UNIVERSITY OF CALIFORNIA AT BERKELEY
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE105 Lab Experiments

Experiment 2: Diodes, Bipolar Junction Transistors and MOS Characterization

Contents

1 Introduction

The diodes, bipolar junction transistors and MOS are basic circuit elements in the integrated circuits. Having a good grasp of the basic characteristics is the key to understand their operation and applications. In this lab, we will explore the characteristics of those devices.

2 Materials

The items listed in Table (1) will be needed. *Note: Be sure to answer the questions on the report as you proceed through this lab. The report questions are labeled according to the section in the experiment.*

Table 1: Lab 2 Components

Component	Quantity
Diode 1N4148	1
NPN BJT 2N4401	1
NMOSFET BS170N	1

3 Lab

3.1 Diode Parameter Characteristic

3.1.1 I-V Measurements

Connect the silicon diode to two SMUs of the parameter analyzer. Sweep the voltage from $-1V$ to $1V$ to generate the I-V curve. Based on the diode equation $I_D = I_s(e^{V_D/nV_T} - 1)$, extrapolate the saturation current I_s, ideality factor n from the I-V data. At high current injection, the current is limited by the series resistance R_s. Identify the series resistance limited region in the I-V curve and measure this series resistance.

3.1.2 Diode Capacitance Measurements

Plug in the diode to the parameter analyzer (Agilent 4155C). Reverse bias the diode with voltage from $1V$ to $5V$ with $1V$ step and measure the capacitance the reverse-biased pn junction. *Note: The capacitance measurement will be performed on a specific parameter analyzer. Please consult GSI for the measurement details.*

Fit the capacitance with the step junction model and calculate the zero bias junction capacitance $C_{j0}A$.

3.2 Bipolar Junction Transistor Characterization

The bipolar junction transistor BJT was invented in 1948 by William Shockley at Bell Labs, and became the first mass-produced transistor. In this lab, we will explore the BJTs four regions of operation and also determine its characteristic values. The transistor used in this lab is the 2N4401, an NPN device. It is strongly recommended that you read and understand the section on BJT physics before beginning this experiment.

3.2.1 I-V measurements

The schematic of 2N4401 NPN BJT is shown in Figure (1). Connect the transistor to the parameter analyzer with the measurement setup in Figure (2). Set the base voltage bias from $1\mu A$ to $10\mu A$, with $1\mu A$ step, measure the corresponding i_c v_{CE} curves. What is the forward current gain β_F? How does it depend on the collector current i_C? Based on the measured I-V curves, determine the early voltage V_A of the transistor from the average of the ten measurements.

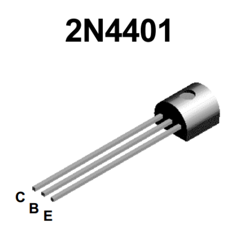

Figure 1: 2N4401 Schematic

3.2.2 Base Collector Junction Capacitance Measurements

Use the parameter analyzer (Agilent 4155C), measure the base collector junction capacitance C_{BC} under different reversed bias voltage, from 1V to 5V with 1V step. *Note: The capacitance measurement will be performed on a specific parameter analyzer. Please consult GSI for the measurement details.*

Fit the capacitance with the step junction model and calculate the zero bias junction capacitance $C_{j0}A$.

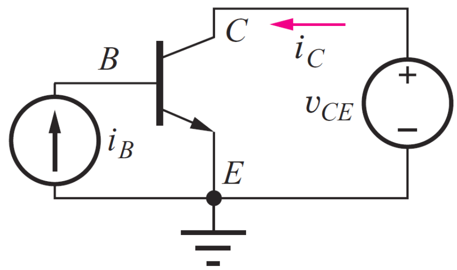

Figure 2: NPN BJT Measurement Configuration

3.3 MOSFET Characterization

The MOS transistor is another circuit element typically used in integrated circuits. Although they have similar functions to BJTs and can be placed into several analogous topology (e.g. the cascode, common drain, common gate, common source), MOS transistors are completely different in terms of their characteristics and physical mechanisms underlying their operation. The NMOSFET BS170 will be characterized in this lab.

3.3.1 I-V Measurements

For BS170 NMOS transistor (Figure (3)), the configuration for the I-V measurement is shown in Figure (4). Step V_G from $2.0V$ to $2.3V$ in $0.05V$ increments and sweep V_D from $0V$ to $3V$ to obtain the MOSFET I-V characterization curves. On the I-V family curves, label the cutoff, triode and saturation regions. Attach this plot in your lab report. What is the expression that describes the boundary between the saturation and triode region?

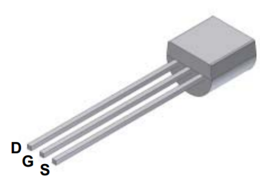

Figure 3: BS170 Schematic

Given a bias of $V_{GS} = 2.1V$ and $V_{DS} = 1.5V$, extract the transconductance G_m. What region of operation is this? Given a bias of $V_{GS} = 2.1V$ and $V_{DS} = 0.06V$, extract the transconductance G_m. What region of operation is this?

Using the I-V characteristic plot, extract the channel length modulation factor λ from the slop of the plot. Note that this will vary somewhat depending on which V_{GS} you use.

Now, connect the NMOS as shown in Figure (5). Sweep V_G from 0V to 2.5V and measure the current V_D. Plot $I_D^{\frac{1}{2}} vs. V_G$. Note: you may have to limit the range of the voltage to avoid taking the square root of the negative currents. $(\frac{1}{2K_n})^{\frac{1}{2}}$ is the slope of the linear portion of the curve, find K_n. The threshold voltage V_{TH} can be found by measuring where the linear portion of the $I_D^{\frac{1}{2}} vs. V_G$ curve would intersect the V_G axis if it was extended. Find V_{TH}.

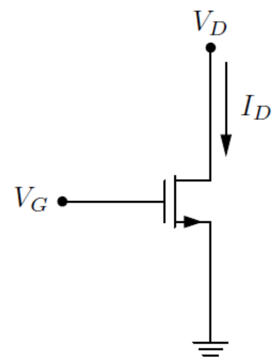

Figure 4: NMOS I-V Measurement Configuration

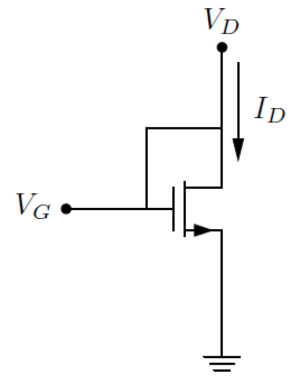

Figure 5: NMOS Diode Connected Configuration

3.3.2 C-V Measurements

Connect the source and gate to the parameter analyzer while leaving the drain open. Measure the capacitance as a function of V_{gs} from $2.0V$ to $2.3V$ with $0.1V$ step. Connect the drain and gate to the parameter analyzer, leaving the source open. Measure capacitance C_{gd} with zero bias.