The Early Voltage and Current Gain of InGaAs Double Heterojunction Bipolar Transistor

A thesis submitted to the Department of Electrical, Electronics and Communication Engineering, Military Institute of Science and Technology, in partial fulfillment of the requirements for the degree of BACHELOR OF SCIENCE IN ELECTRICAL, ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

MAJOR MUHAMMAD SANBIR HASAN MOJUMDER

JOAIRIA CHOWDHURY

Supervised by

YEASIR ARAFAT

Assistant Professor

Department of Electrical and Electronic Engineering (EEE)

Bangladesh University of Engineering and Technology (BUET)

Dhaka-1000, Bangladesh

December, 2013

The thesis titled **"The Early Voltage and Current Gain Of InGaAs Double Heterojunction Bipolar Transistor"** submitted by Major Muhammad Sanbir Hasan, Student No: 200816002, Joairia Chowdhury, Student No: 201016029, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of BACHELOR OF SCIENCE IN ELECTRICAL, ELECTRONICs AND COMMUNICATION ENGINEERING on December, 2013.

APPROVAL OF THE SUPERVISOR

Yeasir Arafat
Assistant Professor
Department of Electrical and Electronic Engineering (EEE)
BUET, Dhaka-1000, Bangladesh.

DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signatures of candidates

______________	______________
Major Muhammad Sanbir Hasan Mojumder	Joairia Chowdhury
Student No:200816002	Student No:201016029

DEDICATION

To Our Parents

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABBREVIATION	ELABORATION
CB	Conduction Band
BC	Base-collector
DHBT	Double Heterojunction Bipolar Transistor
e.g.	For example
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
IGBT	Insulated Gate Bipolar Transistor
IC	Integrated Circuit
JFET	Junction Field Effect Transistor
op-amps	Operational amplifier
MBE	Molecular Beam Epitaxy
MOS	Metal Oxide Semiconductor
EB	Emitter-Base
ECL	Emitter Coupled Logic
HFET	Heterojunction Field Effect Transistor
HEMT	High Electron Mobility Transistor
HBT	Heterojunction Bipolar Transistor
GHz	Giga Hertz
FET	Field Effect Transistor
etc	et cetera

ABBREVIATION	**ELABORATION**
SHBT	Single Heterojunction Bipolar Transistor
VB	Valance Band
VCO	Voltage Controlled Oscillators
DOS.	Density of States
CVD	Chemical Vapour Deposition
vs	versus

LIST OF SYMBOLS

SYMBOL	**DESCRIPTION**
I_B	Base current
I_C	Collector current
I_E	Emitter current
β	Current gain
f	Frequency
f_r	Unity gain cut off frequency
f_{max}	Maximum oscillation frequency
GaAs	Gallium Arsenide
In	Indium
InGaAs	Indium Gallium Arsenide
J_p	Current density for holes
J_n	Current density for electron
J_{nl}	Electron current density for low injection region
J_c	Collector current density
y_{av}	Average In mole fraction
a	0.7743
b	1+3yav
c	0.342/[0.342+ y_{av} (1- y_{av})]
x	Distance along base
y	In mole fraction
y_c	In fraction at the collector end of the base
y_E	Indium fraction at emitter end of the base
y_D	In dose
γ_E	Emitter charge storage delay time
γ_C	Total delay time from emitter collector
v_s	Saturation velocity in GaAs
v_{sA}	Saturation velocity in InGaAs alloy

SYMBOL	**DESCRIPTION**
$D_n(x)$	Diffusion co-efficient of electron
D_{max}	Maximum value of diffusion co-efficient
D_n	Diffusion co-efficient of electron EB junction
D_{no}	103.6 cm^2/s
$D_p(x)$	Diffusion co-efficient of hole
$D_{nInGaAs}$	Diffusion co-efficient of electron at InGaAs alloy
$n_{ie}(x)$	Effective intrinsic carrier concentration
$n_{ieGaAs}(x)$	Effective intrinsic carrier concentration for GaAs
$n_{ieInGaAs}$	Effective intrinsic carrier concentration for InGaAs
$n(x)$	Injected minority carrier for all level of injection
$n_{l(}x)$	Injected minority carrier for low injection
$n(0)$	Injected electron concentration at EB junction for all injection
$N_B(x)$	Base doping concentration
$N_B(0)$	Peak base doping concentration
N_r	Reference concentration
$p(x)$	Hole concentration in the base
$\mu_{n(}x)$	Electron mobility
$\mu_{p(}x)$	Hole mobility
$\mu_{nInGaAs(}x)$	Electron mobility inside InGaAs alloy
$E(x)$	Electric field
E_c	Critical electric field
$E_{lInGaAs}$	Electric field inside InGaAs alloy under low injection
E_{InGaAs}	Electric field inside InGaAs alloy under all level of injection
W_B	Basw width
W_{BC}	Width for base collector space charge layer
E_g	Energy gap between conduction and valance band
$D_{EgIn}(x)$	Bandgap narrowing due to the pressure of Ge
$D_{EgHD}(x)$	Bandgap narrowing due to heavy doping
D_{ECG}	Difference between conduction band energies

SYMBOL	**DESCRIPTION**
γ	1~2
γ_1	0.42
γ_2	$V_{gHD}/V_T = 0.69$
γ_3	V_{gGe}/V_T
γ_r	Ratio of effective DOS in InGaAs to the effective DOS in GaAs
V_{gIn}	750mV
V_{gHD}	18mV
V_T	Thermal voltage
V_A	Early voltage
η	Slope of base doping
η_{In}	Gradient of In mole fraction
C_{EB}	Emitter base depletion capacitance
C_{BC}	Base collector depletion capacitance
R_B	Intrinsic base resistance
R_C	Collector resistance
r_o	Stator resistance
m	Ratio of slope of base doping to base width
m_{IN}	Ratio of gradient in In mole fraction to base width
m_1	$M\gamma_1$
m_2	$m\ \gamma_2$
m_3	$m_{IN}\ \gamma_3$
m_{32}	m_3-m_2
m_{023}	$m+m_{32}$
m_{012}	$n(1+\gamma_1-\gamma_2)/W_B$
m_{0123}	$m_{012}+m_3$
g_m	Trans conductance
K	Boltzmann constant
T	Absolute temperature
InAlAs	Indium Aluminum Arsenide

SYMBOL	DESCRIPTION
InP	Indium Phosphide
SiC	Silicon Carbide
q	Electron charge

ACKNOWLEDGEMENTS

All thanks belongs to Almighty Allah who has created us and helped us to do all deeds on earth, also who has united many kind hearts to accomplish any great job for mankind.

The author like to express their sincere gratitude to the supervisor, Yeasir Arafat, Assistant Professor of EEE Department, BUET for his tremendous efforts by both encouraging and guiding from the very beginning of this thesis to final draft. The author is highly obliged to their supervisor for spending his lots of valuable times, also for close monitoring every step of this work. The author owes him for continuous supervision and valuable advices, without which it might not be possible at all. Besides that he also helped the author with his wholehearted assistance during the period of understanding previous research related to this work and makes a deep insight in each section of this research. The author is indebted to their supervisor for the whole life for his generosity and kind sympathy.

Finally, we sincerely thank to our parents, family, and friends, who provide the advice and financial support. The product of this research paper would not be possible without all of them.

ABSTRACT

Early effect is the variation in the width of the base in a bipolar junction transistor (BJT) due to a variation in the applied base-to-collector voltage, named after its discoverer James M. Early. An increase in the collector-base voltage causes a greater reverse bias across the collector-base junction which increases the collector-base depletion region width, and decreasing the channel width of the base, which is defined as "Early Effect". The early effect has been studied extensively in conventional bipolar junction transistors (BJTs). In the present work closed form analytical model were derived for Early Voltage (V_A) and common emitter current gain (β) for uniform and exponential base doping profiles with arbitrary Indium (In) profiles heterojunction bipolar transistor (HBT). Field depended mobility ($D_{nInGaAs}$), band gap narrowing (BGN) (due to both heavy doping and presence of Indium content in the base) and electron velocity saturation effects (v_s) were considered in this model. The effects of base doping profiles and Indium profiles on V_A and β are observed in this work. Here it is observed that if Indium mole fraction at emitter and (y_E) is 0.01 and it increases at collector and (y_C) from.0.01 to 0.5 it increases V_A exponentially. It can be found from this analysis that y_C increases due to BGN effect, effective intrinsic carrier concentration ($n_{ieInGaAs}$) increases towards base-collector junction which minimizes "Early Effect" and increases V_A. For a particular $y_{C\ and}\ y_E$, V_A found highest for uniform base doping profiles. The results shows that VA is proportional to base doping concentration. Also keeping y_C at 0.5 and if y_E vary from 0.01 to 0.5 it reduces V_A. It was also observed that by keeping y_E at 0.01 if y_C can be increased from 0.01 to 0.5 it reduces collector current density (J_{CO}). It can also be observed that vS has significant impact on both J_{CO} and $D_{nInGaAs}$ for uniform and exponential base doping profiles. The results obtained by using this analytical model compared with the results available in the previous literature and found in good agreement.