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A current–voltage–temperature method for fast extraction of schottky diode static parameters

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ABSTRACT

We propose a simple graphical method to extract the static parameters of an arbitrary schottky diode. The method is an extension of the current–voltage method by the inclusion of a temperature aspect, and hence may be referred to as a current–voltage–temperature (*I*–*V*–*T*) method. The voltage–temperature characteristics are first obtained at two constant currents. Then, by considering the points on the characteristics with common attributes of either voltage or temperature under specified current density, a specific parameter is calculated. This abstraction is shown mathematically to greatly simplify the calculation of ideality factor, barrier height and diode resistance. The diode is first considered to be ideal with zero current modulation by a base resistance. The effect of non-zero base resistance is then subsequently quantified. Finally, the analysis of simulations on the commercial BAT54 schottky diode and published data for fabricated Au/n-Ge, Au/n-Si and Au/n-GaAs schottky diodes are presented. Application of the *I*–*V*–*T* method to different regions of the characteristics produces much lower variances in calculated barrier height, ideality factor and forward resistance in contrast to those based on the source publications. This suggests that the *I*–*V*–*T* method is a feasible alternative to characterize these diodes. The underlying reason being that control is exerted on the current density by the experimenter.

1. Introduction

A schottky diode is created when a junction forms between a metal and a semiconductor, creating a potential energy barrier that is referred to as a schottky barrier [1–3]. The characterization of the schottky barrier will continue to be important. For instance, during device fabrication the metallization of a semiconductor surface for external device connection may cause it to exhibit a potential barrier at the connection. However, in all its modern forms and importance it can be difficult to characterize with respect to its static parameters. A common parameter of interest is the schottky barrier height (SBH) that is usually deduced from transport measurements of barrier diodes created on non-degenerate semiconductors [4,5]. A number of measurement methods of varied complexity and usefulness have been presented over the years. The basic methods fall into four broad categories, namely current–voltage (*I*–*V*), activation energy, capacitance–voltage (*C*–*V*) and photoelectric measurements [2]. Often, these measurements are made under simplifying assumptions which, while being neither particularly easy to apply nor very accurate, give a reasonable indication of expected parameter ranges and variations. The *C*–*V* method, for instance, is carried out mostly in reverse-bias using a high-frequency excitation signal, where it is expected that the diode will not exhibit a low-voltage resonance peak [4]. It is believed that the peak is caused by interfacial charges that track the alternating current signal and generally contribute to measured capacitance at frequencies lower than 1 MHz [6,7]. The predominant assumption in that case is that the capacitance of interest arises entirely from the space charge [4]. In the *I*–*V* method it is essential, as we shall show, to model the effect of the forward resistance

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of the diode. Existing models that are used in the *I–V* extraction are broadly classified into three categories, namely: simplistic models that rely on thermionic emission theory, physical analytical models that achieve closed-form solutions of transport equations and finally numerical models of the diode that are based on Poisson's equation together with drift-diffusion and continuity equations [5,8]. Many of the available engineering methods of processing *I–V* curves for the static parameters may have restrictive assumptions about parametric values that are acceptable to the method [5]. This is clearly not applicable to all schottky diodes. For instance, the methods in [11–13] are confined to base resistances in the range of 10–20 Ω. These methods determine Φ_b and n in a low-current mode where the effect of the resistance can be ignored. This approach can prove troublesome when dealing with locally synthesized barrier devices whose properties are only amenable to probing with higher currents. Additionally the methods may have features that may affect the accuracy of the method directly and adversely. A point of departure of this article from these methods is that we examine the role of temperature more closely and show that it can lead to better accuracy in the calculated static parameters. There is already evidence in the literature [9,10] that suggests that a temperature-based analysis produces more accurate static parameter values. The primary interest in the role of temperature in the literature has mostly been with respect to thermal degradation [14]. The only requirement of this new approach is a reinterpretation of existing *I–V* data, which already has implicit temperature behavior i.e. *I–V* data at different temperatures, to the constant current *V–T* format.

The primary aim of this article is to present an *I–V–T* method that is shown to simplify the graphical extraction of the static parameters namely barrier height, ideality factor and forward resistance of a schottky diode. The method also leads to a reasonable estimation of the effective Richardson's constant of a diode of specified cross-sectional area. We derive the mathematical basis starting at the diode current density and show how specific points on the constant current characteristics impact the calculation of the static parameters of interest. We begin by illustrating the method on results of an LT-Spice [15] simulation of the commercial BAT54 schottky diode [16]. There are a number of valuable specifics with the BAT54. For instance, it is generally operated at much higher currents and temperatures. There is also a manufacturer data sheet from which the static parameters can be estimated, but with particular emphasis on the verifiable values of the dynamic resistance from its known room temperature *I–V* characteristic. The contemporary interest in metal–semiconductor junctions continues to generate much data in the literature for a wide range of schottky barrier diodes. These data are typically presented graphically as *I–V* curves measured at different temperatures. For the analysis in this article the numerical data were first extracted from published graphs into raw, equivalent tables and then converted to the constant current, voltage versus temperature format. There are several ways to do this, for instance using a software digitizer such as Engauge [17]. The ease of data re-representation makes the method applicable to a vast number of arbitrary, new and existing laboratory schottky barrier diodes. As examples of potential application we recalculate the static parameters for three experimental schottky diodes from different sources, constructed of gold and different semiconductors. These diodes are: Au/n-Si published by Sharma [18], Au/n-GaAs published by Singh et al. [19] and Au/n-Ge (100) published by Chawanda et al. [20]. Application of the *I–V–T* method to different regions of the characteristics produces much lower variances in calculated barrier height, ideality factor and forward resistance when cited by their originators.

2. Theory

From thermionic emission theory [2,5,8], the ideal schottky diode current density J can be written

$$J = A^{*}T^{2}\exp[-q\Phi_b/(nkT)](\exp[qV/(nkT)] - 1), \tag{1}$$

where A^{*} is the effective Richardson's constant, Φ_b is the barrier height on the metal side, k is Boltzmann's constant, n is the ideality factor of the diode and T is absolute temperature. Suppose that the two current densities are in a known ratio a, such that

$$J_2 = aJ_1, \quad \text{for} \quad 0 < a < 1. \tag{2}$$

Fig. 1 illustrates the *general* effect of the constant current densities J_1 and J_2 on the diode voltage as it is cooled [21,22]. In the experiment the diode is heated to a high initial temperature T_0 beyond point A in the figure under forward current density equal to J_1. The diode is then allowed to cool to T_1 where its forward voltage is V_{F1} (point B in Fig. 1). The current density is then switched to a new constant value J_2. A new terminal voltage V_{F2} is observed (point C). As the diode continues to cool down under the new current I_2 its terminal voltage will eventually reach V_F again, at which the measured temperature will be T_2.

At temperature T_1 Eq. (1) becomes

$$J_1 \approx A^{*}T_1^{2}\exp[-q\Phi_b/(nkT_1)]\exp[qV_F/(nkT_1)]. \tag{3}$$

Similarly, at temperature T_2

$$J_2 = aJ_1 \approx A^{*}T_2^{2}\exp[-q\Phi_b/(nkT_2)]\exp[qV_F/(nkT_2)]. \tag{4}$$

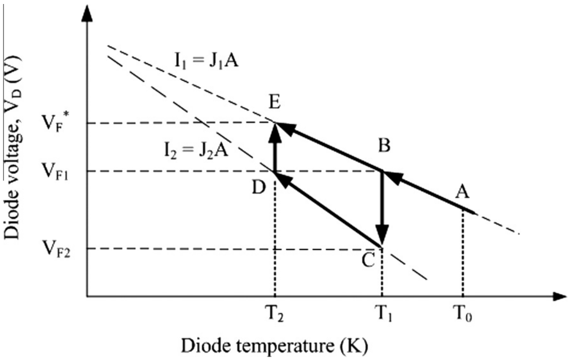

Fig. 1. Measurement trajectory (BCDE) applied to the schottky diode.