



E41039

คณะกรรมาธิการการต่างประเทศ



E41039

เซลล์แสงอาทิตย์โครงสร้างเฮเทอโรจันคอะลูมิเนียมแกเลียมอาร์เซना이드/แกเลียมอาร์เซนาไซด์

นาย บุญปอน แก้วมณีวงศ์



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิชาวิศวกรรมไฟฟ้า ภาควิชาวิศวกรรมไฟฟ้า

คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2553

ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย



5 2 7 0 7 2 0 2 2 1

AlGaAs/GaAs HETEROSTRUCTURE SOLAR CELLS

Mr. Bounpone Keomanivong

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Electrical Engineering

Department of Electrical Engineering

Faculty of Engineering

Chulalongkorn University

Academic Year 2010

Copyright of Chulalongkorn University

Thesis Title AlGaAs/GaAs HETEROSTRUCTURE SOLAR CELLS
By Mr. Bounpone Keomanivong
Field of Study Electrical Engineering
Thesis Advisor Professor Somsak Panyakeow, Ph.D.
Thesis Co-Advisor Associate Professor Choopol Antarasena, Dr.Ing.

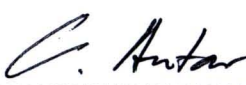
Accepted by the Faculty of Engineering, Chulalongkorn University in Partial
Fulfillment of the Requirements for the Master's Degree

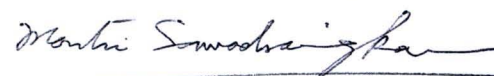
.....  Dean of the Faculty of Engineering
(Associate Professor Boonsom Lerdhirunwong, Dr.Ing.)

THESIS COMMITTEE

.....  Chairman
(Associate Professor Banyong Toprasertpong, Dr.Ing.)

.....  Thesis Advisor
(Professor Somsak Panyakeow, Ph.D.)

.....  Thesis Co-Advisor
(Associate Professor Choopol Antarasena, Dr.Ing.)

.....  External Examiner
(Associate Professor Montri Sawadsaringkarn, Dr.Ing.)

บุญปอน แก้วมณีวงศ์: เซลล์แสงอาทิตย์โครงสร้างเฮเทอโรโรชนิดอะลูมิเนียมแกลเลียมอาร์เซไนด์/แกลเลียมอาร์เซไนด์. (AlGaAs/GaAs HETEROSTRUCTURE SOLAR CELLS).
 อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ.ดร.สมศักดิ์ ปัญญาแก้ว, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: รศ.ดร.ชุมพล อินทรเสน, 72 หน้า.

E41039

เซลล์แสงอาทิตย์โครงสร้างเฮเทอโรโร จำนวน 8 โครงสร้าง ถูกออกแบบและทำการผลิตด้วยเทคโนโลยีปลูกผลึกชนิด MBE และชนิด LPE เซลล์แสงอาทิตย์กลุ่มแรก 6 โครงสร้าง ซึ่งประกอบด้วย ไดโอดแบบขดที่เบเรียวของ GaAlAs จำนวน 1 โครงสร้าง ไดโอดหัวต่อเฮเทอโร GaAlAs(n)/GaAs(p) แบบมีชั้นหน้าต่างช่องว่างแถบพลังงานคงที่ จำนวน 1 โครงสร้าง และ ไดโอดหัวต่อเฮเทอโร GaAlAs(n)/GaAs(p) แบบมีชั้นหน้าต่างช่องว่างแถบพลังงานเป็นขั้นบันได จำนวน 4 โครงสร้าง ถูกผลิตด้วย MBE ในขณะที่อีก 2 โครงสร้างของไดโอดหัวต่อเฮเทอโร GaAlAs(P)/GaAs(n) แบบมีชั้นหน้าต่างช่องว่างแถบพลังงานคงที่ ผลิตด้วย LPE จากนั้นนำทุกตัวอย่างมาวัด ลักษณะสมบัติทางแสง และทางไฟฟ้า เห็นได้ชัดเจนว่าชั้นรับแสงช่องว่างแถบพลังงานกว้างของเซลล์แสงอาทิตย์โครงสร้างเฮเทอโร แสดงความเป็นหน้าต่างแสงได้ชัดเจน แต่ชั้นหน้าต่างแสงก็ไม่สามารถช่วยปรับปรุงสมรรถนะของเซลล์แสงอาทิตย์ที่ผลิตได้ สรุปในภาพรวมเซลล์แสงอาทิตย์ทำงานที่ 1 ชั้น แสดงค่า กระแสลัดวงจร (I_{sc}) อยู่ในช่วงระหว่าง 0.6 ถึง 1.5 มิลลิแอมป์ (mA), แรงดันวงจรเปิด (V_{oc}) อยู่ในช่วงระหว่าง 0.43 ถึง 0.7 โวลต์ (Volt) กำลังไฟฟ้าสูงสุด อยู่ในช่วงระหว่าง 0.15 ถึง 0.5 มิลลิวัตต์ (mW) ฟิลล์แฟกเตอร์ (FF) อยู่ในช่วงระหว่าง 0.38 ถึง 0.61 และ ประสิทธิภาพ (η) อยู่ในช่วงระหว่าง 2.3 ถึง 5 % สาเหตุหลักที่ทำให้เซลล์ทั้งหมดมีสมรรถนะต่ำ มาจากคุณภาพของผลึกและหัวต่อที่ไม่ดี รวมทั้งโครงสร้างที่ได้รับการออกแบบยังไม่เหมาะสม

ภาควิชา วิศวกรรมไฟฟ้า.....

สาขาวิชา วิศวกรรมไฟฟ้า.....

ปีการศึกษา 2553.....

ลายมือชื่อนิสิต.....

ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก.....

ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม.....

##5171632821: MAJOR ELECTRICAL ENGINEERING

KEYWORDS : AlGaAs, GaAs AND AlGaAs/GaAs HETERSTRUCTURE SOLAR CELL.

BOUNPONE KEOMANIVONG: AlGaAs/GaAs HETEROSTRUCTURE SOLAR CELLS. ADVISOR: PROF. SOMSAK PANYAKEOW, Ph.D., CO-ADVISOR: ASSOC. PROF. CHOOMPOL ANTARASENA, Dr.Ing. 72 pp.

E 41039

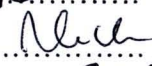
Eight structures of Heterostructure Solar Cells have been designed and fabricated, by Molecular Beam Epitaxy (MBE) and by Liquid Phase Epitaxy (LPE) technologies. The first group, which consists of six structures: one of GaAlAs Schottky Barrier Diode, one of constant band gap window layer GaAlAs(p)/GaAs(n) heterojunction and three of step or stair case band gap window layer GaAlAs(n)/GaAs(p) heterojunction were realized by MBE, whereas the other two structures of constant band gap window layer GaAlAs(P)/GaAs(n) heterojunction were produced by LPE. Optical and electrical properties of all samples were then examined. It is evident that the GaAlAs wide band gap window layer of all heterostructure solar cells can behave in the role of window effect but it can not improve the overall performance of solar cells as expected. In conclusion, these solar cells perform at 1 sun with short circuit current (I_{sc}) in the range of 0.6 to 1.5 mA, open circuit voltage (V_{oc}) in the range of 0.43 to 0.7 Volt, maximum output power (P_{max}) in the range of 0.15 to 0.5 mW, fill factor (FF) in the range of 0.38 to 0.61 and efficiency (η) in the range of 2.3 to 5 %. The main reasons that cause all samples to have low performance are due to low quality of the crystal layers and of junction interface, together with unsuitable designed structures.

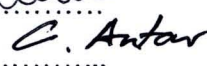
Department: Electrical Engineering.....

Field of Study:....Electrical Engineering.....

Academic Year:..2010.....

Student's Signature . 

Advisor's Signature . 

Co-Advisor's Signature. 

ACKNOWLEDGEMENTS

I would like to firstly express my profound gratitude and appreciation to my kind advisor; Prof. Dr. Somsak Panyakeow, for his helpfulness and meaningful advices. He always shared his valuable time to cooperatively discuss my research. My deepest thankfulness is also addressed to my co-advisor; Assoc. Prof. Dr. Choompol Antarasena, for his friendly discussion, guidance, and supportive thought. In particular, working with them was an excellent chance for me to gain more invaluable knowledge and experiences which will be useful for the next step in my life.

My thanks and respects are also given to my thesis committees; Assoc. Prof. Dr. Banyong Toprasertpong and Assoc. Prof. Dr. Montri Sawadsaringkarn, who are friendly and generous lecturers. They kindly provided me fruitful suggestions and comments for conducting my research. Moreover, I would like to thank all lecturers in Chulalongkorn University, who gave me useful instructions and advices to expand my knowledge.

My profound thanks is given to all of Lecturers of Semiconductor Devices Research Laboratory (SDRL), who kindly help me to have a chance to do the experiment to get the necessary data and information for conducting my thesis. Unforgettably, I wish to deeply thank Mr. Supachok Thainoi, Mr. Pornchai Changmoang, Mr. Ongarj Tangmattajittakul, Mr. Chalernchai Himwas, and Mr. Nirat Patanasemakul for their continuous help and strong cooperation in my experiment at SDRL.

I would like to extend my grateful thanks to all official staffs employed in International School of Engineering and AUN/SEED-Net, who always distributed the updated information to me. I also thank to AUN/SEED-Net which was the main financial supporter for me.

Finally, very special thank from the bottom of my heart is gratefully addressed to my respectful parents; Kee Keomanivong and Chanh Keomanivong, and my beloved sister, who constantly cared and encouraged me every time I felt down. My parents have tried to do everything and worked hard all the time in order to enable their son and daughter to be able to study from primary school until university. One thought is given to them "I am very proud to be your son".

CONTENTS

ABSTRACT (THAI).....	iv
ABSTRACT (ENGLISH).....	v
ACKNOWLEDGEMENTS.....	vi
CONTENTS.....	vii
LIST OF FIGURES.....	ix
LIST OF TABLES.....	xii
 CHAPTER I: INTRODUCTION.....	 1
1.1 Introduction.....	1
1.2 Problem statements.....	4
1.3 Objective.....	4
1.4 Scope of research.....	4
1.5 Research methodology.....	4
1.6 Expected benefits.....	5
 CHAPTER II: FUNDAMENTAL OF SOLAR CELL.....	 6
2.1 General.....	6
2.2 Fundamental definition, and operation of solar cells.....	6
2.2.1 Spectral response and collection efficiency.....	8
2.3 Output characteristics of solar cells.....	17
2.3.1 Energy conversion efficiency.....	18
2.3.2 Short circuit current.....	18
2.3.3 Open circuit voltage (V_{oc}).....	19
2.3.4 Fill factor.....	21
2.4 Application of heterojunction solar cells or window effect.....	21
 CHAPTER III: RESEARCH METHODOLOGY.....	 24
3.1 General.....	24
3.2 Literature review.....	24
3.3 Experimental Data Correction.....	24
3.3.1 Liquid phase epitaxy (LPE).....	24

3.3.2	Molecular beam epitaxy (MBE).....	27
3.3.2.1	The MBE system.....	27
3.3.2.2	In-situ characterization tools.....	34
3.3.3	Photoluminescence (PL).....	36
3.4	GaAs and AlGaAs for LPE.....	37
3.4.1	Material preparation.....	37
3.4.2	Material weight calculation.....	41
3.5	Growth process.....	43
3.5.1	Liquid phase epitaxy.....	43
3.5.2	Molecular beam epitaxy.....	46
CHAPTER IV: EXPERIMENTAL RESULT AND DISCUSSION.....		49
4.1	General.....	49
4.2	Heterostructure Solar cells realization.....	49
4.2.1	MBE samples.....	49
4.2.2	LPE samples.....	54
4.3	Results and discussion.....	55
CHAPTER V: CONCLUSIONS.....		69
5.1	Heterostructure solar cells.....	69
5.2	Limitation of study.....	69
5.3	Further study.....	69
REFERENCES.....		70
BIOGRAPHY.....		72

LIST OF FIGURES

Figure 1.1 Amount of energy in the sunlight reaching the Earth's surface is equivalent to around 10,000 times the world's energy requirements. Consequently, only 0.01 per cent of the energy in sunlight would need to be harnessed to cover mankind's total energy needs	2
Figure 2.1 Schematic illustration of 2 dimensional crystal structure (a) and band diagram of n type and p type semiconductors (b).....	7
Figure 2.2 Schematic of n-p junction structure (a) and energy band diagram (b).....	8
Figure 2.3 Structure and energy band of solar cell.....	10
Figure 2.4 Energy band diagram and schematic structure of (a) Schottky barrier, and (b) MIS solar cell.....	15
Figure 2.5 Calculation result of collection efficiency of schottky barrier solar cell...	16
Figure 2.6 Structure of solar cells where n-type energy band diagram is greater than p-type.....	17
Figure 2.7 Equivalent circuits of solar cells.....	19
Figure 2.8 Maximum outputs of solar cells.....	20
Figure 2.9 Band diagrams of AlGaAs/GaAs homojunction solar cells.....	22
Figure 3.1 Horizontal LPE systems.....	25
Figure 3.2 Multi-bin graphite boats.....	26
Figure 3.3 (a) diagram of growth chamber and (b) schematic illustration of a RIBER 32P MBE system.....	28
Figure 3.4 Temperature profile of the pre-heat process.....	30
Figure 3.5 Temperature of Ga and In effusion cells. The effusion cell is closed in the dotted line range and opened in solid line range during respective temperature ranges.....	31
Figure 3.6 Temperature profile of As effusion cell and substrate. The effusion is closed in the dotted line range and opened in solid line range during respective temperature ranges.....	31
Figure 3.7 (a) temperature profile of the oxide desorption process and RHEED pattern when the temperature increases and (b) photo took from view port showing RHEED spotty pattern at de-oxide temperature at 580°C.....	33
Figure 3.8 Schematic diagram of mass spectrometer.....	34

Figure 3.9 Schematic diagram presentation of RHEED geometry shows incident electron beam at an angle Θ to the surface plane.....	36
Figure 3.10 Schematic diagram of PL experiment set up.....	36
Figure 3.11 Liquidus composition versus reciprocal temperature for GaAs, GaP and InP.....	39
Figure 3.12 Room temperature hole concentration in GaAs versus the atom fraction of Ge in the liquid along the 800 and 900°C and the lower curves are the room temperature electron concentration in GaAs versus the atom fraction of Sn in the liquid along the 700 and 800°C.....	39
Figure 3.13 Solidus compositions in $\text{Al}_x\text{Ga}_{1-x}\text{As}$ as a function of liquidus composition.....	40
Figure 3.14 Liquidus isotherms in the AlGaAs system.....	40
Figure 3.15 (a) Basic set up of LPE system, (b) and (c) schematic profile of the furnace temperature versus the growing time duration, samples G and H	45
Figure 4.1 Schematic diagrams of Schottky heterostructure solar cells (sample A)...50	50
Figure 4.2 Schematic diagram of heterojunction solar cells with fixed Al content of 0.3 (sample B).....	51
Figure 4.3 Schematic diagram of heterojunction solar cell having $\text{Al}_x\text{Ga}_{1-x}\text{As}$ window with stepped Al mole fractions (sample C).....	52
Figure 4.4 Schematic diagram of heterojunction solar cell, the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ window with a stepped Al mole fraction having thin 200nm GaAs buffer layer (sample D)...52	52
Figure 4.5 Schematic diagram of heterojunction solar cell, the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ window with a stepped Al mole fraction (sample E).....	53
Figure 4.6 Schematic diagram of heterojunction solar cell, the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ window with a stepped Al mole fraction (sample F).....	53
Figure 4.7 (a), (b) Schematic diagram of the heterostructure solar cells, (sample G and H) grown by LPE technique.....	54
Figure 4.8 (a), (b) and (c) Spectral responses of samples A , B and C	57
Figure 4.9 Normalized spectral responses of samples B and C	57
Figure 4.10 (a), (b) and (c) Spectral responses of samples D , E and F	59
Figure 4.11 Normalized spectral responses of samples D , E and F	59
Figure 4.12 (a), (b) and (c) Photoluminescence of samples A , B and C , respectively.....	61

Figure 4.13 (a), (b), (c), (d) and (e) I-V curves in dark and one sun of AlGaAs/GaAs heterostructure solar cells, samples **B**, **C**, **D**, **E** and **F** respectively.....63

Figure 4.14 (a) Spectral responses of sample **G**, **(b)** Spectral responses of sample **H** and **(c)** normalized spectral responses of sample **G** and **H**.....65

Figure 4.15 (a) and (b) I-V curves in the dark and one sun of AlGaAs/GaAs heterostructure solar cells, sample **G** and **H** respectively.....66

LIST OF TABLES

Table 2.1 lattice mismatch and band discontinuity of semiconductor that we make the heterojunction anisotype.....23

Table 3.1 Material weight.....43

Table 4.1 Solar cell parameters of samples **B, C, D, E** and **F**.....64

Table 4.2 The calculated solar cell’s output parameters of sample **G** and **H**.....67