IMPACT OF CARRIER LIFETIME AND TEMPERATURE ON INGAN SINGLE-JUNCTION SOLAR CELL

PROJECT WORK: B. SC. 4TH YEAR

MARCH 3, 2022

DEPARTMENT OF PHYSICS, TRICHANDRA MULTIPLE CAMPUS, TRIBHUVAN UNIVERSITY
Ghantaghar, Kathmandu, Nepal

A Project Work

IMPACT OF CARRIER LIFETIME AND TEMPERATURE ON INGAN SINGLE-JUNCTION SOLAR CELL

SUBMITTED TO

THE OFFICE OF THE CONTROLLER OF EXAMINATION,

TRIBHUVAN UNIVERSITY,

BALKHU, KATHMANDU, NEPAL

(IN THE PARTIAL FULFILLMENT FOR THE REQUIREMENT OF BACHELOR'S DEGREE OF SCIENCE IN PHYSICS)

SUBMITTED BY

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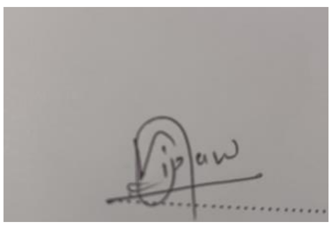
07 MARCH, 2022

DECLARATION

Project report entitled, "**Impact of Carrier Lifetime and Temperature on InGaN Single-Junction Solar Cell",** which is being submitted to the Department of Physics, Tri-Chandra Multiple Campus, is a project work carried out by me under the supervision of Asst. Prof. Dr. Deependra Parajuli and co-supervision of Mr. Devendra K. C. I hereby declare that this a written submission represents my ideas in my own words and where other's ideas or words have been included as reference which are inadequately cited with their original sources.



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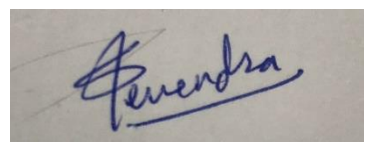
RECOMMENDATION

It is certified that Mr. Viplaw Bhandari has carried out the project work entitled "**Study of Impact of Carrier Lifetime and Temperature on InGaN Single-Junction Solar Cell"** under my supervision.

I recommend the project work in the Partial fulfillment for the requirement of Bachelor's Degree of Science in Physics.



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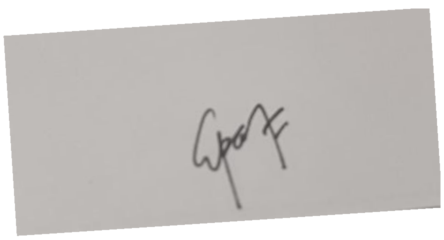
CERTIFICATE

This is to certify that the project work "**Study of Impact of Carrier Lifetime and Temperature on InGaN Single-Junction Solar Cell"** carried out by Mr. Viplaw Bhandari of Bachelor of Science in Physics, Fourth year during the year 2021-2022 is a bona fide work submitted to the Department of Physics, Tri-Chandra Multiple Campus, Tribhuvan University, Kathmandu, Nepal in partial fulfillment of requirement of degree of Bachelor of Science in Physics.



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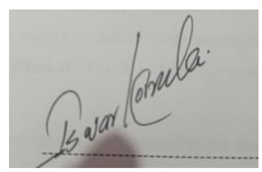

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ACKNOWLEDGEMENT

First of all, I would like to express my deep gratitude and sincere respect to my supervisor **Asst. Prof. Dr. Deependra Parajuli** for his continuous support to my work. I could not have imagined having a better advisor and mentor for my study. His constant guidance helped me to complete my work in proper time. Without his scientific vision, understanding of the subject matter and tactfulness to deal with student, the dissertation would have never taken this present form. Simultaneously, I want thank **Mr. Devendra K. C**. for his support computational techniques in PC1D as a co-supervisor.

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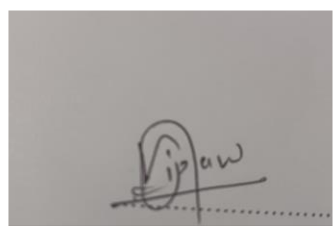
Finally, I am greatly indebted to my parents and other family members for their support and encouragement throughout my life. Without their support, it is difficult for me to complete my Bachelor degree.



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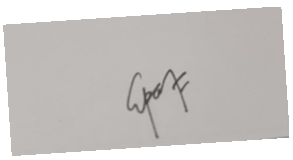
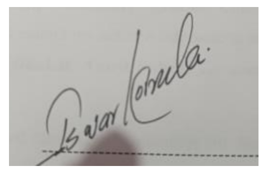
LETTER OF APPROVAL

We certify that we have read this project work and in our opinion it is good in the scope and quality as project work in the Partial fulfillment for the requirement of Bachelor's Degree of Science in Physics.





LIST OF SYMBOLS

AND

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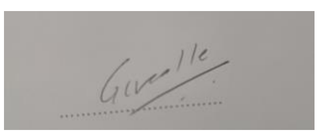

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External Examiner

ABBREVIATIONS

Symbol	Unit	Description
α	cm^{-1}	absorption coefficient
α_o	$(eV^{1/2})/cm$	absorption coefficient fitting parameter
ε	-	Strain
ε_x	-	strain in direction of basal a-plane of wurtzite crystal
ε_z	-	strain perpendicular to basal a-plane of wurtzite crystal
η	%	Efficiency
λ	µm, nm	Wavelength
μ	$cm^2/V \cdot s$	mobility of electron or hole
σ_P	C/m^2	polarization-induced charge density
τ	s, ms, µs, ns	minority carrier lifetime
Φ	eV	work-function
φ_n	V	electron quasi-fermi potential
φ_p	V	hole quasi-fermi potential
χ	eV	electron affinity
ψ	V	electrostatic potential
2DEG	-	two-dimensional electron gas
2DHG	-	two-dimensional hole gas
a	Å	lattice constant of unit cell
a_e	Å	lattice constant „a" of epilayer
a_e"	Å	strained lattice constant „a" of epilayer
a_s	Å	lattice constant „a" of substrate
b	(variable)	bowing factor (used during interpolation of band gap, polarization, etc.)
c	Å	lattice constant of unit cell
C_{11}	GPa	elastic constant
C_{13}	GPa	elastic constant
D	C/m^2	electric flux density
E	V/cm	electric field
e_{31}	C/m^2	piezoelectric constant
e_{33}	C/m^2	piezoelectric constant

E_C	eV	conduction band energy level
E_F	eV	semiconductor fermi energy level
EG	eV	band gap
E_i	eV	semiconductor intrinsic energy level
E_V	eV	valence band energy level
FF	%	fill factor
$In_xGa_{1-x}N$	-	indium gallium nitride with indium composition of „x"
		and gallium composition of „1-x" ($0 \leq x \leq 1$)
IQE	%	internal quantum efficiency
I_{SC}	A	short-circuit current
J_{SC}	A/cm^2	short-circuit current density
MBE	-	molecular beam epitaxy
MOCVD	-	metal-organic chemical vapor deposition
n_s	m^{-2}	surface carrier concentration
P	C/m^2	Polarization
P_{PZ}	C/m^2	piezoelectric polarization
P_{SP}	C/m^2	spontaneous polarization
QE	%	quantum efficiency
R	-	interface relaxation factor ($0<R<1$)
RC	µm	strain relaxation coefficient
V_{bi}	V	built-in potential
V_{OC}	V	open-circuit voltage
x	m	thickness

LIST OF FIGURES

ABSTRACT

Photovoltaic (PV) cells convert the energy from the sun into useful electrical energy. Indium gallium nitride (InGaN) is III-N type semiconductor material, meaning elements from group III are combined with nitrogen to produce a semiconductor that is gaining ground in the PV market as a viable and tunable device. We studied the optimization value from the simulation on PC1D and compared the graph between base current and base voltage by changing the values of temperature and bulk recombination for analysis, we looked at the values of base current and open circuit voltage from the PC1D simulation. And we portrayed the graph from the origin software. We employed the graph which was plotted by the origin software to study the impact of temperature and bulk recombination. And we employed the graph of PC1D to find out the optimization. The Study of the Impact of Carrier Lifetime and Temperature on InGaN Single-Junction Solar Cell was performed by Graph using Origin software, which resulted from a PC1D simulation. We also computed the value of efficiency when we looked at impact carrier lifetime and temperature. The efficiency was optimized at 18.258 at 25°C and 1000µs bulk recombination of N-InGaN and P-InGaN. It is used to study the effects of temperature and bulk recombination on the InGaN single junction solar cell after changing the value of a parameter. We can also analyze the importance of the impact of temperature and bulk recombination for different values of parameters.

सार

फोटोभोल्टिक (PV) कोशिकाहरूले सूर्यबाट प्राप्त ऊर्जालाई उपयोगी विद्युत ऊर्जामा रूपान्तरण गर्छन्। इन्डियम ग्यालियम नाइट्राइड (InGaN) III-N प्रकारको अर्धचालक सामग्री हो, जसको अर्थ समूह III बाट तत्वहरूलाई नाइट्रोजनसँग मिलाएर अर्धचालक उत्पादन गरिन्छ जुन PV बजारमा व्यवहार्य र ट्युनेबल यन्त्रको रूपमा जग्गा प्राप्त गर्दैछ। हामीले PC1D मा सिमुलेशनबाट अनुकूलन मान अध्ययन गर्यौं र तापमान र बल्क पुन: संयोजनको मानहरू परिवर्तन गरेर आधार वर्तमान र आधार भोल्टेज बीचको ग्राफ तुलना गर्यौं। विश्लेषणको लागि, हामीले PC1D सिमुलेशनबाट आधारभूत वर्तमान र खुला सर्किट भोल्टेजको मानहरू हेर्यौं। र हामीले मूल सफ्टवेयरबाट ग्राफ चित्रित गर्यौं। हामीले तापमान र बल्क पुन: संयोजनको प्रभाव अध्ययन गर्न मूल सफ्टवेयरद्वारा प्लट गरिएको ग्राफलाई प्रयोग गर्यौं। र हामीले अप्टिमाइजेसन पत्ता लगाउन PC1D को ग्राफ प्रयोग गर्यौं। InGaN सिंगल-जंक्शन सोलार सेलमा क्यारियर लाइफटाइम र तापमानको प्रभावको अध्ययन मूल सफ्टवेयर प्रयोग गरेर ग्राफद्वारा गरिएको थियो, जुन PC1D सिमुलेशनको परिणाम हो। हामीले प्रभाव वाहक जीवनकाल र तापक्रम हेर्दा हामीले दक्षताको मूल्य पनि गणना गर्यौं। दक्षता 18.258 मा 25°C र 1000s मा N-InGaN र P-InGaN को बल्क पुन: संयोजनमा अनुकूलित गरिएको थियो। यो एक प्यारामिटर को मान परिवर्तन पछि InGaN एकल जंक्शन सौर सेल मा तापमान र बल्क पुन: संयोजन को प्रभाव को अध्ययन गर्न को लागी प्रयोग गरिन्छ। हामी मापदण्डहरूको विभिन्न मानहरूको लागि तापक्रम र बल्क पुन: संयोजनको प्रभावको महत्त्वलाई पनि विश्लेषण गर्न सक्छौं।

CONTENTS

TITLE

STUDY OF IMPACT OF CARRIER LIFETIME AND TEMPERATURE ON INGAN SINGLE-JUNCTION SOLAR CELL

CHAPTER 1 : INTRODUCTION

Background

The photovoltaic effect was experimentally demonstrated first by French physicist Edmond Becquerel. In 1839, at age 19, he built the world's first photovoltaic cell in his father's laboratory. Willoughby Smith first described the "Effect of Light on Selenium during the passage of an Electric Current" in a 20 February 1873 issue of Nature. In 1883 Charles Fritts built the first solid state photovoltaic cell by coating the semiconductor selenium with a thin layer of gold to form the junctions; the device was only around 1% efficient. Other milestones include: In1888 – Russian physicist Aleksandr Stoletov built the first cell based on the outer photoelectric effect discovered by Heinrich Hertz in 1887 [1]. In 1905 – Albert Einstein proposed a new quantum theory of light and explained the photoelectric effect in a landmark paper, for which he received the Nobel Prize in Physics in 1921 [2]. In 1941– VadimLashkaryov discovered *p-n*-junctions in Cu_2O and Ag_2S proto cells [3].In 1946 – Russell Ohl patented the modern junction semiconductor solar cell [4], while working on the series of advances that would lead to the transistor. In 1948 - *Introduction to the World of Semiconductors* states Kurt Lehovec may have been the first to explain the photo-voltaic effect in the peer reviewed journal *Physical Review* [5, 6].In 1954 – The first practical photovoltaic cell was publicly demonstrated at Bell Laboratories [7]. The inventors were Calvin Souther Fuller, Daryl Chapin and Gerald Pearson [8].In 1957 – Egyptian engineer Mohamed M. Atalla develops the process of silicon surface passivation by thermal oxidation at Bell Laboratories [9, 10]. The surface passivation process has since been critical to solar cell efficiency [11].In 1958 – Solar cells gained prominence with their incorporation onto the Vanguard I satellite.

1.2 Motivation

Improvements were gradual over the 1960s. This was also the reason that costs remained high, because space users were willing to pay for the best possible cells, leaving no reason to invest in lower-cost, less-efficient solutions. The price was determined largely by the semiconductor industry; their move to integrated circuits in the 1960s led to the availability of larger boules at lower relative prices. As their price fell, the price of the resulting cells did as well. These effects lowered 1971 cell costs to some $100 per watt [12].

In late 1969, Elliot Berman joined Exxon's task force which was looking for projects 30 years in the future and in April 1973 he founded Solar Power Corporation (SPC), a wholly owned subsidiary of Exxon at that time [13, 14, 15]. The group had concluded that electrical power would be much more expensive by 2000, and felt that this increase in price would make alternative energy sources more attractive. He conducted a market study and concluded that a price per watt of about $20/watt would create significant demand.[13] The team eliminated the steps of polishing the wafers and coating them with an anti-reflective layer, relying on the rough-sawn wafer surface. The team also replaced the expensive materials and hand wiring used in space applications with a printed circuit board on the back, acrylic plastic on the front, and silicone glue between the two, "potting" the cells [16]. Solar cells could be made using cast-off material from the electronics market. By 1973 they announced a product, and SPC convinced Tideland Signal to use its panels to power navigational buoys, initially for the U.S. Coast Guard [14].

1.3 Objective

Following are the major objectives of this work:

- We want to investigate the effect of temperature on single junction InGaN solar cell.
- We want to study the variation of bulk recombination of N type and P type region.
- We want to study the optimization value from the simulation on PC1D.

- We want to compare the graph between base current and base voltage by changing value of temperature and bulk recombination.

1.4 Significance of the Study

Following are the significances of my research work:

- Study of impact carrier lifetime and temperature effect of InGaN solar cell is important to know the temperature effect.
- PC1D is a computer program used for modelling crystalline semiconductor devices, with emphasis on photovoltaic devices. It is widely used as a simulation tool for photovoltaic research and industry, not only helping users to understand the fundamental mechanism and operation of solar cells, but also efficiently giving reliable and predictable results for research purposes.
- Solar cell is important to convert the energy of sunlight into the electricity by the photovoltaic effect which is the ability of matter to emit the electrons when a light is shone on it. The photovoltaic solar cells are thin silicon disks that convert the sunlight into the electricity, and these disks act as energy sources for a wide variety of uses.
- Study of InGaN solar cell to compare the current and voltage by changing the bulk recombination value for impact carrier lifetime.

1.5 Limitations of the Study

Following lists the limitations of my research work:

- The effect of surface recombination of velocity can't be studied from study of impact of carrier lifetime.
- Optimal Doping Concentration of the Front Layer can't be studied from study of impact of carrier lifetime.
- The Temperature Dependence of In0.622Ga0.378N SJ Solar Cell can't be studied from effect of temperature.
- One limitation of PC1D is that the number of time steps in transient excitation mode is limited to 200. As a result, if long duration simulations are required, big time steps should be chosen. Conversely, if small time steps are desired, only short duration simulations can be achieved. It is impossible for users to perform simulations that require both long duration and small time steps. This is a

limitation within the PC1D source code set by the size of the cache memory at the time the program was written and compiled.

- Optimal Performance of In0.622Ga0.378N SJ Solar Cell can't be studied from my project work.

CHAPTER 2 LITERATURE REVIEW

2.1 Solar

2.1 .1 Solar cell

A photo voltaic cell, or photovoltaic cell, is an electrical machine that converts the power of mild at once into electrical energy by means of the photovoltaic effect, which is a bodily and chemical phenomenon. It is a structure of photoelectric cell, described as a machine whose electrical characteristics, such as current, voltage, or resistance, fluctuate when uncovered tolight. Individual photovoltaic modulus units are regularly the electrical constructing blocks of photovoltaic modules, regarded colloquially as photovoltaics pannel. The frequent single junction silicon photo voltaic modulus can produce a most open-circuit voltage of about 0.5 volts to 0.6 volts.

Solar cells are described as being photovoltaic, irrespective of whether or not the supply is daylight or a synthetic light. In addition to producing energy, they can be used as a photo detector (for instance infrared detectors), detecting mild or different electromagnetic radiation close to the seen range, or measuring mild intensity.

Electricity can be without delay produced from daylight through a photovoltaic machine or photo voltaic cells in which the photovoltaic impact is accountable for this conversion. The phrase photovoltaic defines as “photo” refers to mild and “voltaic” to voltage. In 1839, physicist Alexander-Edmund Becquerel studied the photo voltaic spectrum and credited the discovery of the photovoltaic effect. In this experiment, he cited that daylight appearing on a silver chloride-coated platinum electrode in a variety of electrolytes produces photocurrent and photo-voltage [7].

Photo voltaic units generate electrical energy immediately from daylight by way of photoelectric impact and can be used to electricity something from small electronics such as calculators and street symptoms up to residences and giant industrial businesses.

A photovoltaic mobile used in shooting photo voltaic electricity receives photons (the sun’s rays), which silicon absorbs. This motion releases an electron from a silicon atom every time a photon strikes as proven in Fig. 1.4. Oppositely charged poles on both facet of the cellphone result in the electrons to shape a current. After the discovery of the photovoltaic effect, later in 1883, Charles Edgar Fritts has invented the first actual working photo voltaic modulus through coating a vast plate of copper with selenium and an extraordinarily skinny semitransparent gold layer on pinnacle and determined nearly 1% efficiency [8]. Based on the above invention, in 1954, the first silicon photo voltaic phone used to be developed by way of the Bell laboratories and tested 6% efficiency [9]. After this work, the first contemporary Si photo voltaic modules had been accessible commercially in 1956, however the manufacturing price is very high, as stated 300 cents/watt. Solar cells are commonly made from a range of semiconductor materials. Crystalline silicon is the most extensively used semiconductor material, representing over 90% of international business PV module manufacturing in its quite a number varieties [10]. A regular silicon cell, with a diameter of four inches, can produce extra than 1 W of direct cutting-edge (DC) electrical strength in full sun. Individual photo voltaic cells can be related in collection and parallel to reap preferred voltages and currents [11]. These businesses of cells are packaged into general modules that defend the cells from the surroundings whilst imparting beneficial voltages and currents. PV modules are extraordinarily dependable due to the fact they are solid-state and have no shifting parts.

2.1.2 InGaN solar cell

Semiconductors of the kind III-N are of developing pastime in the scientific world. This is justified by using the truth that III-N semiconductors are robust, having a excessive thermal conductivity and a high melting point, and, moreover, a direct forbidden band gap. They presently characterize ideal materials for the improvement of mild emitting diodes (LEDs) working in the green-blue and UV ranges of the electromagnetic spectrum. Among these semiconductors, we discover in most cases aluminum nitride (AlN), gallium nitride (GaN) and indium nitride (InN), respectively with a hole of 6.2eV, 3.4eV and 0.7eV. The power of the band hole of the ternary or quaternary can be adjusted from infrared to ultraviolet relying on the composition. The direct hole adjustable over a wide range makes these substances very useful for photovoltaic purposes due to the fact of the opportunity of achieving now not solely multi-junction photo voltaic cells with excessive efficiency, however additionally 0.33 era kinds of solar cells such as intermediate band photo voltaic cells, based totally solely on the nitride alloys. In order to obtain terrestrial photovoltaic efficiencies of over 50% with multi-junction photo voltaic cells, one of the junctions wants to be from a material with a gap above 2.4 eV. In addition to their massive bandgap range, III-Nitrides additionally show off different fascinating photovoltaic houses such as low effective masses of cost carriers, excessive mobility massive absorption coefficients, and an excessive tolerance to radiation.

The science of III-V nitrides has demonstrated its potential to develop crystal buildings of high pleasant and manufacture optoelectronic devices, which confirms it's attainable for excessive efficiency.

2.1.3 Solar energy

Sun oriented quality is the power that changes over into electrical or thermal power from the sun powered directly. It is the cleanest, openly, and most significant renewable power supply accessible. Sun oriented control is the foremost without issues helpful and free supply of control considering the truth that ancient times. Sun based photovoltaic makes utilize of the sun's warmness to create electrical vitality for lighting installations household and building, going for strolls engines, pumps, electric fueled apparatuses, and lighting. Sun based power can meet three superb applications: warming water, warming discuss, and innovation of electrical vitality in any private or trade setting. There are three major strategies to tackle photovoltaic power such as photovoltaic, sun based warming and cooling, and concentrating photovoltaic quality. Sun powered connected sciences can tackle power for a extend of employments, comprehensive of creating power, providing mellow for ease inside environmental, and warming water for domestic, and industrial use.

2.2 Impact of temperature

Like all other semiconductor devices, solar cells are sensitive to temperature. Increases in temperature reduce the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is therefore needed to break the bond. In the bond model of a semiconductor band gap, a reduction in the bond energy also reduces the band gap. Therefore increasing the temperature reduces the band gap. In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage. The impact of increasing temperature is shown in the figure 2.2.1.

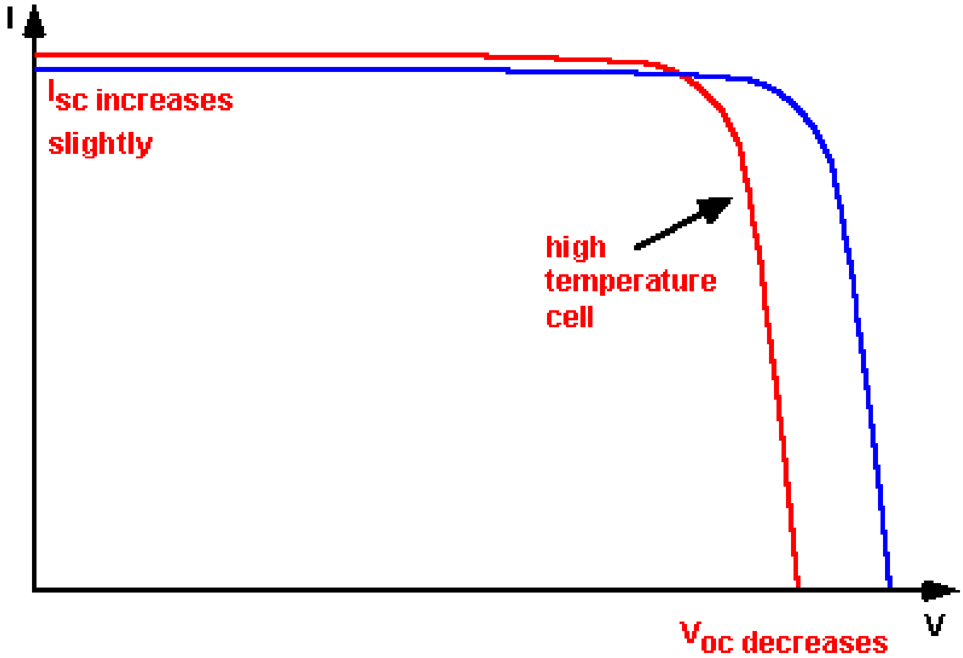

Fig 2.2.1 The effect of temperature on the IV characteristics of a solar cell

Like all different semiconductor devices, photo voltaic cells are touchy to temperature. Increases in temperature minimize the band gap of a semiconductor, thereby effecting most of the semiconductor cloth parameters. The minimization in the band hole of a semiconductor with growing temperature can be seen as growing the electricity of the electrons in the material.

Lower electricity is consequently wished to damage the bond. In the bond mammequin of a semiconductor band gap, a discount in the bond electricity additionally reduces the band gap. Therefore, growing the temperature reduces the band gap.

In a photo voltaic cell, the parameter most affected by using an amplifier in temperature is the open-circuit voltage. The effect of growing temperature is proven in the figures 2.2.2: *[17]*

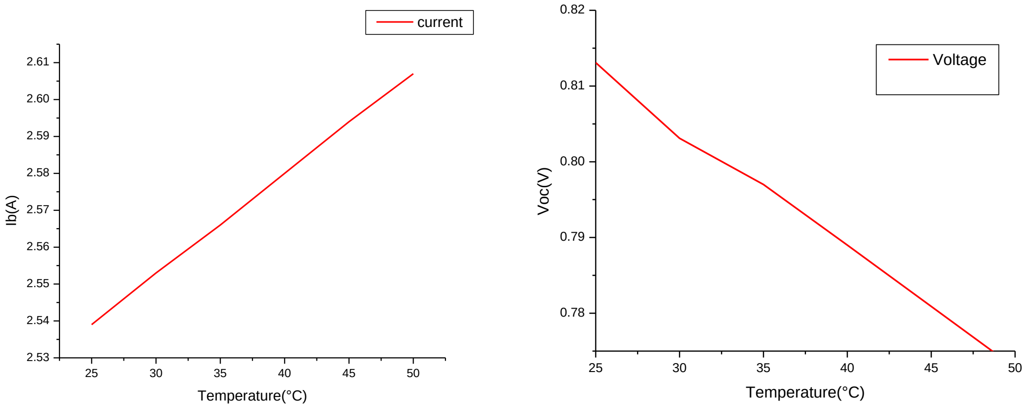

Figure 2.2.2: Graph between temperature variation with current and voltage

2.3 IV Curve

The IV curve of a solar cell is the superposition of the IV curve of the solar cell diode in the dark with the light-generated current. The light has the effect of shifting the IV curve down into the fourth quadrant where power can be extracted from the diode. Illuminating a cell adds to the normal "dark" currents in the diode so that the diode law becomes:

$$I = I_0 [\exp (qVnkT) - 1] - IL$$

Where, I_L = light generated current.

The ideal short circuit flow of electrons and holes at a p-n junction. Minority carriers cannot cross a semiconductor-metal boundary and to prevent recombination they must be collected by the junction if they are to contribute to current flow. The effect of light on the current-voltage characteristics of a p-junction.

The equation for the IV curve in the first quadrant is:

$$I = I_L - I_0 [\exp (qVnkT) - 1]$$

The -1 term in the above equation can usually be neglected. The exponential term is usually >> 1 except for voltages below 100 mV. Further, at low voltages, the light generated current I_L dominates the I_0 (...) term so the -1 term is not needed under illumination.

$$I = I_L - I_0 [\exp (qVnkT)]$$

Plotting the above equation gives the IV curve below with the relevant points on the curve labeled and discussed in more detail on the following pages. The power curve has a maximum denoted as P_{MP} where the solar cell should be operated to give the maximum power output. It is also denoted as P_{MAX} or maximum power point (MPP) and occurs at a voltage of V_{MP} and a current of I_{MP}.

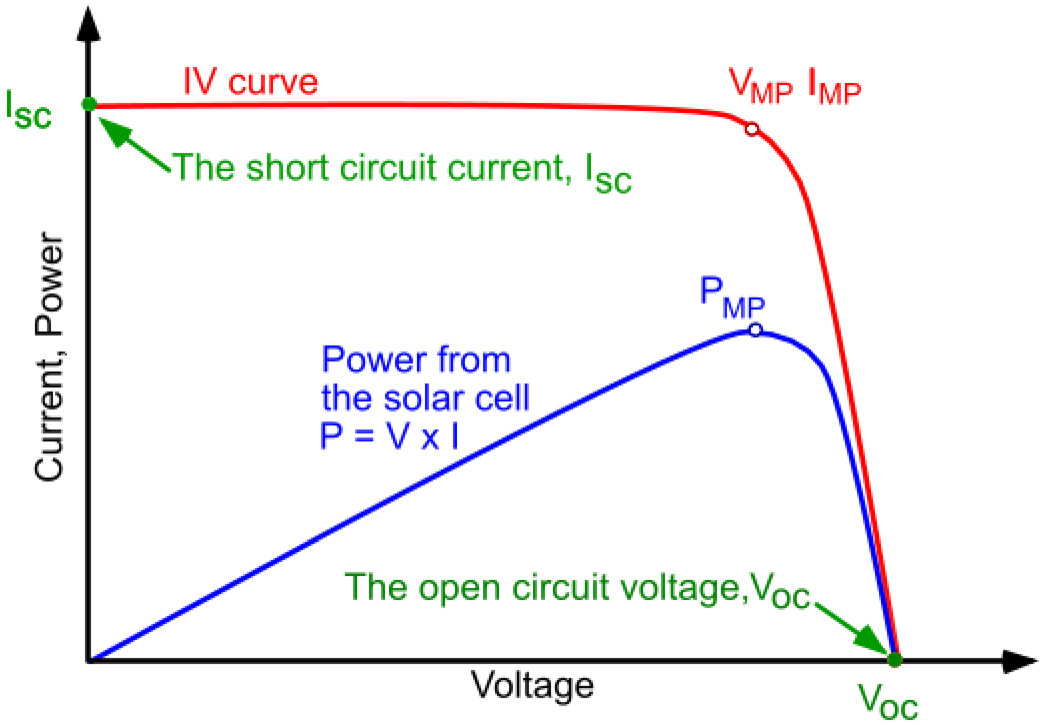

Figure 2.3: IV curve [18]

2.4 Fill Factor

The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero. The "fill factor", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc} so that:

$$FF=P_{MP}/V_{OC}\times I_{SC}$$

$$FF=V_{MP}I_{MP}/\ V_{OC}\times I_{SC}$$

Graphically, the FF is a measure of the "squareness" of the solar cell and is also the area of the largest rectangle which will fit in the IV curve. The FF is illustrated in figure 2.4. As FF is a measure of the "squareness" of the IV curve, a solar cell with enough energy to overcome the work function W of the grain and the coulomb potential, (if the grain is positively charged), they can be injected into the gas phase with excess kinetic energy. The average energy per ionization is depends on the ionization cross section of the grain, kinetic energy of photo electron and the density. In case of PAH molecule, ionization potential is 5 eV and average energy per ionization of neutral grain becomes 4.31 eV (50,000 K) .

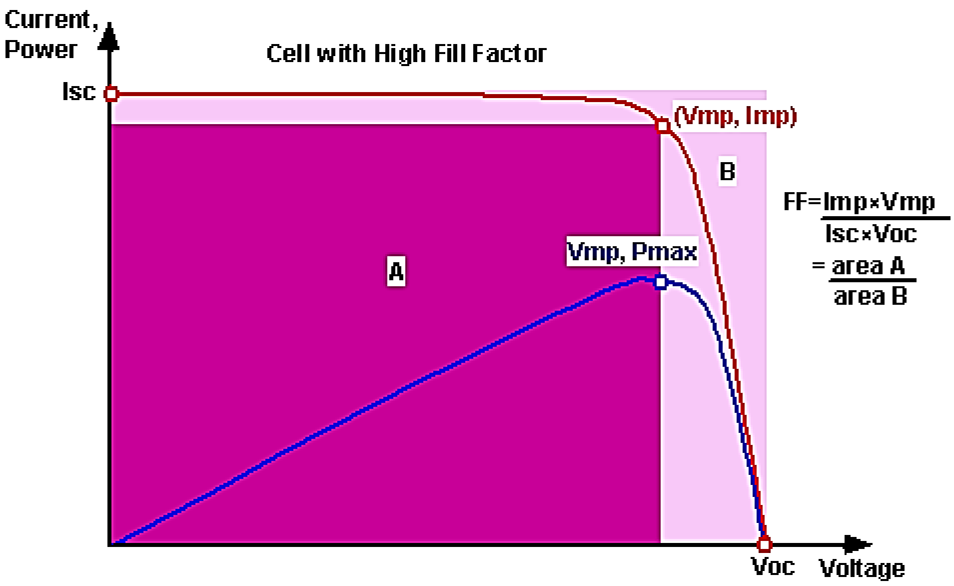

Figure: 2.4: Graph of cell output current (red line) and power (blue line) as a function of voltage. Also shown are the cell short-circuit current (I_{sc}) and open-circuit voltage (V_{OC}) points, as well as the maximum power point (V_{mp}, I_{mp}). [19,20].

2.5 PC1D

PC1D is the most commonly used of the commercially available solar cell modelling programs. Its success is based on its speed, user interface and continual updates to the latest cell models. It is used to simulate new device performance and also for new users to develop an understanding of device physics. PC1D is now available free of charge from the University of NSW. The raw source code of PC1D is now available on Source Forge for programmers and developers. PV Lighthouse has more PC1D resources including a batch file generator. The user can alter the cell parameters and either use internal models or provide externally measured data.

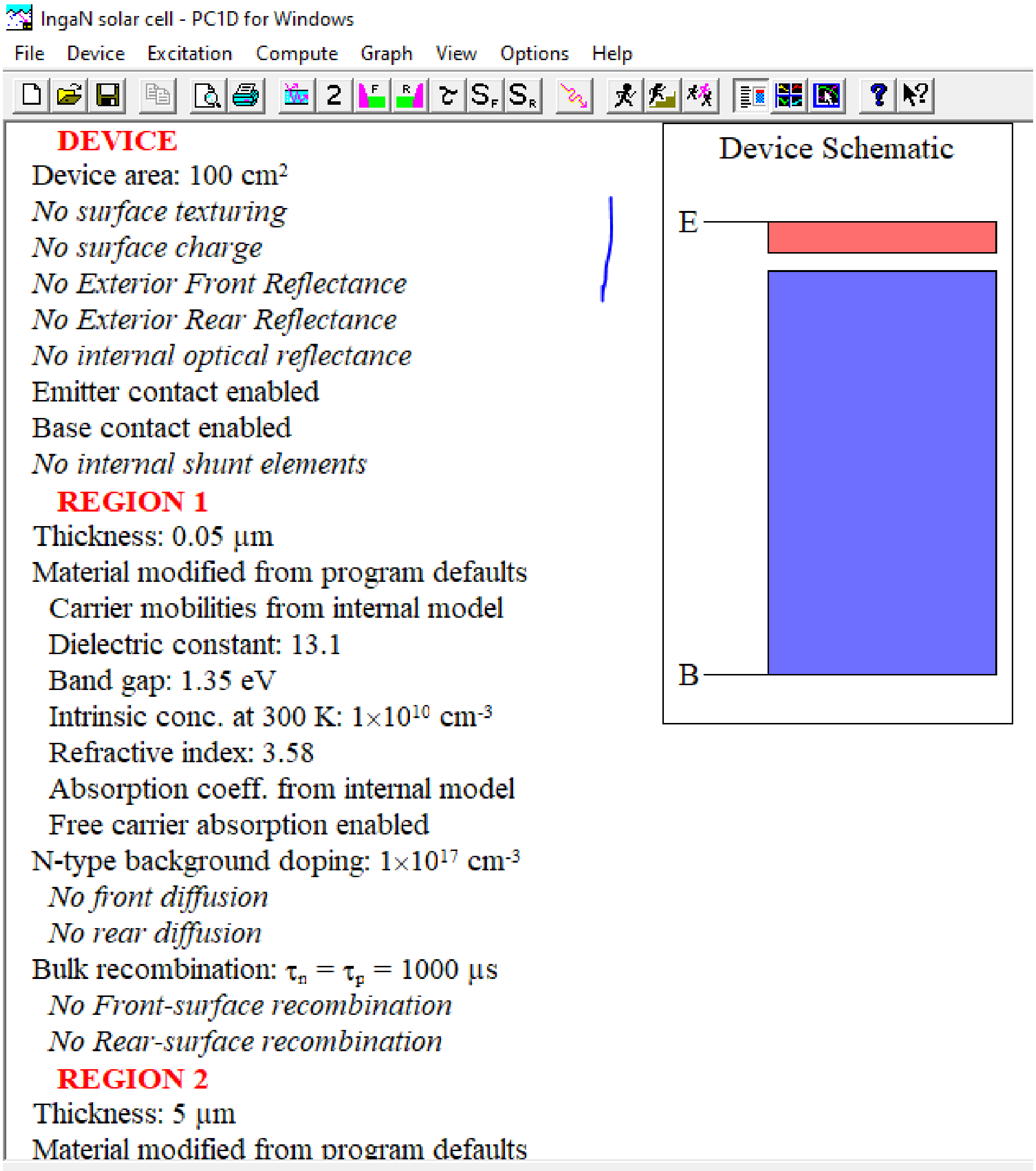

Figure 2.7: Setup of a problem in PC1D.

2.6 Lifetime

2.6.1 Carrier lifetime

A definition in semiconductor physics, carrier lifetime is defined as the average time it takes for a minority carrier to recombine. The process through which this is done is typically known as minority carrier recombination. The energy released due to recombination can be either thermal, thereby heating up the semiconductor (*thermal recombination* or non- radiative recombination, one of the sources of waste heat in semiconductors), or released as photons (*optical recombination*, used in LEDs and semiconductor lasers). The carrier lifetime can vary significantly depending on the materials and construction of the semiconductor. Carrier lifetime plays an important role in bipolar transistor and solar cells. In indirect band gap semiconductors, the carrier lifetime strongly depends on the concentration of recombination centers. Gold atoms act as highly efficient recombination centers, silicon for some high switching speed diodes and transistors is therefore alloyed with a small amount of gold. Many other atoms, e.g. iron or nickel, have similar effect [21].

2.6.2 Bulk Lifetime

As discussed elsewhere, there are various recombination mechanisms within even a uniformly doped piece of semiconductor. In the bulk of the material the carriers recombine by either radiative (also known as band-to-band) recombination, Auger recombination or Shockley-Read-Hall (SRH) via traps within the energy gap. The lifetime of carriers in the material bulk τ_b is composed of radiative lifetime τ_{rad}, Auger lifetime τ_A and a SRH lifetime τ_{SRH} with the relation:

$$\frac{1}{\tau_b} = \frac{1}{\tau_{rad}} + \frac{1}{\tau_A} + \frac{1}{\tau_{SRH}}$$

For an indirect band gap semiconductor such as silicon, τ_{rad} is very large and usually neglected [22].

2.7 Optimization

Intelligent control strategies and optimization methods are utilized in solar energy systems. Optimizations strategies reduce emissions and costs of system into maximizing reliability. Solar energy systems enhance the output power and minimize the interruptions in the connected load. The cell design is optimized by identifying the properties of the optimal matching materials for a given absorber and a set of values of various physical parameters is determined for all the other layers. Optimization the process of taking highest value of efficiency when we vary any parameter by simulation on solar cell.

CHAPTER 3 REGION OF INTEREST

3.1 Temperature changes

Step 1: Variation of I_b and V_{oc} when temperature changes at bulk recombination 1000 µs:

We had taken the value of base current and base voltage when temperature was changed. We had changed the value of temperature in this project. When we increased the value of temperature, the value of base current was slightly increased and value of base voltage was slightly decreased.

Step 2: Variation of power and efficiency when temperature changes and bulk recombination 1000 µs:

We had taken the value of power and efficiency when temperature was changed. We had changed the value of temperature in this project. When we increased the value of temperature, the value of power and efficiency was slightly increased at equal ratio.

3.2 Bulk recombination changes of N- InGaN

Step 1: Variation of I_b and V_{oc} when bulk recombination of N –InGaN changes at temperature 25°C and bulk recombination of P-InGaN 1000 µs: We had taken the value of base current and base voltage when bulk recombination of N –InGaN changes at temperature 25C and bulk recombination of P-InGaN 1000 µs. We had changed the value of bulk recombination of N- InGaN in this project. When we increased the value of bulk recombination of N- InGaN, the value of base current was constant at one value and value of base voltage was slightly increased.

Step 2: Variation of power and efficiency when bulk recombination of N –InGaN changes at temperature 25°C and bulk recombination of P-InGaN 1000 µs: We had taken the value of power and efficiency when bulk recombination of N –InGaN was changed. We had changed the value of bulk recombination of N –InGaN in this project .When we increased the value of bulk recombination of N –InGaN, the value of power and efficiency was increased at equal ratio.

3.3 Bulk recombination changes of P- InGaN

Step 1: Variation of I_b and V_{oc} when bulk recombination of P–InGaN changes at temperature 25°C and bulk recombination of N-InGaN 1000 µs:

We had taken the value of base current and base voltage when bulk recombination of N –InGaN changes at temperature 25C and bulk recombination of P-InGaN 1000 µs. We had changed the value of bulk recombination of N- InGaN in this project. When we increased the value of bulk recombination of N- InGaN, the value of base current was constant at one value and value of base voltage was slightly increased.

Step 2: **Variation of power and efficiency when bulk recombination of P –InGaN changes at temperature 25°C and bulk recombination of N-InGaN 1000 µs:**

We had taken the value of power and efficiency when bulk recombination of P –InGaN was changed. We had changed the value of bulk recombination of P –InGaN in this project .When we increased the value of bulk recombination of P –InGaN, the value of power and efficiency was increased at equal ratio.

CHAPTER 4 METHODS OF ANALYSIS

4.1 PC1D Simulation

Each value of interest are analyzed using software PC1D software. PC1D is the most commonly used of the commercially available solar cell modelling programs. Its success is based on its speed, user interface and continual updates to the latest cell models. It is used to simulate new device performance and also for new users to develop an understanding of device physics. PC1D is now available free of charge from the University of NSW. The raw source code of PC1D is now available on Source Forge for programmers and developers. PV Lighthouse has more PC1D resources including a batch file generator.

4.2 Origin software

Origin is primarily a GUI software with a spreadsheet front end. Unlike popular spreadsheets like Excel, Origin's worksheet is column oriented. Each column has associated attributes like name, units and other user definable labels. Instead of cell formula, Origin uses column formula for calculations.Recent versions of Origin have introduced and expanded on batch capabilities, with the goal of eliminating the need to program many routine operations. Instead the user relies on customizable graph templates, analysis dialog box Themes which save a particular suite of operations, auto recalculation on changes to data or analysis parameters, and Analysis Templates™ which save a collection of operations within the workbook..

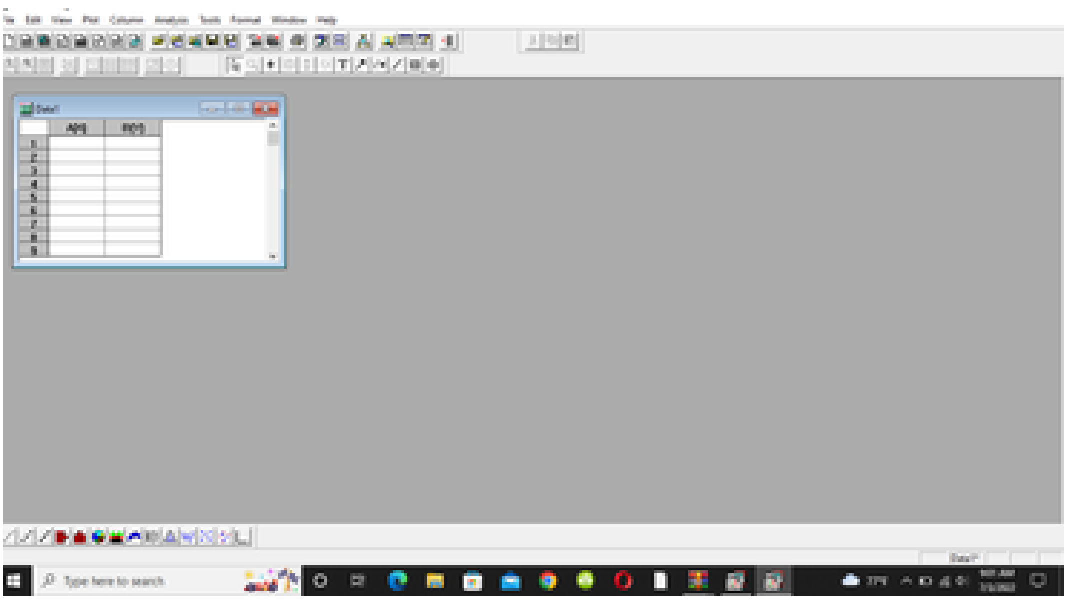

Figure 4.2.1: Screenshot of Origin (data analysis software)

Origin also has a scripting language (LabTalk) for controlling the software, which can be extended using a build languagues. Other programming options include an embedded Python environment, and an R Console plus support for Reserve. Origin can be also used as a COM server for programs which may be written in Visual Basic .NET, C#, LabVIEW, etc.Origin project files (.OPJ) can be read by the open source LabPlot or SciDAVis software. The files can also be read by QtiPlot but only with a paid "Pro" version.[23]

4.3 Impact of temperature

We studied the temperature variation takes the all parameter fixed lying in the Pc1D software by simulation of device area 100 cm^2. We took the fixed value of parameter of InGaN solar cell to find the impact of temperature .and we found the changes of base current and voltage when we changed the value of temperature. Therefore, we got the impact of temperature.

4.4 Impact of Bulk recombination

We studied the bulk recombination variation takes the all parameter fixed lying in the PC1D software by simulation of device area 100 cm^2.We took the fixed value of parameter of IngaN solar cell to find the impact of carrier lifetime .and we found the changes of base current and voltage when we changed the value of bulk recombination. Therefore, we got the impact of carrier lifetime.

4.5 Solar cell Efficiency

Solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted via photovoltaic into electricity by the solar cell. The efficiency of the solar cells used in a photovoltaic system, in combination with latitude and climate, determines the annual energy output of the system. For example, a solar panel with 20% efficiency and an area of 1 m^2 will produce 200 kWh/yr at Standard Test Conditions if exposed to the Standard Test Condition solar irradiance value of 1000 W/m^2 for 2.74 hours a day. Usually solar panels are exposed to sunlight for longer than this in a given day, but the solar irradiance is less than 1000 W/m^2 for most of the day. A solar panel can produce more when the sun is high in the sky and will produce less in cloudy conditions or when the sun is low in the sky. The sun is lower in the sky in the winter.

In a high yield solar area like central Colorado, which receives annual insolation of 2000 kWh/m^2/year,[24] such a panel can be expected to produce 400 kWh of energy per year. However, in Michigan, which receives only 1400 kWh/m^2/year, annual energy yield will drop to 280 kWh for the same panel. At more northerly European latitudes, yields are significantly lower: 175 kWh annual energy yield in southern England under the same conditions [25].

Schematic of charge collection by solar cells. Light transmits through transparent conducting electrode creating electron hole pairs, which are collected by both the electrodes. The absorption and collection efficiencies of a solar cell depend on the design of transparent conductors and active layer thickness.[26]

Several factors affect a cell's conversion efficiency value, including its reflectance, thermodynamic efficiency, charge carrier separation efficiency, charge carrier collection efficiency and conduction efficiency values.[27][26] Because these parameters can be difficult to measure directly, other parameters are measured instead, including quantum efficiency, open-circuit voltage (V_{OC}) ratio, and § Fill factor (described below). Reflectance losses are accounted for by the quantum efficiency value, as they affect "external quantum efficiency."

Recombination losses are accounted for by the quantum efficiency, V_{OC} ratio, and fill factor values. Resistive losses are predominantly accounted for by the fill factor value, but also contribute to the quantum efficiency and V_{OC} ratio values. In 2019, the world record for solar cell efficiency at 47.1% was achieved by using multi-junction concentrator solar cells, developed at National Renewable Energy Laboratory, Golden, Colorado, USA[28]

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{max}=V_{OC}I_{SC}FF$$

$$\eta=V_{OC}I_{SC}FF/P_{in}$$

Where: V_{oc}, I_{sc}, FF and η open-circuit voltage, short-circuit current, fill factor and efficiency respectively.

CHAPTER 5

RESULT AND DISCUSSION

A schematic diagram of proposed p–n InGaN homojunction solar cell. P-layer and n-layer thickness values are 5 μm and 50 μm, respectively in figure below.

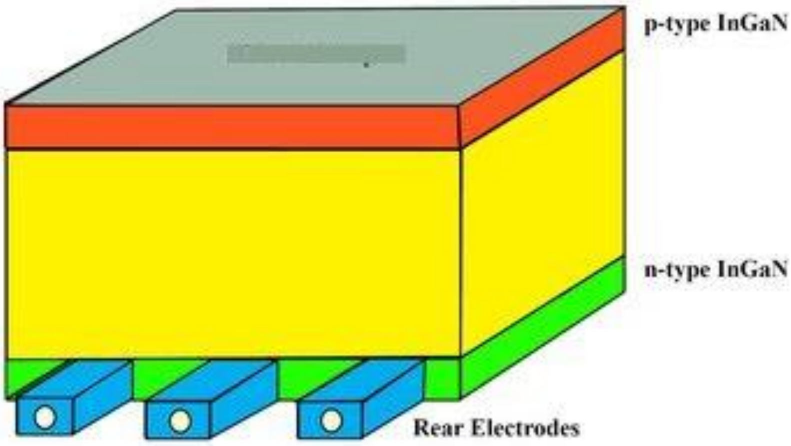

Fig. 5. - A schematic diagram of proposed p–n InGaN homojunction solar cell

Here ,we can see the figure of InGaN single junction solar cell .We assumed the value of thickness of P-InGaN is nearly 0.05μm and N –InGaN is 5 μm in figure below respectively.

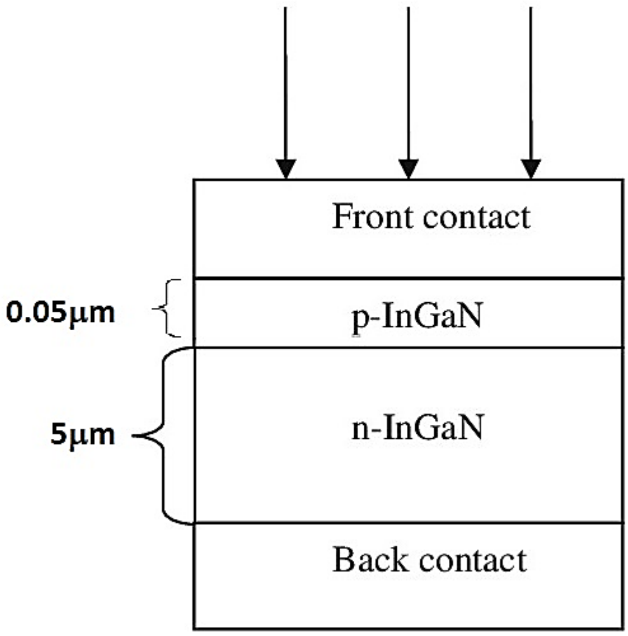

Fig.5.0-InGaN single junction solar cell

Table I. Material parameters used in PC1D simulation tool on InGaN solar cell

Parameter	**Value N- InGaN**	**Value P InGaN**
Thickness	0.5 μm	5 μm
Dielectric constant	13.1	13.1
Band gap	1.35eV	1.35eV
Intrinsic conc.	1×10^{10} cm^{-3}	1×10^{10} cm^{-3}
Refractive index	3.58	3.58
Doping	$1\times10^{17} cm^{-3}$	$1\times10^{17} cm^{-3}$
Electron number	1000	1000
Hole number	170	170

5.1 Impact carrier of N-InGaN Solar cell:

For achieving the best performance of a cell under standard solar illumination, 0.5 μm and 1.35eV, thickness and bandgap of the n region then should be optimized. For the efficiency optimization, it is assumed that proposed cell has maximum efficiency in the active region. Same as the detailed balance theory evaluation, which is based on thermodynamical approach to determine maximum efficiency. Our calculations show that maximum efficiency conversion occurred about 25 °C temperature and bulk recombination of N - InGaN is 1000μs. Bulk recombination of P - InGaN is constant.

In this project work, we see the variation of bulk recombination of N - InGaN semiconductor at bulk recombination of P - InGaN of semiconductor is 1000 μs and temperature 25 °C remain constant. We have taken the value of bulk recombination of N - InGaN are 0.001, 0.01, 0.1, 1, 10, 100, 1000 μs respectively. And we tried to get changes of current and voltage.

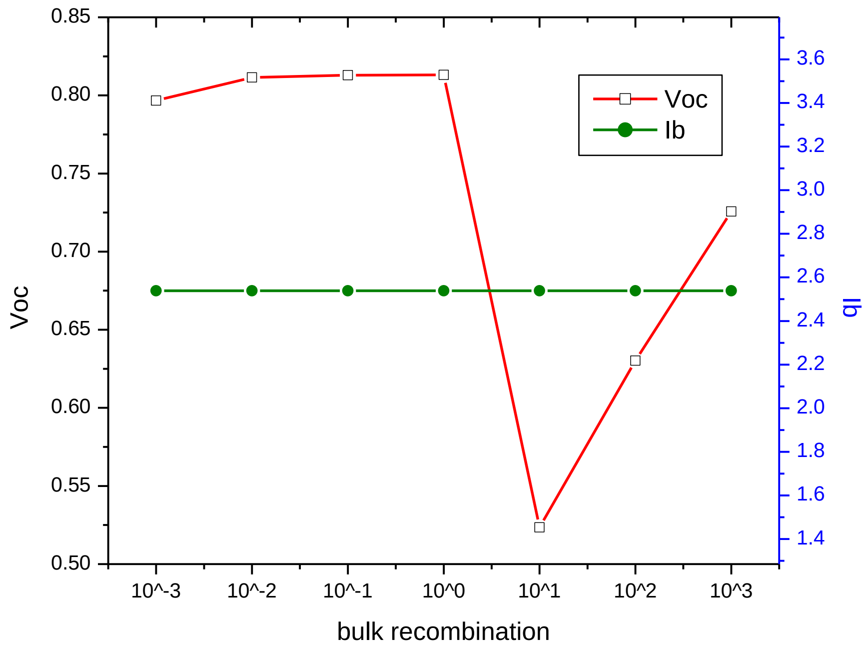

Fig.5.1 (a): graph of variation base current and base voltage with bulk recombination of N –InGaN

It is the variation of bulk recombination of N type taking temperature constants at 25 °C and bulk recombination of p - InGaN is constant which is 1000µs.We have shown graph between base voltage(V) and current(A) with bulk recombination of N - InGaN.

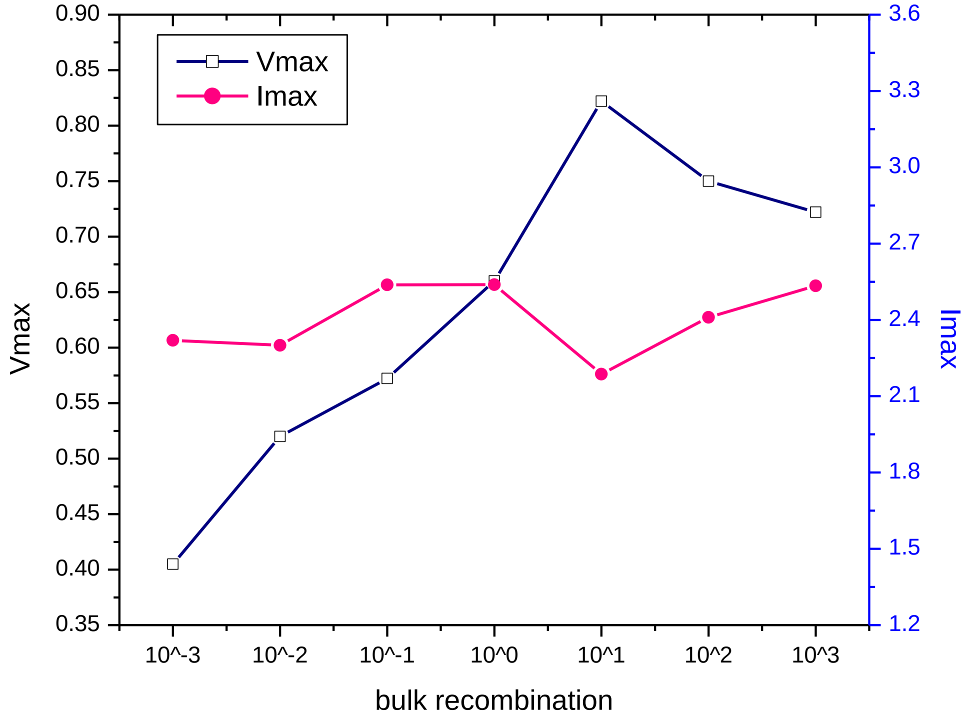

Fig: 5.1(b) –graph between Imax and Vmax with bulk recombination of N-InGaN

It is shown that graph between maximum voltage and maximum current with bulk recombination of N - InGaN.

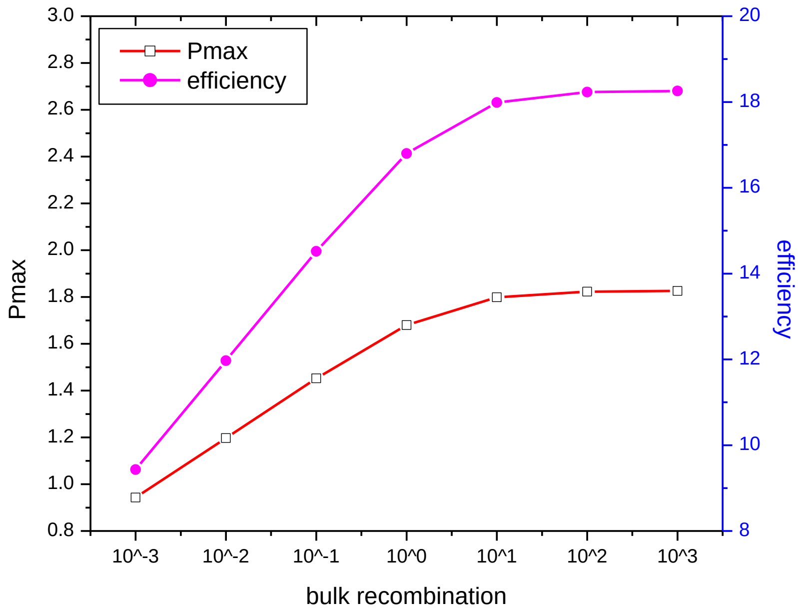

Fig: 5.1(c) – graph between Pmax and efficiency with bulk recombination of N-InGaN

This show the graph between maximum power and efficiency with bulk recombination of N type in fig. 5.1. (c) Here, We tried to get variation of bulk recombination of N - InGaN and keeping temperature and P - InGaN bulk recombination is constant. We have plotted the graph between base current and base voltage .maximum voltage and maximum current and also maximum power and efficiency. From these graph, we got the optimization of power at 25°C and 1000 µs bulk recombination of N - InGaN.

5.2 Impact carrier of P -InGaN Solar cell

For achieving the best performance of a cell under standard solar illumination, 0.5 µm and 1.35eV, thickness and bandgap of the p region then should be optimized. For the optimization, it is assumed that proposed cell has maximum efficiency in the active region. Same as the detailed balance theory evaluation, which based on thermodynamical approach to determine maximum efficiency. Our calculations show that maximum power conversion occurred about 25 °C temperature and bulk recombination of P type is 1000µs. And Bulk recombination of N - InGaN is constant.

In this project work, we see the variation of bulk recombination of P - InGaN semiconductor at bulk recombination of N - InGaN of semiconductor is 1000us and temperature is 25°C remain constant. We have taken the value of bulk recombination of P-InGaN are 0.001,0.01,0.1,1,10,100,1000 us respectively and we tried to get changes of current and voltage.

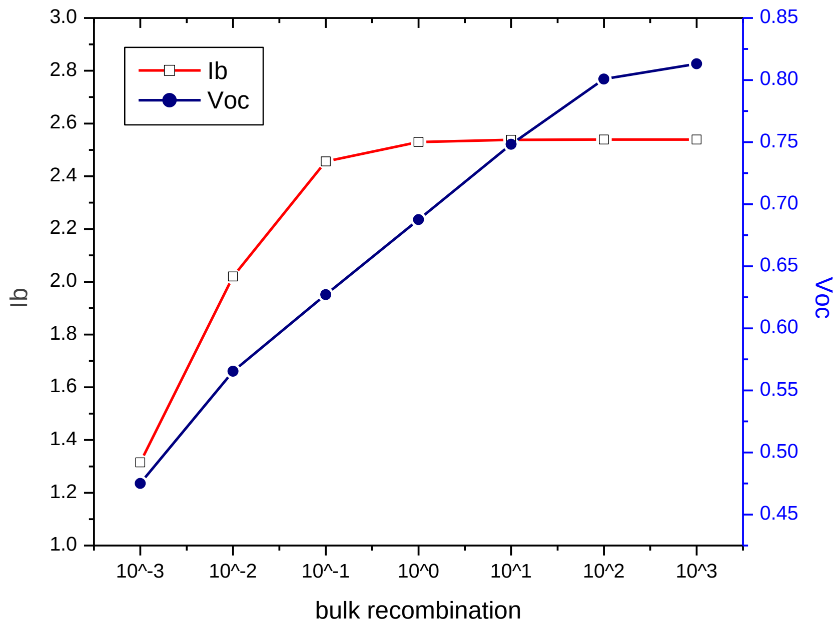

Fig 5.2(a): Graph between the base voltage and current with bulk recombination variation

It is the variation of bulk recombination of P - InGaN taking temperature constants 25 °C and bulk recombination of N - InGaN is constant which is 1000μs.We have shown graph between base voltage(V) and current(A) with bulk recombination of P type Fig . 5.2(a)

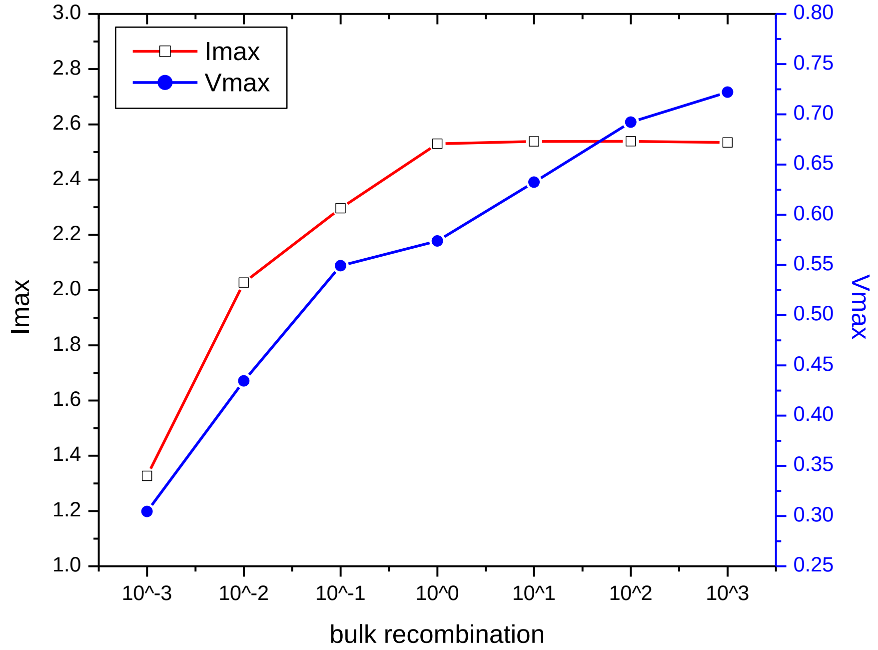

Fig: 5.2(b) – graph between Imax and Vmax with bulk recombination of P - InGaN

It is shown that graph between maximum voltage and maximum current with bulk recombination of P - InGaN in fig.5.2 (b)

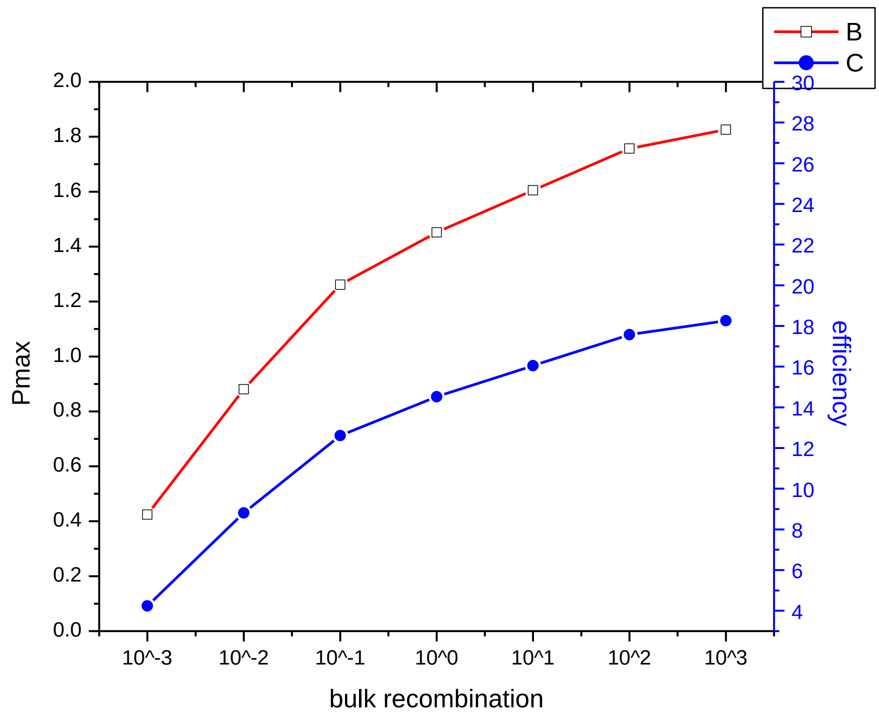

Fig 5.2(c)-graph between Pmax and efficiency with bulk recombination of P-InGaN

This show the graph between maximum power and efficiency with bulk recombination of P type is fig.5.2(c) Here, we tried to get variation of bulk recombination of P - InGaN type and keeping temperature and N - InGaN bulk recombination is constant. We have plotted the graph between base current and base voltage .maximum voltage and maximum current and also maximum power and efficiency. From these graph, we got the optimization of power at 25 °C and 1000 µs bulk recombination of N - InGaN.

5.3 Impact of temperature

For achieving the best performance of a single junction InGaN solar cell under effect of temperature. We use the value of bulk recombination of both N and P region is fixed that is 1000 µs .and we use the value of all parameter of InGaN single junction solar cell. We increases the value of temperature from 25 °C to 50°C and we have done simulation on PC1D .We get the value of base voltage ,base current and power .We compute and compare the graph of above value .We also see the maximum power ,At which value of temperature ,we get maximum power. We can get optimization from this. We are showing the graph of temperature effect with current and voltage, maximum current and voltage, maximum power and efficiency.

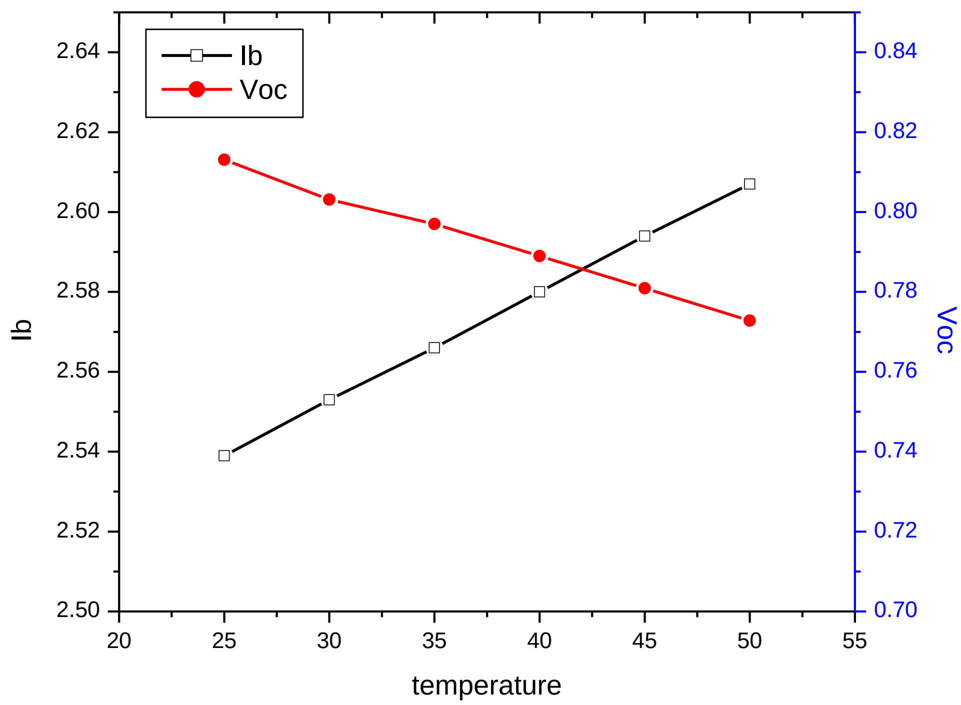

Fig.5.3 (a) –Graph between Ib and Voc with temperature

It is the variation of temperature and bulk recombination of P InGaN and bulk recombination of N - InGaN is constant with value 1000µs. We have shown graph between base voltage (V) and current (A) with variation of temperature as in Fig.5.3 (a).

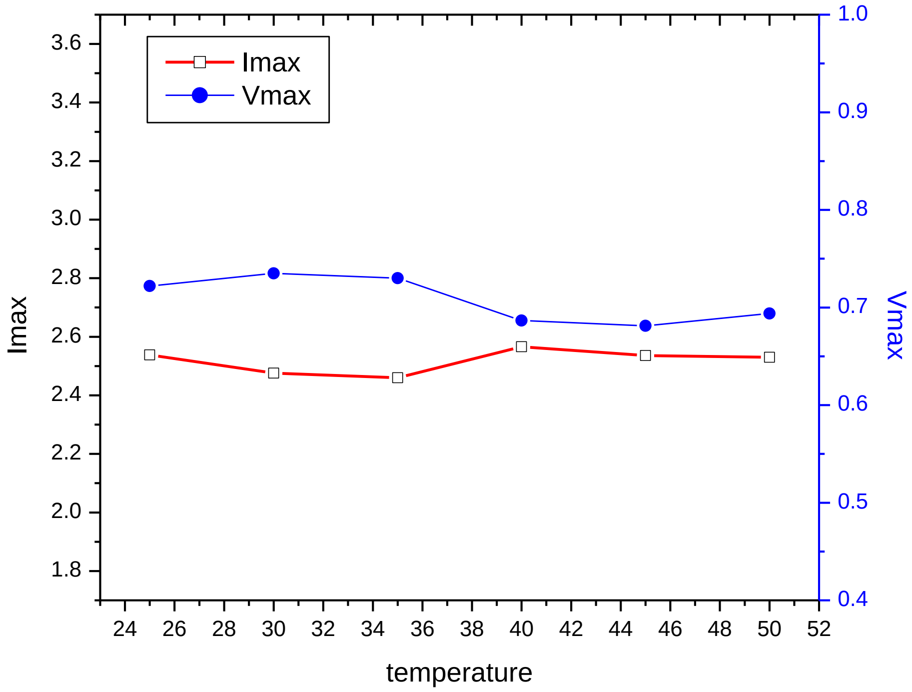

Fig.5.3 (b)-graph between Imax and Vmax with temperature

It is shown that graph between maximum voltage and maximum current with variation of temperature fig.5.3 (b)

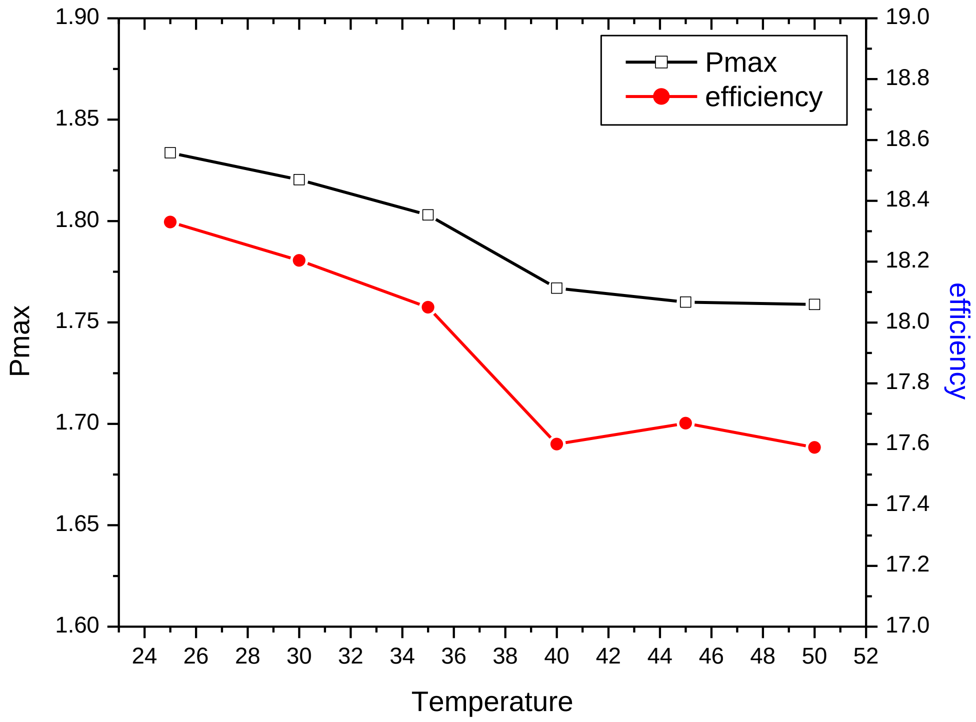

Fig.5.3(c)-graph between Pmax and efficiency with temperature

This show the graph between maximum power and efficiency with temperature variation is as shown in fig.5.3. (c)

Here, we tried to get variation of temperature and keeping bulk recombination of P type and N type is constant. We plotted the graph between base current and base voltage .maximum voltage and maximum current and also maximum power and efficiency. From these graph, we got the optimization at 25 °C and 1000 µs bulk recombination of N-InGaN and P - InGaN region.

5.4 Optimization

In solar cell simulation, we tried to study of impact carrier life time and temperature effect of InGaN single junction solar cell. We take the different value of bulk recombination of P type and N type single junction solar cell and we take variation of temperature .From simulation, we get the base current, base voltage and power. Then, we calculate efficiency and take the maximum value of efficiency .When we change the value of bulk recombination of P-InGaN and N-InGaN region and temperature ,we get maximum efficiency at one value .This is the optimize value and this calculation is optimization.

In this section, three steps are performed, the first one is variation of bulk recombination of N - InGaN keeping bulk recombination of P-InGaN (1000 µs) is constant and temperature (25°C) is constant. The second is variation of bulk recombination of P region keeping bulk recombination of N region (1000 µs) is constant and temperature (25°C) is constant. Third one is variation of temperature keeping bulk recombination of N - InGaN (1000 µs) and bulk recombination of P - InGaN (1000 µs) is constant.

In the first InGaN simulation, the layer configuration were adjusted as follows:

The N - InGaN layer thickness was 0.5 μm, the P - InGaN layer thickness was 5 μm ,the doping concentrations for these layers are 1×10^{17} cm^{-3}, dielectric constant is 13.1, bad gap 1.35eV, instrinsic constant 1×10^{10} cm^{-3}, refractive index 3.58, electron number and hole number 1000 and 170 . The obtained results were extracted from the *I-V* curve characteristics for the model as shown in Figure. The open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), and the efficiency of this initial simulation were found, respectively: V_{oc} =0.8131V, Isc = 2.539A, efficiency = 18.258, and. A maximum power can be observed in Figure. We got this value in above three steps. We got the optimization at 1000 µs when we took variation of bulk recombination of N-InGaN keeping temperature (25°C) and bulk recombination of P - InGaN (1000 µs) constant .also ,we got optimization at 1000 µs when we took variation of bulk recombination of P type keeping temperature (25°C) and bulk recombination of N - InGaN (1000 µs).In third step ,we got optimization at 25°C when we took variation of temperature keeping bulk recombination of N type and P type layer is constant(1000 µs).We got the same value of V_{oc}, I_{sc} ,power and efficiency. We get highest efficiency at temperature 25°C and bulk recombination of N type and P type 1000 µs. This three has same graph or I-V curve as shown in figure below

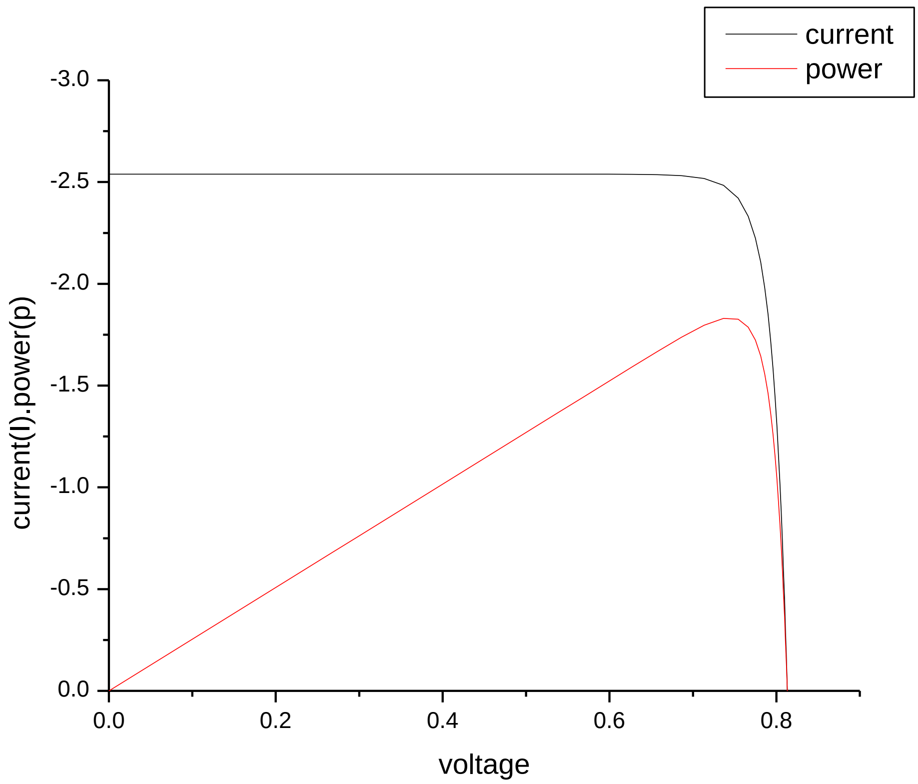

Fig.5.4- Base I-V/Power curve

Optimization is as shown in figure Fig. 5.4. We have got the optimization on the value of bulk recombination of N and P type region is 1000 µs and at 25°C temperature. Here, we have plotted the graph between base voltage vs. current and power.

CHAPTER 6

CONCLUSIONS

Study of Impact of Carrier Lifetime and Temperature on InGaN Single-Junction Solar Cell was performed by graph using origin software which result came from PC1D simulation. We also computed the value of efficiency when we looked forward the impact carrier lifetime and temperature. We got the optimization of efficiency 18.258 at temperature 25°C and bulk recombination of N -InGaN and P - InGaN.

Our conclusion are as follows:

- The impact of temperature when change the value of temperature at constant bulk recombination was showed the changes of base current and base voltage which was slightly increasing and decreasing during temperature was increasing.
- The impact of carrier lifetime of N-InGaN when change the value of bulk recombination of N–InGaN at constant temperature and constant bulk recombination of P –InGaN was showed the changes of base current and voltage which was constant and increasing slightly.
- The impact of carrier lifetime of P-InGaN when change the value of bulk recombination of P–InGaN at constant temperature and constant bulk recombination of N–InGaN was showed the changes of base current and voltage which was increasing.
- The optimize value has been got at the 1000 μs bulk recombination of N-InGaN and P–InGaN and 25°C temperature. We got highest efficiency at that value of temperature and bulk recombination which was 18.258. This is called optimize value and process is optimization. This suggests that our result is applicable on all value of InGaN parameter in all those variables.
- The total device area is 100 cm^2
- The dielectric constant is 13.1.
- The bad gap 1.35eV.
- The intrinsic constant is 1×10^{10} cm^{-3}.
- The doping concentration is $1\times10^{17} cm^{-3}$.
- Electron number and hole number 1000 and 170 respectively.
- Refractive index is 3.58.

6.1 Future work

The InGaN/GaN QW gadget is a beneficial approach for enhancement of photon absorption in extremely skinny cells designed for most effective photovoltaic response. The Quantum nicely thickness and duration of the MQW lively place want to be optimized for maximizing mild absorption. Generally, GaN based totally photovoltaic's have been fabricated on sapphire (Al_2O_3) substrates because it have been a great deal favored due their highest quality performance, however their massive purposes of these devices have been hindered due to the greater fee of the substrate, low thermal conductivity and unavailability in giant diameter. Silicon can be used as choice substrate thinking about the advantage of low cost, availability in giant diameter, excessive thermal-conductivity(1.5W/cm-K) and have properly characterized electrical and thermal properties. Thus, the usage of Si as a substrate, InGaN appreciate to its excessive effectivity and value effectiveness. The excessive overall performance and low prize photovoltaics cells can berealized via suitab;e polarization/band engineering, cautious system design, simulation prior to fabrication.

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