The American university in Cairo
Physics Department

Fall 2005

PHYS 551 : Advanced Topics in Solids

Advanced Semiconductor and MEMS Devices and Technology

COURSE PROJECT I

The goal of the project is to enhance student understanding of pn junction diodes and bipolar junction transistors through measurement of current-voltage DC characteristics of the devices by means of the web-Lab (iLab) and extract the device parameters from the measurements. The project uses the MIT Microelectronics WebLab which consists of an online microelectronics device characterization test station developed by Prof. del Alamo and his students at MIT.
The measurement device consists of an HP4155B Semiconductor Parameter Analyzer which is basically a curve tracer that allows you to obtain current-voltage (I-V) characteristics of semiconductor devices.
You have been trained by Joseph Zekry to how to access the MIT Microelectronics WebLab. And how to use the menu, to choose your device, to select a measurement and all other measurement details. If you have any problem consult the manual or contact Joseph to help you in solving it.

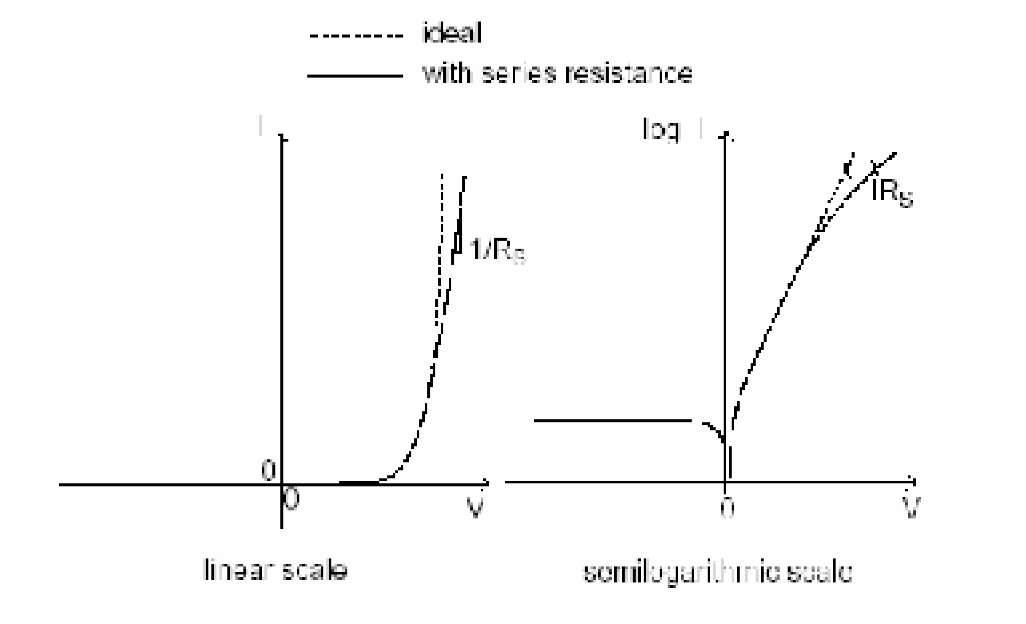
This project is guided by the device characterization projects of Spring 2003 of Prof. J. Del Alamo, published on his MIT site.

Part 1: Characterization of pn junction diode	**(50 points)**

This problem is about characterizing a pn diode. You will have to:
1. **(20 points)** Measure the I-V characteristics in the range of voltage -2, 1 Volt. Take enough data to cover all regions of interest. The maximum current that can be reached is 100 mA and the minimum is 100 nA. Take a screen shot of what you see on the analyzer.
   a. linear I – linear V plot
   b. semi-log plot log I – linear V

2. **(10 points)** Download the data and plot the I-V characteristics in both modes (linear and semilog) using Excel or Matlab.

3. **(20 points)** Fit the pn junction equation to your results and extract values of the junction reverse saturation current I_o and the temperature T.
a. Compare your extracted temperature with the temperature indicated by the iLab. Be careful at low voltage of the non-ideal behavior of the junction.
b. The series resistance will deviate the characteristics from ideality at relatively high current as shown in Fig.1. The diode equation becomes; $I = I_o \exp (V\text{-}IR_s)/kT$. You'll need to iterate your calculations since I occurs at both sides of the equation.



Part 2: Characterization of bipolar junction transistors (50 points)

In this project, you will characterize the current-voltage characteristics of an npn bipolar junction transistor. Be carefull to connect correctly the three terminals of the device. In thisproject you'll:

1. (20 points) I_C-V_{CE} output characteristics

a) Measure the Common Emitter output characteristics (I_c versus V_{CE} with I_B as a parameter). V_{CE} is kept between 0 and 4 V and I_B varies from 0 to 100 μA with a step of 20 μA). Take screen shots of the characteristics as displayed on the analyzer (curve tracer).

b) Download the data and make your own plots. Determine the Early voltage.

2. (20 points) Transfer characteristics (Gummel plots)

Measure and download the common-emitter transfer characteristics of the BJT in the forward active regime. This consists of determining the plots of I_C and I_B (logarithm of) vs V_{BE} (linear scale). Fix $V_{CE} = 2.5$ V.

3. (10 points) The Gummel plots can be analytically expressed by the equations below. Therefore, from the plots you can extract two of the device parameters very accurately. These are: I_S, which is equal to $\alpha_F I_{ES}$ where α_F is the forward common base current gain and $I_{ES}$is the reverse saturation current of the emitter base junction. You can also extract the forward common emitter current gain (β_F). Relates its value to α_F through ($\alpha_F = \beta F/(1+\beta_F)$ and determine I_{ES}.
Determine also the temperature from the collector current plot and compare it to the value indicated by iLab. Note that determining the temperature from the collector current Gummel plot is one of the most accurate method for temperature measurements.

4. (5 points) Repeat 3 when connecting the transistor in the reverse active mode. Prove that reciprocity is respected. Use the Gummel plots in this case to determine the reverse common emitter current gain β_R, α_R and I_{CS} the reverse saturation current of the base-collector junction.

5. (5 points) Comment on the values of the four parameters extracted.

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In the forward active regime, the Ebbers Moll equations simplify to:

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\begin{aligned}
I_C &\simeq I_S \exp \frac{qV_{BE}}{kT} \\
I_B &\simeq \frac{I_S}{\beta_N}(\exp \frac{qV_{BE}}{kT} - 1) \\
I_E &\simeq -I_S \exp \frac{qV_{BE}}{kT} - \frac{I_S}{\beta_N}(\exp \frac{qV_{BE}}{kT} - 1)
\end{aligned}
$$