



Study Of Current Voltage Characteristics Of Schottky Diode Using Gaussian Distribution Method

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Abstract-The current-voltage characteristics of inhomogeneous Schottky diodes can be generated either using analytically solved equation for total current through all the elementary diodes integration over the entire barrier height range. The simulation approaches yields current-voltage characteristics with different features. In this work approaches of modeling of inhomogeneous Schottky contacts are analyzed and compared. For this the nature of each elementary diode representing Gaussian distribution of barrier heights in inhomogeneous Schottky contact is investigated to make approaches yield similar current-voltage characteristics.

Key words : simulation , current-voltage ,Gaussian distribution

1. INTRODUCTION

Simulation of I-V characteristics of inhomogeneous Schottky diodes with Gaussian distribution of barrier heights has been performed by two different methods. One method namely "*numerical approach*" is based on calculating the total current through inhomogeneous diode by evaluating current $i(V, \phi)$ through each elementary barrier by Newton Raphson's iteration method using equation (1.20) for ideality factor value of unity and performing numerical integration given by equation (1.24) applying Simpson's one third rule over a barrier height range, after multiplying current through each barrier by its probability distribution function $\rho(\phi)$ as given by equation (1.23). Another method namely "*analytical approach*" is based on calculating the total current by Newton Raphson's iteration method using equation (1.27), which has been obtained after analytically solving integral equation (1.24). The $\ln(I)$ -V curves of inhomogeneous Schottky contact are generated using these two approaches and analyzed for the consistency between the them.

2. THEORETICAL BASIS

We have plots to occur at very high currents. Since, current at higher bias in saturation region is predominantly due to high barriers, near the mean BH, they should have high resistance (say, few ohms) to make saturation occur at low currents about few mA as observed in the analytical plots. Moreover, the numerical plots shown in figure 1, although intersect for 1 nano- Ω but they do not exhibit initial linear region at low bias. For these to intersect like analytical plots with initial linear region and saturate at about mA current value, the resistance of elementary barriers should increase from less than even 1 nano- Ω for low barriers to few Ohms for high barriers with BH near $\bar{\phi}$. These plots exhibit intersection only for very low value of series resistance, say 1 nano-Ohm and even 1 micro-Ohm resistance is high enough to cause saturation and inhibit intersection. We have Investigated the nature of elementary diodes of inhomogeneous Schottky contact and are of the opinion that the low and high BH patches on either side of the mean, which occur over very small area proportional to probability of their occurrence at the metal-semiconductor contact interface, should have proportionally

low series resistance associated with them. On the other hand, the high barrier phases having BH value very close to the mean have large occurrence probability and are proportionally spread over large contact area and should have relatively high series resistance, say few Ohm. Any physical effect/ phenomenon causing different probability of occurrence for different BH patches may as well give rise to different resistance associated with them. Thus, we assume that in numerical approach each elementary diode should be assigned different series resistance proportional to its probability of occurrence in the distribution.

Consider the diode resistance dependence of the type

$$R_s(\phi) = \left| \frac{m \times R_0}{\sigma_{R_s} \sqrt{2\pi}} \exp \left[-\frac{(\phi - \bar{\phi})^2}{2\sigma_{R_s}^2} \right] \right| \quad (1)$$

For generating $\ln(I)$ -V plots by numerical approach. In equation (1), 'm' is a constant scaling factor, R_0 is the series resistance considered for generating $\ln(I)$ -V plots by analytical approach with which the corresponding $\ln(I)$ -V plots generated by numerical approach has to be compared σ_{R_s} is width of the Gaussian curve representing variation of series resistance, analogous to the standard deviation σ of the Gaussian distribution of barrier heights. It is obvious from this expression that barriers of mean BH i.e., $\bar{\phi}$ in the distribution, will attain maximum value of resistance. Generating series resistance R_s using equation (1) in simulation by numerical approach and adjusting m and σ_{R_s} by trial, we found that the $\ln(I)$ -V plots becomes almost identical to those obtained by numerical approach. Clearly these plots now have features similar to those of the plots obtained by the analytical approach for $m=0.4$ and $\sigma_{R_s} = \sigma$ for these values of the

3. RESULTS AND DISCUSSION

This can be seen by generating $\ln(I)$ -V curves by two approaches at constant T and σ for different R_s values varying from 20Ω to $1\text{ n}\Omega$ in steps. [1, 2, 3, 4, 5, 6, 7, 8]. The curves thus, obtained are shown in figure.1. It is clear from the figure.2 that with decreasing R_s the integrated curves approaches those obtained by using equation 1 and the mismatch between the two decreases. It appears that the current at low bias is predominantly due to low BHs while that at higher bias it is contributed by high BHs around $\bar{\phi}$. This can be seen by generating $\ln(I)$ -V curves for a range of BHs with different lower limits of integration. Figure 1 shows these curve obtained for various lower

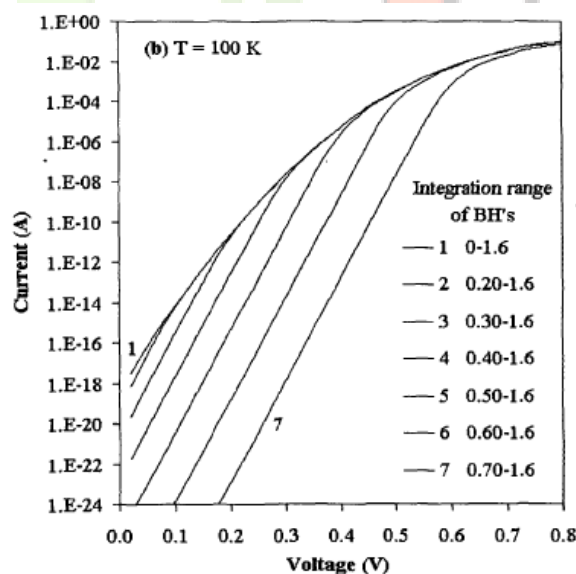


Figure 1 The $I(n)$ -V curves obtained by numerical integration over different barrier height ranges, excluding low BH's, at temperature 100 K.

Limits of integration at two different temperatures along with that for full BHs range of 0-1.6 V. It is obvious from figure 1 that as lower limit of integration is shifted to higher

Values the total current decreases. This decrease in current occurs up to a bias only beyond which current becomes equal to that obtained for full range of integration limits. The current decreases more as the lower limit of integration is further rose. Also the bias up to which the decrease in current occurs from the total current for full integration range, shift toward higher bias value. This effect is much pronounced at low temperature as shown figure 1 this observation clearly indicates that current at low bias is predominantly contributed by low BHs in the distribution. It is evident from figures that current at low bias is predominantly due to low barriers in the distribution.

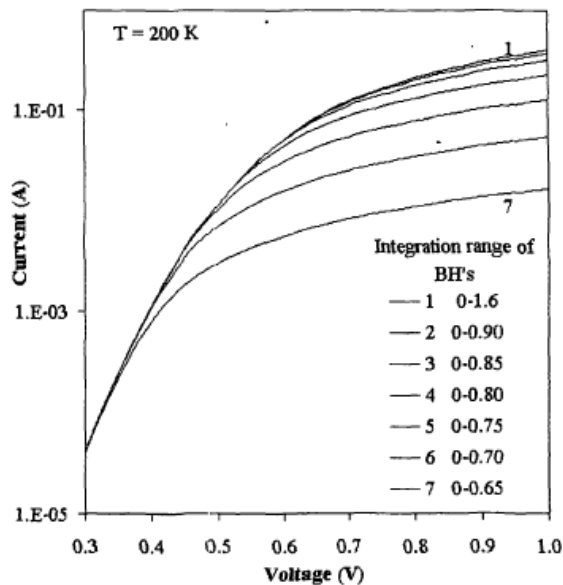


Figure 2 The I-V curves obtained by numerical integration over different barrier height ranges, excluding high BH's, at temperature 200 K. Obviously the current at higher bias is mainly due to high barriers in the distribution.

In the same manner the effect of high BHs in the distribution can be observed. Figure 2 shows $\ln(I)$ -V curves obtained for various values of higher integration limits. Figure 2 clearly depicts that the 'current at higher bias is contributed mainly by high BHs in the distribution. As the higher integration limit is shifted to lower side i.e., towards mean ($\bar{\phi}$) of the distribution, the total current through the diode decreases. It is also clear from figure 2 that is insensitive to the higher limit of the integration, far from ($\bar{\phi}$) It is because the current due to very high BHs as well as their probability of occurrence both decreases and they contribute negligibly towards the total current obtained by performing numerical integration. Since, the current at low bias is due to the low BHs in the distribution, for exact matching between two types of $\ln(I)$ -V curves (shown in figure 2) over entire bias range the each elementary barrier of the distribution should be treated with different R_s while performing numerical integration in such a way that R_s should be assigned varying value say $n\Omega$ for low barriers to 20Ω for high barriers. Modelling this way is, however, difficult but will yield similar $\ln(I)$ -V curves by two approaches. The effect of series resistance in affecting the $\ln(I)$ -V plots in numerical approach can be checked by generating these plots for zero series resistance i.e. $R_s = 0$, for which they do not show such differences and exactly coincides over entire bias range. This clearly indicates that the different behavior of the $\ln(I)$ -V plots obtained by two approaches is certainly due to the series resistance. The $\ln(I)$ -V plots obtained by analytical approach show intersecting behaviour, which is, however, not observed in the plots obtained by numerical approach. In addition to this, the two types of plots have other differences as pointed above. It appears that the intersection between the curves Obtained by numerical approach has to be there, but it is the constant series resistance R_s , assumed for all elementary barriers in the distribution, which inhibit it by bending the $\ln(I)$ -V plots downward due to current saturation effect.

The series resistance 20Ω is although low for Schottky diode of apparently high BH (of about 0.6V or higher) but is large enough for low BH elementary diodes in the distribution to cause current saturation in them at low bias. Since, current at low bias is due to low barriers in the distribution, it leads to the bending of $\ln(I)$ -V plots and does not cause intersection between them. This intersection is inhibited here due to the series resistance of the diode in the same manner, as it is shown unobservable even for a homogeneous diode of

constant barrier height [27]. This effect of R_s can be seen by generating $\ln(I)$ -V plots at various T for very low value of R_s - Figure 3 (a) shows $\ln(I)$ -V

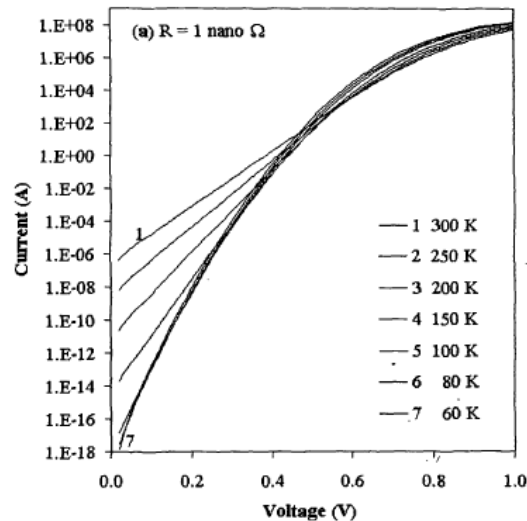


Figure 3(a) The simulated $\ln(I)$ -V plots generated using numerical integration over BH's range 0 to 0.6 V, for series resistance of 1 nano-Ohm.

Plots generated for very low R_s of $1\text{ nano-}\Omega$ and clearly depicts that these plots generated for $R_s = 1\text{ nano-}\Omega$ intersects each other and the point of intersection is temperature dependent exactly in the same way as is observed for the plots obtained by analytical approach, shown in figure 3(a). However, the $\ln(I)$ -V plots generated at various T for slightly higher R_s value of $1\text{ micro-}\Omega$ shown in figure 3(b), continuously bends downward without intersecting and approach each other at higher bias. It is because $1\text{ micro-}\Omega$ series resistance is quite high to cause bending due to saturation effect and inhibits intersection between them at low temperatures. Thus, for very low R_s these plots intersect each other but at the same time, the low resistance makes current saturation in

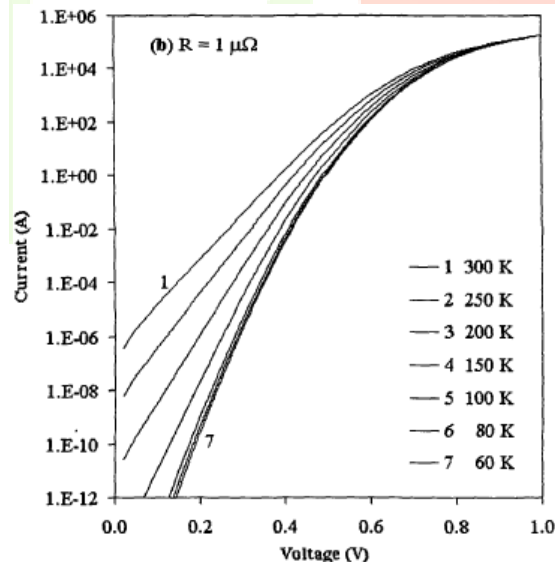


Figure 3(b) The simulated $\ln(I)$ -V plots generated using numerical integration over BH's range 0 to 0.6 V, for series resistance of 1 micro-Ohm.

4. CONCLUDING REMARKS

The current-voltage characteristics of inhomogeneous Schottky diodes with Gaussian distribution of BHs are generated by two approaches. The nature of elementary diodes representing distribution of BHs is investigated and it is observed that the common series resistance considered for all elementary diodes makes the two approaches yield different I-V characteristics indicating apparently that the two approaches of analysis of inhomogeneous Schottky contacts are inconsistent. It is proposed that each elementary diode in the distribution has different series resistance associated with it, which is in direct correlation with its probability of occurrence in the distribution. It is shown that performing the numerical integration over the barrier height range by considering variation in series resistance yields current-voltage curves identical to those obtained by analytical approach.

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