THE SIMULATION OF ELECTRICAL I-V CHARACTERISTICS OF THE BIPOLAR JUNCTION TRANSISTOR (BJT) SEMICONDUCTOR BY USING PISCES IIB.9009

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I hereby declare that this dissertation contains my original research work. Sources of finding reviewed here in have been duly acknowledged.

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ABSTRACT

PISCES-IIB device simulator is used to study the characteristics silicon (Si) base bipolar junction transistor device. The difference of concentration, depth and width parameters of BJT will affect the electrical *I-V* characteristics. A bipolar junction transistor (BJT) is a type of transistor. It is a three-terminal device constructed of doped semiconductor material and may be used in amplifying or switching applications. Si is used in this study because Si is the existence of silicon dioxide, one of the best insulators. Silicon dioxide can easily be incorporated onto silicon circuits. POSTMINI is used to read the mesh files from the simulation programs PISCES-IIB and allows the user to examine or plot quantities stored in the mesh file. The most important part in BJT is output characteristics common emitter current-voltage curve. For common emitter arrangement, they have three regions, such as saturation region, active region and cut-off region. The collector curves in this study are not flat but increase slightly with collector voltage. For the given transistor model, the curves would be flat because the collector current-source's current output is not affected by the voltage across it. But actual transistors are better modeled by including a resistance (r_o) from collector to emitter. It typically has a large value and can usually be disregarded. The collector curves slope downward toward the left and intersect the V_{ce} axis at V_A. Ideal I_c should have been flat because minority slope remains intact, A second feature of the collector curves is that they voltage saturate below 0.1 V.

ABSTRAK

Pensimulasi peranti PISCES-IIB digunakan untul mengkaji ciri-ciri silikon transistor dwikutub. Perbazaaz ketumpatan, kelebaran dan ketebalan lapisan Bipolar Junction Transistor (BJT) akan memberi kesan terhadap mengkaji ciri-ciri elektrik *IV*. Transistor dwikutub ialah sejenis transistor. Ia merupakan cantuman tiga bahagian semikonduktor dan boleh digunakan sebagai aplikasi amplifier dan suis. Si digunakan dalam kajian kerana Si kewujudan silikon dioksida. Silikon dioksida adalah salah satu penebat yang sangat baik. Silikon dioksida senang mengabungkan dalam litar silikon. POSTMINI adalah digunakan untuk membaca fail mesh daripada program simulasi PISCES-IIB dan memberikan pengguna memeriksa kuantiti plot yang disimpan dalan fail mesh. Bahagian yang paling penting dalam BJT ialah cirri keluaran tatarajah pemancar sepunya. Bagi susunan pemancar sepunya, ia terdapat tiga kawasan, iaitu kawasan ketepuan, kawasan operasi dan kawasan pemotongan. Tatarajah pemungut dalam kajian tidaj datar tetapi pertambahan sedikit dengan voltan pemungut. Ciri keluaran tatarajah contoh transistor yang diberi adalah datar kerana arus pemungut tidak terjejas oleh voltan pemancar sepunya. Akan tetapi transistor sebenar adalah contoh yang baik bagi termasuk rintangan (r_o) daripada pemungut kepada pemancar. Ia biasanya menpunyai nilai yang besar dan biasanys boleh tidak mempedulikan. Kecerunan tatarajah pemungut dipanjangkan ke kiri dan bersilang paksi V_{ce} di V_A. Ideal I_c patut mempunyai datar dalan kawasan operasi kerana kecerunan minority tidak terjejas. Sebab kedua ialah voltan tepu tatarajah pemungut di bawah 0.1 V.

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E_C	minimum conduction band energy
E_{Fn}	Fermi level on the n-side of a pn junction
E_{Fp}	Fermi level on the p-side of a pn junction
E_i	intrinsic Fermi level
E_V	maximum valence band energy
e	exponent
h_{fe}	common emitter current gain
I_B	base current
I_C	collector current
I_{Cn}	DC collector current due to holes
I_{Cp}	DC collector current due to electrons
I_E	emitter current
I_{En}	DC emitter current due to holes
I_{Ep}	DC emitter current due to electrons
I_{rec}	recombine current
k	boltzmann constant
L_n	diffusion length of electrons
L_p	diffusion length of holes
n_E	doping concentration in the BJT emitter
n_i	intrinsic carrier concentration
n_{no}	electron concentration in n-type semiconductor (majority carriers) in equilibrium
n_p	electron concentration in p-type semiconductor (minority carriers)
n_{po}	electron concentration in p-type semiconductor (minority carriers) in equilibrium
P_n	hole concentration in n-type semiconductor (minority carriers)
P_{no}	hole concentration in n-type semiconductor (minority carriers) in equilibrium

P_{po}	hole concentration in p-type semiconductor (majority carriers) in equilibrium
q	magnitude of the electronic charge
T	temperature in unit Kelvin
V_A	early voltage
V_{BB}	DC supply voltage to BJT
V_{bi}	"built-in" junction voltage
V_{CE}	common emitter current
$V_{CE(sat)}$	saturation collector emitter current
V_{ceo}	collector-to-emitter breakdown voltage when I_E=0
V_{EB}	emitter base current
V_F	forward bias of rectifier
V_R	reverse bias of rectifier
W	device width
W_B	total width of the base in a BJT
X_n	n-side width of the pn junction depletion region
X_p	p-side width of the pn junction depletion region
α_0	common base current gain
α_T	base transport factor
β	emitter base current gain
γ	emitter efficiency

Al	Aluminium
BJT	bipolar junction transistor
CMOS	complementary metal-oxide-semiconductor
DC	direct current
GaAs	gallium arsenide
i.e.	that is
I-V	current-voltage
MOS	Metal Oxide Semiconductor
Si	silicon
TCAD	technology computer aided design

CHAPTER 1

INTRODUCTION

1.1 Introduction

A bipolar junction transistor (BJT) is a type of transistor. It is a three-terminal device constructed of doped semiconductor material and may be used in amplifying or switching applications. Since the action of both electrons and holes is important in this device, it is called a bipolar transistor (Shur, 1996; Streetman, 1995).

PISCES-IIB device simulator is used to study the characteristics os silicon (Si) base device base BJT device. A common-emitter output characteristics current-voltage (*I-V*) graph show that the relationship between the DC current through an electronic device and the DC voltage across its terminals.

This paper focuses on the simulation of electrical *I-V* characteristics of *npn* bipolar junction transistor (BJT). The different of base current, I_b, concentration and device size parameters will effect the electrical *I-V* characteristics of the BJT.

1.1.1 Silicon Technology

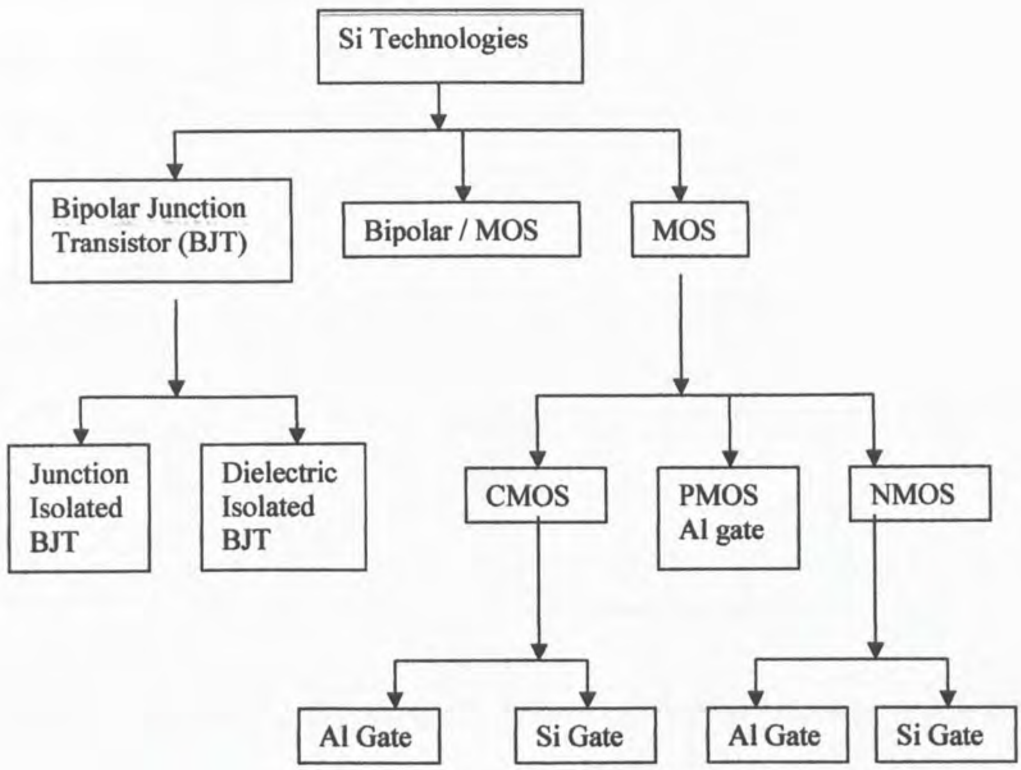

Figure 1.1 Categories of Silicon Technology

1.1.2 Structure and Principle of Operation

A bipolar junction transistor (BJT) is comprised of two back-to-back p-n junction (Kwyro *et al.*, 1993). This forms a sort of a sandwich where one kind of semiconductor is placed in between two others. There are two kinds of bipolar junction transistor, such as the *npn* and *pnp* varieties (Dorf, 2006). The three layers of the sandwich are conventionally called the collector, base, and emitter (Rutkowski & Oleksy, 1992).

The term bipolar means that the BJT's operation depends on the movement of two different carriers, such as electrons and holes. In *npn* BJT's, the electron is the majority carrier and the hole is the minority carrier.

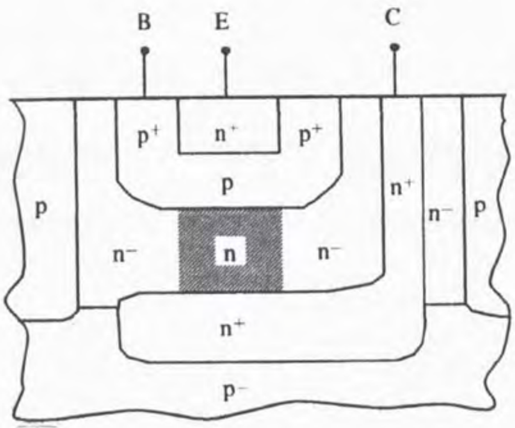

Figure 1.2 Schematic cross section of a modern *npn* bipolar transistor. (**Yuan**, 1998)

1.2 Purpose

To study the electrical current-voltage characteristics of the *npn* bipolar junction transistor (BJT) by using PISCES-IIB.

1.3 Project Objectives

- Design a bipolar junction transistor (BJT) device simulation by using PISCES-IIB.
- To study the electrical *I-V* characteristics of the BJT by increase the base current, I_b.

- To study the electrical *I-V* characteristics of the BJT in different structure, such as width, depth and concentration parameters.

1.4 Project Scope

The scope of this research paper is analyzing the electrical current voltage characteristics of bipolar junction transistor by using PISCES-IIB. The parameter to be study are base current, depth, width, and concentration at room temperature, T=300K.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Semiconductor experiments at Bell Telephone Laboratories led to new theoretical concepts and William Shockley proposed an idea for a semiconductor amplifier that would critically test the theory (Smith, 1987). The actual device had far less amplification than predicted and John Bardeen suggested a revision of the theory. In December 1947, Bardeen and Walter Brattain discovered a new phenomenon and created a novel device (Smith, 1987). The next year Shockley invented the junction transistor. Nowadays, the use of the BJT has declined in favour of CMOS technology in the design of digital integrated circuits.

2.1.1 NPN Transistor

NPN is one of the two types of bipolar transistors, in which the letters "N" and "P" refer to the majority charge carriers inside the different regions of the transistor. Most bipolar transistors used today are NPN, because electron mobility is higher than hole mobility in semiconductors, allowing greater currents and faster operation.

NPN transistors consist of a layer of P-doped semiconductor (the "base") between two N-doped layers. A small current entering the base in common-emitter mode is amplified in the collector output. In other terms, an NPN transistor is "on" when its base is pulled high relative to the emitter.

2.2 Extrinsic Semiconductor

The impurity atoms frequently employed to dope pure silicon or germanium are the elements of group III and group V of the periodic table (Puri & Babbar, 1996). These group III or group V elements (materials) added to the pure semiconductor (mostly the silicon) are called impurities (Pokharel & Karki, 2007). The resulting semiconductor was known as extrinsic semiconductor (Pokharel & Karki, 2007). Obtain different type of extrinsic semiconductors by adding different types of impurities to the pure semiconductor. There are four valence electrons in silicon. By adding pentavalent impurities, such as arsenic, which had a valence of more than four will participate to form covalent bond with neighbouring silicon atoms (Kasap, 2006), whereas the fifth electron cannot participate in bonding since all the bonds are saturated. This extra electron can be contributed to the conduction band. The impurity atom was donating an extra electron to the conduction band of the semiconductor. Such semiconductors are called n-type. Similarly, we can obtained a p-type semiconductor by adding trivalent impurities like boron, aluminum, gallium, etc (Pokharel & Karki, 2007).

2.2.1 n-Type and p-Type Silicon

Intrinsic silicon at room temperature had an extremely low free-carrier concentration. Therefore, its resistivity was very high (Yuan & Ning, 1998). Intrinsic silicon hardly exists at room temperature, since it would require materials with an unobtainable high purity. Most impurities in silicon introduce additional energy levels in the forbidden gap and can be easily ionized to add either electrons to the conduction band or holes to the valence band, depending on where the impurity level is (Yuan & Ning, 1998). The electrical conductivity of silicon was then dominated by the type and concentration of the impurity atoms, or dopants and the silicon was called extrinsic (Yuan & Ning, 1998).

2.3 BJT Configurations

In a typical transistor circuit, the transistor was connected to an input circuit and an output circuit or load (Figure 2.1). (Additional components are often necessary to bias the BJT.) One of the terminals of the BJT (emitter, base or collector) was connected to both the input and the output circuit. The configuration of a BJT in a circuit was named after this common terminal. Thus, they are called common-emitter, common-base and common-collector configurations.

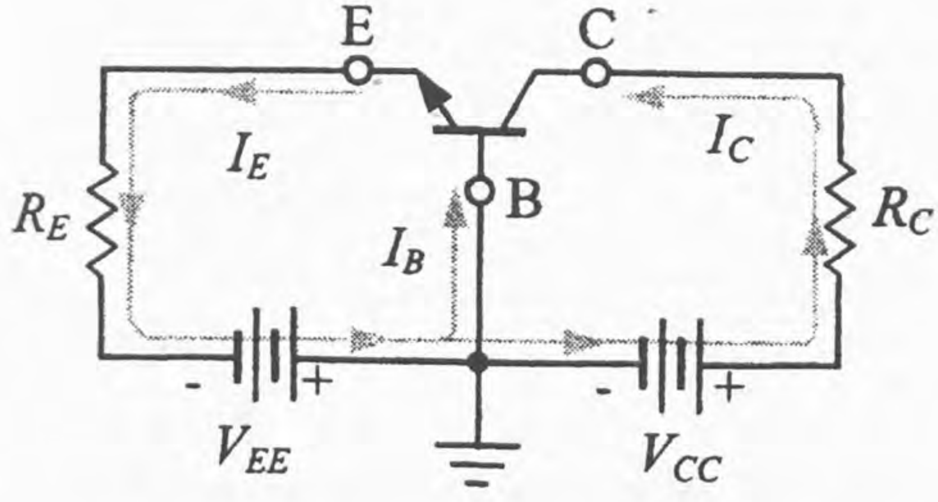

Figure 2.1 Direction of conventional current flow in a biased *npn* transistor (Aminian & Kazimierczuk, 2004).

2.3.1 Common-Collector

In an common-collector circuit with the collector connected to +V and a load connected between the emitter and ground, the voltage applied to the base minus the base emitter forward voltage drop (~0.6 V) will appear across the load (i.e., 5 V base = 4.4 V emitter). The only caveat was that the voltage source at the base must be able to supply about 5% of the load current without appreciable voltage drop. This was a non-inverting voltage follower circuit.

2.3.2 Common Emitter

In the common-collector, the emitter will be the common reference or the ground to both the base and the collector terminals (Aminian & Kazimierczuk, 2004) and +V, a voltage connected to the base which exceeds the base emitter forward voltage (0.6V) will rapidly turn on the transistor in proportion to the voltage rise as the base emitter current rapidly increases for a small increase in base voltage. The base voltage source must be able to supply about 5% of the load current into the base emitter diode (i.e., short circuit) for the circuit to develop a large voltage across the load. This was an inverting voltage amplifier circuit.

2.3.3 Common Base

The common-base stage was used primarily in high-frequency applications due to the fast that three was no direct capacitative feedback from output (collector) to input (emitter) as a result of the common or grounded base terminal (Whitaker, 2000). The base grounded (or at a reference voltage) and the load connected between the collector and +V, a control voltage connected to the emitter which was more negative than the base emitter forward voltage (~0.6V) causes the transistor to rapidly turn on. The control voltage source must be able to supply about 105% of the load current to develop the full voltage across the load. This was a non-inverting voltage amplifier circuit.

2.4 Operating modes of the BJT

The operating mode of a BJT depends on how its junctions are biased (Table 2.1). The active region of the BJT was defined by a forward-biased base-emitter junction and a reverse-biased collector base junction. This region was of importance in linear or amplifying application. Two other region of importance in switching application was the cutoff and saturation region (Comer, 2003). Most BJTs in digital circuits (logic gates, memory) operate in these two modes. The reverse active mode was rarely used and was listed here for reference.

Table 2.1 Operating modes of the BJT (Ng, 2002).

Operating mode	Emitter-Base junction	Collector-Base junction
Active	forward	reverse
Cut-off	reverse	reverse
Saturation	forward	forward
Inverse	reverse	forward

2.4.1 Active

A transistor was said to be operating in the active region when the base-emitter junction was forward biased and the collector-base junction was reverse biased (Paynter, 2003). Most bipolar transistors are designed to afford the greatest common-emitter current gain, β_f in forward-active mode. If this was the case, the collector-emitter current was approximately proportional to the base current, but many times larger, for small base current variations.

2.4.2 Cut-off

When a transistor was in cutoff, both junction are reverse biased and the current through all three terminals was nearly zero (Paynter, 2003), which corresponds to a logical "off", or an open switch.

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