SIMULATION OF THE TUNNEL JUNCTION IN TOP CELL OF THE InGaP/GaAs/Ge MULTIJUNCTION SOLAR CELLS USING ATLAS SOFTWARE

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DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been fully acknowledge.

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ABSTRACT

Silvaco work with Atlas was selected for modeling of the advanced solar cells because of the suite of tools and reusable models. Specific models of tunnel junction in the InGaP/GaAs/Ge of multijunction solar cells are prepared and simulated. The exotic materials used in such designs were identified and all their major electrical and optical parameters were researched or derived. Besides that, software code was developed to adjust and calibrate Atlas for the task of simulating solar cells. The scope of this research is focus on the tunnel junction. The major stages of the process are explained and the simulation results are compared to experimental data. Finally the example results are shown throughout the whole process. Through the research, the tunnel junction is simulated with the absent of Power files codes in the source code. The graph have the range of the voltage is from 0 V to 1.4 V and the current range from 0 A to 60 A.

MENSIMULASI SEL TERATAS SIMPANG TEMBUSAN PADA SEL SURIA SIMPANG BERGANDA InGaP/GaAs/Ge DENGAN MENGGUNAKAN PROGRAM ATLAS

ABSTRAK

Silvaco dengan perisian Atlas digunakan untuk memodelkan sel suria lanjutan kerana ia merupakan peralatan yang lebih sesuai dan model yang boleh digunakan semula. Model spesifik yang digunakan ialah simpang sel suria berganda InGaP/GaAs/Ge disediakan dan disimulasikan. Rekabentuk bahan asing dalam kajian ini dapat dikenalpasti serta elektrik majoriti dan parameter optik dapat dikaji dan deduksikan. Selain itu, kod program dapat direka untuk mengubah dan menandakan skala pengukuran Atlas bagi tujuan simulasi sel solar. Skop kajian adalah fokus pada simpang tembusan. Kaedah utama proses diterangkan dan keputusan simulasi dibandingkan dengan data eksperimen. Akhir sekali , keputusan ditunjukkan melalui keseluruhan proses. Beberapa ciri-ciri elektrik dikenalpasti. Simpang tunnel telah disimulasikan tanpa menggunakan kod fail kuasa. Graf yang diperolehi mempunyai julat voltan dari 0 V sehingga 1.4 V dan julat arus adalah dari 0 A sehingga 60 A.

CONTENTS

	Page
FRONT PAGE	i
DECLARATION	ii
CERTIFICATION	iii
ACKNOWLEDGEMENTS	iv
ABSTRACT	v
ABSTRAK	vi
TABLES OF CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF SYMBOLS AND ABBREVIATIONS	xiv
LIST OF APPENDIX ES	xvii

CHAPTER 1 INTRODUCTION

1.1	General Statement	1
1.2	Objective	3
1.3	Scope	3
1.4	Hypothesis	4

CHAPTER 2 LITERATURE REVIEW

2.1	Introduction to semiconductor	5
	2.1.1 Crystal Structure	8
	2.1.2 Carriers	9
	2.1.3 Fermi Level	15
	2.1.4 Mobility	18
	2.1.5 Recombination	20
	2.1.6 Tunneling	22
2.2	The P-N Junction	24
	I Forward Bias	26
	II Reverse Bias	27
	III Breakdown	27

	IV	Characteristics of Light	28
	V	Semiconductor-Metal Junction	30
	2.2.1	Ohmic Contact	31
	2.2.2	Tunnel Junction	33
	2.2.3	Thickness	34
	2.2.4	Voltage	37
	2.2.5	Direct and Indirect Tunnel	38
	2.2.6	Heterojunction	39
2.3	Solar Cells		40
	2.3.1	Optical Properties	41
	2.3.2	Multijunction Solar Cells	42

CHAPTER 3 METHODOLOGY

3.1	Introduction		45
3.2	Materials and Equipments		45
3.3	Working with ATLAS		45
	1.	Mesh	46
	2.	Region	47
	3.	Electrodes	47
	4.	Doping	48
	5.	Material Properties	48
	6.	Models	48
	7.	Light	48
	8.	Simulation Results	49

CHAPTER 4 RESULTS AND DICUSSIONS

4.1	Introduction		50
4.2	The Mechanically Stacked Tandem Cell		52
	4.2.1	Mesh, Region, Electrode and Doping	53
	4.2.2	Material Properties, Models and Lights	61
4.3	Tunnel Junction		64
	4.3.1	Mesh, Region, Electrode and Doping	65
	4.3.2	Material Properties, Models and Lights	69

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion 76

5.2 Recommendations 77

REFERENCES 78

APPENDIXES 80

LIST OF TABLES

Table	Description	Page
2.1	Gallium arsenide compared with silicon at 300K	20
4.1	Recombination Models	62
4.2	Function of power files	71

LIST OF FIGURES

Figure Description Page

Figure	Description	Page
1.1	Tunnel junction on InGap/GaAs/Ge	4
2.1	Electrical conductivity in a conductor, semiconductor, and insulator	6
2.2	Transition of an electron form one shell to another	7
2.3	Three types of cubic unit cells	9
2.4	The diamond like structure of a crystal of semiconductor. Each atom has four nearest neighbours to which it is bound by covalent bonds.	10
2.5	A diagram of a crystal lattice: (a) at low temperature when all the electrons are held in covalent bonds; (b) at a higher temperature when some electrons have escaped, leaving holes behind.	13
2.6	Doping a silicon crystal	14
2.7	Fermi-Dirac distributions of electron energies around the Fermi level: (a) at two different temperatures; (b) superimposed at a particular temperature on band structure of pure silicon; (c) superimposed on *n*-type silicon with its raised Fermi level giving increased density in the conduction band and decreased density in the valence band.	16
2.8	(a) Radiative recombination in a direct band-gap semiconductor	21
	(b) Indirect Recombination	22
2.9	Band diagram of two close- by semiconductor	23
	(a) Tunneling as probability	23
	(b) Tunneling as wave function	23
2.10	A *pn* junctions	24
2.11	Drift and diffusion currents in a *pn* junction	26
2.12	(a)Forward Bias	26
	(b)Reverse Bias	27
2.13	The *I-V* characteristics if the semiconductor diode	27
2.14	Dark (blue) and illuminated (red) characteristics curve of solar cell	29
2.15	(a) Band structure semiconductor and metal (closer distance) when they are still separated, $e\phi_m$ is the metal work function and e_χ the semiconductor electron affinity.	31

(b) Band structure semiconductor and metal (contact between) when they are still separated. 31

2.16 Band diagrams of (a) Schottky and (b) tunneling Ohmic junction 32

2.17 A schematic diagrams showing the tunneling of a particle through a potential barrier. The wave function inside the barrier is a decaying function. 33

2.18 Simplified energy band diagrams of tunnel diode at (a) reverse bias; (b) thermal equilibrium. Zero bias; (c) forward bias such that peak current is obtained; (d) forward bias such that valley current is approached; and (e) forward bias with thermionic current flowing. 34

2.19 Partial transmission of an electron beam trough a narrow potential barrier 35

2.20 *I-V* characteristic of tunnel junction 38

2.21 A solar cells formed from a p-n junction. When sunlight strikes it, the solar cell acts like a battery, with + and – terminals. 40

2.22 Refraction and reflection at an interface, here when medium 2 has the higher refractive index. 41

2.23 Refraction occurs because wave speed and wavelength differ in the two media. 42

2.24 Absorption energies and wavelengths for GaInP, GaAs and Ge on AM0 (air mass zero) spectrum 43

2.25 Tandem cells 44

3.1 Typical Mesh 46

3.2 Specification of the Region 47

3.3 Electron concentration diagram and *I-V* schematic diagram 49

4.1 Spectrolab`s multijunction cell 51

4.2 Whole structure of the multijunction cell 52

4.3 The structure after define the mesh, region, electrodes and doping 55

4.4 Typical Mesh for whole structure 56

4.5 Typical meshes for two cells 57

4.6 (a)The expended view of the multijunction cell 58

(b) Expanded view between the junction 58

4.7 The order of each layer with the specified thickness and electron concentrations. 59

4.8	Graph of Light intensity	63
4.9	A tunnel junction	64
4.10	Structure of the tunnel junction	64
4.11	A region of a tunnel junction	66
4.12	General visualization of tunneling	66
4.13	A typical mesh of tunnel junction	68
4.14	Graph of light intensity for tunnel junction	70
4.15	AM0 and AM1.5 solar spectrum distributions	72
4.16	*I-V* Curve of the tunnel junction	74
4.17	*I-V* characteristics of the tunnel junction	74

LIST OF SYMBOLS AND ABBREVIATIONS

LEK	Liquid encapsulated Kyropoulus
VGF	Vertical Gradient Freezing
EHP	Electron Hole Pair
Ga	Galium
In	Indium
As	Arsenide
Ge	Germanium
Si	Silicon
ρ	decaying wave vector inside the barrier
L	width of the potential barrier
E	electric field
E	Energy
E_g	Energy gap
E_F	Fermi level energy
hv	photon energy
p	proton
n	neutron
n	electron density
p	hole density
eV	electron volts
p_0	hole densities
N_d	donor density
n_0	electron densities

n_i	intrinsic carrier density
T	Kelvin
k_B/k	Boltzmann`s constant $(1.38\times10^{-23}JK^{-1})$
P(E)	probability of an energy level
$V\text{-}I$	current voltage
μ	mobility
μ_n	electron mobility
μ_p	hole mobility
FF	Fill factor
f	Fermi direct distribution
f_k	function that depends on time, space and momentum
f_p	Fermi function in the proton
f_n	Fermi function in the neutron
$V\gamma$	offset voltage
V_Z	Zener voltage
I_s	small reverse saturation current
I_d	diffusion current
$e\phi_m$	metal work function
$e\chi$	electron affinity
k_e	initial electron momentum
k_{ph}	phonon momentum
c	speed of light
v	wavelength
n	index of refraction

I_{sc}	short circuit voltage
I_{max}	maximum current
P_{inc}	incident power
P_{max}	maximum power
V_{max}	maximum voltage
V_{oc}	open circuit voltage
η	power conversion efficiency
$\hbar$	Planck constant
α	alpha
β	beta

LIST OF APPENDIXES

Appendix	Description	Page
A	Complete Source Code of The Whole Structure	79
B	Tunnel Junctions Source Code	83
C	Some Physical Constants	86
D	SI Metric	86
E	SI Derived Units	87
F	Magnitude Prefixes	89

CHAPTER 1

INTRODUCTION

1.1 General Statement

The generation of voltage when a device is exposed to light is known as the photovoltaic effect. A solar cell is a *p-n* junction device with no voltage applied directly across the junction. A solar cell converts photon power to the load.

Since solar cell is used as a power generating source, the series resistance is a critical factor. The main steps of photovoltaic power generation are (i) light absorption to produce excess carriers, followed by, (ii) the separation of these carriers.

The development of growth technologies to manufacture high quality and high-purity crystals during the last century possible the fabrication of electronics and optoelectrics devices can only be fabricated from high-quality materials that are grown under well-controlled conditions. Bulk crystals growth techniques include liquid-encapsulated Kyropoulos (LEK), and vertical gradient freezing (VGF) methods. There are also many improved methods available for the growth of bulk semiconductor crystals.

Tandem cells have been developed in a variety of materials combination. Two terminal designs have been more widely studied than four terminal design, because of the technologically appealing possibility of integrating different junctions in a single multilayer device by using 'tunnel junction' to connect different *p-n* junctions. The tunnel junction is a heavily doped *n-p* junction which is generally assumed to introduce an Ohmic contact between the *p* terminal of one cell and the *n* terminal of the next. III-V materials are preferred on account of the high absorption coefficient and the possibility of tuning the band gap by compositional variation of ternary and higher alloys.

The Tunneling effect was first reported by Esaki in 1959 in a narrow germanium *pn* junction. So far, there are many devices based on the Tunneling effect such as resonant tunneling diodes, point contact diodes, Schottky diodes, bipolar transistors, and field-effect transistors. One important feature of the Tunneling effect is that the Tunneling time of carriers is proportional to the function $\exp(-2\rho L)$, where ρ equal to the decaying wave vector inside the barrier and L is stand width of the potential barrier. The wave functions of the tunneling carriers are characterized as propagating waves in the wells and evanescent waves inside the barriers.

The ATLAS device simulator from Silvaco International has the capability has to model a wide variety of physical device characteristics. It is predicts the electrical characteristics of physical structures by simulating the transport of carriers through a 2D grid. Band gap, electron and hole state densities, electron and hole motilities, permittivity, electron affinity, radioactive recombination rate and optical parameters are all important parameters needed for solar cell in ATLAS. This software was also used to modify and calibrate parameter values in modeling advanced solar cells. Such parameters include electrical and optical properties of exotic materials, usually use in high-cells. At most they continue to be studied by the photovoltaic community; their properties must be interjecting from the properties components. Due to the non-linearity participated, several bowing parameters are applied in more complex interjection functions.

By applying same approach, an InGaP cell is formed. Both cells are then placed in a mechanically stacked configuration to investigate shadowing phenomena. An appropriate tunnel junction is also developed to electrically interconnect the two cells, forming in a invention of a multijunction cell. The dimensions and structural characteristics used are identical to those in published cells. The fact that the results also match is a good indication of the validity of this methodology.

1.2 Objective

The research issues addressed in this thesis research to simulate the top cell of tunneling junction in InGaP/GaAs/Ge multijunction solar cells by using ATLAS software.

1.3 Scope

The scope of this research is modeling the tunnel junction on the top cell of the InGaP/GaAs/Ge multi junction solar cells. It shown as the figure below:

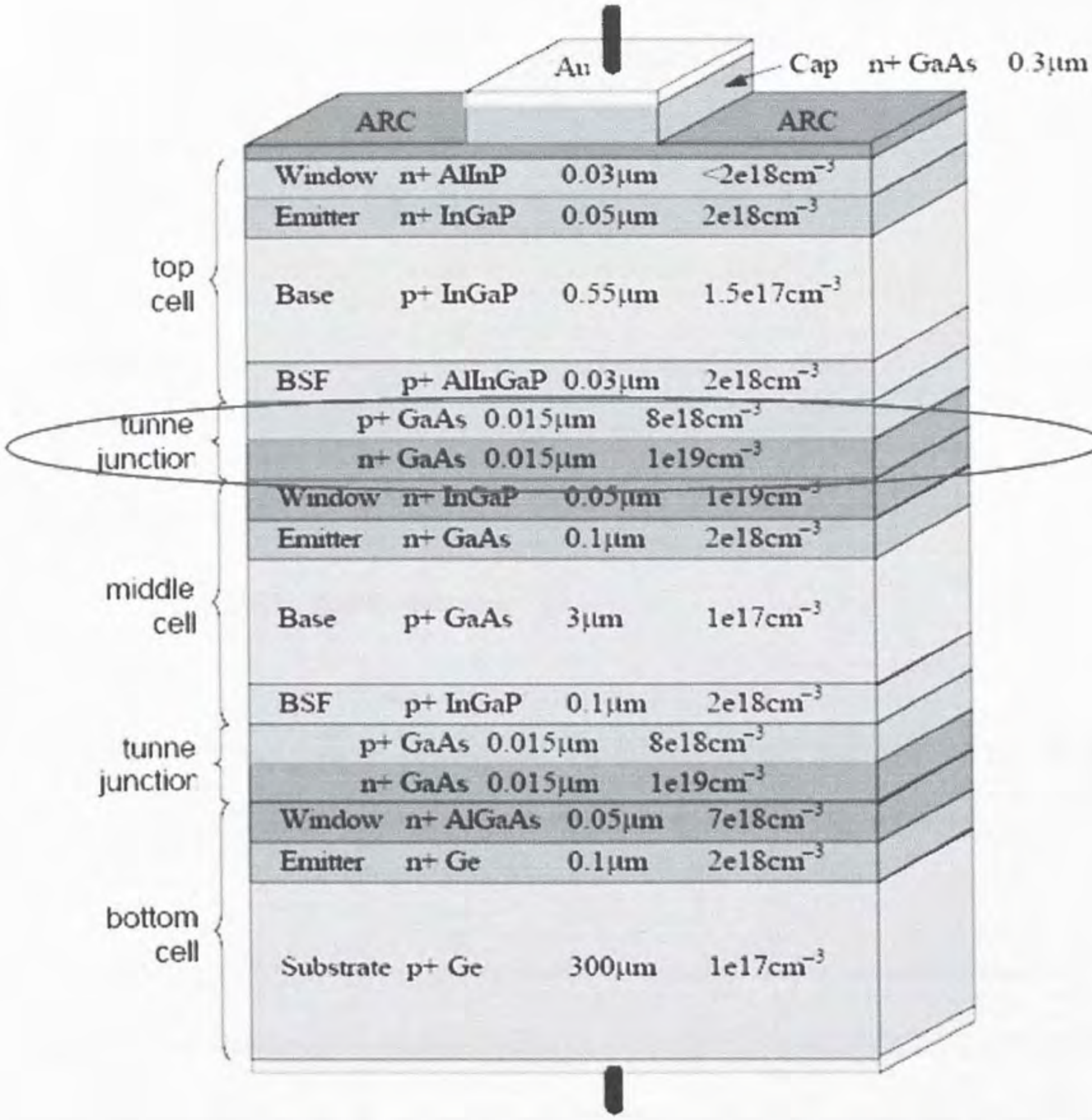

Figure 1.1 Tunnel junction on InGaP/GaAs/Ge (Panayiotis Michalopoulos, 2002)

1.4 Hypothesis

In the small of thickness, the value of the voltage is proportionally to the current when under the absent of the light.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Semiconductor

The various materials can be categorized according to their electrical properties as conductors (metals), semiconductors (metalloids) and insulators (nonmetals).

Conductors (metals). No gap between the valence and conductions bands of a conductor, thus electrons flow when even a tiny electrical potential different is applied. Greater random motion of the atoms hinders electron movement when the temperature rising, which decreases the conductivity of a metal.

Semiconductors (metalloids). In a semiconductor, a relatively few energy gap appears between the valence and conductions bands. Thermally excited electrons can cross the gap, allowing a small current to pass. Thus, in contrast to a conductor, the conductivity of a semiconductor increases when it is heated.

Insulators (nonmetals). In an insulator, the large gaps between the bands make the electron hard to jump even when the substance is heated, so no current is observed.

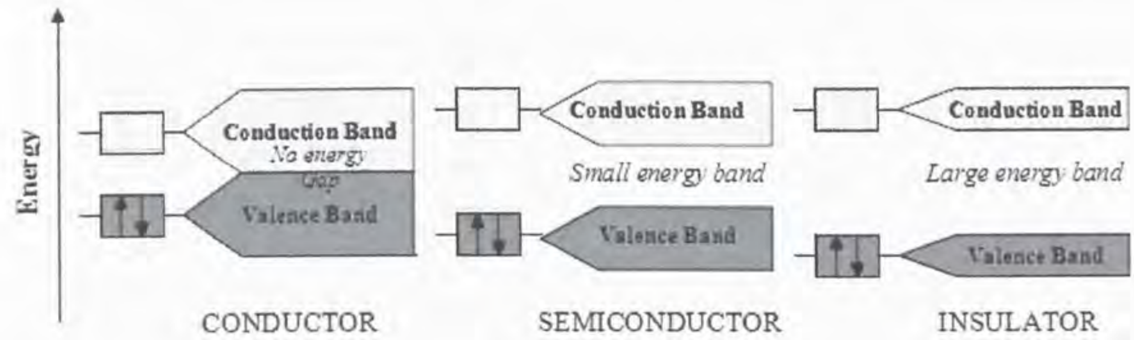

Figure 2.1 Electrical conductivity in a conductor, semiconductor, and insulator. Band theory explains differences in electrical conductivity in terms of the size of the energy gap between the material's valence and conduction bands. (Silberberg, 2003)

Niels Bohr (1885-1962) proposed three postulates:

1. *The H atom has only certain allowable energy levels*, which Bohr called stationary states. Each of these states is associated with a fixed circular orbit of the electron around the nucleus.
2. *The atom does not radiate energy while in one of its stationary states.* That is, even though it violates the ideas of classical physics, the atom does not change energy while the electrons move within an orbit.
3. *The atom changes to another stationary state*(the electron moves to another orbit) *only by absorbing or emitting a photon whose energy equals the difference in energy between the two states:*

$$E_{photon} = E_{stateA} - E_{stateB} = hv \qquad (2.1)$$

where the energy of state A is higher than that of state B. A spectral line results when a photon of specific energy (and thus specific frequency) is emitted as the electron moves from a higher energy state to a lower one. Therefore, Bohr`s model explains that an atomic spectrum is not continuous because the atom's energy has only certain discrete levels, or states. (Silberberg, 2003)

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