Determining a Circuit Model for CdTe/CdS Solar Cells Considering the Back Contact Effect

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Abstract

An electrical model was established in spice, for simulation of CdTe thin-film PV cells. In this paper, an algorithm, based on Genetic algorithm, is introduced for determining circuit parameters. The measured i-v data of fabricated solar cell are used to match circuit model parameters. This method is an efficient way for accurate measurement of the lumped parameters of a solar cell such as series resistance, parallel resistance and leakage current of PN junction. This model can also be used for simulation of PV Modules and behavior of PV system.

The importance of series resistance on efficiency and fill factor of the solar cell was revealed from sensitivity analyzes of this model. Fill factor is reduced by back contact effect that is considered.

Keywords: Back contact diode, CdTe/CdS, Circuit model, Genetic algorithm, Solar cell

1. Introduction

Photovoltaic solar cells are known as one of the clear sources of energy. These cells are produced from Si, GaAs, SiGS, Cd/Te, organic material and Nano structures and among these, thin film solar cells such as Cd/Te play an important role. Intensive researches in the field of thin film solar cells in recent years led solar cells based on CIGS and CdTe absorber layers. They combine reasonable conversion efficiencies with a low cost production process [8, 12, 7], so were commercialized now. Of course, many researchers are trying to reduce production issues such as cost and to increase production efficiency. For CdTe with its nearly ideal band gap, E_g equal to 1.45eV, conversion efficiencies for laboratory solar cells of approximately 16% have already been realized [8]. However, such cells are not suitable for widespread terrestrial applications, because of a degrading cell performance due to instable, Cu containing back contacts [8]. Manufactured module efficiencies of 10% have been achieved and may increase to over 12% over time.

The basic structure of CdTe has a glass super substrate (the thick glass layer that acts as the substrate, actually covers the front surface of the cell where the sunlight should come in) and a layer of transparent conducting oxide (TCO) as a front contact. This contact is usually composed of an In_2O_3-layer (ITO, 250nm) with a fluorine doped SnO_2 diffusion barrier (30nm).The n-type material is CdSyCdTe (heterocontact) or cadmium sulphide (CdS) is intend to be less than 150nm and the p-type is the cadmium telluride (CdTe) is deposited by close spaced sublimation, followed by a $CdCl_2$-activation step to achieve good cell performances [1]. Then there is a metallic rear contact. (Fig. 1) shows a cross section of a typical CdTe/CdS solar cell.

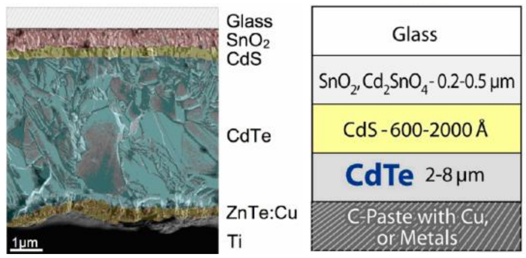

Fig. 1: Structure of CdTe/CdS.

Good weatherproof properties, high spectral sensitivity characteristics over a wide wavelength range, high-voltage type solar cells can be formed at a high density on a single glass substrate and easy to produce them with larger surface areas, are several benefits of these thin film cells. The production experience shows that polycrystalline form of CdTe has higher efficiency than the crystalline one. Polycrystalline grains that are seen in (Fig. 1), limit the thickness of the layers. Reducing thickness of CdS to less than 50nm is interested but it is impossible because of these grain's boundaries short the CdS layer. This paper proposed a circuit model for solar cell and has tried to achieve an algorithm to match its parameters with fabricated cells. This model is used to simulate solar cell systems and must have important features of cells accurately. In [11] several methods of modeling are compared. Also, in [3, 8, 10, 13] models based on diode presented. [2] Introduced model in PSIM software. A circuit-oriented model is introduced in [1] which can be used in spice. Low resistance ohmic and stable back contacts are still one of the major issues in improving CdTe based solar cells. In Addition, according to band alignment arguments chemically inactive and conductive materials of high work functions are most promising for CdTe back contacts. Because of that in our work back contact effect is considered at model.
In section two, the circuit model is developed. In section three proposed algorithm are explained. Results and conclusion are brought in the last section.

2.Circuit model

In many papers the model that has come in (Fig. 2) is used. During the operation, the efficiency of solar cells is reduced by the dissipation of power across internal resistances.

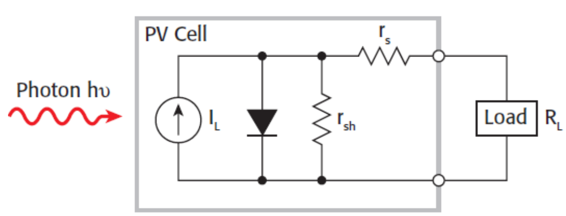

Fig. 2: circuit model for solar cell.

As depicted in (Fig. 2), these parasitic resistances can be modeled as a parallel shunt resistance (R_p) and series resistance (R_s). For an ideal cell, (R_p) would be infinite and would not provide an alternate path for current to flow, while (R_s) would be zero, resulting in no further voltage drop before the load. Diode is a model for PN junction of cell that absorbs light energy. (I_l) represents current is produced by electrons and holes which generated in PN junction. Variation of this current versus voltage is known as (I-V) came in (Fig. 3) for dark and light situation.

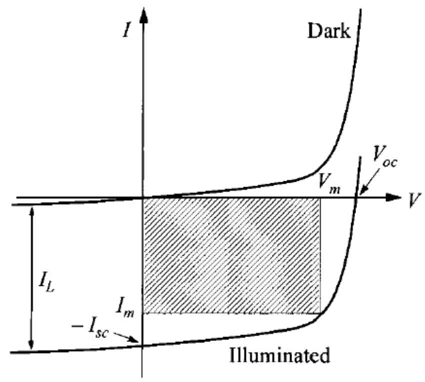

Fig. 3: (I-V) characteristic of solar cell for dark and light.

The short circuit current (I_{sc}) corresponds to the short circuit condition when the load impedance is low and is calculated when the voltage equals zero. (I_{sc}) Occurs at the beginning of the forward-bias sweep and is the maximum current value in the power quadrant.

$$I_{sc} = AqN_C N_V \left(\frac{1}{N_A}\sqrt{\frac{D_n}{\tau_n}} + \frac{1}{N_D}\sqrt{\frac{D_p}{\tau_p}}\right) exp\left(\frac{-E_g}{kT}\right) \quad (1)$$

D is Einstein coefficient, τ denotes life time, N_A and N_D are acceptor and donor materials density, respectively. A is efficient area, N_C and N_V are physical coefficient. Also, T is temperature and is Boltzmann factor. For an ideal cell, this maximum current value is the total current produced in the solar cell by photon excitation. The open circuit voltage (V_{oc}) occurs when there is no current passing through the cell.

$$V_{oc} = \frac{kT}{q}\, ln\left(\frac{I_l}{I_s} + 1\right) \approx \frac{kT}{q}\, ln\left(\frac{I_L}{I_s}\right) \quad (2)$$

The power produced by (P = IV) that at the (I_{sc}) and (V_{oc}) points, the power will be zero. The voltage and current at this maximum power point are denoted as (I_{mp}) and (V_{mp}) respectively.

$$I_m = I_s \beta V_m\, exp\,(\beta V_m) \approx I_l\left(1 - \frac{1}{\beta V_m}\right) \quad (3)$$

$$V_m = \frac{1}{\beta}\, ln\left[\frac{(I_l/I_s)+1}{1+\beta V_m}\right] \approx V_{oc} - \frac{1}{\beta}\, ln\,(1 + \beta V_m) \quad (4)$$

And the maximum value for power will occur between the two (P_{max}) .

$$P_m = I_m V_m = F_f I_{sc} V_{oc} \approx I_l\left[V_{oc} - \frac{1}{\beta}\, ln\,(1 + \beta V_m) - \frac{1}{\beta}\right] \quad (5)$$

Efficiency is defined as below.

$$\eta = \frac{P_m}{P_{in}} = \frac{I_m V_m}{P_{in}} = \frac{{V_m}^2 I_s (q/kT)\, exp\,(qV_m/kT)}{P_{in}} \quad (6)$$

Achieving the envisaged conversion efficiencies of at least 12% for large area modules ($120=60cm^2$) from the production lines an improvement of the back contact is one of the major issues.
'Non-ohmic' or instable back contacts are one of the main limiting factors for the conversion efficiency of CdTe solar cells. In general, for most materials deposited on CdTe a barrier for the hole transport is induced. Up to now the best and technologically feasible back contacts were obtained by chemical etching of the CdTe substrates before deposition of a metallic back contact, although it is known that this back contact shows a non-ideal electrical characteristic.
Considering materials can be used in back contact, it is understood that full ohmic contact has been impossible so far. Thus a diode that represents back contact barrier is added to model. This diode bounds the efficiency of the solar cell. So modified models in dark and light situation have come in (Fig. 4).

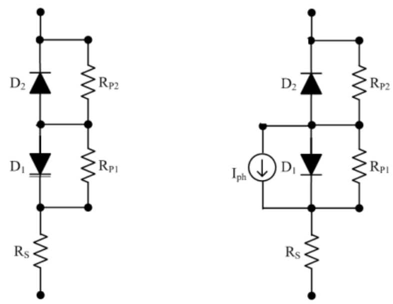

Fig. 4: Equivalent circuit model considering back gate barrier.

Which (D_1) denote operation of solar cell and (D_2) indicate rear contact schottky barrier.
Leakage current of (D_2) and parallel resistance (R_{p2}) are important to close measurement data. In this paper spice model of diode with its parameters are used for simulation which comes in (Table 1).

Function	Parameters
DC parameters of D_1 and D_2	IBV, IK, IKR, IS, ISW, N, RS, VB, RS
Geometric junction of D_1 and D_2	AREA, M, PJ
Geometric capacitance of D_1	L, LM, LP, SHRINK, W, WM, WP, XM, XOJ, XOM, XP, XW
Capacitance of D_1	CJ, CJP, FC, FCS, M, MJSW, PB, PHP, TT
Noise of D_1	AK, KF
DC parameters of $D_1$and D_2	IBV, IK, IKR, IS, ISW, N, RS, VB, RS
Circuit elements	Rs, Rp1, Rp2 and IL

Table 1. Parameters used in proposed model.

In the final stage the current which is delivered to load is calculated by the following formulation.

$$I = I_l - I_o\left(exp^{\frac{q(V+I.R_S)}{n.k.t}} - 1\right) - \frac{V+I.R_S}{R_p} \quad (7)$$

Where (I_o) is the saturation current of the diode, (q) is the elementary charge 1.6x10-19 Coulombs, (k) is a constant of value $1.38x10^{-23}$J/K, (T) is the cell temperature in Kelvin, and (V) is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias). And (n) is the diode ideality factor), and (R_S) and (R_p) represents the series and shunt resistances that are described. It is necessary to consider effect of temperature and light incident on discussed parameters. For example SP75 manufactured by SIEMENS has (R_s) equal to range 3.65×10^{-3} to 1.14×10^{-2} [9] When operational temperature changes from -25°C to +75°C, so relations can be revised to below [2, 11].

$$I_{sc} = \left(I_{scT} - K_{sc}(T - T_n)\right) * S \quad (8)$$
$$V_{oc} = V_{ocT} + K_{oc}(T - T_n)$$

That (K_{sc}) and (K_{oc}) are related temperature coefficients. (S) is incidence light. (I_{scT}) and (V_{ocT}) and (T) are short circuit current and open circuit voltage and temperature, respectively. In addition, inverse saturation current depends on variation of temperature and incident beam can be model with formulation (Eq. 9).

$$I_s = \frac{I_L}{e^{\frac{V_{oc}}{V_{T-1}}}} \quad (9)$$

It is clear that dependency hide in (V_{oc}) and (I_L). Considering (Eq. 7) current of the maximum power equals:

$$I_{MP} = I_L - I_s\left(e^{\frac{V_{MP}+R_s*I_{MP}}{V_T}} - 1\right) \quad (10)$$
$$R_s = \frac{\left[V_T * ln\left(\frac{I_L - I_{MP} + I_s}{I_s}\right) - V_{MP}\right]}{I_{MP}}$$

3. Proposed Algorithm

Genetic algorithm as a global optimizer is [4,5] used to determine parameters mentioned are brought in (Table 1). Each chromosome has gens according this table that mean gens are real number between minimum and maximum determined for correspond parameters. For example (R_s) ranges between 100μΩ to 100Ω. Of course the operation of algorithm is not sensitive to these values.

$$ch_k = \left\{g_j = dj \middle| d_j = R_s,\ R_p, R_{p2}, I_{PHI}, I_{s1}, I_{s2}\ and\ \ j = 1,2, \dots, N\right\} \quad (11)$$

(N) is total number of parameters used in simulation and we select that 30. With applying these operators next generation of population is generated.

$$G^{k+1} = S\left(C\left(M(G^k)\right)\right) + E(G^k) \quad (12)$$

Operator (S) demonstrates the selection and here we use Roulette wheels. (M) indicates mutation operator that due to the type of chromosome structure, has two parts which are operating on different segments of chromosome. In the first part continuous values of each gene (layers thickness) are added with a Gaussian noise. (C) is crossover, (M) denotes mutation and (E) is elitism operator [6].

4. Simulation and implementation Result

In (Figs. 5~7) (I-V) characteristics of these solar cells are brought. (I-V) characteristics were measured at 28°C in light and dark using an Oriel brandAM1.5G solar simulator calibrated to 100mW/cm^2 and as a function of temperature from -50°C to 80°C at several intensities with GE-ELH-type lamps. The data were analyzed as described below. To reducing effect of back contact different techniques were applied to fabricate thin film CdTe/CdS solar cells. Wet and dry etching and no etching methods for forming the primary contact (Cu_2Te) were used.

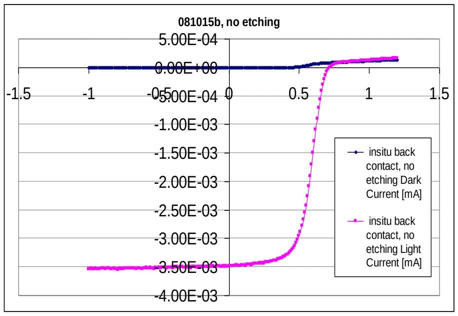

Fig. 5: No Etching.

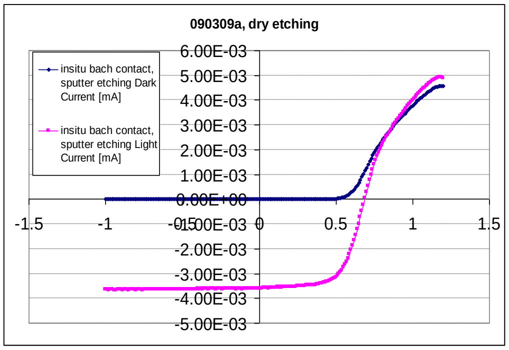

Fig. 6: Dry Etching.

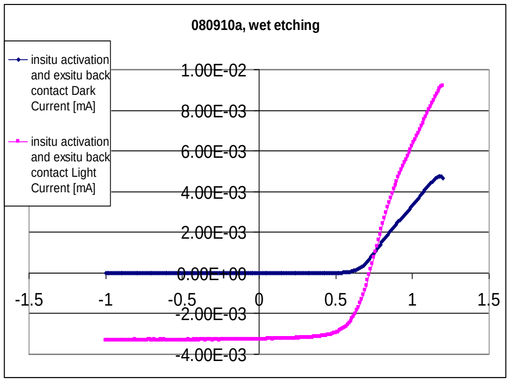

Fig. 7: Wet Etching.

The (I-V) curve of an illuminated PV cell has the shape shown in (Fig. 3) as the voltage across the measuring load is swept from zero to (V_{oc}), and many performance parameters for the cell can be determined from this data, as described in the sections below. For this solar cell proposed algorithm are applied. In (Fig. 8) (I-V) circuit model come up.

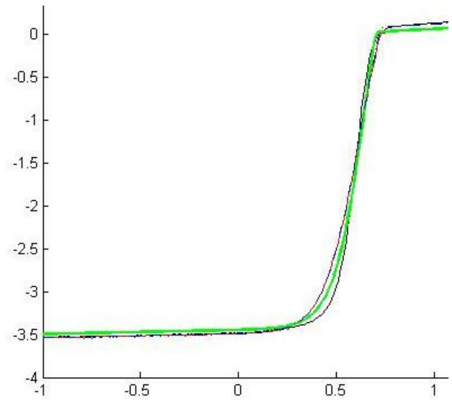

Fig. 8: (I-V) of circuit model.

These circuit model important parameters have come in (Tables 2~4).

	Dark Current	Light Current
Rs	20 Ω	20 Ω
IS (D1)	5×10-7 A	5×10-7 A
RP1	2 MΩ	25 kΩ
Iph	0 A	3.5×10-3 A
IS (D2)	5×10-4 A	5×10-4 A
RP2	8 kΩ	8 kΩ
I2	6.5×10-5	6.5×10-5

Table 2. back contact, no etching.

	Dark Current	Light Current
Rs	20 Ω	20 Ω
IS (D1)	5×10-7 A	5×10-7 A
RP1	2 MΩ	25 kΩ
Iph	0 A	3.3×10-3 A
IS (D2)	4×10-6 A	9×10-8 A
RP2	150 Ω	150 Ω
I2	5.4×10-3	1.15×10-2

Table 3. Activation and existence back contact

	Dark Current	Light Current
Rs	20 Ω	20 Ω
IS (D1)	5×10-7 A	5×10-7 A
RP1	2 MΩ	25 kΩ
Iph	0 A	3.63×10-3 A
IS (D2)	5×10-7 A	3×10-8 A
RP2	150 Ω	150 Ω
I2	5.4×10-3	6.5×10-3

Table 4. Back contact, sputter etching

(Fig. 9) illustrates the importance of complete removal of back contact effect. I-V characteristic compared with for circuit model while eliminating rear contact. Fill factor for these two situations, have come in (Fig. 9), show eliminating this diode indicate approximately 16% increase at it.

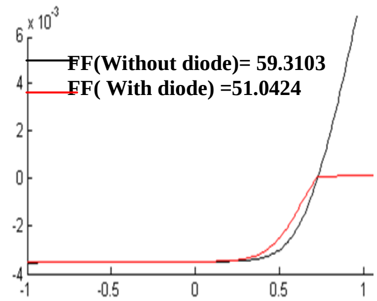

Fig9: IV Characteristic with back contact and without it.

5. Conclusions

In this paper by the use of presented algorithm based on GA and the simulation of circuit model in spice, the parameters of circuit model are calculated. Results show that obtained model has the characteristic close to experimental data. The key point in achieving the circuit model, is regarding leakage current and parallel resistance of cell layers (R_{p2}) as a designing parameters. Considering back contact diode (D_2) and series resistance (R_s). Without these parameters data fitting was impossible. The presented circuit model describes the behavior of thin film solar cells of CdTe/ CdS, but it can be used in simulating different solar modules. The presented algorithm imposes no limitation in calculating circuit parameters and can be used for other kinds of solar cells.

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