Pergamon

0038-1101(94)00141-3

Solid-State Electronics Vol. 38, No. 1, pp. 265–266, 1995

0038-1101/95 $9.50 + 0.00

NOTE

A GENERALIZED MODEL FOR A TWO-TERMINAL DEVICE AND ITS APPLICATIONS TO PARAMETER EXTRACTION

(Received 24 January 1994; in revised form 28 June 1994)

1. INTRODUCTION

The current of semiconductor devices, such as diodes and short-channel MOSFETs, is influenced strongly by the series resistance. A number of methods have been proposed to estimate the series resistance and the other device parameters for diodes[1–5] and for MOSFETs[5–7]. These methods often rely on differentiating the current–voltage with respect to certain variables.

In this note, we present a simple and novel model for the current–voltage characteristics of a generalized two-terminal device including the effects of series resistance. The model is developed based on the integration of the current with respect to the voltage, thus simplifying the exponential equation problem into a quadratic equation. The integration[8] acts as a low-pass filter, thus contributing to lessen the effects of possible measurements errors on the extraction procedure. Based on this model, a simple technique is also derived to extract the series resistance and other parameters associated with the two-terminal device. In Section 2, a simple and general model accounting for the series resistance is derived based on the integration of the current with respect to the voltage. A specific application of the generalized model, the parameter extraction of a diode, is discussed in Section 3. Experimental results and extracted diode parameters are given in Section 4.

2. GENERAL THEORY

Let us analyze a two-terminal device that is connected to a series resistance R_s and obeys a current–voltage characteristic defined by:

$$I = f(V_i), \tag{1}$$

and:

$$V_i = V_e - IR_s, \tag{2}$$

where V_i and V_e are the intrinsic and the extrinsic voltage respectively and I is the current.

Let us choose an arbitrary value of $I = I_0$ for which $V_i = V_{io}$ and $V_e = V_{eo}$; then, performing integrations by part, we obtain:

$$\int_0^{V_{e0}} I\,dV_e = I_0 V_{e0} - \int_0^{I_0} V_e\,dI, \tag{3}$$

and

$$\int_0^{V_{i0}} D\,dV_i = I_0 V_{i0} - \int_0^{I_0} V_i\,dI. \tag{4}$$

Subtracting eqn (4) from (3) and using eqn (2) we get:

$$\int_0^{V_e} I\,dV_e = \frac{R_s}{2} I^2 + \int_0^{V_i} I\,dV_i. \tag{5}$$

Now, let us assume that the two following functions can be analytically obtained: (i) the integration of the current with respect to the intrinsic voltage:

$$\int_0^{V_i} I\,dV_i = \int_0^{V_i} f(V)\,dV_i \equiv F(V); \tag{6}$$

and (ii) the inverse function of $f(V_i)$ defined in eqn (1):

$$V_i = f^{-1}(I). \tag{7}$$

Finally, substituting (5) and (6) into (4) we obtain:

$$\int_0^{V_e} I\,dV_e = \frac{R_s}{2} I^2 + F[f^{-1}(I)], \tag{8}$$

which means that the integration of the current with respect to the extrinsic voltage can be expressed as a function only of the current and not of the voltage.

3. PARTICULAR EXAMPLE: THE DIODE

The current of a diode is frequently modeled by the following single exponential equation:

$$I = I_s\left[\exp\left(\frac{V - R_s I}{nV_t}\right) - 1\right], \tag{9}$$

where I_s is the reverse current, R_s is the series resistance, $V_t = K_B T/q$ is the thermal voltage, and n is the diode ideality factor. In eqn (9) the term -1 is negligible for the forward bias condition under study; therefore, for this case, using eqns (1), (2), (6) and (7):

$$I = f(V_i) \approx I_s \exp\left(\frac{V_i}{nV_t}\right), \tag{10}$$

$$V_i = f^{-1}(I) \approx nV_t \ln\left(\frac{I}{I_s}\right), \tag{11}$$

and

$$F(V) = \int_0^{V_i} f(V)\,dV_i \approx nV_t I_s \exp\left(\frac{V}{nV_t}\right). \tag{12}$$

Finally, the combination of eqns (8), (11) and (12) yields:

$$\int_0^{V_e} I\,dV_e = \frac{R_s}{2} I^2 + nV_t I. \tag{13}$$

A plot of the numerical integration of the measured current with respect to voltage will indicate the regions for which each term on the right hand side of eqn (13) is dominant. Therefore, n can be evaluated from the linear portion of the integration of I vs V plot, and R_s can be estimated from the quadratic region.

4. PARAMETER EXTRACTION MEASUREMENT

To extract the parameters using the present technique, we measured the current–voltage characteristics of the parasitic diodes formed by the source–body and drain–body junctions of the Siliconix SD210DE MOSFET. The data

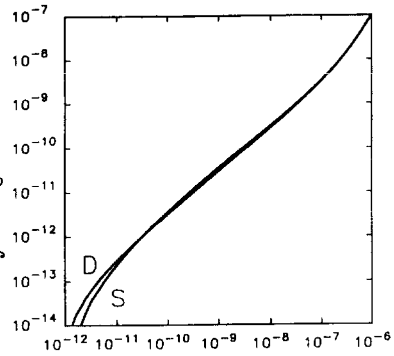

Fig. 1. The integration of the measured current with respect to voltage for the source–body (S) and the drain–body diodes (D).

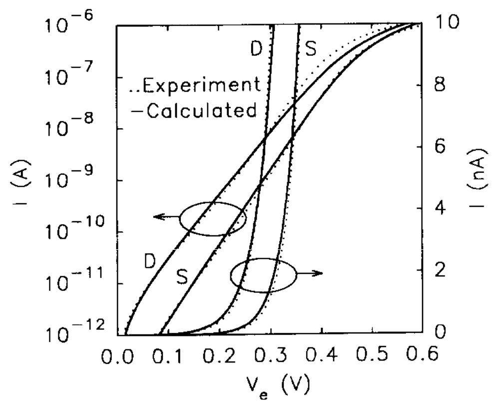

Fig. 2. The experimental and calculated I–V results, using a semilogarithmic and a linear plot, for the source–body (S) and the drain–body diodes (D).

was taken, at room temperature, using a semiconductor parameter analyzer (HP4145B) with a step voltage of 5 mV.

Figure 1 shows the numerical integration of the measured current with respect to voltage for the source–body and the drain–body diodes. We find in this logarithmic plot that the slope is 1 for the range 10^{-11} A $< I < 10^{-7}$ A; therefore, the integration is proportional to I inside this range. We also see in this figure that the plot is not linear either for very low or very high current. For very low current, $I < 10^{-11}$, I is comparable to I_s and eqn (13) is not applicable. For very high current, $I > 10^{-7}$, the quadratic term in (13) is significant. Using $V_t = 26$ mV for room temperature and the slope of the linear plot of the integration for the range 10^{-11} A $< I < 10^{-7}$ A, we obtain: $n = 1.15$ for the drain–body diode and $n = 1.38$ for the source–body diode. The ideality factor for the drain–body diode is different to that of the source-body diode because the MOSFET is not symmetrical. The deviation from linearity for $I > 10^{-7}$ allows us to estimate R_s to be 100 kΩ for both diodes. We would like to point out that we have not obtained more accurate values of R_s because in these devices this resistance is not constant since it presents a weak dependence on the current. Adjusting the modeled current to the experimental values we get: $I_s = 7 \times 10^{-14}$ A, for the drain–body diode; and $I_s = 2 \times 10^{-12}$ A for the source–body diode.

Figure 2 presents, using linear and semilogarithmic plots, the measured and the calculated I–V characteristics for both diodes. We find in this figure a reasonably good agreement between the experimental data and the single exponential diode model calculated using the parameters extracted by this technique.

5. CONCLUSIONS

We have presented a simple and generalized model for a two-terminal device including the effects of a series resistance. The model is derived from the integration of the current with respect to the voltage, which has the advantage of simplifying the exponential equation problem. The integration acts as a low-pass filter, thus contributing to lessen the effects of possible measurements errors. The model has been successfully used for the particular case of a diode.

REFERENCES

1. H. Norde, *J. appl. Phys.* **50,** 5052 (1979).
2. N. Brutscher and M. Hoheisel, *Solid-St. Electron.* **31,** 87 (1988).
3. P. Chattopadhyay and B. Raychaudhuri, *Solid-St. Electron.* **35,** 1023 (1992).
4. A. Ortiz-Conde, F. J. García Sánchez, P. E. Schmidt and R. J. Laurence Jr, *Proc. Int. Semiconductor Device Research Symp.* **2,** 531 (1993).
5. J. J. Liou, *Advanced Semiconductor Device Physics and Modeling*. Artech House, Norwood (1994).
6. K. K. Ng and J. R. Brews, *IEEE Cir. Dev.* **6,** 33 (1990).
7. F. J. García Sánchez, A. Ortiz-Conde, M. García Núñez and R. L. Anderson, *Proc. IEEE Int. Conf. Microelec. Test Struct.* **7,** 190 (1994).
8. G. L. Araujo and E. Sánchez, *IEEE Trans. Electron Devices* **ED-29,** 1511 (1982).

A. Ortiz-Conde[1]†
F. J. García Sánchez[2]
J. J. Liou[1]
J. Andrian[3]
R. J. Laurence[3]
P. E. Schmidt[3]

[1]*Department of Electrical and Computer Engineering*
University of Central Florida
Orlando, FL 32816-2450
U.S.A.

[2]*Departimento de Electrónica*
Universidad Simón Bolivar
Apdo. 89000
Caracas 1080A
Venezuela

[3]*Department of Electrical and Computer Engineering*
Florida International University
University Park
Miami, FL 33199
U.S.A.

†On sabbatical leave from Universidad Símon Bolívar.