either Pt Si/p-Si or Au/p-Si.

4. Conclusion

As shown in the synthesis of Table 1, from $I$-$V$-$T$ measurements and the use of different methods, up to nine parameters have been extracted on a Si-based MS
contact with unknown metal and semiconductor-type materials. Two of those parameters, i.e. the shunt resistance ($R_{sh}$) and the semiconductor doping concentration ($N_A$ or $N_D$), have been derived from reverse $I$-$V$-$T$ data. All the remaining seven parameters have been determined from forward $I$-$V$-$T$ data. Those are the ideality factor ($n$), the series resistance ($R_s$), the reverse saturation current ($I_s$), the effective Schottky barrier height ($SBH, \Phi_B$), the SBH at zero bias ($\Phi_{B0}$), the product of the contact’s electrical active area ($A$) and the effective Richardson constant ($A^*_{\infty}$), and the built-in potential ($V_{bi}$). Some of those seven parameters have been extracted by using two or three different approaches. The main features of each approach, including prevailing current transport mechanism, operation conditions and other assumptions, have been clearly stated. From one parameter to another, results have been discussed in terms of structure performance, parameter’s temperature or voltage bias dependence, accordance or discordance with data from other works, and comparison on one another of results obtained from different methods. Furthermore, a comparison of results on the $n$, $\Phi_B$, $\Phi_{B0}$, and $N_A$ or $N_D$ parameters of Table 1 with some available data on the same parameters in literature, has led to state that the analyzed SBD is either Pt Si/p-Si or Au/p-Si.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References


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