

Laboratory exercise: the Bipolar Transistor

Semiconductor Physics 2012

Lab meeting point – k-space at Solid State Physics

This exercise consists of one experimental part, and one simulation part.

In the experimental part you will be measuring the IV -characteristics in the common emitter mode as well as analysing the gain of the transistor in a so called Gummel plot.

In the simulation part you will be using commercial software which is used for industrial design of semiconductor devices. In this case we will use the simulation tool to “look inside” the device and deduce physical parameters like the electric field and the minority carrier concentration inside the actual device. This information is difficult to obtain experimentally, but it may easily be simulated in the computer.

As a preparation for this exercise we recommend you to study the handout and the chapter about the bipolar transistor in the text book (chapter 5).

Experimental Part 1:

We will start the experimental part by measuring the IV -characteristics of a Si npn bipolar transistor in the common emitter mode. These measurements will be performed by the measurement set-up shown below. We will be using Keithley semiconductor analyzer 4200-SCS. This system exploits Source-Measure Units (SMUs) for biasing and measuring currents and voltages. We will configure one of the SMUs to inject current between emitter and base. We then connect another Source Measure Unit to the collector in order to apply a collector bias V_{CE} and to measure the current I_C through the collector. These measurements are performed for a set of different base currents I_B and hence we get the IV -characteristics for a bi-polar transistor in common-emitter mode (fig 8b p. 256 in Sze).

Connect the instruments as shown below:

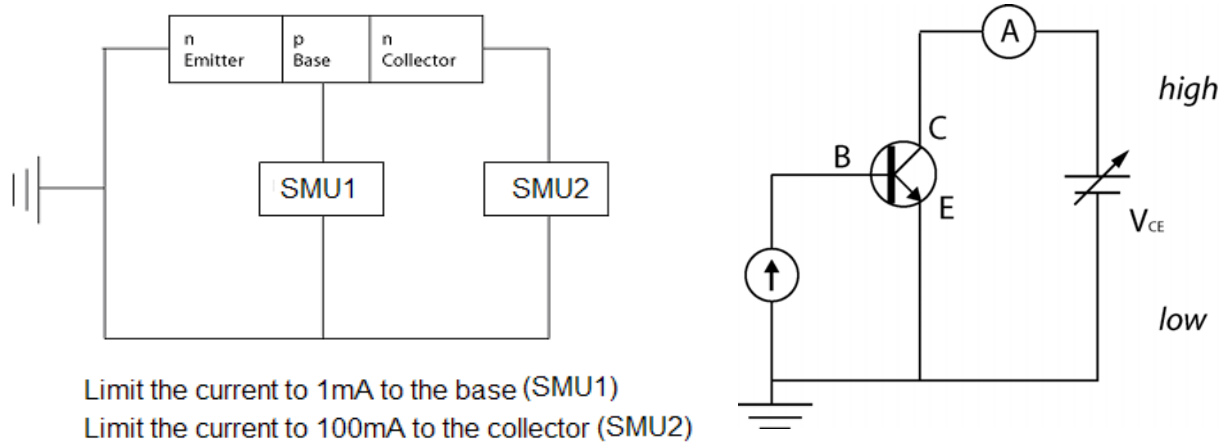


Figure 1 Experimental set up for IV characterisation in common emitter mode. The SMU1 is used to set the base current to the desired value, whereas the SMU2 is used to apply a bias to the collector and to measure the collector current. The corresponding circuit is shown to the right.

- Measure the IV characteristics (use $V_{\text{start}} = 0\text{V}$, $\text{step} = 0.1\text{V}$, $V_{\text{stop}} = 6\text{V}$,
Start base current = 0A , Stop base current = $100\mu\text{A}$, $\text{step} = 20\mu\text{A}$)
- Measure I_{CE0}
- The IV curves have a certain slope. Explain the reason!

The gain of a transistor is a key parameter and we will be measuring it in a so-called Gummel plot (for an example, see fig 5 p. 251 in Sze). We will study the base- and collector current as a function of the base-emitter bias at a fixed collector voltage (2V). The relation of these two currents (I_C/I_B) will give the common emitter gain, β , of the device. The measurement set-up will be similar to the previously described one, but we will use a different program (**Gummelplot**) to control the instruments.

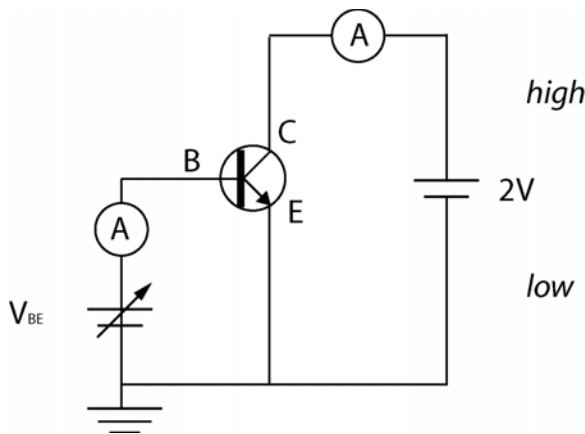


Figure 2 Experimental set up to obtain a Gummel plot. The Keithley 236 source-measure unit is used to set the base-emitter bias to the various values and to measure the base current, whereas the Keithley 2400 source-measure unit is used to apply a bias to the collector and to measure the collector current.

- Connect the instruments as shown above
- Measure the Gummel plot (base and collector current and sweep the Base voltage; use
- $V_{\text{start}} = 0.1\text{V}$, $V_{\text{stop}} = 1.1\text{V}$ and $V_{\text{step}} = 0.05\text{V}$. Plot I_C and I_B vs V_{BE}).
- Estimate β , and calculate the common base gain, α .
- How is the gain (β) varying with the collector current? Why does it saturate?
- Discuss the problems of obtaining a high gain in the device. Is it, for instance, possible to combine a high gain and a high current level?
- If the transistor is used in common collector configuration instead, would you expect a higher or lower gain?

Simulation Part:

The simulation of semiconductor devices is based on the numerical solution to a set of coupled differential equations, namely the Poisson equation and the continuity equation. The solution to these two equations, and their proper boundary conditions, determine all intrinsic parameters, like the potential, the electric field and the carrier concentrations. The method of simulation is based on a finite element method, where the device geometry is divided into a fine mesh. Numerical iteration is then performed for each mesh point in order to determine the solution to the differential equations.

About the software:

We are using a commercial software, ATLAS by Silvaco, for the simulations. The program basically consists of a numerical solver, which finds a solution to the mathematical equations by iterations as described above. The program is controlled via a set of tools for graphical interaction. In this exercise, we will be using one module called **Deckbuild**, in which we use a special code to define the device geometry, to tell the computer to deduce solutions at various boundary conditions (biases or current levels) and to save the solutions in files.

The code which will be used in this exercise is attached to this document. The second module we will use is a graphical interface called **Tonyplot**, which displays the calculated values graphically. We can for instance obtain 2D plots of the device

geometry and of physical parameters, like the electrical field and the carrier concentration. In addition to the 2D plots we can also make cuts through the device geometry and study 1D cross-sections of the device. These cross-sections will be similar to the images in the textbook. Finally, Tonyplot may also be used to plot the calculated IV-characteristics.

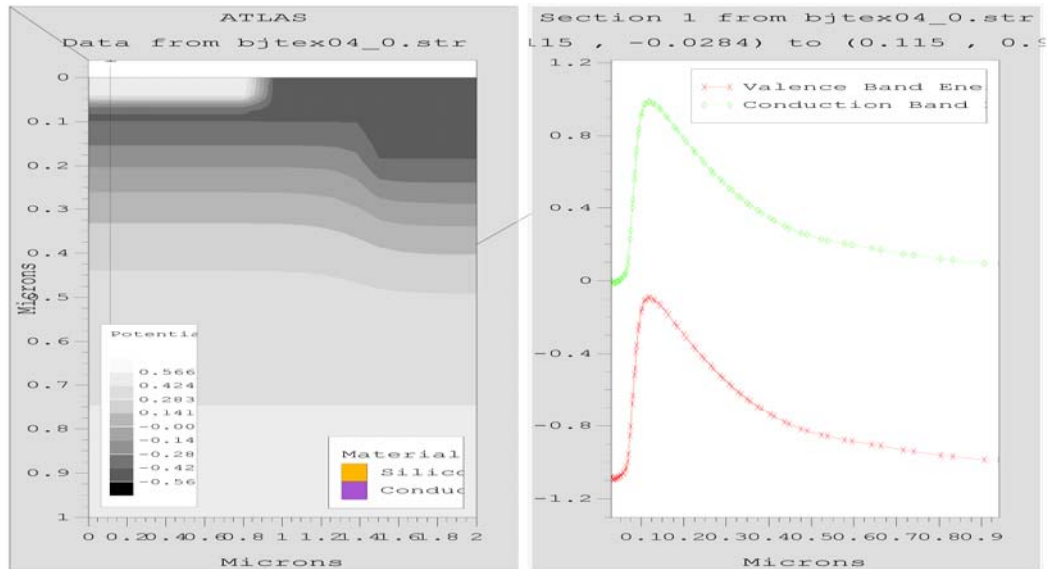


Figure 3. Example of output from the Silvaco modelling system on a npn bipolar transistor.

Start the simulation tool Silvaco Deckbuild a shortcut is located on the desktop. For the licence the computer must be connected to the licence server via LU Web-logon.

The device that we will study is an npn bipolar transistor. The structure layout is similar to the picture on p. 53 in the handout.

(A) Initiation and basic plots

Load `bjtex04.in` located in <c:\SilvacoWork\Bipolar Transistor>

The `.in` file is a set of instructions to tell the software what the device look like and what properties to extract. For now, just press start (green arrow) to see what happens.

After some simulation time you should have a number of plots on the screen. Play around with Tonyplot to see what information you can extract. Especially the Plot/display../contours command and the Tools/cutline tool are very useful.

(B) Reading the code and observing different bias conditions

Take a look at the .in file. The first part sets the geometry and doping levels of the devices. You could in principle change parameters as you like to tailor your device. The second part solves for carrier concentrations, band structure etc. and creates output files. There is no need for you to understand each command but the overall structure of the program should be clear.

Follow the code downwards. As the program proceeds with calculating the Gummel plot and the IV-curve, it makes several outputs of the cross-section under different bias conditions. See if you can locate these in the program code. You can find the output files in the Silvaco BJT folder with names bjtex04_?.str where the ? is a number. Study these plots and read the bias conditions from the code.

What can you observe? What can you say about the injection? Can any high injection be observed etc.?

Experimental Part Two:

This part of the laboratory exercise aims at giving a short introduction to how to actually use a BJT in an electrical circuit. Your job is to amplify the small current from a photoresistor so that it can drive a computer-fan. The idea is that the light in the room should control the speed of the fan. You should use the transistor in common-emitter mode.

Start by examining the parts:

- Measure the resistance of the photoresistor in darkness and bright light. Let's assume that it can handle a current of approx 5 mA, what is the maximum voltage it can be connected to?
- How much current does the fan draw?
- What is the maximum current and voltage the transistor BC548B, can take? (Datasheet will be available.) Maximum power dissipation? What is the maximum inside (junction) temperature of the transistor?

Make a sketch of how you would like to realize the circuit and show it to the supervisor.

Do some calculations:

- What is a suitable base current in order to make the fan go at full speed?
- What is the minimum total resistance you need to connect at the base in order to not go above the previously calculated base current? Assume that $V_{BE} = 0.6$ V.

Remember – there is nothing limiting the current into the base of a BJT. It will blow up immediately if you connect it directly to the supply!

Now connect the components on the prototype board and connect the supply. Check for smoke and smell of hot components. Check if the circuit is working as supposed.

Do some measurements on the circuit:

- What is the voltage drop over the fan at high and low illumination?
- What is the base-emitter voltage at high illumination?

For the lab report:

- a) Experimental part one: plot the measured data of the transistor (IV characteristics and Gummel plot) and answer the questions in the text.
- b) Simulation part: show some results of the simulation and explain what you see. Answer the questions in the text.
- c) Experimental part two: show a sketch of the circuit. Answer the questions in the text.