Diode Parameter Extraction by a Linear Cofactor Difference Operation Method

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ABSTRACT

The direct extraction of the key static parameters of a general diode by the new method named Linear Cofactor Difference Operator (LCDO) method has been carried out in this paper. From the developed LCDO method, the extreme spectral characteristic of the diode voltage versus current curves has been revealed, and its extreme positions are related to the diode characteristic parameters directly. Two different diodes are applied and the related characteristic parameters such as the reverse saturation current, the series resistance and non-ideality factor have been extracted directly and the results have also been discussed.

Keywords: LCDO, diode, parameter extraction, ideality factor, series resistance.

1 INTRODUCTION

The static parameters of the diode such as series resistance, ideality factor and reverse saturation current play an important role in determination of the terminal current in the simulation and modeling of devices. Hence, a number of methods have been proposed to extract the device parameters of diodes [1-4]. But these methods often rely on the complex algorithm and various approximations.

In this paper, a novel parameter extraction method, named Linear Cofactor Difference Operator (LCDO) has been applied to extract the reverse saturation current, ideality factor and series resistance of the practice diodes. From this method, the unique extreme spectral characteristics of the current-voltage of the diode have been revealed, and then the related diode parameters could be determined from these extreme spectral characteristics. Its mathematical simplicity and physical concept clearness are the main advantages of this method over the traditional approaches, thus this method will be a useful tool in the analysis of the diode characteristics and the extraction of the diode static parameters, as shown in the following discussion.

2 LCDO METHOD APPLICATION

As shown in [5], If a function *f(x)* is strictly monotonic, non-linear, continuous and differentiable over region (x_0, x_1), there definitely exists a point x_p, $x_0 < x_p < x_1$, so that

$$G(x_p) = \frac{\partial G}{\partial x}\Big|_{x=x_p} = 0 \tag{1}$$

Where

$$G(x) = \Delta LCDO(x) = b + K_p x - f(x) \tag{2}$$

is the linear cofactor difference of the measured *f(x)* and $\Delta LCDO(x)$ is the linear cofactor difference operator, *b* and K_p are the LCDO intersection and linear factor, respectively.

The constants b and K_p can be determined via equations

$$G(x_1) = \mathrm{b} + K_p x_1 - f(x_1) = 0 \tag{3}$$

$$G(x_0) = \mathrm{b} + K_p x_0 - f(x_0) = 0 \tag{4}$$

The detail description of this LCDO method principle has been found in [11-13]. Here we apply the application of this method to the extraction of the static parameter of a general diode.

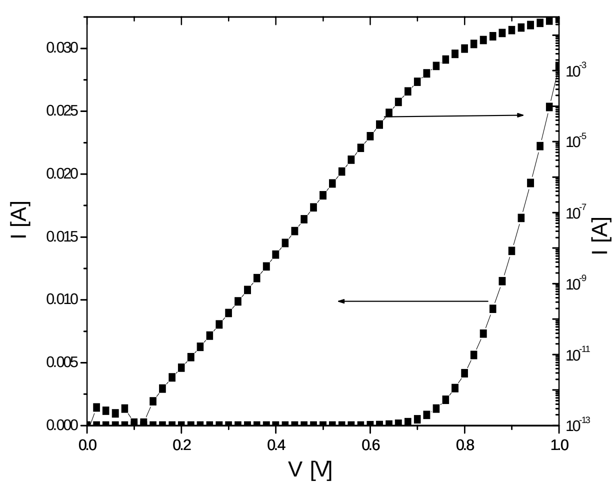

Fig 1 Measured I-V Characteristics of D1.

A measured diode current-voltage characteristics are shown in Fig 1. According to the semiconductor device physics, the current of a diode is frequently modeled by the following single exponential equation [1-5]:

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$$I_d = I_s\left[\exp\left(\frac{V - R_s I_d}{nV_t}\right) - 1\right] \quad (5)$$

Where I_s is the reverse saturation current, R_s is the series resistance, V_t=K_BT/q is the thermal voltage, and n is the diode ideality factor.

In Equation (1), the term (–1) is negligible for the forward bias condition; therefore, the Equation (5) can be rewritten as

$$V = nV_t \ln\left(\frac{I_d}{I_s}\right) + I_d R_s \quad (6)$$

The LCDO method is applied onto Equation (6) with b=0 and then the following equation is obtained

$$\Delta lcdoV(I_d) = K_p I_d - nV_t \ln\left(\frac{I_d}{I_s}\right) - I_d R_s \quad (7)$$

Where K_p is a linear cofactor difference factor.

Therefore, we define

$$\frac{\partial \Delta lcdoV(I_d)}{\partial I_d}\bigg|_{I_d = I_{dP}} = 0 \quad (8)$$

The extreme spectral of the linear cofactor difference diode voltage versus the current can be obtained. Substituting Equation (8) into Equation (7) at the extreme position point I_{dP} , we can obtain

$$R_s = K_p - \frac{nV_t}{I_{dP}} \quad (9)$$

For a given diode current versus voltage curve, the diode ideality factor can be obtained from Equation (9) by using two different linear cofactor difference operator factors, K_{p1} and K_{p2}.

$$n = \frac{I_{dP1} I_{dP2}(K_{p1} - K_{p2})}{V_t(I_{dP2} - I_{dP1})} \quad (10)$$

Where I_{dp1} and I_{dp2} are current values in the linear cofactor difference diode voltage extreme point positions corresponding to the two different factors K_{p1} and K_{p2} respectively. Consequently, R_s can be determined from Equation (9) and then I_s from Equation (5).

3 RESULTS AND DISCUSSION

In order to apply this method to the practical diode, the measurement of the current-voltage (I-V) characteristics of two different diodes (D1 and D2) has been carried out first. The resultant data are taken at room temperature, using a semiconductor parameter analyzer HP-4156 with a step voltage of 0.02V. Fig 2 shows the linear cofactor difference voltage characteristics under the conditions of the difference linear cofactor difference factor K_p.

$K_{p1} = 43.6$， $K_{p2} = 55.76$， $K_{p3} = 76.5$

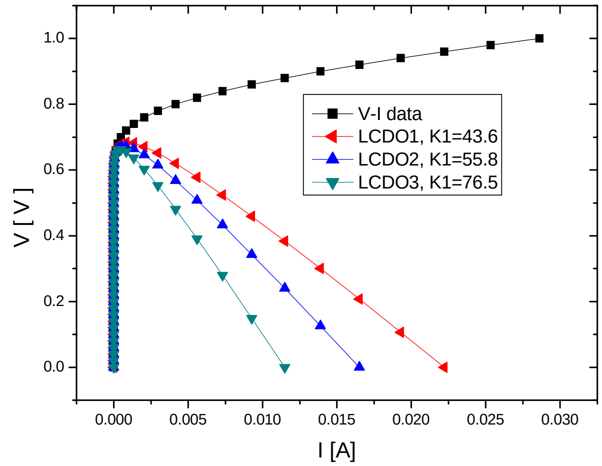

Fig 2 Diode voltage linear cofactor difference versus current for different values of K_p.

These extreme points and corresponding linear cofactor difference diode current are shown in Table 1.

Table 1 LCDO extreme points and linear cofactor difference diode voltage of D1 with different LCDO factors.

Linear cofactor difference operator factor K_p	Extreme point and corresponding LCDO diode current	
	Extreme point I_{dP} (*A*)	LCDO voltage (*V*)
43.6	8.36×10^{-4}	0.684
55.8	8.36×10^{-4}	0.673
76.5	34.8×10^{-4}	0.663

Based on the obtained extreme spectral peak magnitude and positions, the related diode static parameters can be easily extracted from the present formula.

From the extreme points and linear cofactor difference values at these extreme points, we obtain the consistent ideality factor n=1.2 for D1 from Equation (10) under difference combination of K_p. Then we can obtain the series resistance $R_s = 6.28\Omega$ from Equation (9) with any known K_p, n and I_d, even if the LCDO peak values and peak positions are different for different K_p values. Adjusting Equation (5) to the experimental values, we get $I_s = 9.4\times10^{-14} A$

Fig 3 shows the measured and extracted I-V characteristics of D1, which represents that the calculated line matches the measured one. The deviation in the small current region between both is due to the fact that the practical I-V characteristic of this diode does not follow the single exponential Equation (5) in the small current region.

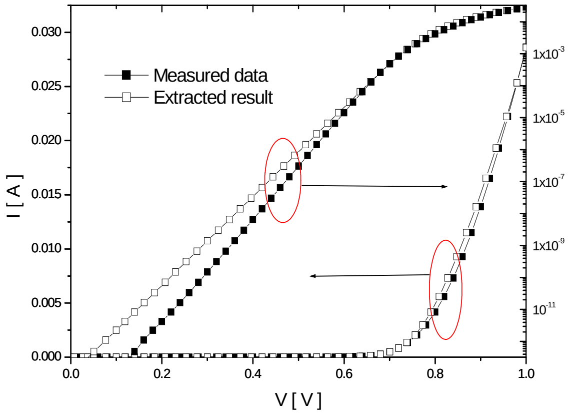

Fig 3: Comparison between measured and extracted I-V Characteristics of D1.

To demonstrate the efficiency of LCDO method, another practical diode (D2) is used for parameter extraction with this method. The measured I-V characteristics is shown in Fig 4.

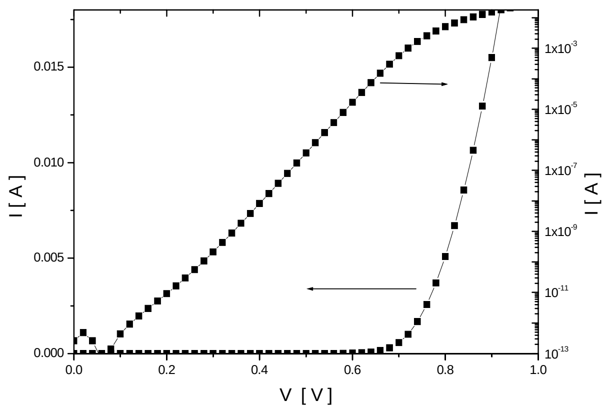

Fig 4: Measured I-V Characteristics of D2.

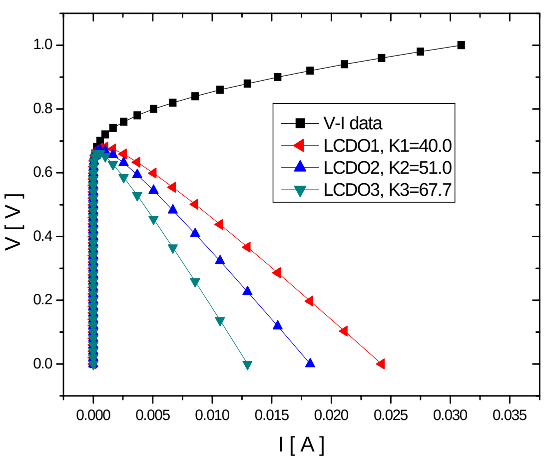

Fig 5: Diode voltage linear cofactor difference versus current for different values of K_p.

Fig 5 shows the diode linear cofactor difference voltage versus current result with the measured voltage-current characteristics for D2 with the linear cofactor difference factors:

$$K_{p1} = 40, K_{p2} = 51, K_{p3} = 67.7.$$

Following the same steps as used in the parameter extraction of D1, we obtain

$$n = 1, R_s = 5.4\Omega, I_s = 1.176\times10^{-15} A$$

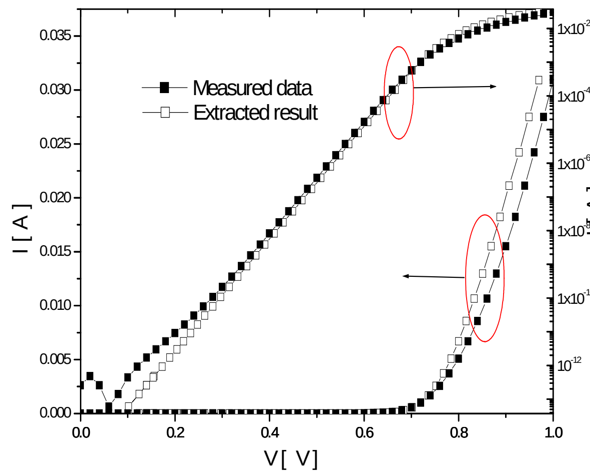

Fig 6: The comparison between the measured and extracted I-V characteristics of D2.

As Fig 6 shows, the extracted result matches the measured one in the most regions. However, there are some deviations either in the small current region or in the large current region. This is due to that the practical diode data does not really follow a simple equation as shown in Equation (5), it involves more complex current mechanisms in the small region such as R-G current and in the large current region such as high-level inject. In these cases, the LCDO method may be applied in separate regions to get better result. Such a treatment, however, would complicate the parameter extraction. So we can conclusion that the LCDO method for extracting the static parameters of diode is useful and effective in most diode operation region.

4 CONCLUSIONS

The extraction of the static parameters of two general diodes has been carried out in this paper by the linear cofactor difference operator method. The principle of this method is to apply the special extreme spectral characteristics of the diode voltage versus the current to obtain the related physical parameters such as the series resistance, ideality factor and reverse saturation current. The extraction practice for two different diodes has been carried out, showing the effective of the method presented.

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