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Modified methods for the calculation of real Schottky-diode parameters

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Abstract. Two methods are described to determine the Schottky-diode parameters from forward I–V characteristics. The first method includes the presentation of the standard $I=f(V)$ function as $V=f(I)$ and the determination of the factors C_0, C_1, C_2 of this function that provides the calculation of the Schottky-diode ohmic component R, the barrier height φ and the ideality factor n. The second method is based on a similar application of the special function proposed by Norde. These methods permit the automation of the measurement process. The possible dependence based on the experimental data between Schottky-diode quality and series resistance is shown.

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It is known that the $I-V$ characteristic of a real Schottky diode can be described by

$$I = I_s \exp(\beta V_D/n) \tag{1}$$

if $V_D \gg kT/q$ and

$$I_s = AA^*T^2 \exp(-\beta\varphi) = I_0 \exp(-\beta\varphi), \tag{2}$$

where V_D is the voltage across the metal-semiconductor interface in the Schottky diode, n is the ideality factor, A is the area of the Schottky diode and $\beta = q/kT$.

Since any real Schottky diode has a series resistance R which consists of the conductor elements, semiconductor substrate etc., the value of V_D in (1) can be given by

$$V_D = V - RI, \tag{3}$$

where V is the experimentally measured voltage in the Schottky-diode circuit and IR is the voltage across the series resistance of the diode itself.

The presence of the ohmic component R causes the appearance of the upper limit in the known voltage interval $kT/q \ll V \ll IR$, which is necessary for the correct application of φ and n in the standard calculation method. This limit considerably reduces the current measurement area, where the I–V characteristic calculation is admissible, and decreases the accuracy of the calculated data.

In [1] Norde proposed a special function for the Schottky-diode series-resistance calculation

$$F(V) = V/2 - \beta^{-1} \ln(I(V)/I_0), \tag{4}$$

and it was shown that for an ideal Schottky diode ($n=1$) the current value determination in the point corresponding to the minimum of this function permits to calculate the R value.

In the case of a real Schottky diode, the problem of parameter determination is complicated in comparison with [1] because of the presence of a third unknown – the ideality factor. Several methods have been proposed for solving this problem in [2–5]. They are based on the Norde's function and are quite complicated.

Three methods have been presented in [6] without using Norde's function for the determination of the series resistance R, ideality factor n and Schottky barrier height φ. Here the problem of Schottky-diode parameter determination is solved by means of the differential conductivity $G = dI/dV$, which requires the measurement steps as small as possible for the calculation and in this connection very high fidelity of the measurement devices.

1 First method

The method proposed below uses only (1) and is based on the same assumptions as in [6]. However, this method is not critical to the measurement steps and less critical to the measurement device fidelity.

For the realization of this method (1) should be presented taking into account (2) and (3) as follow:

$$V(I) = n\beta^{-1} \ln I - n\beta^{-1} \ln I_0 + n\varphi + IR. \tag{5}$$

Equation (5) is said to be correct if the $I=f(V)$ dependence is strictly monotonic.

Taking into account that for a Schottky diode φ, n and R are the constants for a given temperature function, (5) can be presented in the common form

$$f(x) = C_0 + C_1 x + C_2 \ln(x). \tag{6}$$

The values of factors C_0, C_1, C_2 may be obtained by means of $I_i - V_i$ experimental data array approximation by the least squares method applied to (6), that results in the system of equations

$$C_1 \sum_{i=1}^{N} I_i^2 + C_2 \sum_{i=1}^{N} I_i \ln I_i + C_0 \sum_{i=1}^{N} I_i = \sum_{i=1}^{N} I_i V_i,$$

$$C_1 \sum_{i=1}^{N} I_i + C_2 \sum_{i=1}^{N} \ln I_i + C_0 N = \sum_{i=1}^{N} V_i,$$

$$C_1 \sum_{i=1}^{N} I_i \ln I_i + C_2 \sum_{i=1}^{N} \ln^2 I_i + C_0 \sum_{i=1}^{N} \ln I_i = \sum_{i=1}^{N} V_i \ln I_i.$$

The given system can be easily solved by means of Kramer's rule. The φ, n and R values are determined from the following equations

$$R = C_1, \tag{7}$$

$$n = \beta C_2, \tag{8}$$

$$\varphi = \beta^{-1} C_0/C_2 + \beta^{-1} \ln I_0. \tag{9}$$

2 Second method

A similar approach of φ, n and R determination can be realized using Norde's function, but without minimum search of this function as the methods [1–5] demand.

Taking into account (1) and (3), Norde's function may be given by

$$F(I) = V(I)/2 - \beta^{-1} \ln(I/I_0)$$
$$= 0.5 n\beta^{-1} \ln(I/I_s) + 0.5 RI - \beta^{-1} \ln(I/I_0). \tag{10}$$

Equation (10) is also correct because of the reasons mentioned before.

Furthermore, as in the first method the approximation of the $I_i - F(I_i)$ experimental data array, obtained from the $I - V$ characteristics and (4), is performed by the least squares method to (6). It permits to determine the factors C_0, C_1, C_2 and calculate the Schottky-diode ohmic component R, ideality factor n and barrier height φ from

$$C_1 = R/2,$$

$$C_2 = \beta^{-1}(n-2)/2,$$

$$C_0 = C_2 (n-2)^{-1} \ln(I_0^2/I_s^n).$$

3 Experiment

The parameters of 1256 µm² PtSi/Si Schottky diodes of different quality have been determined by the method described above. The test Schottky diodes have been fabricated on n^+–Si wafers [(100)-oriented, 0.01 Ω cm, 100 mm in diameter) with an n – type epitaxial layer (thickness 3 µm, 4.5 Ω cm) by annealing of a 100 nm Pt film obtained by magnetron sputtering. The measurement have been carried out by the one – probe method, where the current flows through the wafer, which had an In/Si ohmic contact on the reverse side.

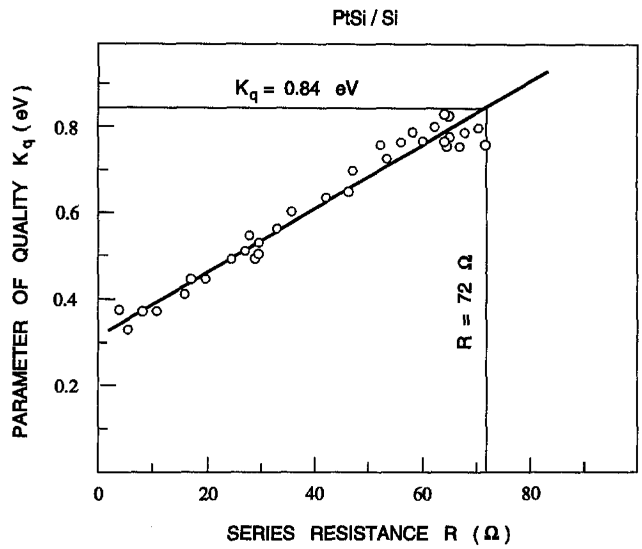

Fig. 1. Correlation between the "coefficient of quality" $K_q = \varphi/n$ and the series resistance R for 1256 µm² PtSi/Si Schottky diodes

The obtained statistical data indicate the possible existence of a connection between the diode quality and the series resistance. For that purpose the diode quality has been determined by the parameter $K_q = \varphi/n$. It is clear that the higher the value K_q the nearer the diode characteristics approach the ideal case, because φ becomes as maximal as possible, but the magnitude n approaches 1. Figure 1 indicates the correlation between the "parameter of quality" K_q and the ohmic component R in the diode. Correlation analysis showed that the experimental data $K_{qi} - R_i$ exhibit a linear dependence, with a correlation of $P = 0.94$. The experimental data approximation to a straight line allows to say that for a 1256 µm² ideal Schottky diode with definite parameters of structure and measurement method, the series resistance R must be of the order of 72 Ω. The decrease of the diode quality results in the reduction of the series resistance. From our point of view this can be caused by the following:

- PtSi/Si interface roughness and an increase of the diode's effective square measure;
- phase nonuniformity (presence of silicide parts in the interface area having the barrier height < 0.84 eV and shunt the diode) [7];
- doping impurity redistribution in the interface area during silicide formation [8].

4 Conclusions

The application of above proposed methods for Schottky-diode parameter measurements shows the absolute identity of received results and permits to carry out the automation of the measurement process. These methods do not depend on the measurement steps and cause insignificant errors in calculations.

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