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## Parameter Extraction Software for Silicon Carbide Schottky, Merged Pin Schottky and Pin Power Diode Models

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## PARAMETER EXTRACTION SOFTWARE FOR SILICON CARBIDE SCHOTTKY, MERGED PIN SCHOTTKY AND PIN POWER DIODE MODELS

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### Abstract:

*A software program for on-state parameter extraction is presented for the realization of a high quality model for SiC Schottky, Merged PiN Schottky, and PiN Power diodes based on McNutt and Mantooth's Comprehensive SiC Diode model [1].*

### Introduction:

There has been an increasing interest in Silicon Carbide (SiC) for many applications in high power electronics. SiC offers high current carrying capabilities, high thermal conductivity, high temperature operation, and a high breakdown field, which makes it superior to silicon semiconductor technology. The advantages of Silicon Carbide (SiC) have been recognized for more than three decades. However, single crystal wafers of SiC have only been accessible since around 1990. Therefore, SiC devices are relatively new and slowly becoming commercially available.

In order to increase the acceptance of a SiC electronic device, providing design engineers with an accurate semiconductor device model is of crucial importance. Design engineers need a reliable representation of the electronic device they are going to utilize in order to simulate proposed designs and detect flaws before building a prototype. This results in the ability of the designer to vary parameters in the design with relative ease. Most importantly, in the case of a faulty design, an accurate device model predicts any undesired behavior of the system, which in turn prevents the waste of financial resources as well as any personal injuries to users of the design.

McNutt [1] has developed an accurate model and parameter extraction procedure for SiC Schottky, Merged PiN Schottky and PiN Power diodes. Nevertheless, the model parameter extraction is a cumbersome, time-consuming task. This is the reason for the efforts made in developing software to extract the parameters of the model. The software here presented enables

users to extract the on-state model parameters themselves and thus permits the simulation of new SiC diodes as soon as they are introduced.

### Software Platform:

The software platform of choice for the development of the on-state model parameter extraction software is Labwindows/CVI%. Labwindows/CVI% is an integrated C programming environment designed for the development of data acquisition and data processing software. The C programming environment of Labwindows/CVI% allows for the easy implementation of model equations required to extract the model parameters. It also allows the generation of a graphic user interface (GUI) with its numerous controls such as knobs, buttons, menus, numerical displays and graphs. This facilitates the parameter extraction process making the operation of the program and feature selection visually intuitive.

### Organization of Front Panel:

In this section, the organization and structure of the software is described. The software front panel is presented in figure 1. The software provides the user with file managing features on the *File* pull-down menu. The software opens and operates on the current-voltage data provided on a .txt file. The *Edit* pull-down menu allows the user to zoom in an area of interest in the curve as well as to reestablish the initial appearance. The front panel has two graph displays. The top graph display shows the currents through the diode versus voltage across the four ideal diodes that represent the SiC diode as it can be observed from figure 2. The bottom graph display presents the currents through the SiC diode versus voltage across the anode and cathode terminals of the SiC diode. The top right numerical displays X1, Y1, X2, Y2 give the coordinates of the blue and yellow cursors in the top graph display respectively. The temperature numerical display allows the user to extract the parameters at different temperatures. The function of the other buttons and numerical displays will be

explained during the Extraction Sequence section of this paper along with the step to which they are associated.

### Topology and Parameters to be Extracted:

Figure 2 shows the topology for the on-state characteristics of the SiC diode. Four ideal diodes in parallel and a series-connected resistor model the SiC diode. As it can be observed from figure 1, the current  $I$  through the SiC diode is composed of four different currents namely Low-level depletion region combination ( $I_R$ ), Low level injection ( $I_L$ ), High level injection ( $I_H$ ), and Emitter recombination ( $I_E$ ). All these different currents are determined through the basic diode equation as shown in equation (1)

$$I_x = I_{sx} * (\exp(V' / (vt * n_x)) + 1) \quad (1)$$

where  $V'$  is the voltage across the diode, and  $I_{sx}$  and  $n_x$  are the model parameters and are unique for the four diodes illustrated in figure 1. The parameters are  $I_{SR}$ ,  $I_{SL}$ ,  $I_{SE}$ ,  $I_{SH}$ ,  $n_R$ ,  $n_L$ ,  $n_E$ , and  $n_H$ .

The resistor in series with the four diodes limits the exponential growth of the total current  $I$  to a more linear increment. The value of this on-state resistance  $rs$  is needed to determine the voltage  $V'$  across the diodes using equation 2.

$$V' = V - I * rs \quad (2)$$

### Extraction Sequence:

The extraction process is divided into a sequence of steps where only a few parameters are obtained at each step. These steps are 1) Calculating  $rs$ , 2) Plotting  $I-V'$  logarithmically, 3) Calculating the  $I_{sx}$  and  $n_x$  parameters for the regions of low, medium, and high currents and associate them with  $I_R$ ,  $I_L$ ,  $I_E$ , or  $I_H$ . In addition to these steps, the user has the option of providing desired values of  $n_R$ ,  $n_L$ ,  $n_E$ , and  $n_H$  in order to obtain the corresponding  $I_{SR}$ ,  $I_{SL}$ ,  $I_{SE}$ , and  $I_{SH}$ .

#### 1) Calculating $rs$

Figure 3 shows a typical  $I-V$  curve of a SiC diode. As can be seen from this figure, the curve is not purely exponential because of the linear component associated with  $rs$ . The effect of  $rs$  is more noticeable at higher voltages, and it is therefore the best region to extract this parameter. The software allows the user to set the limits of the region where the curve behaves linearly by placing the two cursors as shown in figure 3. Once the limits have been set the *Calculate Slope & Inverse Slope* button calculates the on-state resistance  $rs$  and the voltage  $V'$  using equation (2). The value of  $rs$  is displayed in the *Inverse slope (Rs)* numerical display.

#### 2) Plotting $I-V'$ logarithmically

The next step in the extraction sequence is plotting  $I-V'$  logarithmically. The plot

*Current without  $rs$  effect* button displays the  $I-V'$  curve linearly as in figure 4a. In the linear representation of the  $I-V'$  curve, the contributions of the  $I_R$ ,  $I_L$ ,  $I_E$ , and  $I_H$  currents are not visible because the curve looks purely exponential (that is just one exponential curve) rather than a combination of exponential currents (namely the contribution of  $I_{SR}$ ,  $I_{SL}$ ,  $I_{SE}$ , and  $I_{SH}$ ). The *Plot Mode* switch on the front panel allows the user to plot the graphs linearly or logarithmically. When  $I-V'$  is plotted logarithmically, the contributions of  $I_{SR}$ ,  $I_{SL}$ ,  $I_{SE}$ , and  $I_{SH}$  are more obvious, and the user can distinguish the number and location of the regions that make up the  $I-V'$  curve as shown in figure 4b.

#### 3) Calculating $I_{sx}$ and $n_x$ parameters for the regions of low, medium, and high currents

Figure 4b shows a typical  $I-V'$  plotted logarithmically. The curve exhibits changes in its concavity at different points as shown by the arrows. These different concavities determine the regions that make up the curve. Even though the software does not restrict the user from including all four currents  $I_R$ ,  $I_L$ ,  $I_E$ , and  $I_H$  to form  $I$  through the SiC diode, there are only a few combinations of these that have physical meaning. Additionally, the number of currents  $I_{sx}$  that compose  $I$  are typically two and in some cases three [1]. For the curve shown in figure 4b there are two  $I_{sx}$  currents contributing to the total current. The regions are selected by placing the cursors on the curve delimiting each region. Then each region's parameters are calculated by pressing the *Capture Low*, *Capture Medium*, and *Capture High* buttons depending on the region selected. The values for the saturation currents and their respective  $n$  components are displayed in the *Is Low*, *N Low*, *Is Medium*, *N Medium*, *Is High*, and *N High* numerical displays. The *Associate with* control display allows the user to transfer the values of the parameters extracted to the current component of his or her choice. Then, the numerical displays on the left side of the front panel  $I_R$ ,  $n_R$ ,  $I_L$ ,  $n_L$ ,  $I_E$ ,  $n_E$ ,  $I_H$ , and  $n_H$  will hold these values. The *Plot I diode* control button plots the total  $I$  current through the SiC diode including the effect of all the currents that have been check-selected. Figure 5 shows the data and

fitted curves for both cases where  $rs$  is present (a) and for the purely exponential curve (b), which are in excellent agreement with each other. If the user wishes to display the effect of only one current, he can do so by pressing any of the *Plot  $I_R$* , *Plot  $I_L$* , *Plot  $I_E$*  or *Plot  $I_H$*  control buttons.

One important additional feature of the program is the ability to extract any  $I_{sx}$  value for any given  $n_x$  value. For example, after selecting a region of interest the user may enter any value for  $n_x$  and then press the *Recalculate Low*, *Recalculate Medium*, or *Recalculate High* buttons depending on the region chosen. This will return a value  $I_{sx}$  that will fit that part of the region for the given  $n_x$ .

**Conclusion:**

A parameter extraction software for Silicon Carbide Schottky, Merged PiN Schottky and PiN Power Diode Models is presented. The software here presented enables users to extract the on-state model parameters themselves and thus permits the simulation of new SiC diodes as soon as they are introduced. The graphic interface facilitates the process of the parameter extraction making it visually intuitive. The parameters obtained from this software generate a simulation that is in excellent agreement with the measured data.

**Acknowledgements:**

I would like to recognize Ty McNutt, Dr. A.B. Lostetter, and Maruf Hossain for their important contributions and suggestions to this work.

**References:**

[1] McNutt, T.R.; Hefner, A.R.; Mantooth, H.A.; Duliere, J.L.; Berning, D.W.; Singh, R.; 2002. "Parameter Extraction Sequence for Silicon Carbide Schottky, Merged PiN Schottky, and PiN Power Diode Models." Conf. Proc. of IEEE Power Electronics Specialists Conference (PESC) 3:1269-1276.

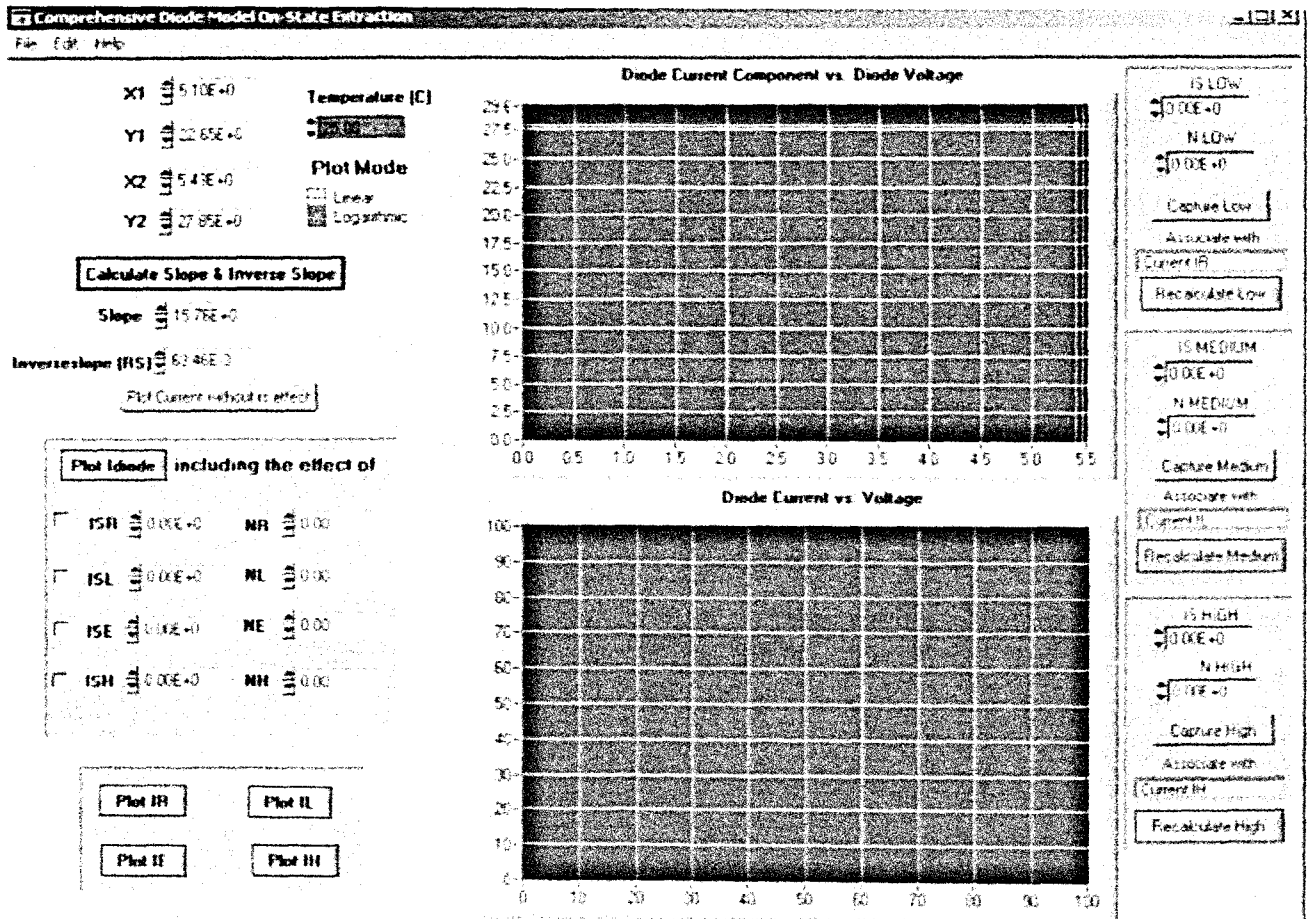


Figure 1- Front panel appearance.

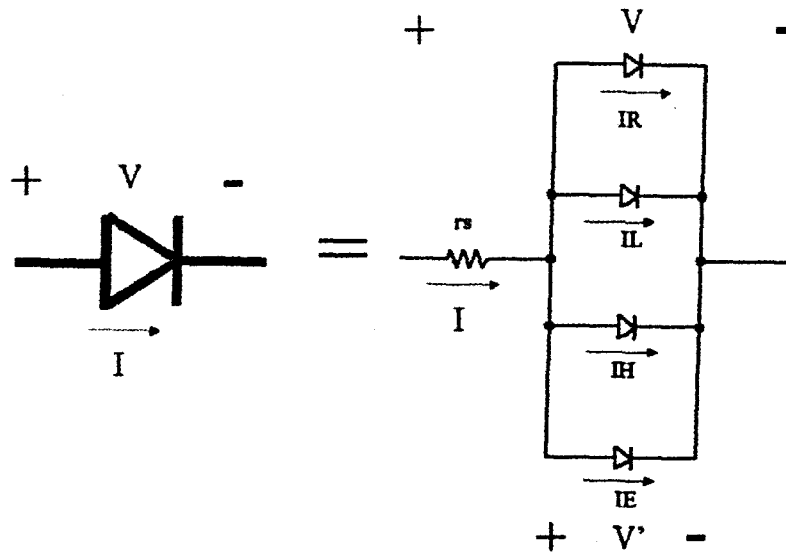


Figure 2- Topology for the on-state characteristics of the SiC diode.

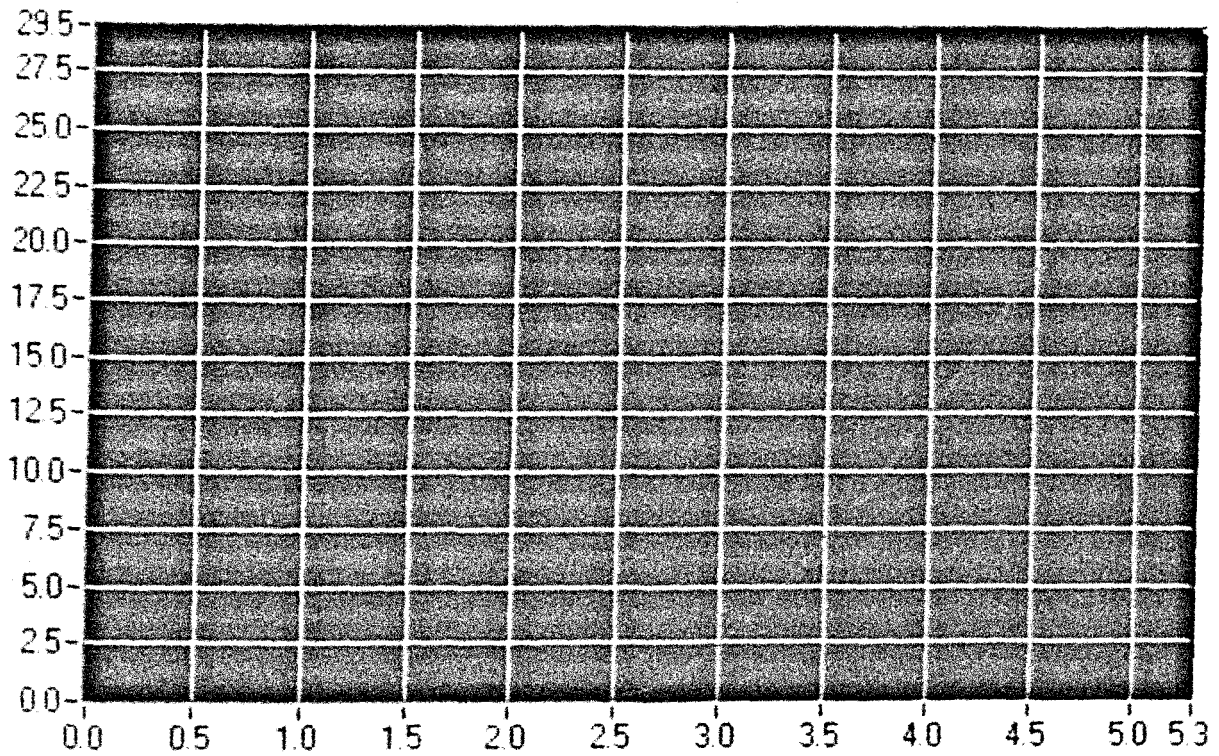
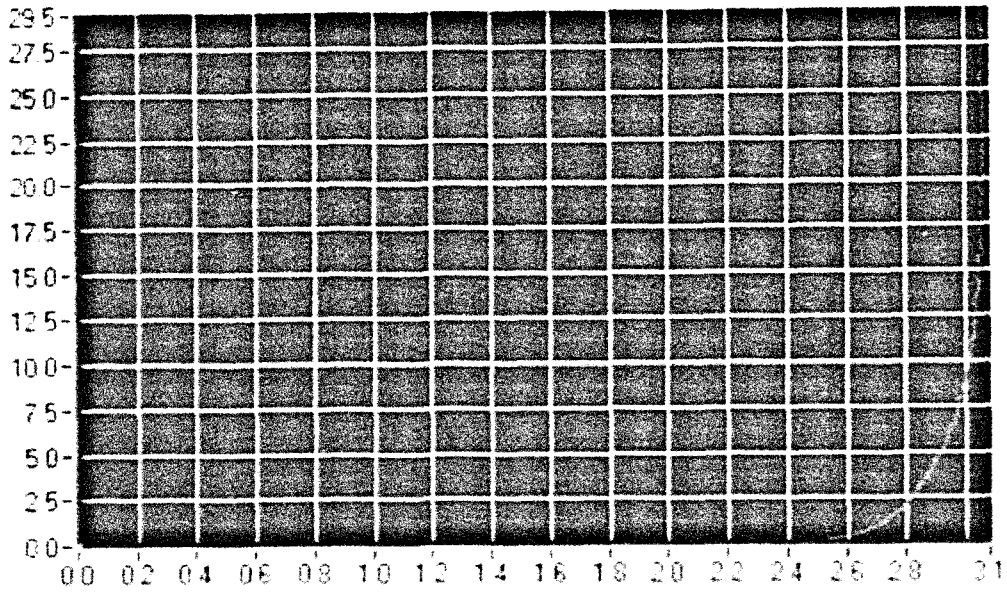


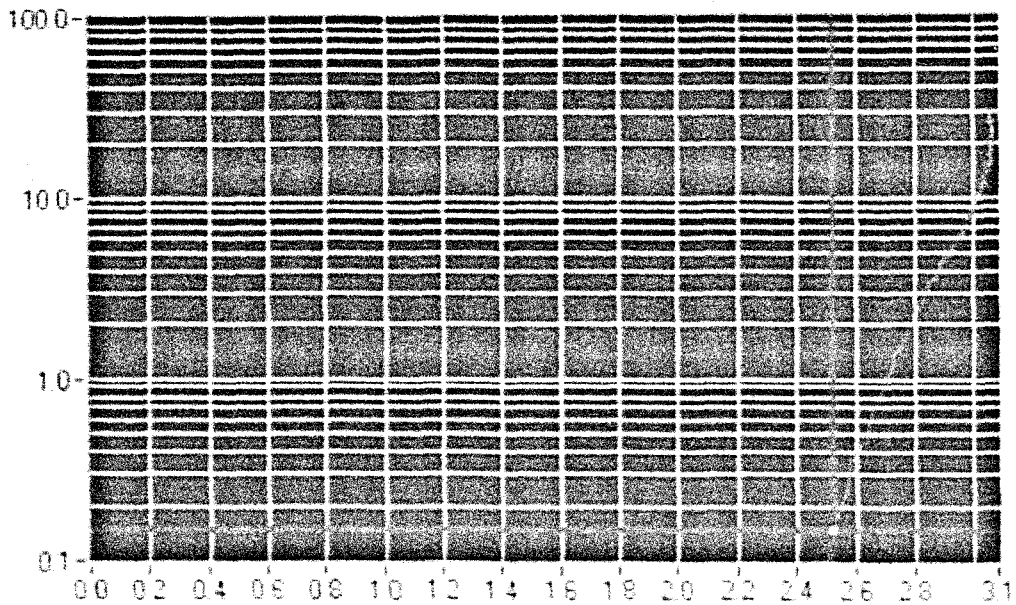
Figure 3- Characteristic I-V curve of SiC diode.

Diode Current Component vs. Diode Voltage



a.)

Diode Current Component vs. Diode Voltage

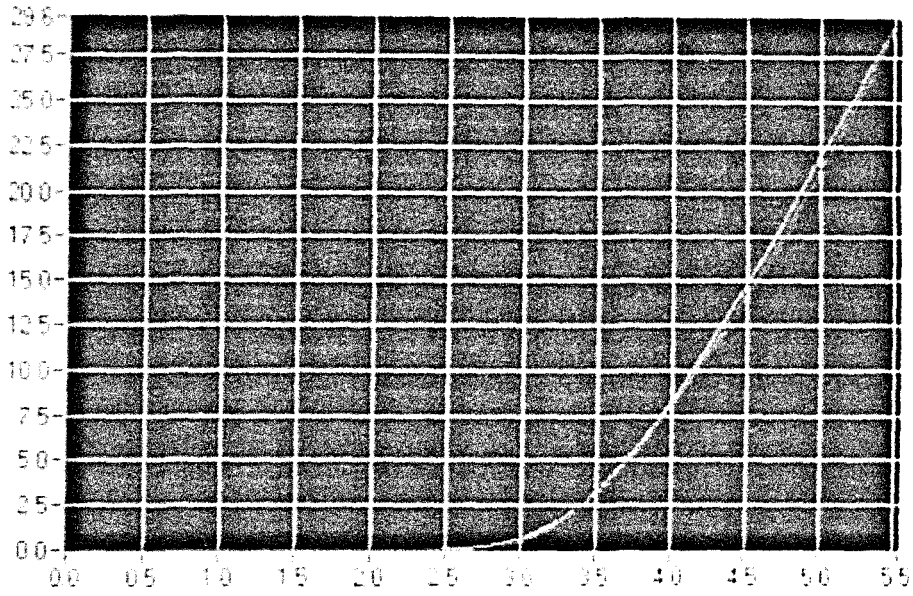


b.)

Figure 4- a) I-V plotted linearly, and b) I-V plotted logarithmically.

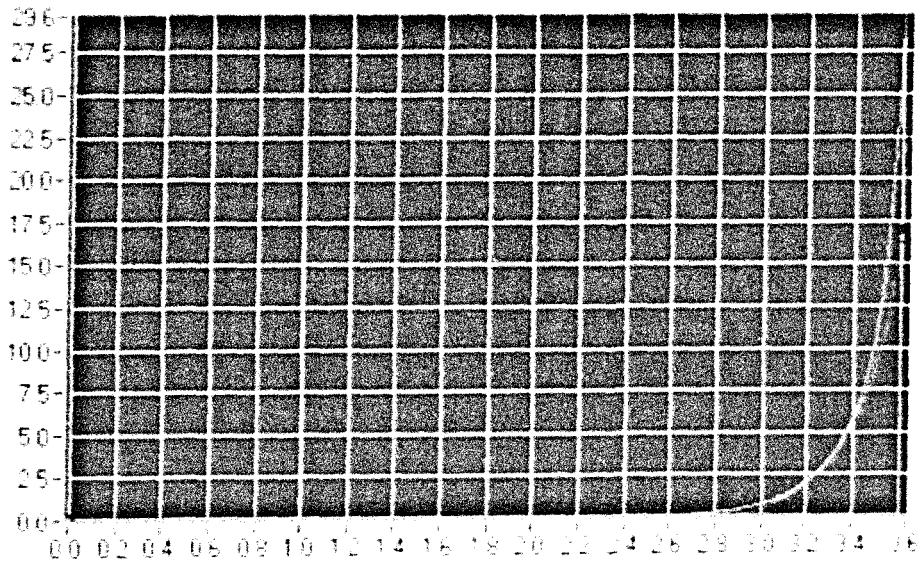


Diode Current vs. Voltage



a.)

Diode Current Component vs. Diode Voltage



b.)

Figure 5- a) Data and fitted curves including  $r_s$ , and b) Data and fitted curves not including  $r_s$ .

**Faculty Comments:**

Alan Mantooth, Mr. Cilio's mentor, made the following comments about his student's work:

Edgar Cilio has worked in the Mixed Signal Computer Aided Design Laboratory for the past 2 years. He will complete his bachelor's degree in electrical engineering this fall. Edgar is a very bright, hard working young man that has done a great job in my lab working on projects relating to silicon carbide device technology. Edgar has a very high grade point average and combines this with the natural curiosity required of all good researchers. Edgar was also a member of the 2003 Solar Electric Boat Team for which I was faculty advisor. He had the responsibility of running the wireless telemetry project.

This project involves designing and building a wireless link from the on board meters and gauges to a laptop computer running special software to track the health of the boat's batteries, the speed of the boat, the efficiency of the solar panel array, and other important functions. This was a new challenge for Edgar, and he did a great job.

Edgar's research in my lab has involved writing software to drive instrumentation, developing custom

test circuitry for silicon carbide device characterization, and developing parameter extraction techniques for those device's compact models. His work will soon enable us to publicly release our device models along with a full complement of parameter extraction tools. This will be extremely well received by the power electronics community.

Another member of the electrical Engineering faculty who is familiar with Mr. Cilio's work, Department chair Aicha Elshabini, had the following to say:

Mr. Cilio's technical and research interests are in the areas of Circuit Design, Artificial Neural Networks, and Digital Signal Processing. His interesting and important undergraduate work in the SiC Power Device Modeling group consists of the automation of SiC electronic device parameter extraction sequences using LabVIEW and LabWindows/CVI. His research work consisted on developing a parameter extraction software for SiC Schottky, Merged PiN Schottky and PiN Power diodes since the parameter extraction procedure is a cumbersome, time consuming task. The software he has developed enables users to extract the on state model parameters themselves and thus permits the simulation of new SiC diodes as soon as they are introduced.