J. Phys. D: Appl. Phys. 55 (2022) 435101 (8pp) https://doi.org/10.1088/1361-6463/ac85ff

An alternative approach to extract diode parameters from metal–semiconductor–metal asymmetric Schottky diodes

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Received 12 May 2022, revised 25 July 2022
Accepted for publication 2 August 2022
Published 26 August 2022

Abstract

Back-to-back connected asymmetric Schottky diodes having metal–semiconductor–metal (MSM) configuration are often encountered practically in solid state devices and, if the intended ohmic contact exhibits rectifying characteristics, then the extraction of diode parameters such as ideality factor and barrier height from forward current–voltage (I–V) plots using conventional methods becomes problematic. In this study, a new approach, which predicts extremums in measured current–voltage (I–V) graph assuming the dominant transport mechanism to be thermionic emission model, have been proposed. Using the proposed method, the first and second derivatives of the voltage- current function in combination to another previously established theoretical approach resulted in significantly accurate extraction of individual barrier heights of a MSM junction from single experimental I–V measurement. On the other hand, if individual barrier heights are known, using the proposed method the individual ideality factors for the two back-to-back junctions can be calculated. The proposed method has been validated by analyzing experimentally fabricated FeGa/n-Si/Ag and Co/n-Si/Ni MSM Schottky diodes. The obtained results from this approach have been compared with other established methods and the values were found out to be in good agreement with each other.

Keywords: Schottky diode, thermionic emission, asymmetric Schottky diodes

(Some figures may appear in colour only in the online journal)

1. Introduction

Metal–semiconductor (MS) Schottky contacts exhibit excellent rectification characteristics due to the formation of potential barrier at the MS interface and, in many applications replaces the conventional p–n junctions. In contrary to a Schottky contact, in the case of an ohmic contact formed between some metals and heavy doped semiconductors, a low voltage drop with symmetric current voltage relationship is observed and the rectifying nature is negligible or absent. Among various factors, a lower potential barrier at the MS interface often aids in ohmic nature of the contact [1]. In practice, MS contacts (both ohmic and Schottky) are often fabricated using various deposition processes [2–8] and formation of a good ohmic contact is very much necessary to carry out accurate current–voltage (I–V) and other electron transport measurements. Assuming thermionic emission (TE) as the dominating charge transport mechanism, the current–voltage relationship of a Schottky diode resembles a p–n one apart from the fact that only majority carriers dominate in case of a Schottky diode, and from semi-logarithmic I–V plot; diode parameters such

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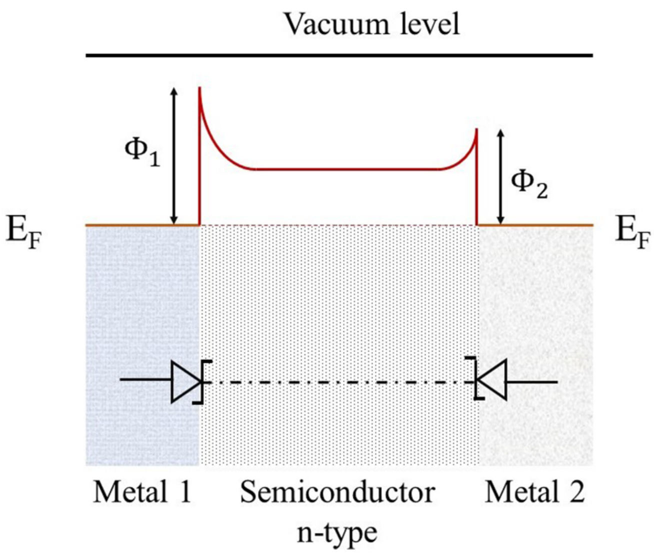

Figure 1. Schematic diagram of a MSM junction on a common semiconductor substrate.

as Ideality factor (n), Barrier Height (Φ), and series resistance (R_S) can be extracted [9]. However some authors have reported different techniques to accurately extract diode parameters of a MS junction from I–V measurements [10, 11]. In practice, the quality of the ohmic contact depends strongly on the doping concentration, depletion layer thickness, interfacial properties and formation of local defects; hence, deposition conditions play an important role and sometimes, formation of microscopic defects at the interface or, presence of an interfacial layer [12] results in formation higher potential barrier at the expected ohmic MS interface. This causes a deviation in the current transport characteristics. However, for devices with this type of ohmic contacts, an additional barrier acts together with the regular MS barrier and results in reduction of total measured current due to more resistance offered in both forward and reverse directions and the obtained value of ideality factor and barrier height from I–V measurements become slightly different than that of conventional single MS junctions. For ease of analysis, this type of ohmic contact can be represented as another MS Schottky diode in addition to the primary MS diode and thus the configuration becomes more like a back-to-back metal–semiconductor–metal (MSM) device on a common semiconductor substrate. The schematic diagram of such type of device is illustrated in figure 1.

A detailed study and deduction of a generalized current–voltage relationship for a MSM configuration has been discussed in [13] and assuming the same ideality factor for both the junctions, values of two barrier heights were extracted separately. Similar current–voltage relationship has also been reported by other authors [14–16] and MSM configuration consisting of metal/SnO_2 nanowire/metal junctions and MoS_2, WS_2 based Nano-devices has been studied based on similar or different approach [17, 18]. However, majority of these studies have assumed both the ideality factors to be same which is a valid assumption for a common substrate but, still the possibility of the two ideality factors to be different remains undiscussed and thus current transport characteristics in this scenario needs to be studied. In most of the experiments, involving any source measuring unit, a set of measured current and voltage data is achieved. Though, theoretically, current is always the dependent variable; practically we can plot or fit current as a function of voltage or vice versa from experimental results or datasets. In present work, an alternative method has been proposed for extraction of individual barrier heights from a MSM configuration or a conventional MS Schottky diode with poor ohmic contact exhibiting Schottky barrier characteristics by observing experimental voltage–current ($V_M - j$) plots and its derivative with respect to current (j). In this method, after plotting measured voltage–current ($V_M - j$) plots of MSM Schottky didoes, a local minima has been observed in the plot of $\frac{dV_M}{dj}$ vs. j where, the value of current, at which minima is observed, is directly dependent on the difference of two saturation current values corresponding to two barriers and the ratio of positive square root of ideality factors. In combination with the method obtained by Nouchi [13] or entirely by this method alone, individual diode parameters such as barrier height, and ideality factor respectively can be calculated. Present method has been validated using experimental I–V data from different fabricated MSM junction and the results obtained are in good agreement with the values obtained by other methods.

2. Theory

In a conventional MS Schottky junction, ignoring the effects of series resistance (R_S) and interface states, the current density (j) according to TE can be expressed as

$$j = j_s\left[\exp\left(\frac{qV}{nk_BT}\right) - 1\right] \tag{1}$$

where, V is the applied bias voltage, n is the ideality factor and, j_s is the thermionic saturation current density at temperature T, given by

$$j_s = A^*T^2\exp\left(-\frac{q\Phi_b}{k_BT}\right) \tag{2}$$

where, A^* is the effective Richardson constant (120 $\mathrm{A\,cm^{-2}\,K^{-2}}$ for n-type Si), q is the electronic charge, k_B is the Boltzmann constant and Φ_b is the zero bias Schottky barrier height. For a reverse biased junction, the sign of j_s and V alters. In these expressions it is assumed that other contributions due to tunneling and field emission is ignored and for the rest of the study we assume TE to be the major conduction mechanism. For a MSM configuration, (i.e. two MS interfaces on a common semiconductor substrate) when the whole device is under forward bias, one MS junction will be forward biased while the other one is reverse biased. For convenience let them be designated as D_1 and D_2, where, the later one represents the reverse biased MS junction (typically an ohmic contact with a considerably large barrier height exhibiting rectifying nature). Rewriting equation (1), the voltage drops across these junctions can be expressed as

$$V_1 = \frac{n_1}{\beta} \ln\left[\frac{j}{j_{s1}} + 1\right] \tag{3}$$

$$V_2 = -\frac{n_2}{\beta} \ln\left[1 - \frac{j}{j_{s2}}\right] \tag{4}$$

where, $\beta = \frac{q}{k_B T}$, j_{s1} and j_{s2} are the thermionic saturation current densities of D_1 and D_2 respectively, j the measured current across the device and the other representations are as usual. The subscripts 1 and 2 are used to represent different diode parameters for D_1 and D_2 respectively. The total voltage drop across the device is then $V_M = V_1 + V_2$. Rewriting, and adding equations (3) and (4) yields

$$\exp\left[\frac{\beta V_1}{n_1} + \frac{\beta V_2}{n_2}\right] = \frac{1 + {}^{j}/_{j_{s1}}}{1 - {}^{j}/_{j_{s2}}}. \tag{5}$$

After simplifying equation (5), the total current j can be expressed in terms of individual voltage drops as

$$j = \frac{j_{s1} j_{s2} \left\{\exp\left[\frac{\beta(n_2 V_1 + n_1 V_2)}{n_1 n_2}\right] - 1\right\}}{j_{s2} + j_{s1} \exp\left[\frac{\beta(n_2 V_1 + n_1 V_2)}{n_1 n_2}\right]}. \tag{6}$$

Equation (6) represents in a generalized way, the total current across the device in terms of each voltage drops (V_1, V_2), barrier heights (Φ_1, Φ_2) and ideality factors (n_1, n_2).

Further, it can be also observed from equation (6) that j cannot be directly plotted against the total voltage drop V_M and analyzed due to the complexity created by the different values of ideality factors. Usually, by experimental methods it is quite difficult to measure individual voltage drops across different junctions for a device and, as the total voltage drop across the whole device is the sum of V_1 and V_2, the only possible way to further simplify equation (6) is to assume that $n_2 = n_1 = n$. Then using equation (6) j can be explicitly plotted against V_M as [13, 14]

$$j = \frac{2 j_{s1} j_{s2} \sinh\left(\frac{\beta V_M}{2n}\right)}{j_{s1} \exp\left(\frac{\beta V_M}{2n}\right) + j_{s2} \exp\left(-\frac{\beta V_M}{2n}\right)}. \tag{7}$$

It can be noted that if either one of the junctions is ohmic (say D_2), as there is very small voltage drop across the ohmic junction when compared to the active region ($V_1 \gg V_2$) and barrier height is also low, so $V_2 \to 0$, and for an ohmic junction low barrier height is desired, which increases the saturation current, so $j_{s2} \gg j_{s1}$. Considering these two assumptions, equation (7) reduces to single Schottky diode equation [18] i.e.

$$j \approx j_{s1} \left\{\exp\left[\frac{\beta V_1}{n_1}\right] - 1\right\}. \tag{8}$$

According to equation (7) the first derivative of $j, j' = \frac{\mathrm{d}j}{\mathrm{d}V_m}$ has a maximum when,

$$V_M = n(\Phi_2 - \Phi_1). \tag{9}$$

From which, the two different barrier heights can be extracted. Simulated plots of equation (7) while keeping D_2 as forward biased and D_1 as reverse biased, with different values of barrier heights and ideality factor and no series resistance ($R_S = 0$) have been illustrated in figure 2(a) and the first derivative of equation (7) with respect to j is plotted against V_M in figure 2(b). As it can be observed from figure 2(a) that in the forward region with increase in ideality factor n, the $j - V$ plot bends towards the forward region without affecting both the forward and reverse saturation currents. The saturation currents in both forward and reverse regions solely depend on the values of the barrier heights of the two junctions. Keeping the ideality factor constant, when the value of Φ_2 is decreased, the reverse saturation current is increased (bottom figure 2(a)). Similar nature has also been observed while changing the value of Φ_1 resulting a change in the forward saturation current.

It is observed that interestingly, the forward current is always limited by the saturation current of the reverse biased diode and vice versa. It can also be observed from figure 2(b) that in the forward region, a peak has been observed in the first derivate of current–voltage plot and the position of the peaks for different barrier heights and ideality factor has been well established by the relation $V_M = n(\Phi_2 - \Phi_1)$.

However, in a different approach, using equations (3) and (4), V_M can be expressed as

$$V_M = \frac{n_1}{\beta} \ln\left(1 + \frac{j}{j_{s1}}\right) - \frac{n_2}{\beta} \ln\left(1 - \frac{j}{j_{s2}}\right). \tag{10}$$

The first order derivative of equation (10) with respect to j, $V_M' = \frac{\mathrm{d}V_M}{\mathrm{d}j}$ can be expressed as

$$\frac{\mathrm{d}V_M}{\mathrm{d}j} = \frac{n_1}{\beta} \frac{1}{j_{s1} + j} + \frac{n_2}{\beta} \frac{1}{j_{s2} - j} \tag{11a}$$

which, for the special case when $n_1 = n_2$, represents the inverse function of the first derivative of equation (7) but omits the necessity of the two ideality factors to be equal. When the polarity of the diodes is reversed i.e. D_1 is reverse biased and D_2 is forward biased. The first order derivative, $V_M' = \frac{\mathrm{d}V_M}{\mathrm{d}j}$ can be expressed as

$$\frac{\mathrm{d}V_M}{\mathrm{d}j} = \frac{n_1}{\beta} \frac{1}{j_{s1} - j} + \frac{n_2}{\beta} \frac{1}{j_{s2} + j}. \tag{11b}$$

Some authors have defined equations (11a) and (11b) as a special resistance function [19] due to its analogy to the total resistance (again ignoring the series resistance as in ideal scenario, it has no current or bias dependence) exhibited by the two Schottky junctions. The simulated plots of V_M' vs. j using equation (11b) using different values of n_1, n_2 and Φ_1, Φ_2 are illustrated (Y axis is depicted in log scale, and absolute values of the first derivative is plotted to visualize the well like shape) in figure 3, assuming $\Phi_1 < \Phi_2$ and D_2 is the main MS junction. It can be observed from figure 3(a) that reverse current and thus the rectification property has a significant dependency on the value of Φ_1 or in other word on the quality of the ohmic contact if we assume D_1 as the ohmic junction which will be reverse

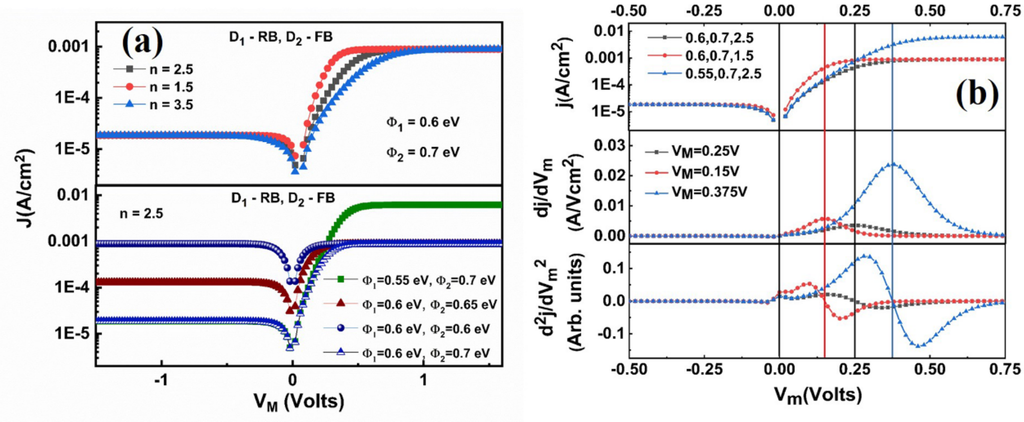

Figure 2. Simulated plots of j vs V_m (a) j′ and j″ vs V_m (b) for different values of barrier height and ideality factors.

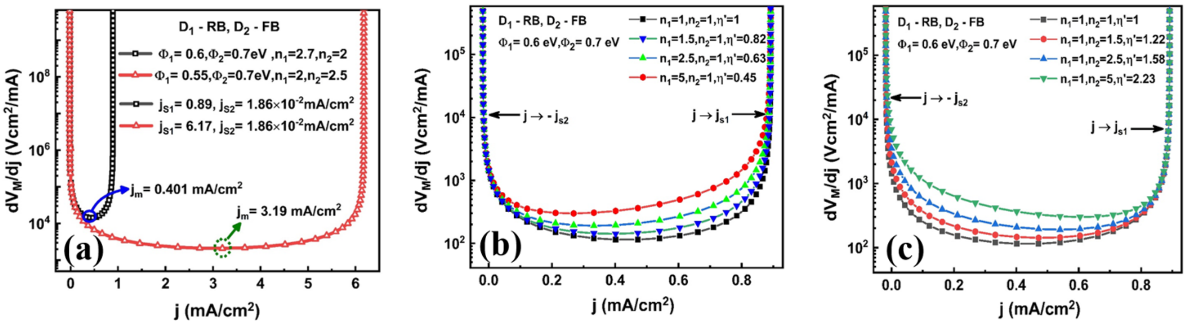

Figure 3. Simulated plots of V_M' vs, j for different values of (a) barrier heights and ((b), (c)) ideality factors.

biased when the main MS junction and the whole device is forward biased. As predicted from equation (11*b*) the plot has two regions approaching exceptionally large values, corresponding to the two individual saturation currents. In the left region of figure (3) as $j \to -j_{s2}$, V_M' approaches infinitely large values and towards the right region as $j \to j_{s1}$, V_M' again approaches infinitely large values. Thus, for a MSM configuration the plot of V_M' vs. j should have two discernible infinitely large peaks similar to a well like plot, corresponding to the two barriers (figure 3), in between these two peaks there exists a unique value of j where, V_M' has to be minimum.

If equation (11*a*) has minima in the forward range, the second order derivative has to be zero. Differentiating equation (11*a*) with respect to j and equating to zero we have

$$V_M'' = \frac{\mathrm{d}^2 V_M}{\mathrm{d}j^2} = -\frac{n_1}{\beta (j_{s1}+j)^2} + \frac{n_2}{\beta (j_{s2}-j)^2} = 0 \tag{12}$$

or,

$$\frac{j_{s1}+j}{j_{s2}-j} = \sqrt{\frac{n_1}{n_2}} = \eta \tag{13}$$

where, η is a dimensionless parameter defining the positive square root of the ratio of the ideality factors. Solving for j we have

$$j = \frac{\eta j_{s2} - j_{s1}}{1+\eta} = j_m. \tag{14}$$

And when their polarity is reversed (D_1 is reverse biased and D_2 is forward biased) in a similar approach differentiating equation (11*b*) with respect to j, equation (14) becomes

$$j = \frac{\eta' j_{s1} - j_{s2}}{1+\eta'} = j_m. \tag{15}$$

Where, η' is defined as the reciprocal of η. From figure 3(a) is can be observed that simulated values of V_M' is plotted against a predefined range of current for two different values of barrier heights and ideality factors. For MSM diode having barrier height values of 0.55, 0.70 eV respectively and ideality factor values of 2.2.5 respectively and ideality ratio of 1.118, the minima occurred at $j = 3.19$ mA cm^{-2} which is in good agreement with the calculated value of 3.2 mA cm^{-2} using equation (13), similarly for the second one having values of barrier heights 0.6, 0.7 eV and ideality ratio of 0.86 the minima occurred at $j = 0.4$ mA cm^{-2} which also agrees well with equation (13). Furthermore, to study the effect of different ideality factors or precisely different values of η', figures 3(b) and (c) is constructed using simulated data from equation (11*b*) for different values of η'. In figure 3(b) $\frac{\mathrm{d}V_M}{\mathrm{d}j}$ is plotted against total current (j) for different values of n_2 ($n_2 > n_1$) while fixing $n_1 = 1$, thus varying η' from 1 to 0.45. For every different value of η', equation (13) was satisfied. Thus, it is evident that from experimental V_M' vs. j plots, if there are two well defined peaks and a minimum it could be strong evidence of MSM configuration where, the later MS interface can be considered to be equivalent to a poor ohmic contact having significant potential barrier at the junction. Furthermore, in addition to the method proposed by Nouchi and other authors, our proposed method can be used to calculate the individual ideality factors if the barrier heights are known and the experimental V'_M vs. j plot has a well-defined minima, using equations (11) and (13) two simultaneous equations of n_1 and n_2 can be formed. Suppose, if the values of barrier heights are obtained by Nouchi's method or other similar methods reported, and the corresponding saturation currents are given as j_{s1} and j_{s2}. From the experimental V'_M vs. j plot if V'_M is minimum at $j = j_m$ and, the minimum value of $\frac{\mathrm{d}V_M}{\mathrm{d}j}$ is found to be $V'_{\min}$ then putting $j = j_m$ in equation (11*a*) and using equation (13) we have

$$\frac{n_1}{j_{s1}+j_m}+\frac{n_2}{j_{s2}-j_m}=\beta V'_{\min} \tag{16a}$$

$$\frac{n_1}{n_2}=\left(\frac{j_{s1}+j_m}{j_{s2}-j_m}\right)^2. \tag{16b}$$

If the values of j_{s1}, j_{s2} and j_m are known, solving these equations will yield the values of n_1 and n_2.

3. Experimental procedure

For verifying the aforementioned method with experimental trials, MSM Schottky devices were fabricated using n-type, both side polished Si (100) substrates. The substrates were first cleaned by ethanol and acetone for 10 min each using an ultrasonic cleaner. The substrates were then etched in 5% HF solution for removal of native oxide layers and were finally cleaned in de-ionized water. A radio frequency sputtering unit capable of producing vacuum up to 10^{-6} was used to deposit the thin film contacts. The first device having the structure of FeGa/n-Si/Ag was formed as discussed. A high purity (99.99%) Ag metal target was sputtered in 1.8 × 10^{-2} mbar argon partial pressure to achieve 200 nm Ag layer. To form the front Schottky contacts a $Fe_{0.77}Ga_{0.23}$ target of 99.9% purity (manufactured by Testbourne Ltd) was sputtered onto the Si (100) substrates having resistivity of 235 Ω cm using a shadow mask to form 1 mm diameter circular contacts. The deposition was carried out at 250 °C with Argon pressure of 5 × 10^{-3} mbar to form a 300 nm FeGa layer. The second device was fabricated by using Cobalt and Nickel on a Si (100) substrate with resistivity of 0.1 Ω cm to produce a Co/n-Si/Ni MSM device. The Co and Ni thin film contacts were also deposited using RF sputtering. And finally, to calculate the barrier height of Ag alone on the same n-Si substrate another sample was prepared where, circular, identical silver contacts of 200 nm thickness were used as active and back Schottky contact in a symmetric measurement configuration. Room temperature current–voltage measurements were carried out using a Keithley 2450 source measuring unit with linear parameter sweep mode.

4. Results and discussions

Room temperature experimental *J–V* characteristics of the fabricated FeGa/n-Si/Ag MSM device with silver as back contact is illustrated in figure 4(a) which shows typical rectification characteristics. The first and second derivatives of current with respect to voltage according to equation (9) is illustrated in figure 4(c).

In the region where, $V_M > 3k_BT/q$ from the straight-line fit using the value of slope and intercept the values of n and Φ can be calculated respectively assuming the whole device as an equivalent single barrier MS junction. The calculated values from the straight-line fit were 2.7 and 0.67 eV respectively. Now according to [13] for a MSM configuration, up to the voltage where, $\mathrm{d}j/\mathrm{d}V_M$ has a maxima, the *J–V* plot is equivalent to a single MS junction and the obtained value of Φ usually represents the larger potential barrier, which, is Φ_2 for present case (formed between FeGa and n-Si) and consequently D_2 is in forward bias. The experimental *J–V* plot resembles the one represented in figure 2 having ideality factor of 2.5, however the increased value of reverse current in the experimental plot indicates a smaller value of Φ_1. From figure 4(c) it can be observed that $\mathrm{d}j/\mathrm{d}V_M$ has a maxima at $V_M = 0.32$ V where, the second derivative (j'') changes sign. From the calculated value of $n = 2.7$, using $V_M = n(\Phi_2 - \Phi_1)$ the value of Φ_1 was calculated to be 0.55 eV which corresponds to the back contact formed between Ag and n-Si. To check the feasibility of the method proposed in this work, experimental data of V'_M is plotted against measured total current j in figure 4(b) and it has the desired well like shape and a minima at $j_m = 2.41 \times 10^{-3}\,\mathrm{A\,cm^{-2}}$ but only one distinct peak corresponding to the main junction (D_2 or FeGa/n-Si) is visible. Now the minima at $j_m = 2.41 \times 10^{-3}\ \mathrm{A\,cm^{-2}}$ is expressed by equation (12). Assuming both the junctions have the same value of ideality factor, $n_1 = n_2 = 2.7$ thus, $\eta = 1$, equation (14) simplifies into

$$j_m = \frac{j_{S1} - j_{S2}}{2}. \tag{17}$$

From the obtained value of $\Phi_2 = 0.67$ eV, j_{S2} was calculated to be $5.93 \times 10^{-5}\,\mathrm{A\,cm^{-2}}$ and $j_m = 2.41 \times 10^{-3}\ \mathrm{A\,cm^{-2}}$ was obtained from the minima in the experimental plot. Using equation (17) the value of j_{S1} was calculated to be $4.87 \times 10^{-3}\ \mathrm{A\,cm^{-2}}$ which according to equation (2) corresponds to a barrier height of $\Phi_1 = 0.56$ eV for the back contact formed between Ag and n-Si. This method has also been tested for the Co/n-Si/Ni MSM device and the corresponding experimental $J - V$ plot and the plot of V'_M is illustrated in figures 5(a) and (b) respectively.

From figure 5(a) it is observed that in contrary to the first device, the current in both forward and reverse direction for this device is more. For the later device i.e. Co/n-Si/Ni MSM device, the measurement probes were placed in such a way that when the whole device is in reverse bias the Co/n-Si junction is forward biased and the Ni/n-Si junction in reverse biased. From the straight line fitting of the semi logarithmic plot in the reverse region (forward region of Co/Si where $V_M > 3k_\mathrm{B}T/q$) the calculated values of ideality factor and barrier height were

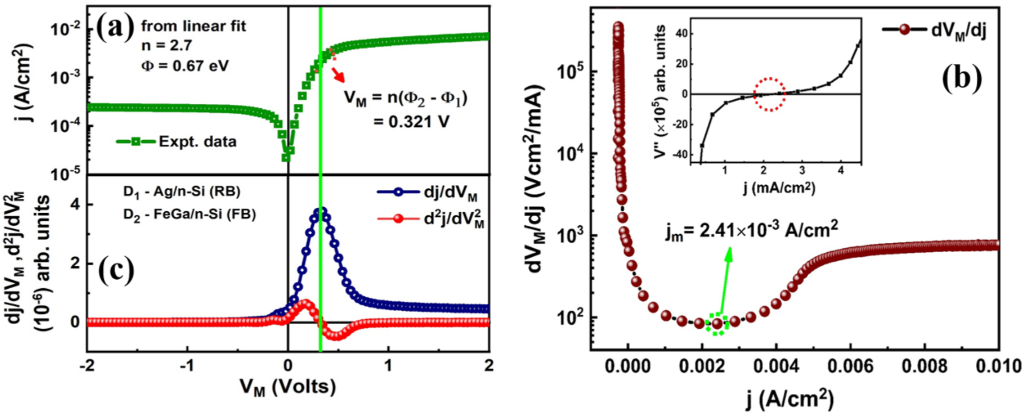

Figure 4. (a) Room temperature experimental I–V characteristics of FeGa/n-Si/Ag MSM device, (b) experimental plot of dV_M/dj vs. j showing a minima in accordance with equation (13) (c) experimental plots of j′ and j″ vs. V_M.

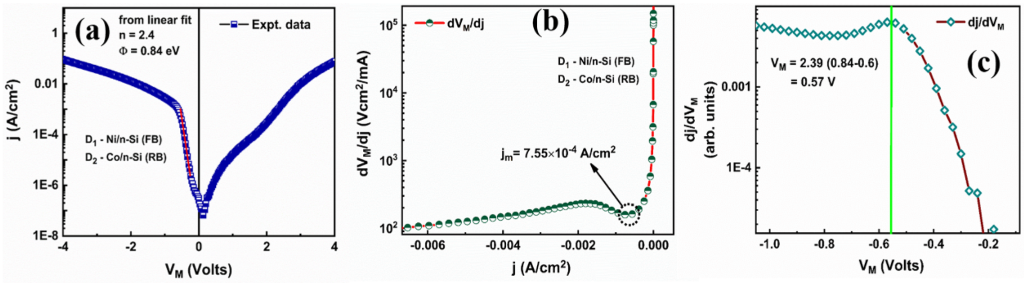

Figure 5. (a) Room temperature J–V plot of the Co/n-Si/Ni MSM device, (b) experimental plot of dV_M/dj vs. j of the same device showing a depressed 'well' like region, (c) experimental plot of V_M'.

2.39 and 0.84 eV respectively. The experimental values of $\frac{dV_M}{dj}$ is plotted with j in figure 5(b). Now it can be easily observed that the nature of this plot is quite different from the one obtained for the FeGa/n-Si/Ag MSM device. In the second one, there indeed exists a 'well' like region where V_M' has a local minimum value. But with further increase in j the plot descends unlike the former device where it gradually saturates. This nature is similar to that of the total current, where in case of the FeGa/n-Si/Ag MSM device, the current also saturates in both forward and reverse regions. The value of j_m was obtained to be 7.55×10^{-4} A cm^{-2} rom figure 5(b). Denoting the Co/Si junction as D_2 having the value of saturation current $j_{s2} = 7.03 \times 10^{-8}$ A cm^{-2} and using equation (17) we have the value of j_{s1} as 1.5×10^{-3} A cm^{-2}. This corresponds to a barrier height of $\Phi_1 = 0.6$ eV for the Ni/Si junction. To cross check the values, According to Nouchi's method [13] there should be a peak in the dj/dV_M plot and the value of corresponding voltage is given by equation (10). Using the values of n, Φ_1, Φ_2 obtained for the second MSM device as 2.39, 0.6 eV and 0.84 eV respectively, the value of V_M was calculated to be 0.57 V which agrees well with the experimental plot (figure 5(c)) which has a visible small peak at around 0.57 V. The calculated values of barrier heights using present approach are in good agreement with the result obtained using the method proposed by [13] and finally the barrier height of Ag contacts alone, deposited on the same substrate was measured in a symmetric device configuration fabricated as Ag/n-Si/Ag and the semi-log forward region I–V plot is shown in figure 6(a). From the intercept of the linear fitted region the value of Schottky barrier height was calculated to be 0.58 eV which is close to the value separately extracted using our proposed method and as reported in some other literature [20]. However, this little discrepancy in the value of barrier height for the later device can be attributed to several critical factors like experimental limitations as these two devices are different, bias dependency of barrier height and presence of any thin interfacial oxide layer in the later device (Ag/n-Si junction) etc. The corresponding V_M' vs. j plot for the Ag/Si junction is given in figure 6(b), where, no such minima or a 'well' like structure has been observed, and the plot shows maximum value as $j \to 0$ and with further increase in j, V_M' gradually decrease similar to that of a single MS junction.

Finally, using the obtained values of individual barrier heights, the experimental plots of the FeGa/n-Si/Ag MSM device (figures 4(a) and (b)) have been fitted with simulated plots using both the proposed method and equation (9). The results of fitting the experimental plots with simulated curves are depicted in figures 7(a) and (b).

From figures 7(a) and (b), it is clearly visible that the experimental plots have been converged well with the theoretical plots within a certain region of the plot, which have been constructed using the obtained values of barrier height and ideality factor. In figure 7(b), the fitting curve was simulated using equation (7) and the experimental plot has been converged well with the theoretical curve in the reverse region and up to low bias range in the forward region. The main reason for

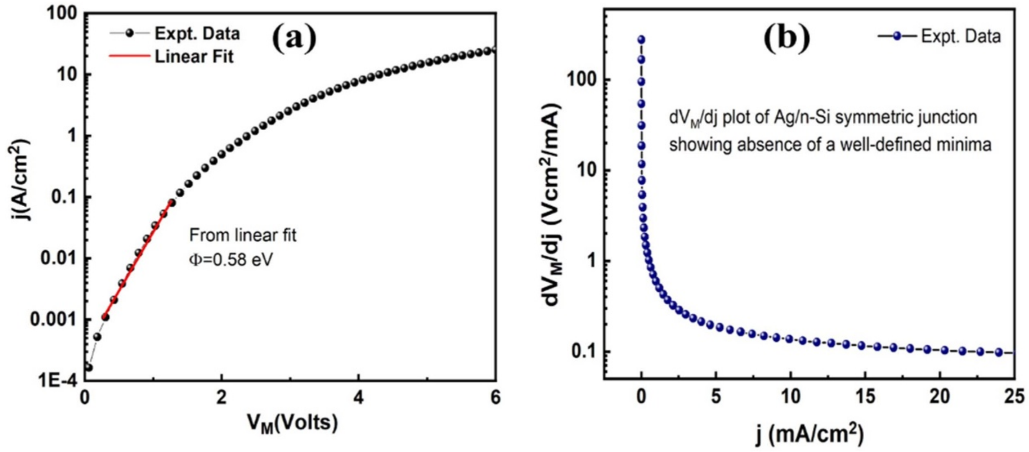

Figure 6. (a) Semilogarithmic forward I–V characteristics of Ag/n-Si junction, (b)dV_M/dJ vs. j plot of the same single symmetric junction showing no well-defined minima.

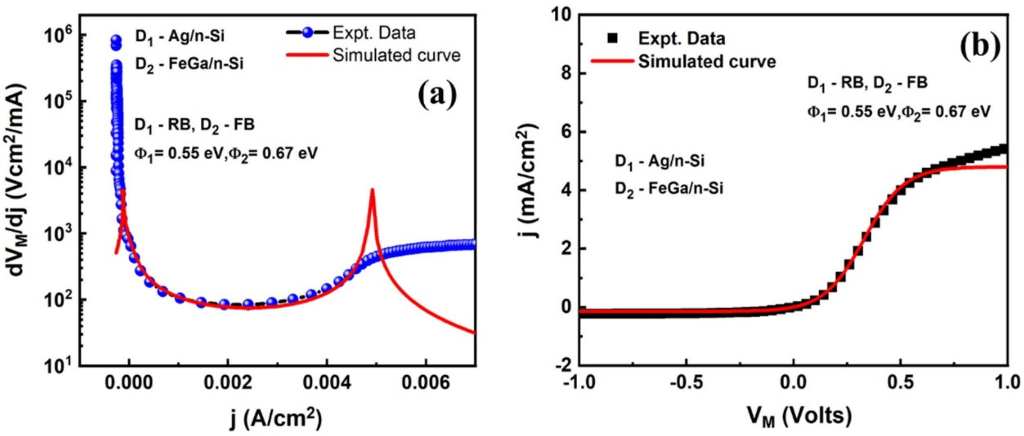

Figure 7. Results of best fits using the obtained values for the FeGa/n-Si/Ag MSM device by using (a) proposed method and (b) equation (9).

this deviation can be attributed to the parameter series resistance (R_S) which was ignored while formulating equation (7), but is almost unavoidable is real Schottky diodes. In the forward region, after the linear part, the *I–V* plot is bowed due to the presence of series resistance as well as total current is also limited by series resistance. The voltage drop becomes $V-(jA)R_s$ in the transport equations where, A is the Schottky junction area. For very low values of series resistance or current, the voltage drop across R_S remains small but for a considerably large value of R_S, the aforementioned equations hold good for low currents only. With increasing current, voltage drop across R_S increases and deviation occurs in the experimental plots. However; series resistance significantly does not influence reverse part of the *I–V* curve (reverse current of the higher-barrier diode D_2) since the value of total current is much lower, thus causing negligible voltage drop across R_S.

5. Conclusions

In present work we have successfully established a novel alternative approach to calculate Schottky barrier heights and different ideality factors individually from a MSM back-to-back connected configuration. In practical fabricated junctions, sometimes poor ohmic contact formation leads to this type of configuration. In present work, an approach has been checked, where, from the experimental voltage-current plot and its derivative plots, there exists a minima, particularly if there is MSM configuration and the value of forward current for which V_M' is minimum is a function of two individual saturation current densities of the two different barriers. To check the viability of our method we have compared experimentally obtained data by present method and a previously discussed different method applicable for MSM configuration. The obtained values of individual barrier heights by these two methods were in good agreement with each other.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Acknowledgments

The authors acknowledge Indian Institute of Technology Kharagpur for precious laboratory facilities. G Bhattacharya acknowledges Indian Institute of Technology Kharagpur for research assistantship.

Conflict of interest

The authors hereby declare that there are no present conflicts of interest with any other author/authors and previously published work.

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