Applied Science Periodical **ISSN 0972-5504**
Volume - XXV, No. 1, February 2023
Journal website: www.internationaljournalsiwan.com
ORCID Link: https://orcid.org/0009-0008-5249-8441
Google Scholar: https://scholar.google.com/citations?user=BRweiDcAAAAJ&hl=en
Refereed and Peer-Reviewed Quarterly Periodical

Simple and Accurate method for increasing the Conversion efficiency of Solar Cells

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(Received: January 17, 2023; Accepted: February 20, 2023;
Published Online: February 28, 2023)

Abstract:

Solar energy has been looked upon as a serious source of energy for many years because of the vast amounts of energy that are made freely available. New technology created by mankind not only provides unprecedented power of economic development, but also provides mankind with a great ability to be harmony with the environment, the solar cell convent light energy into electrical energy and transmits into the load. In this paper, we studies on methods for increasing the conversion efficiency of solar cells, which can lead to more efficiency energy for the space technology, solar cell is a semiconductor photovoltaic element that converts light energy into electrical energy, using the photovoltaic effect of semiconductor, we have found that some of these methods can be Applied, to different solar cell materials can be put into practical production.

Introduction :

Solar energy creates a new life style for mankind and takes society and human into of energy conservation reduce pollution. It is exhaustible, and the use of solar energy will not damage the earth's ecology and environment, safe, low utilization cost and not restricted by geographical conditions.

A number of relevant studies [1-5] have been conducted in this field, but some method that are worth discussing. In fact, there are many factors that affect the conversion efficiency of solar cells. Based on the relevant studies, we have researched the effects of multifunctional materials p-n junction cells and gradient doping on increasing conversion efficiency of solar cells. We found that multi-functional layer p-n junction solar cells can respond to different spectrum, which means that multifunctional layer p-n junction solar cells have a higher conversion efficiency; the increasing gradient doping of the donor impurity and the acceptor impurity in the *n*-region respectively with increasing distance from the depletion layer is beneficial to increase the conversion efficiency.

Formulation :

The sun pours in energy all around us and nature has evolved method of converting the electromagnetic energy of its radiation to a form. The capability of these collection system to concentrate solar energy is described in terms of their mean flux concentration ratio $\tilde{C}$ over a targeted Area A at the focal plane, normalized with respect to the incident normal beam insulation I,

$$\tilde{C} = \frac{Q\ \text{Solar}}{\text{I.A}} \tag{i}$$

Where Q solar is the solar power intercepted by the target. $\tilde{C}$ is often expressed in units of "Sun" when normalized to $I = 1kw/m^2$. For the maximum power output of solar cell, we have the following equation.

$$\eta = \frac{P_m}{P_{in}} \times 100\% = \frac{I_m V_m}{P_{in}} \times 100\% \tag{ii}$$

The maximum possible current in a solar cell is I_{oc}, the maximum possible voltage is V_{co}, and the duty cycle of solar cell is defined as the ratio $\frac{I_m V_m}{I_{oc} V_{oc}}$. The duty cycle, which is a measure of the power that can be achieved by a solar cell, usually ranges from 0.7 to 0.8. The ratio product of the current and voltage of a solar cell at maximum output power to the product of the short-circuit current and open-circuit voltage is called the Fill Factor (FF) [4].

It is an important parameter for evaluating the output characteristics of solar cells. The large value of the fill factor, the more the output characteristics of the solar cell tend to be rectangular, and the higher the photoelectric current-voltage characteristic curve of a solar cell.

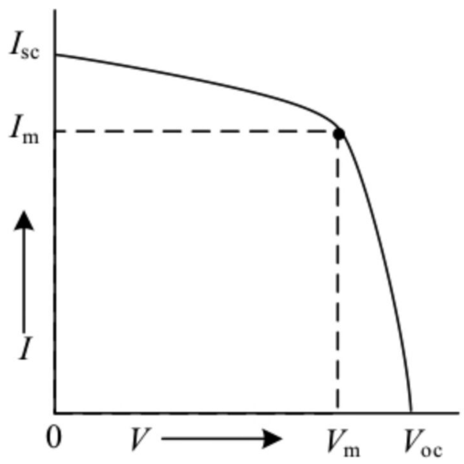

Figure 1 : The current-voltage characteristic curve of a solar cell.

The output power of a solar cell is V_{oc} I_{sc}, to increase the conversion efficiency, it is necessary to increase the three physical quantities of open circuit voltage V_{oc}, closed circuit current I_{sc}, and fill factor [6]. Increasing the open circuit voltage V_{oc} plays an important role in improving the performance of solar cells. The relationship with V_{oc} and the reverse saturation current I_o is : V_{oc} increase as I_o decreases. As the forbidden bandwidth E_g of the semiconductor increase, I_o decreases rapidly and therefore V_{oc} increase as E_g increase I_{sc} decreases because the number of photons with energy than E_g absorbed by the semiconductor material decreases as E_g increase.

This means that there is an optimum E_g for the highest energy conversion efficiency, and therefore the forbidden efficiency. Multifunctional layer p-n junction cells are those in which the different forbidden bandwidths of the layers match different bands in the solar spectrum, thus allowing the solar cell to respond to a wider spectrum and thus increase its conversion efficiency. The same principle is applied to heterojunction solar cells. A heterojunction is a p-n junction formed by two semiconductors with different forbidden bandwidths, and its energy band diagram at thermal equilibrium is shown in Figure 2.

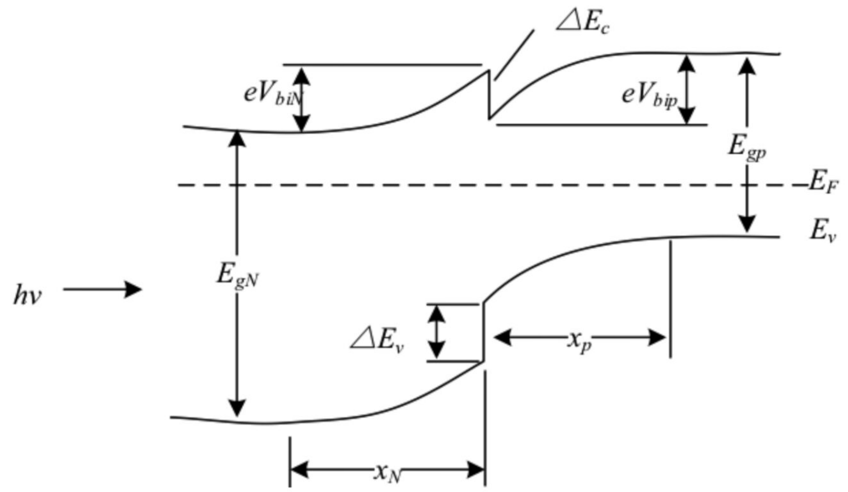

Figure 2 : Heterojunction energy band diagram.

In the case of conventional p-n junction solar cells, since the p-n junction is uniformly doped, carrier diffusion is only present in the depletion layer (about 1 millimeter) at the interface between the *p* and *n* regions, where a small linearity is formed, with zero electric field strength in the rest of the region [7]. When sunlight is incident on the p-n junction only the photogenerated electric field and forms a photogenerated current.

Due to the absence of electric field in other region, the photoelectron-hole pairs cannot be separated efficiently and the compounding rate of photoelectrons and holes is larger, so this part of the photogenerated carriers cannot produce photogenerated current most efficiently. For this conventional uniformly doped solar cell, we consider doping in the *p* and *n* regions, when the p-n junction can form a certain charge distribution under light-free equilibrium condition due to the diffusion of carriers in the homotypic region, thus generating an electric field. The efficient collection of photon-generated carriers is keys to increasing the efficiency of solar cells. Therefore we need to rationally design the electric field distribution within the semiconductor so that electrodes collect as many photogenerated carriers as possible, thereby increasing the closed circuit current I_{sc} and increasing the conversion efficiency of the solar cell.

We know that the ionization energy of doped impurities is much smaller compared to that of intrinsic semiconductor, and therefore doped impurities have more electrons excited from the bound state to the conduction band compared to intrinsic semiconductor. The theoretical studies show that exponential doping is more efficient that linear doping to obtain high intensity additional electric field. We assume that the doped impurities in a solar cell are doped as an exponential function.

$$N_d(\chi) = \alpha \exp(b\chi) \tag{iii}$$

We only need to discuss the electric field distribution within the p-n junction under gradient doping conditions to obtain a method for increasing the closed-circuit current I_{sc}. Then we can obtain the method for increasing the conversion efficiency of the solar cell.

Because the donor impurity is gradient doping in n-region, there is an impurity concentration gradient in the n-region, so the carriers will diffuse in the opposite direction along the x-axis, creating diffusion current in the p-n junction. Since the ionized impurity cannot move, the diffusion movement of carriers will make the carriers gradually and uniformly distributed, which makes the p-n junction semiconductor interior no longer remain electrically natural everywhere, so when the carriers are uniformly distributed, there must be an electrostatic field inside the semiconductor. This electrostatic field in turn generates carrier drift currents inside the p-n junction. For non-simplex semiconductors, when the internal electric field is balanced, the electron concentration satisfies equation (iv), where $n_e(X)$ is the electron concentration and $E_x(X)$ is the component of the electric field strength on the x-axis.

$$\frac{dN_e(X)}{dx} = -n_e(X)\frac{q}{k_B T} \times E_x(x) \tag{iv}$$

The electric field strength also satisfies Poisson's equation (Equation (v)), where ρ is the net charge density and $n_+(\chi)$ is the concentration of ions at that location on the x-axis after ionization of the impurity.

$$\frac{dE_x(x)}{dx} = \frac{\rho}{\varepsilon} = \frac{q}{\varepsilon}[n_+(x) - n_e(x)] \tag{v}$$

For general semiconductors, we consider that at room temperature the impurities in the non-degenerate semiconductor will be completely ionized, i.e.

$$n_+(\chi) = N_d(\chi) \tag{vi}$$

Substituting equation (iv) into equation (v) yields,

$$\frac{1}{n_e(x)}\frac{dn_e(x)}{dx} - \frac{1}{n_e(x)}\frac{d^2 n_e(x)}{dx^2} = \frac{q}{\varepsilon k_B T}[N_d(x) - n_e(x)] \tag{vii}$$

As we discussed earlier, it is only necessary to solve for the electric field distribution $E_\chi(\chi)$ inside the p-n junction under gradient doping conditions to obtain a method for improving the conversion efficiency of solar cells. We consider the electric field generated by each thin plate in the space around it to be a uniform electric field with the magnitude of the electric field strength as shown in equation (viii), where here the ε is the dielectric constant of the semiconductor material.

$$dE_x = \frac{\rho(x)}{2\varepsilon}dx \tag{viii}$$

Since the total charge in the depletion and p-region is zero, the electric field generated by these charges at any point in the n-region has zero strength.

Therefore, we consider that the total electric field at x in the n-region is only generated by the gradient-doped n-region charges. We assume that the width of the n-region is L. Since the width of the depletion layer is much smaller than the entire fen region, we assume that the homotypic diffusion carrier's diffusion. Carriers in the depletion layer are negligible and the total charge of the n-region other than the depletion is zero. The number of charges in the range 0 to χ in n-region must be the same as the number of charges in the range χ to L with opposite electrical properties and the charges in both ranges produce an electric field of equal magnitude and direction at χ. As shown in equation (vii), where n_e is the average concentration of the major carrier.

Discussion of the Results :

With solar technology improving continuously and the supporting of the state government, solar energy applications are increasingly widespread. For multifunctional layer p-n junction solar cells, suppose a photon is incident don a p-n junction with a large forbidden bandwidth. Then photons with energy less than E_{gn} will pass through the semiconductor material with the larger forbidden bandwidth, photons with energy greater than E_{gp} will be absorbed by the semiconductor material with the smaller forbidden bandwidth and photons with energy greater than E_{gN} will be absorbed by the material with the larger forbidden bandwidth (rather than passing through it as photons with energy less than E_{gN} do), with the resulting excess carriers in the diffusion length range are collected. If the value of E_{gN} is sufficiently large, photons with high energy will be absorbed in the spatial electric region be semiconductor materials with a small forbidden bandwidth. For the gradient doping to increase the conversion efficiency of solar cells, from equation (iii) we can obtain that

$$\bar{n_e} = \frac{1}{L}\int_0^L a\exp(bx)dx = \frac{a}{bL}[\exp(bL) - 1] \qquad \text{(ix)}$$

From equation (viii) and equation (ix), we can solver for $E_\chi(\chi)$, as shown in equation (x)

$$E_x(x) = \frac{aq}{b\varepsilon}\left\{[\exp(bx) - 1] - \frac{x}{L}[\exp(bL) - 1]\right\} \qquad \text{(x)}$$

From the above analysis, we find that for gradient doped single crystal silicon semiconductor, the impurities are completely ionized at room temperature condition and in the non-degenerate condition. Due to the diffusive motive of the carriers, the net charge distribution in the n-region outside the depletion layer should change from negative to positive with increasing χ if we use exponentially increasing doping. From equation (viii) and equation (x), we can intuitively see that $E_\chi(\chi)$ is constantly non-positive, which means that the direction of the electric field intensity on the *x*-axis points in the negative direction of the *x*-axis. This is in the same direction as the electric field intensity within the depletion layer, which facilitates the collection of photoelectrons by the electrode in the *n*-region and the drift of holes to the *p*-region, where they are collected by the electrode in the *p*-region under the acceleration of the gradient-doped *p*-region electric field, thus increasing the closed-circuit current I_{sc} of the p-n junction and improving the photo-electric conversion efficiency of the solar cell.

We use AFORS-HET to simulate gradient doping of solar cells and compare it with uniform doping. The main parameters used in the simulations are shown in Table 1 and the photovoltaic performance of uniformly and gradient doped solar cells are shown in Table 2.

Table 1 : Main parameters used in the AFORS-HET simulations

Parameters	**a-Si:H(n)**	**a-Si:H(i)**	**c-Si:H(p)**
Layer thickness (*nm*)	5	5	3×10^5
Dielectric constant	11.7	11.7	11.7
Electron affinity (*eV*)	3.6	3.6	4.05
Band gap (*eV*)	1.70	1.70	1.10
Optical band gap (*eV*)	1.70	1.70	1.10
Effective conduction band density (cm^{-3})	10^{20}	10^{20}	2.8×10^{17}
Effective valence band density (cm^{-3})	10^{20}	10^{20}	1.04×10^{17}
Electron mobility ($cm^2\ V^{-1}s^{-1}$)	5	5	1040
Hole mobility ($cm^2\ V^{-1}s^{-1}$)	1	1	412
Doping concentration of acceptors (cm^{-3})	0	0	1.5×10^{14}

Doping concentration of donators (cm^{-3})	$1\times10^{18} \sim 9\times10^{18}$	0	0
Thermal velocity of donators (cm/s)	1×10^5	1×10^5	1×10^5
Thermal velocity of holes (cm/s)	1×10^5	1×10^5	1×10^5
Layer density (g/cm^{-3})	2.328	2.328	2.328

Table 2 : Enhanced photovoltaic performance of solar cells with gradient doping compared to uniform doping

	V_{oc} (mV)	J_{sc} (mA/cm^{-2})	FF (%)	E_{FF} (%)
Uniform doping	568.00	28.60	80.72	13.12
Gradient doping	710.20	41.40	82.55	24.25
Increments	25.0%	44.7%	2.3%	84.9%

Conclusion :

We have shown that especially for the short wavelength sunlight, multifunctional layer p-n junction solar cells can respond to a different spectrum than single material p-n junction solar cells, which that multifunctional layer p-n junction solar cells have a higher conversion efficiency. For the gradient doping method to increase the conversion efficiency of solar cells, after analysis we find that only the increasing gradient doping of the donor impurity and the accepter impurity in the *n*-region and *p*-region respectively with increasing distance from the depletion layer is beneficial to increase the conversion efficiency. This conclusion applies not only to monocrystalline silicon, but also to other solar semiconductor materials.

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