# DESIGN AND SIMULATION OF THIN FILM HETEROJUNCTION GALLIUM NITRIDE/POLYSILICON SOLAR CELL

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***ABSTRACT:*** *Area of renewable energy has always captivated researchers. Global demand of energy, navies the researchers to do exertion on the active area of renewable energy. Among all available renewable energy resource solar energy is the most feasible and readily obtainable energy. All we need a solar cell panel mounted on the roof top. Scientist and researchers are currently working on efficient design of the solar cell to achieve maximum conversion efficiency. For the very purpose, this paper dowries the design parameters of a thin film heterojunction based Gallium Nitride/p-Si solar cell. The solar cell is simulated in Silvaco Atlas which is a Virtual Wafer fabrication (VWF) tool. The maximum efficiency achieved is greater than 17.5% with short circuit current density of 30.12 mA/cm$^2$ and open circuit voltage of 0.701V.The results also demonstrated that conversion efficiency are reliant on bandgap energy of the window layer. The most important design parameters include selection of material for layers, thickness of layers and doping concentration of solar cell. At initial Gallium Phosphide/p-Si solar cell is simulated in Silvaco Atlas to compare the efficiency of our proposed Gallium Nitride/p-Si cell. Once the mesh properties, material properties, model statements and light file were established, the material for solar cell material and doping concentration of solar cell were modified to get maximum output from solar cell. The simulation program solves Auger recombination mechanisms, Shockley- Read-Hall and computes electron hole pair generation on the basis of optical parameters of each layer. Our proposed novel Gallium Nitride/p-Si solar cell produce superior and promising results.*

**Keywords:** Heterojunction, Solar cell, Thin film, Polysilicon

## INTRODUCTION

Global plea of energy is growing beyond the bounds of installed capacity of generation. Improved and alternative source of energy is needed to fulfill the future need of energy. Renewable energy is the best possible solution to cater global demand of energy. Among all available resources, solar energy is the best possible solution as it is expansively available. Solar panels are easy to install and starts generating electricity immediately. Moreover solar energy is green and environmental friendly. In Germany 25 million tons of carbon dioxide emanations were eluded due to 34.9 Tera Watt hour photovoltaic electricity consumed in year 2014[1].

In a world of photovoltaic, thin film based silicon solar cells were engrossed a prevalent attention due their abundant natural material, they produce no pollution and are easy to fabricate[2]. Substantial interest exists in heterojunction solar cells as the maximum conversion efficiency. Direct bandgap III-V compounds are promising candidates in today's competition of high efficiency solar cells. The cost of these III-V compound substrate is the major limiting factor, but different processing technique has been developed to epitaxial growth of these substrates and low temperature processing of epitaxial growth of silicon on III-V compound such as Gallium Arsenide[3].

Pakistan has faced a major catastrophe in the energy sector. The demand of energy is more than its generation capacity. In Pakistan the researchers are focusing the active area of photovoltaic solar cell. Government is also taking interest in development of solar cells. PECRET a government organization is fabricating silicon solar cell on commercial basis [4]. The PECRET have state of the art equipment for fabricating and processing photovoltaic solar cell. Government also deployed a solar power plant in Bahawalpur that have maximum generation capacity of 1000 Megawatts[5].Crystalline solar cells are installed in Bahawalpur solar park that have maximum efficiency of 15.6%.

The basic operation of solar cell is based on photovoltaic effect. Solar cells are often referred to as photovoltaic converter. The photoelectric explains that photon is absorbed by solar cells and an electron hole pair is generated. Solar cell have three basic phenomena happening in them[2].

a) Absorption of photon
b) Generation of electron and hole pair
c) Flow of charges through load

The simplest form of solar cell is a p-n junction. In recent advancement in photovoltaic solar cells, III-V compound are gaining attention due to high efficiency. Gallium Nitride is a III-V compound with direct bandgap of 3.4 eV[2]. Thus wide bandgap energy of Gallium Nitride is used to improve solar cell efficiency. Gallium Nitride has already find its place in the solar cell industry and used with Indium Gallium Nitride for space and satellite applications. The Gallium Nitride can also be deposited on silicon. Though the lattice mismatch of Gallium Nitride and silicon is too high but the use of buffer layer can easily compensate the mismatch. Gallium Nitride have high heat capacity make it feasible for high temperature processing.The major advantage of Gallium Nitride that doping of silicon can easily make Gallium Nitiride as a n-type material[6].

Solar cells with dimensions less than 10 micrometer are referred to as thin film solar cell. Thin film defines the characteristics of solar cells that they are easy to bend and are portable. Thin film solar cells have replaced bulky and heft crystalline solar cells. Thin film solar cells are used in calculators, watches and solar mobile chargers.

In our paper, thin film heterojunction based Gallium

Nitride/p-Si solar cell is proposed and simulated. Proposed solar cell has a wide band gap Gallium Nitride deposited on polysilicon to form a hetrojunction. Air Mass 1.5 spectrum is chosen which has optical power of 100 $mW/cm^2$[7]. The AM1.5 spectrum is used due to the fact that Pakistan is located on equator and have maximum availability of solar energy. European states that are far from equator used AM1.0 spectrum. Shockley Read Hall Model, Auger recombination method is also used in simulation. Auto meshing has been performed for solar cell structure. Gallium Nitride is used as a window layer. Bandgap of Gallium Nitride is very high which is useful to absorb maximum number of photons, reaching the surface of the solar cell. The series resistance is reduced due to high bandgap which in turn increases the open circuit voltage of the solar cell[8]. The window layer is made thin and heavily doped for enhanced recital.

## SOFTWARE DESCRIPTION

The model was simulated in Silvaco Atlas which is a Virtual Wafer Fabrication[9].Silvaco Atlas is a two dimensional simulation software used to simulate semiconductor devices such as light emitting diodes (LED's), transistors and EEROM's and solar cells. Silvaco Atlas simulate both the electrical and optical properties of physical semiconductor devices. Heterojunction thin film solar cells can easily be simulated and manipulated in it. Dark and light V-I characteristics of device can also be obtained from Silvaco Atlas. Internal parameters such as current density, carrier density, bandgap energy, acceptor and donor concentration are plotted against the length of solar cell. Meshing, thickness of material, definition of electrode and transparent conductive oxide are defined by the user. In Silvaco Atlas, simulation program follow set of sequence mentioned as follow.

a) Structure specification of device
b) Specification of material
c) Specification of models
d) Specification for numerical models and method to solve equations
e) Solution of given problems
f) Plotting of various output curves

Any semiconductor material that is not available in Silvaco Atlas library can easily be added by simple commands and by defining all properties of that material. Silvaco Atlas is an industrial grade simulation software and performed accurate simulation of the device[9].

## METHODOLOGY

An n+-GaN/i-p:Si/p+-Si solar cell is proposed as shown in figure 1. The solar structure. Optical properties of silicon such as refractive index, badngap are taken from[10]. The bandgap energy of Gallium Nitride is defined as 3.4eV however all other parameters of Gallium Nitride are by default in simulation.

Solar cell model is premeditated with much haughtier results. Dimension of solar cells are according to latest thin film technology[11].Solar cell dimension always are major contributor in efficiency. Changing the dimensions of solar cell are utilized in the solar cell optimization. The results of our simulation are compared with a reference cell as shown in figure 2. The reference cell has structure used Gallium Phosphide as a window layer which is also III-V compound. Gallium Phosphide has a direct bandgap of 2.26eV[11]. Gallium Phosphide has lattice mismatch of 0.37% with silicon which eliminate the use of buffer layer and reduction in cost. There are no dislocation issues while growing Gallium Phosphide on Silicon. In our solar cell we used Gallium Nitride due to its high bandgap.

Starting from the bottom, the first layer deposited is a Transparent Conductive Oxide(TCO). TCO are of many types and are used to increase the reception of photons. They are deposited both on top and bottom of solar cell. Indium Titanium Oxide is used as a TCO. Latest technology has yield more impressive TCO, the Aluminum doped Zinc Oxide.ZnO:Al have many advantage such as low cost, efficient and good light capturing ability[12]. Electrode connection is made up on ZnO:Al to extract charge carriers. Polysilicon was deposited on ZnO:Al. Polysilicon is doped with p type impurities. Polysilicon was chose because it is chap and less expensive. Bandgap of polysilicon is 1.12 eV[2]. The p type polysilicon layer was heavily doped to maintain flow of free charge carriers. Then another layer of polysilicon was deposited on p type polysilicon layer. This layer is called as intrinsic layer. This layer has less amount of doping. The thickness of intrinsic layer has direct impact on the efficiency, open circuit voltage and fill factor of the solar cell. The increase in thickness of intrinsic layer has direct relation with open circuit voltage. Increase in thickness will cause increase in open circuit voltage.

The window layer which is made up of Gallium Nitride was deposited on the top of intrinsic layer. The window layer should always be of such material that have high bandgap energy to absorb high energy photons. Gallium Nitride has many advantages as compared to other III-V compound such as high bandgap energy, nontoxic, long useful lifetime and ease to process. Gallium Nitride was doped with n type impurity as n type doping of Gallium Nitride is straightforward. A layer of ZnO:Al was also deposited on Gallium Nitride. The layer thickness of Aluminum doped ZnO can be optimized to get maximum efficiency[12].

The basic parameters calculated for Gallium Nitride/p-Si solar cells are as follows[2]

a) Open Circuit Voltage
b) Short Circuit Current Density
c) Fill Factor
d) Maximum Power

Open circuit voltage of the solar cell is given by

$$Voc = \left(\frac{KT}{q}\right)\ln(1 + \frac{Iph}{Io}) \qquad (1)$$

Where
K=Boltzman constant
Q= Charge on electron
$I_{ph}$=Photon current
$I_0$=Dark current

We see that there is point on V-I characteristics that have maximum current and maximum voltage which is called as maximum power point Pmax. Maximum power point tracking is implemented by using controllers to get maximum output from solar panels.

$$Pmax= Imax.Vmax. \qquad (2)$$

The current of a solar cell can be obtained by the equation

$$I = Iph - Io\,(e^{\frac{qv}{KT}} - 1) \qquad (3)$$

Fill factor is defined as maximum squareness on the V-I characteristic curve of the solar cell. Fill factor should be greater to have maximum output from solar cell. Greater the fill factor higher the value of short circuit current and open circuit voltage .Fill Factor of solar cell can be given by equation,

$$FF = \frac{Vmpp.Impp}{Voc.Isc} \qquad (4)$$

In the simulation software the solution of all these parameters is possible by using a simple command. Software has ability to generate many output specifications according to the length of solar cell. The main specification include electric field, bandgap energy, acceptor and donor concentration, electron affinity, potential and current density along the length of solar cell.

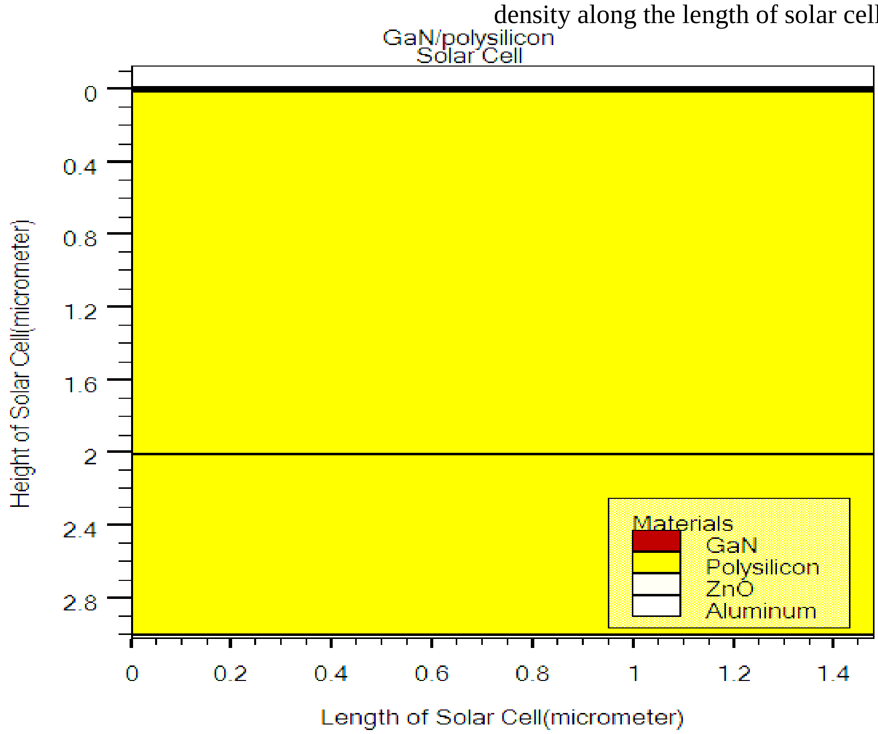


**Figure 3: Gallium Nitride/polysilicon solar cell**

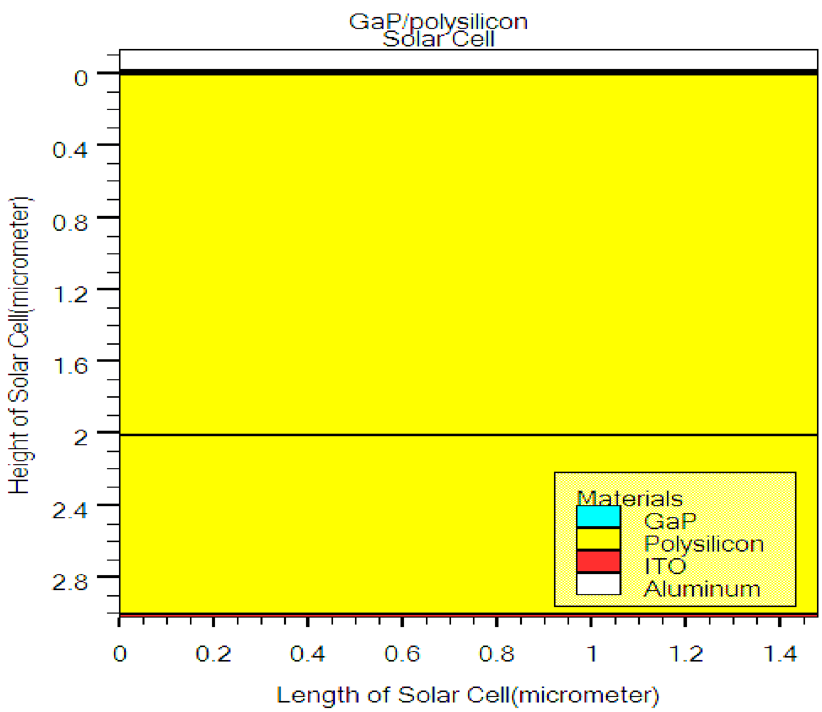


**Figure 2: Gallium Phophide/polysilicon solar cell**

## SIMULATION

The proposed Gallium Nitride/polysilicon solar cell is simulated and the results of the solar cells are compared with Gallium Phosphide/polysilicon reference solar cell. The simulation model for the two solar cell is given in table 2 and 3. Our solar cell have dimensions of reference solar cell but have different doping concentration than the Gallium

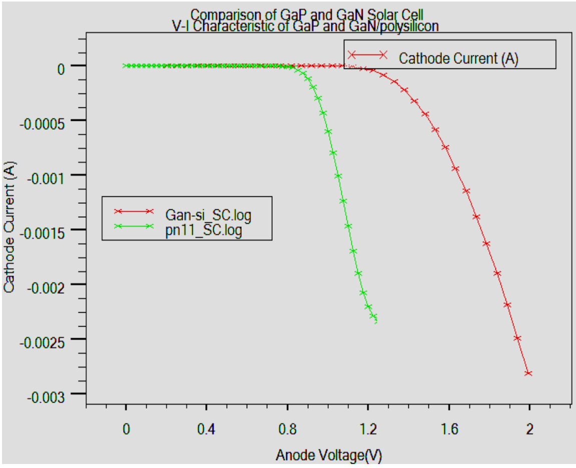


**Figure 3: Comparison of V-I Characteristics of GaP/polysilicon and GaN/polysilicon solar cell**

Porous polysilicon have less conduction due to dislocation of atoms. Crystalline silicon have high conductivity as compared to porous polysilicon but have higher conductivities than amorphous silicon[15].

A step voltage of 2.5V with step size of 0.025V is given in order to find the open circuit voltage of the solar cell. In practical scenario it is done by using a voltage source connected in parallel with solar cell. A null detector such as ammeter is connected between them. Open circuit voltage is found when current flowing through the ammeter become zero.

Electrodes are the most imperative component of solar cell to conduct majority charge carriers through load[2]. Different materials are available to be used as an electrode material but Aluminum electrodes are most feasible due to their efficiency and availability. In our design we used Aluminum electrode. The size of electrode was further optimized to get maximum efficiency[16].

## RESULTS DISCUSSION

After simulation, our proposed Gallium Nitride/p-Si solar cell we achieved short circuit current density Jsc, of 25.92 mA/cm2 and open circuit voltage Voc, of 0.72 V. Now by changing the doping concentration of n doped window layer to 1.5x1019 achieved short circuit current density Jsc, increases to 28.32 mA/$cm^2$ and open circuit voltage increases to 0.718V. Best combination of optimum value of voltage and current density is obtained by doping n type and p type material with doping concentration of $2X10^{19}/cm^3$. Intrinsic layer which is also a polysilicon material has low doping level. Due to low doping, static charges increases which in turn increases the electric field in intrinsic region. Electric field created will stop further recombination.

Phosphide/polysilicon solar cell. Doping concentration has a major role in determinng the efficiency of solar cel l [13]. We optimized doping concentrations firstly by using doping concentration of the reference solar cell. The results are not up to the mark. Then we used different doping concentration and find out the optimum value of doping concentration. Our proposed solar cell is optimized at donor concentration $N_D$ of $2X10^{19}$ /$cm^3$ and acceptor concentration $N_A$ of $2X10^{19}$ /$cm^3$. The window layer which is made up of Gallium Nitride is doped with n type impurity has major impact on open circuit voltage as bandgap energy is the function of open circuit voltage. III-V compound have maximum efficiency when they are deposited on silicon as a heterojunction solar cell. The Gallium Nitride has previously used with Indium Gallium Nitride for space applications. In our design we deposit Gallium Nitride with polysyilicon material which is porous. The reference solar cell used pure polysilicon with bandgap energy of 1.12 eV[2]. The pure polysilicon has drawback that it is brittle and easily breakable. In our solar cell design we introduce porous polysilicon with a bandgap energy of 1.5 eV[14] by introducing defects in polysilicon. Our proposed Gallium Nitride/p-Si shows superior results as compared to Gallium Phosphide/p-Si solar cell. Gallium Nitride proven to be superior due to high bandgap energy as compared to Gallium Phosphide. Gallium Phosphide have only 0.37 % lattice mismatch with Silicon. In contrast Gallium Nitride has disadvantage that it have large value of lattice mismatch with Silicon.

The comparison of V-I characteristics of two solar cell is given in figure 3. The characteristics clearly show that Gallium Nitride/p-Si solar cell have high value of open circuit voltage and short circuit current density. As compared Gallium Nitride/p-Si solar cell.The comparison of two solar cells parameter is given in table 3.

## CONCLUSION

A heterojunction thin film Gallium Nitride/polysilicon solar cell is simulated with an efficiency of 17.5%.Computer simulations provide an easy way to improve the design of solar cell. Dimensions of Gallium Nitride/polysilicon solar cell is same as Gallium Phosphide/polysilicon solar cell. Area of two solar cell is 1.48µm x 3.01 µm. Doping concentration of two solar cell is different. Doping of Gallium Nitride/polysilicon solar cell has to be different due to diverse nature of Gallium Nitride material. Intrinsic layer thickness which has direct impact on solar cell efficiency is optimized by changing the doping level. The thickness of intrinsic layer is maintained at 2µm to have best optimal combination of short circuit current density and open circuit voltage. Doping concentration of intrinsic polysilicon layer has best result at 1.5x1019 /cm3. The minority carrier lifetime of p type material was maintained greater than minority carriers of n type material. Results show that increase in doping concentration increase current density but increase open circuit voltage. Authors strappingly believed that fabrication of proposed Gallium Nitride/polysilicon solar cell will be a milestone in research area of solar cell design.

**Table 1: Parameters of Reference Gallium Phosphide/p-Si Solar cell[11]**

| Layer Material | Bandgap(eV) | Dielectric constant | Refractive Index | Electron mobility ($cm^2$/V-s) | Hole Mobility ($cm^2$/V-s) | Minority Carrier Lifetime(s) |
|---|---|---|---|---|---|---|
| GaP(window) (n-type, $10^{16}cm^{-3}$) | 2.26 | 11.1 | 3.02 | 150 | 150 | $1\times10^{-6}$ |
| Si(Absorber) (p-type, $10^{16}cm^{-3}$) | 1.12 | 11.7 | 3.42 | 1200 | 400 | $1\times10^{-6}$ |
| Si (BSF layer) (n-type, $10^{18}cm^{-3}$) | 1.12 | 11.7 | 3.42 | 1000 | 300 | $1\times10^{-7}$ |

Table 3: Parameters for simulation for Gallium Nitride/Polysilicon Solar Cell

| Material | n-GaN | i-p/Si | p-p/Si |
|---|---|---|---|
| Electron Mobility | - | 600 | 200 |
| Hole Mobility | - | 100 | 300 |
| Conduction band density at 300K | - | $1x10^{20}$ /$cm^3$ | $1x10^{20}$ /$cm^3$ |
| Conduction band density at 300K | - | $1x10^{20}$ /$cm^3$ | $1x10^{20}$ /$cm^3$ |
| Minority carrier lifetimes forElectrons | - | $1x10^{-6}$s | $1x10^{-7}$s |
| Minority carrier lifetimes forHoles | - | $0.1x10^{-6}$s | $0.1x10^{-6}$s |
| Bandgap Energy | 3.4eV | 1.5eV | 15eV |

Table 3: Comparison of GaP/p-Si and GaN/p-Si Solar cell

| Solar Cells | Jsc (mA/$cm^2$) | Voc (V) | FF | Efficiency (%) |
|---|---|---|---|---|
| GaP/polysilicon | 28.42 | 0.5882 | 0.8274 | 13.83 |
| GaN/polysilicon | 30.12 | 0.701 | 0.792 | 17.5 |

## FUTURE WORK

The simulation of solar cell can be further improved if data of buffer layer should also be incorporated. Buffer layers are needed as there is large mismatch between Gallium Nitride and Silicon. Back to back p-i-n junction can also be formed to obtain maximum output from solar cell. Intrinsic layer of solar cell can be optimized by changing the length of the layer. Moreover a material for intrinsic layer is chosen that have maximum value of absorption coefficient so that incident photon should have minimum reflections.

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