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Research note

A new method to extract diode parameters under the presence of parasitic series and shunt resistance

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Abstract

A simple method is presented for extracting the diode ideality factor and saturation current in the presence of significant series and parallel parasitic resistances. Additionally, the values of both resistances can be determined. The method is compared to conventional direct optimization, which fails when both resistances are simultaneously significant. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Parasitic series and parallel resistances are frequently significant [1–3] in semiconductor devices. Parasitic series resistance is originated from [4] metal–semiconductor contact resistances to the device and from the resistances of the semiconductor regions. On the other hand, parallel resistance arises from [4] surface leakage along the edges of the device or possibly by crystal defects. Many methods [5–8] have been presented to extract the parameters of a diode, having only a series resistance, from experimental I–V characteristics. The shunt resistance has been extracted for the case of solar cells under illumination [1,2] and for diodes in which the effects of the series and parallel resistance do not overlap [3]. Two main different approaches have been developed to extract the parameters of a diode: direct optimization [3,5] from I–V characteristics, and parameter extraction using clever algorithms [6–8] that separate the effects of the different parameters. Here, we will develop a clever algorithm to extract the parameters in the presence of significant series and parallel resistances and we will compare it with direct optimization.

2. Proposed method

Fig. 1 presents a frequent circuit model for a diode which includes a series parasitic resistance (R_s) and a parallel parasitic resistance (R_{sh}). Using this model, the I–V characteristics is obtained from the following transcendental equation:

$$I = I_S\left(\exp\left(\frac{V\left(1+\frac{R_s}{R_{sh}}\right) - I R_s}{n V_{th}}\right) - 1\right) + \frac{V}{R_{sh}} \qquad (1)$$

where I is the current, V is the voltage, I_S is the saturation current, n is the ideality factor, and $V_{th} = kT/q$ is the thermal voltage.

Direct vertical optimization of the parameters [5] from the I–V data consists of minimizing the quadratic error on the vertical axis (i.e. the current). It was shown [5] that the direct vertical optimization method is quite computational intensive. Recently direct lateral

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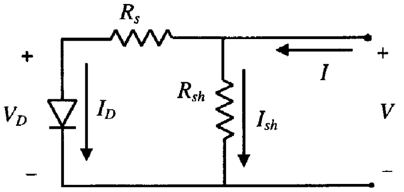

Fig. 1. Diode equivalent circuit including the parasitic series and parallel resistances.

optimization was presented [5] for a diode having only series resistance, based on the approach of minimizing the error on the lateral axis (i.e. the voltage). The motivation for doing so is that the voltage can be directly evaluated from Eq. (1), for a given current, for the case of a diode with only series resistance (R_{sh} tends to infinity).

The integration of the current with respect to voltage [7] was successfully used to extract the parameters of a diode with only series resistance. This method is more immune to measurement errors because the integration is equivalent to a low-pass filter [7]. For the case of a negligible parallel resistance (R_{sh} tends to infinity) and $I > > I_S$, it was proved that the following function eliminates the effects of the series resistance:

$$G(I, V) \equiv \frac{IV - 2\int_0^V I \mathrm{d}V}{I} \approx n\, V_{th}\left(\ln\left(\frac{I}{I_S}\right) - 2\right). \tag{2}$$

Function G is obtained by numerical evaluation of the previous definition using the experimental data. According to the right-hand side of Eq. (2), a plot of function G vs $\ln(I_D)$ should produce a straight line; therefore, the slope and intercept on the voltage axis allow the determination of n and I_S, respectively. Note that the parameters extracted by the integral function method are not affected by the value of the parasitic resistance R_s. It should be also noted that the lower limit of integration does not have to be zero, i.e. the function can be applied to any part of the I–V characteristics. Here we will use the complete range since the diode is to be modeled by a single exponential.

Fig. 2 presents AIM-SPICE [9] simulated I–V characteristics for the parameters: $I_S = 1 \times 10^{-12}$ A, $n = 1.5$ and different values of R_s and R_{sh}. The ideal case of not having parasitic resistance ($R_s = 0$ and $R_{sh} = \infty$) is also illustrated. It is important to note that the effect of R_s is very important at high voltages and that the effect of R_{sh} is significant at low voltages. For example, for the case of $R_s = 100$ Ω and $R_{sh} = 10$ MΩ, there is a region, at medium voltage (0.5–0.7 V), in which neither R_s nor R_{sh} are significant. For this particular case the direct vertical optimization method is able to extract the parameters. In contrast, for the case of $R_s = 1$ kΩ and $R_{sh} = 1$ MΩ, the effects of R_s and R_{sh} overlap and the direct vertical optimization method fails to extract the parameters.

In order to estimate the effects of integration accuracy for $G(V)$, we selected the case in which the integration can be analytically evaluated: $R_s = 0$ and $R_{sh} = \infty$. For the range of $0 < V < 1$ V and using an step of 50 mV, our numerical evaluation of $G(V)$ yields an error of 1%. By decreasing the step to 10 and 5 mV, the errors were reduced to 0.05% and 0.01% respectively.

Function G cannot be applied directly to the general case of having R_{sh} in addition to R_s, but if we estimate a value of R_{sh} (R_{she}), we can calculate the current in the branch containing the diode:

$$I_D = I - \frac{V}{R_{she}}. \tag{3}$$

Then, we can apply function G to the I_D–V data and now this plot should be a straight line. Selecting the plot that best fits a straight line will determine the correct value of $R_{she} = R_{sh}$.

To illustrate the approach, we use the previously simulated data with the parameters: $I_S = 1 \times 10^{-12}$ A, $n = 1.5$, $R_s = 1$ kΩ and $R_{sh} = 1$ MΩ. We present in Fig. 3 plots of the function G, using V and the I_D defined in Eq. (3), for several values of R_{she}. The best straight line of the function G with respect to $\ln(I_D)$, as implied in (2), will define the correct value of R_{she}. Fig. 4 shows the quadratic errors of these linear fits vs the values of R_{she}. We see in Fig. 4 that the minimum

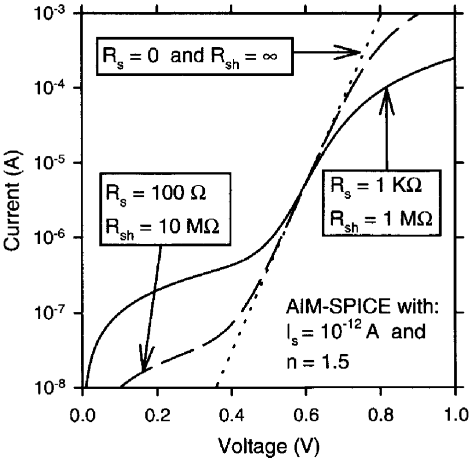

Fig. 2. I–V characteristics obtained from AIM-SPICE simulations using the parameters of $I_S = 1 \times 10^{-12}$ A, $n = 1.5$, and various combinations of R_s and R_{sh}.

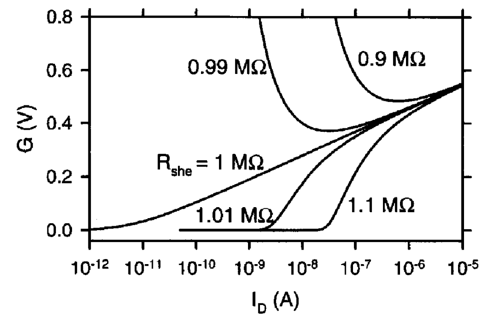

Fig. 3. Function G vs the logarithm of the estimated I_D. The estimated I_D is obtained from (3) by assuming a value of R_{she}.

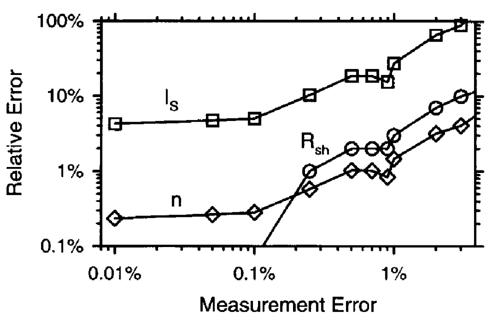

Fig. 5. The relative errors of R_{sh}, n and I_S extracted from the present method for various levels of measurement noise.

quadratic error occurs at $R_{she} = 1$ MΩ which is in fact the correct value. This complete procedure was implemented under the environment of the statistical language S-plus [10].

To account for possible errors in measurements, we have added various levels of noise [5] to the simulated current. The parameter extraction with added noise was repeated 10 times for each case, and the largest value of the errors was selected. We observe in Fig. 5 that the extracted parameters (R_{sh}, n, and I_S) have very small relative errors when the measurement noise is below 1%, which is well within the tolerance of a typical experimental setup. This demonstrates the robustness of the present method for a case in which the direct vertical optimization method fails. It is noteworthy to point out that the effect of the measurement errors is more important at low levels of current because of Eq. (3). In the present case, G vs I_D was fitted above 0.6 V.

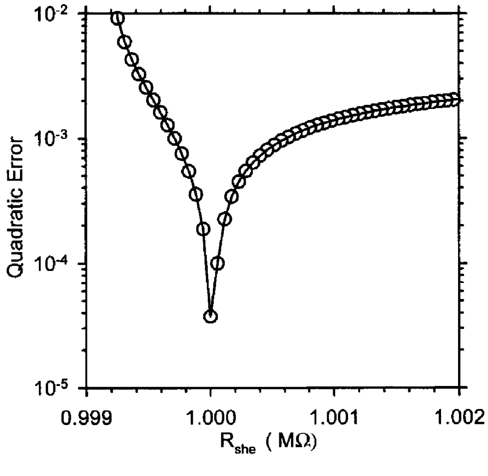

Fig. 4. The quadratic errors, in the linear fit of the function G as a function of $\ln(I_D)$ vs R_{sh}. The minimum quadratic error occur at $R_{she} = 1$ MΩ which is the correct value.

3. Conclusion

The present method is an accurate, efficient, and robust method to extract the diode parameters under the simultaneous presence of parasitic series and shunt resistance. The widely used direct vertical optimization method, on the other hand, presents two main disadvantages: (1) it fails when the effects of both parasitic resistance are simultaneously significant; and (2) it much less efficient than the present method.

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