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Parameter Extraction of Schottky Solar Cell in Wide Temperature Range Using Genetic Algorithms

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This paper proposes a new method based on a genetic algorithm (GA) approach to optimize the electrical parameters such as height barrier, ideality factor, fill factor, open-circuit voltage and power conversion efficiency, in order to improve the electrical performance of Schottky solar cells in an over wide range of temperature. Thus the parameters research process called objective function is used to find the optimal electrical parameters providing greater conversion efficiency. The proposed model results are also compared to experimental and analytical I-V data, where a good agreement has been found between them. Therefore, this approach may provide a theoretical basis and physical insights for Schottky solar cells.

Keywords: Schottky-barrier height, Genetic algorithm, Ideality factor, Fill factor.

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1. INTRODUCTION

Metal-semiconductor (MS) is one of the most commonly used semiconductor devices, and it has advantages of low turn-on voltage and high response frequency [1-3]. Schottky-barrier diode (SBD) are the basis of a number of semiconductor electronic devices, including microwave diodes, field-effect transistors (FETs), solar cells, and photo detectors [4-7]. Determining the fundamental SBD model parameters including Schottky-barrier height (SBH) and ideality factor, which must be taken into account in practical application, plays an important role in the designing and manufacturing process [6-8]. The Schottky barrier junctions can operate as a solar cell and the main advantage of Schottky barrier solar cells is easiness of production, as they do not require high temperature processing, and thus, the processing cost is remarkably reduced[9, 10]. Recently, the methods based on evolutionary computation algorithms have attracted much attention in the area of the SBD parameter extraction. For example, in literature, a technique based on genetic algorithms (GAs) is proposed to improve the accuracy of the SBD parameter extraction [11, 12]. The performance of this technique also surpasses the quasi-Newton method, a gradient-based search and optimization algorithm. Although GAs has been widely used in parameter estimation and many others, recent research has identified some deficiencies in GA performance. Especially, the degradation in efficiency is apparent in applications with highly epistatic objective functions, i.e., where the parameters being optimized are highly correlated. In this case, the crossover and mutation operations cannot ensure better fitness of offspring because chromosomes in the population have similar structures and their average fitness is high toward the end of the evolutionary process. [13].

In the present study, the electrical and photovoltaic properties of the Schottky diode have been investigated in wide temperature range to determine the possibility of use in photovoltaic applications as a solar cell. The aim of this study is the extraction of the electrical parameters in wide temperature range solar cell such as height barrier, ideality factor, the fill factor and power conversion efficiency, using the GA method. The results are also compared to experimental and analytical I-V data. We have evaluated that the Schottky diode can be prepared in the form of the Schottky solar cell.

2. MODELING METHODOLOGY

The forward bias *I-V* characteristics, according to thermionic emission of the SBD model with a series resistance, can be expressed as [6, 7].

$$I = I_0\left[\exp\left(-\frac{q(V-IR_s)}{nkT}\right)-1\right] \tag{1}$$

Where

$$I_0 = AA^{*}T^2\exp\left[-\frac{q\Phi_b}{KT}\right]$$

I_0 the saturation current, I the diode current at bias V, q the electron charge, k the Boltzmann constant, T the absolute temperature, A the effective diode area, A^* the effective Richardson constant and equals to 32 A/cm^2·K^2 for *p*-type Si [6, 7], Rs the series resistance, Φ_b the SBH and n the ideality factor.

R_s, Φ_b and n are the unknown parameters and should be determined as accurately as possible. The typical *I-V* characteristics of the SBD model is reported in reference [6, 7].

In this work, we consider that the SBD model indicated by Equation (1) can be rewritten as:

$$V = \frac{nkT}{q}\log\left(\frac{I}{I_0}+1\right)+IR_s$$

The characteristic $I(V)$ of the solar cell under illumination 100 mW/cm^2. The current-voltage relation for the Schottky barrier solar cell is expressed by the following relation.

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$$I = I_{ph} - I_0 \left[\exp\left(-\frac{q(V-IR_s)}{nkT}\right)\right], \tag{2}$$

where I_{ph} is the photocurrent. The current-voltage characteristics of the diode give a short circuit current I_{sc}, and open circuit voltage, V_{oc}.

$$V_{oc} = \left(n\frac{K.T}{q}\right)\ln\left(\frac{I_{sc}}{I_0}\right) \tag{3}$$

Therefore, by minimize the errors on the voltage, the values n and Φ_b can be optimized according to the temperature by basing on the experimental results which present the effect of temperature over the range 140 to 300 K. The variations of the barrier height and those of the ideality factor are expressed by the following relations:

$$n(T) = \left(\frac{n_1}{T_0}\right) \times T^2 - \left(\frac{n_2}{T_0}\right) \times T + n_3 \tag{4}$$

$$\Phi_b(T) = -\left(\frac{\Phi_1}{T_0}\right) \times T^2 + \left(\frac{\Phi_2}{T_0}\right) \times T + \Phi_3 \tag{5}$$

With: $T_0 = 100$ K and n_1, n_2, n_3, Φ_1, Φ_2, Φ_3 are the parameters to optimized by the genetic algorithms.

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity. It is the major characteristic that appreciates the quality of a solar cell and is defined as:

$$\eta = \frac{P_{max}}{P_{inc}} = \frac{I_{max}V_{max}}{P_{inc}} = \frac{FF I_{sc}V_{oc}}{P_{inc}}, \tag{6}$$

where FF is the fill factor, P_{inc} is the incident power. P_{max} the maximum power from the solar cell.

In our application, the seven parameters: n_i, Φ_i with $i = 1, 2, 3$ and R_s, are treated as the chromosomes of *GA*. These parameters are to be optimized by the minimization of the fitness function f which is used for evaluation of the chromosomes and is defined as:

$$f = \frac{1}{M}\sum_T \sum_I \left[\frac{V_{exp} - V_{GA}}{V_{exp}}\right]^2, \tag{7}$$

where M represent the size of the experimental data base, while exp and *GA* indicate the experimental and calculated data by *GA* technique, respectively. The flowchart of our proposed approach to find the optimal parameters and suitable with those of experimental, is detailed in Fig. 1.

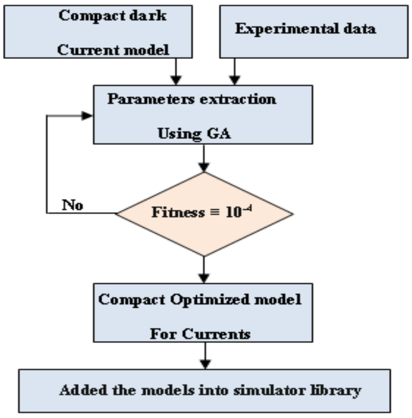

Fig. 1 – Our proposed approach to study the SBD

3. RESULTS AND DISCUSSION

In order to minimize equation (7), routines from *GA* toolbox in MATLAB are used. An initial population of 20 random candidates is generated and evolved for 90,000 generations. More specifically, 10 pairs of parents are chosen by uniform selection, at each iteration. Each of these 10 couples produces two children using two crossovers. These 20 children have uniforms applied and the children are then sorted by fitness function. For this configuration, the fitness function was 0.000105 and almost 100 % of the submitted cases were learnt correctly. For obtained *GA* configurations, the obtained results are summarized in Table 1. Summarize the obtained optimized parameters of our analytical *I-V* model, where the performances of *GA* optimization process the best fitness value decreases rapidly and converge at about 30,000 generations.

Table 1 – Results of parameter determination obtained by genetic algorithm

Parameters	n_1	n_2	n_3	Φ_1	Φ_2	Φ_3	Rs
GA	0.0016	0.854	2.12	0.0013	0.6672	0.0097	41.732

Based on the results found by the *GA* technique, the parameters obtained in Table 1 are replaced in equations (4) and (5) in order to find the ideality factor (n) and the barrier height (Φ). Thus, optimized model of *I-V* for different tempera ures can be found by replacing the ideality factor (n) and the barrier height (Φ) in equation 1 the *I-V* characteristics for over a wide range of temperature as shown in Fig. 2.

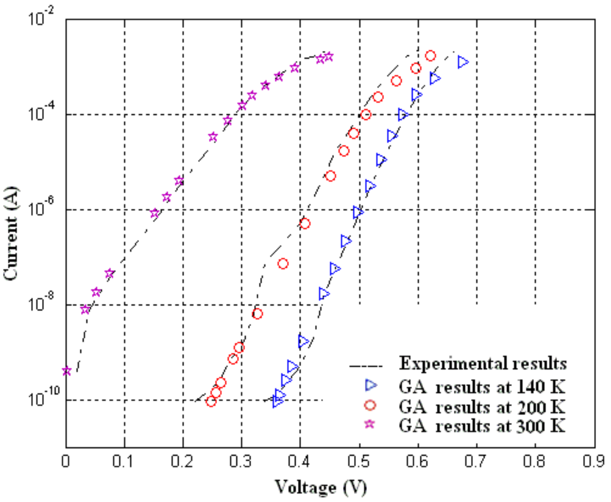

Fig. 2 – Comparisons of the experimental and GA resultants of the forward bias current-voltage characteristics of the SBD at various temperatures

We are interested in this section to study the characteristic $I(V)$ of the solar cell under illumination 100 mW/cm^2. The Table 2 summarizes the results of the analytical approach that we have developed. The analytical results have been compared with those of *GA* at various temperatures. From the table, we can see that a good agreement is found between the analytical and *GA* approaches which permit us to consider our approach *GA* a theoretical basis to study a Schottky solar cell.

Table 2 – Results of parameter determination obtained by genetic algorithm with analytical *I-V* data at various temperatures

	Analytical results				GA results			
T (K)	I_{sc} (mA)	V_{oc} (mV)	FF	η (%)	I_{sc} (mA)	V_{oc} (mV)	FF	η (%)
140	0.034	606	0.862	2.27	0.034	606.0	0.86	2.27
160	0.036	581.4	0.826	2.24	0.036	595.8	0.81	2.23
180	0.038	558.9	0.793	2.20	0.038	576.8	0.78	2.19
200	0.040	533.4	0.763	2.14	0.040	550.0	0.75	2.12
220	0.042	502.1	0.745	2.05	0.042	520.0	0.72	2.04
240	0.044	464.9	0.732	1.96	0.044	483.6	0.71	1.93
260	0.046	429.6	0.713	1.88	0.046	444.1	0.70	1.82
280	0.048	396.3	0.699	1.70	0.048	400.1	0.69	1.70
300	0.049	351.3	0.666	1.48	0.049	351.3	0.66	1.48

The impact of increasing temperature is shown in Fig. 3 which shows that I_{sc} increases slightly, while V_{OC} decreases more significantly. This increase in current can be neglected to the point I_{sc} but not to the point of maximum power where it knows an important shift that affects the performance of the cell changes from 1.489 % to 2.270 % with decreasing temperature.

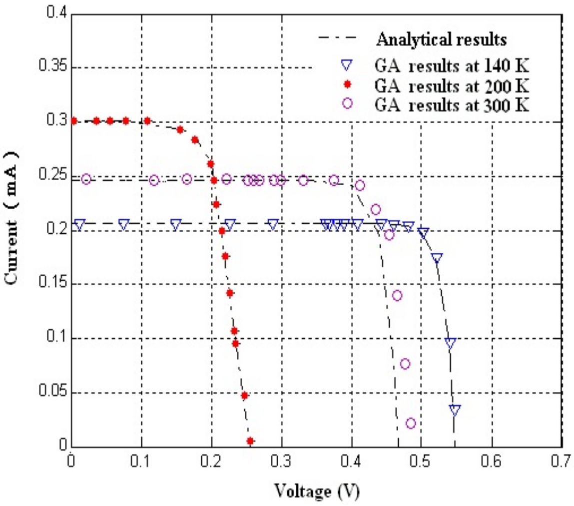

Fig. 3 – Comparisons of the analytical and *GA* resultants of the *I*(*V*) of the solar cell variation in the temperature range of 140-300 K

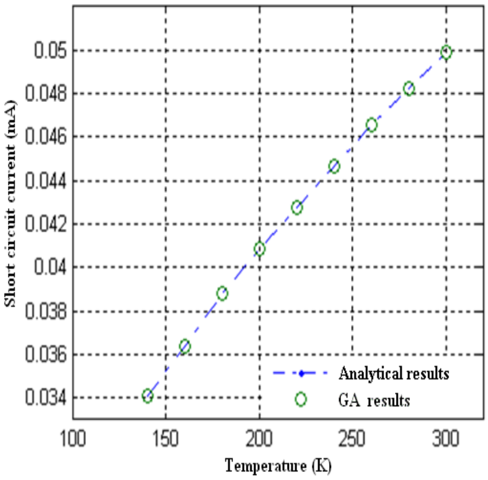

Fig. 4 – Comparisons of the analytical and GA resultants of short circuit current at various temperatures

The Short circuit current I_{sc} is maximum current, at zero voltage. It is depended on temperature as shown in equation (3). Fig. 4 shows the effect of temperature variation on the I_{sc}. At 140 K, the Isc has it lower value of 0.0341 mA. Therefore, the short circuit current I_{sc} increases with temperature and tends to reach its maximum value of 0.0499 mA at temperature of 300 K, practically linear with variation ratio around 0.002 mA per 20 K.

The open circuit voltage V_{oc} is one of the most important parameters for the solar cell efficiency. It is depended on temperature as shown in equation (3). Fig. 5 shows the effect of temperature variation on the V_{oc}. At 300 k, the V_{oc} has it lower value of 351.33 mV and increased with decreased temperature to reach its maximum value of 606 mV at 140 K. Therefore, we can see that the decrease ratio of the parameter is in the order of 1 mV/K.

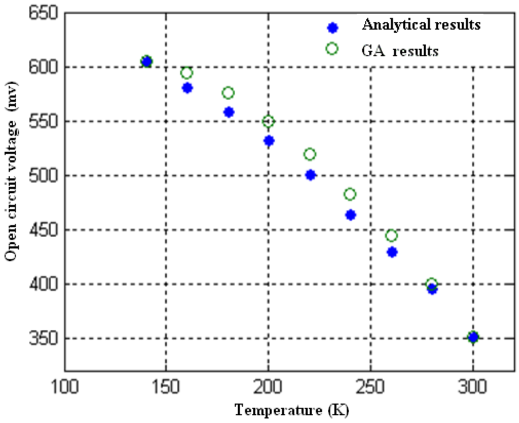

Fig. 5 – Comparison of the analytical and *GA* resultants of open circuit voltage at various temperatures

Fig. 6 shows the effect of temperature variation on the efficiency η increased to reach its maximum value of 2.270 % at $T = 140$ K. The temperature still increased whereas the efficiency decreased from 160 k. The efficiency of 1.489 % is obtained at higher temperature of 300 K.

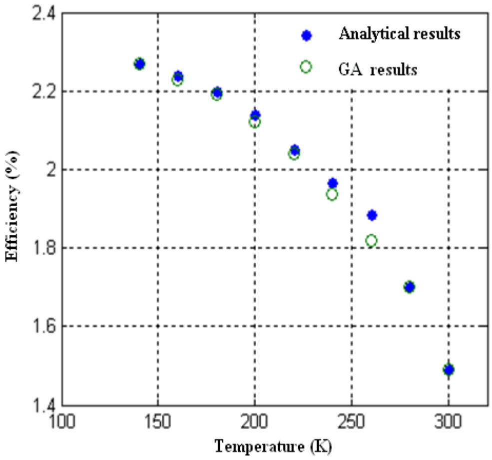

Fig. 6 – Comparisons of the analytical and *GA* resultants of efficiency at various temperatures

4. CONCLUSION

In this paper, we show the applicability of the technique GA to study the effect of temperature on the electrical and photovoltaic properties of Schottky barrier diode. The simulation results presented in this work shows that the GA technique offers, in term of convergence, a better strategy to extract the parameters for finding the global optimal solution. The model results have been verified and validated using experimental measurements, where a good agreement is observed between them, which were the predictive property validation of our compact optimized model; it can be used to predict other combinations of input variables.

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