Simultaneously Improvement of Heterojunction Solar Cells Efficiency by Electron Irradiation and Varying Series and Parallel Resistances

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Abstract: In this study, the relationships between in series and parallel resistances with Hetero Junction (HJ) solar cells and coincidently their behavior have been investigated under different doses of electron irradiation. V-I characteristics of heterojunction solar cell have been studied under various conditions. The variations of efficiency, JSC, VOC and fill factor have been studied under above conditions. The structure of heterojunction solar cells prepares a suitable situation to have variable stats.

Keywords: Electron irradiation ray, heterojunction, series and parallel resistances, solar cell

INTRODUCTION

In this research that all of works have been done of labratovars in institute of radiation problems at national science academy Baku Azerbaijan, we have experienced the behaviors of Hj solar cells at different conditions. One of the important problem is solar cell efficiency under radiation electron ray and at the same time varying series and parallel resistance and review their effects. This study was conducted based on the first-order criteria for the selection of Hetero Junction (HJ) solar cell materials. A figure of merit is developed and compared some of the many possible candidates for HJ couples. By using a low lattice-mismatch, isotype HJ to provide a window for a homo junction (i.e., a heteroface structure), a considerable reduction of surface recombination loss for direct band-gap materials can be obtained. The AlGaAs/GaAs cell is discussed as an example of such a structure and design of solar cells for concentrator systems. Finally, the CdS/InP cell is considered as an example of an isotype. HJ in which the properties of low lattice mismatch appear to be directly advantageous to junction transport. On the other hand theoretical efficiency predictions for hetero-junction solar cells are difficult to make. In many hetero-junctions the dominant mechanism is recombination generation in depletion layer but the transport may be modified so much by interfacial recombination, band-edge iscontinuities and tunneling that J0 and A cannot be predicted by injection and diffusion in the absorber quasi-natural region (A = 1). Hence in this article we calculate the effect of Series and parallel resistance on hetero-junction solar cell in n-AlGaAs-Ga-As and compare the efficiency in experimental case with simulation. In any real cell Rs>0 and Rp<<∞, resulting in some power losses. In this study the contributions to Rs and Rp are discussed and means to evaluate their effects are considered (Nault, 2005; Luque and Hegedus, 2003).

THE EFFECT OF SERIES AND PARALLEL RESISTANCE

The current-voltage J-V characteristics of an ideal cell with a single dominant current transport mechanism can be represented by an expression such as:

\[ J = J_0 \left[ \exp \left( \frac{qV}{AKT} \right) - 1 \right] - JL \]  

The least amount of J determines the solar efficiency. The dark J-V curve is transformed downward by the magnitude of the light generated by current JL without change in shape, as shown in Fig. 1. This ideal characteristic is the result of superposition and in this case the short-circuit current \( J_{SC} = -|J_L| \).

Two additional quantities are important. The open-circuit voltage is given by:

\[ V_{OC} = \frac{kT}{q} \ln \left( \frac{|J_L|}{J_0} + 1 \right) \]  

The fill factor \( ff \), given by:

\[ ff \equiv \frac{P_m}{JSCVOC} \]  

\( ff \) is a measure of the "squareness " of the J-V curve. In terms of \( V_{OC} \) and \( ff \) the solar efficiency is given by:

\[ \eta_S = V_{OC} \left( J_{SC} \right) \frac{ff}{P_S} \]
Fig. 1: Light and dark J-V curves for an ideal cell (The power output is shown by the dashed curve)

Fig. 2: Simplified equivalent circuit for a solar cell

Although the fundamental parameters of the solar cell are $J_L$, $J_0$, A and $R_S$, the usual description is in terms of $V_{OC}$, $J_{SC}$ and ff. These parameters are useful, intuitive and easily measured. For nearly ideal cells $J_{SC}$, $V_{OC}$ and ff have been usually treated almost as independent parameters in the literature.

In many devices, it is sufficient to lump $R_s$ and $R_p$ contributions into the equivalent circuit shown in Fig. 2, i.e., a current source shunted by a diode and $R_p$ all in series with $R_s$, to produce a terminal voltage $V$ and $I$. To obtain more precise evaluation, particularly in the case of thin, resistive films in the current path, various distributed resistance models must be used that may be evaluated by numerical or analytic means. Finally, the physical origins of $R_s$, $R_p$ and the contact resistance are briefly considered (Crabtree and Lewis, 2007).

First-order evaluation of $R_s$ and $R_p$ losses: The effect of simple $R_s$ on a cell can be illustrated by graphical addition, at constant current, of the I-V characteristics of the cell and a resistance characteristics with slope $1/R_s$ in Fig. 3.

It is seen that $V_{OC}$ is unchanged by simple $R_s$ and that $I_{SC}$ is changed very little unless $R_s$ is quite large, in which case the cell characteristic approaches $1/R_s$ and ff approaches 0.25. Similarly, the characteristic for simple $R_p$ can be obtained by addition, at constant voltage, of the zero resistance I-V curve and $1/R_p$. Its seen in this case that $I_{SC}$ is unchanged whereas $V_{OC}$ may be changed slightly. An approximate limit on $R_s$ for small power loss can be obtained by assuming that the cell operates near the maximum power point and all the loss can be attributed the $J_{SC}^2 R_s$. Then the power loss fraction is given by:

$$L_s = \frac{J_{SC}^2 R_s}{J_m V_m}$$

For a 3% loss at $J_{SC} = 40 \text{ m A cm}^{-2}$ $V_{OC} = 0.6 \text{ V}$, $R_s$ must be less than $0.5 \Omega$ for each square centimeter of cell area. Similarly, the power loss fraction due to $R_p$ is given by:

$$L_p = \frac{(V_{OC}^2/R_p)}{J_m V_m} = \frac{V_{OC}}{J_{SC} R_p}$$

For a 3% loss due to $R_p$, $R_p$ must be greater than 500 $\Omega$ for each square centimeter of cell area. These approximations are quite accurate for $L_s$, $p<5\%$. For the small-loss case $V_{OC}$ and $J_{SC}$ remain almost unchanged and the major effect is reduction of ff, approximately by the factor $1 - J_{SC} R_s/V_{OC} - V_{OC}/J_{SC} R_p$.

The cell characteristics including $R_s$ and $R_p$ is given by:
Fig. 4: Fill factor as a function of $I_L$ showing the effect of $R_s$ and $R_p$. Assumed: $I_p = 10^{-3} \text{Acm}^{-2}$, $A = 1$, total area active = 1 cm$^2$ and $R_s \rightarrow \infty$ for all cases except for the dashed curve, where, $R_p = 10^3 \Omega$.

Fig. 5: Current flow paths in a grid cell structure with the thickness of the front layer $t_1$ much less than of the base $t_2$.

Fig. 6: Cross section of front gridded solar cell for analytical distributed resistance analysis.

\[ I = I_0 \left\{ \exp\left[ q(V-I_R) \frac{AKT}{q}\right] - 1 \right\} + \frac{(V-I_R)}{R_p I_L} \]  

(7)

With the addition of $R_s > 0$, superposition no longer holds and the light $J-V$ curve cannot be described by a simple translation of the dark curve. The $\beta$ formulation approach (which comes in below) can be used obtain accurate $\eta$ and $ff$ values for the simple lumped element circuit of Fig. 2. For the case involving only $R_s$:

\[ B = \left[ 1 + \frac{1}{1 + 2R_s I_L \beta(q/AT)} \ln(\beta I_L / I_0) \right]^2 \]  

(8)

with $P_m$ given by:

\[ P_m = -\frac{(AKT/q)I_L'}{(1-\beta)\ln(\beta I_L'/I_0) + R_s I_L^2 (1-\beta)^2} \]  

(9)

and $ff$ by:

\[ ff = \frac{P_m}{I_{sc}(AKT/q)\ln(I_L'I_0)} \]  

(10)

The term $I_{sc}$ must remain in the denominator of Eq. (10) since for large $R_s$, $I_L$ may be different from $I_{sc}$ (which may be quickly found by iteration). The variation of $ff$ with $J_L$ (or, equivalently, the light intensity), shown in Fig. 4 with the effects of series and parallel resistance, provides a valuable diagnostic tool for preliminary investigation of experimental cells (Tansley and Owen, 1976).

**DISTRIBUTED RESISTANCE MODELS**

Most solar cells contain a thin front layer in which current is collected laterally by a grid structure. The resistance loss is distributed within the film and more accurate models must be used. An example of such a grid cell structure is shown in Fig. 5.

The series resistance of the device includes the following contributions:

- $R_g$ Resistance of the front grid structure.
- $R_{c1}$, $R_{c2}$ Contact resistances (inversely proportional to contact area).
- $R_1(x) = \rho_1 x / \omega t_1$ Lateral resistance to current flow along the plane of the film depending on the distance $x$ (where $\rho_1$ is the bulk resistivity of the film and $t_1$ is its thickness).
- $R_2 = \rho_2 t_2 / AD$ Transverse resistance through the base layer (of bulk resistivity $\rho_2$, thickness $t_2$ and the area $AD$).
- $R_{s2}$ Spreading resistance of the back contact sheet.

Given the total allowed $R_s$, the cell designer can then allocate the contributions according to the material constraints of the device. The problem of distributed resistance may be handled approximately by various lumped element equivalent circuits, by analytic solutions using simplifying assumptions, or, more exactly by computer-numerical solutions for finite element models. The analytic approach can yield useful results for some simple geometries such as the one-dimensional example that follows. Current flow in the front layer is assumed to be in the plane of the layer as shown in Fig. 6 whereas the current flow in the base and at the junction is perpendicular to the cell area.
Consider an elemental volume of the front layer $\Delta x_{1w}$ bounded by $x$ and $x + \Delta x$. The lateral current density at the two boundaries is $J_{in} = \frac{(dV/dx)}{\rho}$ and $J_{out} = \frac{(dV/dx)}{x+\Delta x/\rho}$. The difference $J_{out} - J_{in}$ is balanced by the current flow through the junction plane $J(V)$ at the bias voltage considered:

$$J_{out1w} - J_{in1w} = J(V) \Delta x_w$$  \(11\)

The quantity $(dV/dx)|_{x+\Delta x}$ can be expanded in a Taylor series about $x$ to obtain:

$$\frac{d^2V}{dx^2} = \frac{J(V)}{\rho} / t_1$$  \(12\)

A solution of Eq. (12) can be obtained easily by assuming that $J(V) = J_m$ is a constant (the current at the maximum power point) giving a parabolic relation for $V(x)$. The distributed resistance power loss per unit area may be obtained directly in terms of the grid spacing $x_g$:

$$P_{loss} = \frac{J_m^2}{\rho} \frac{x_g^2}{12t_1}$$  \(13\)

(or an equivalent series resistance of $R_{sequiv} = px_g^2/12t_1$).

By using finite element models for the treatment of the distributed resistance problem, accurate results can be obtained for more complex diode relations and geometries and for both distributed series and parallel resistances. By assuming a trial voltage $V(0)$ for this element, the current through the element $I(0)$ can easily be calculated and then $V(1)$ and $I(1)$ and the succeeding values up to the terminals of the cell. By varying the trial parameter $V(0)$, the terminal I-V curve for the device can be generated for even the most complex diode characteristics. Calculations are done here for a hypothetical heterojunction cell with the following parameters:

- $X_g = 0.10$ cm, $J_g = 10^{-9}$ A cm$^{-2}$.
- $A = 2$, $J_L = 0.03$ A cm$^{-2}$.
- $W = 1$ cm, $A_D = 1$ cm$^2$.

all other $R_s$ contributions = 0.1 $\Omega$ cm$^2$

- $t_1 = 2 \times 10^{-6}$ cm, grid coverage = 5%

These calculations indicate a limiting bulk resistivity of about 0.2 $\Omega$ cm for a negligible power loss in the front layer, as shown in Fig. 7.

A result of this analysis is that $V_{oc}$ can be reduced from its $R_s = 0$ value by appreciable distributed series resistance because of shunting by the portion of the cell diode structure that is shadowed by the grid. This is especially important for experimental cells when $R_s$

may be quite large and the grid shadowing area can be a large fraction of the active area of the cell.

**Variation V-I characteristics of HJ solar cells under electron irradiation and series, parallel resistances:**

Several techniques are employed to produce solar cells of A$^3$B$^2$ complex and their solid solution used in different fields of technology and the problem to have a steady radiation remains unsolved. It has been found that the power operating parameters of solar cells are degraded after a long-term operation in radiation zone which in turn results in a reduced life time of the cell. Because of reduction of inner activity, production process and recombination as well as velocity of recombination will be increase in the junction. In lux-ampere characteristic $V_{oc}$ and $J_{sc}$ will vary at different irradiation doses. $V_{oc}$ and $J_{sc}$ will increase with the increase of electron radiation dose at the Lux constant amount. In addition, the quality degradation of structural parameters ($\beta, R, J_0$) which modifying the structure and depends on the nature of structure defects and the probability of complex layers and their impact should be considered. To research this issue, the influence of accelerated electron ray on properties of photoelectric for HJsc like AlGa-GaAs is investigated.

The hetero-junction has been prepared on the base of n-GaAs-p-GaAs-p-Al$_{0.75}$Ga$_{0.25}$As. The n-GaAs layer with the density of $n = 1-3 \times 10^{17}$ cm$^{-3}$ is on the layer of Zinc, with a thickness 15-20 $\mu$m as a solid solution. The thickness of p-GaAs layer is 1 $\mu$m. During construction zinc metal powder is poured on its surface. Zinc layer is placed to reduce thickness of p-layer, with high concentration and low contact resistance. The case study surface is 2 cm$^2$ (Andreev et al., 1983; Egorov et al., 1982).

At the firm of measurement, the curve of electrical characteristics of solar radiation spectrum (AM1.5) is
used to determine the V-I characteristics of solar cells under the uniformly radiation. This solar cell is uniform under radiation with the power of $p_g = 91$ mw/cm$^2$, $J_{sc} = 20-25$ mA/cm$^2$, $V_{oc} = 0.92-0.95$ (V) and efficiency $\eta = 16-20\%$. This sample was under radiation with electric energy $4.5$ Mev by electron ray of ELIT-6 equipment. The n-GaAs-p-GaAs-p-Al$_{0.75}$Ga$_{0.25}$ As solar cell structure has been checked with different kinds of V-I characteristics by electron rays and variation of series and parallel resistance. Solar cell's V-I characteristics have been illustrated in Fig. 8 before and after irradiation. Increasing the electron ray dose causes $J_{SC}$ to decrease, while $V_{OC}$ is slightly changed (Andreyev et al., 1983; Andrev et al., 1989).

The parameters are calculated according to the curves of Fig. 8, independently to the radiation dose, are shown in Fig. 9. It is shown that the influence of electron rays on solar cells cause a significant alternation in $J_{SC}$ while $V_{OC}$ is only slightly altered. $J_{sc}$ (p), $voc$ (p) are functions of electron ray radiation and because of the electron ray (Sojoudi et al., 2011).

CONCLUSION

Heterojunction solar cells have a suitable situation to solve many problems about solar cells. In this research, we experience effects of series and parallel resistances in solar cells electrical equivalent circuit. In this paper we researched on $R_S$ and $R_P$ variations for solar cell efficiency and other parameters like $J_{SC}$ and $V_{OC}$. The important fact, which was been shown in this study, is improvement of lifetime for solar cells after working for a long time. The improvement of lifetime problem for solar cells is solved by the electron irradiation rays.

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