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Optimization of Ultra-thin Cd Te /Cd S Solar Cell with GA

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Abstract Cd Te/Cd S solar cells are one of the prospective candidates for widespread commercial success in solar energy conversion. They have shown an efficiency values higher than 17%. In this paper we use transfer matrix method to calculate the thickness and triple radiative properties of absorption, transmission and reflection of multilayer structure. The derivation results optimized with genetic algorithm at 25°C at the wavelength 0.8 micrometer in the Near-Infrared region in the case of un- polarize condition for ultra-thin multilayer. So depending on industry needs by investigating and analyzing the wave impact angle and wavelength frequency applied on the solar cell the optimized condition can be selected. It was seen that for all cases transmission coefficient is approximately zero and other of triple coefficients behave in the form of sinusoidal curves oppositely.

Keywords: Thin film Cd Te/Cd S solar cell, Genetic algorithm, Absorption coefficient, Reflection coefficient, Transmission coefficient

بهینه‌سازی یک سلول خورشیدی Cd Te/Cd S خیلی نازک توسط الگورینم ژنتیک

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چکیده: سلول‌های خورشیدی Cd Te/Cd S در فرآیندهای تبدیل انرژی خورشیدی بطور وسیع گزینه موفقی در تجارت می‌باشند. این سلول‌ها دارای راندمان بالغ بر ۱۷٪ را دارا هستند. در این مقاله با کاربرد روش انتقال ماتریس ضخامت و پارامترهای سه‌گانه تابش؛ ضرایب جذب، عبور و بازتابش ساختار چندلایه محاسبه می‌شود. نتایج حاصل بوسیله الگوریتم ژنتیک در دمای ^{o}C ۲۵ در طول موج ۸,۰ میکرون در نزدیکی محدوده مادون قرمز برای حالت بدون پلاراسیون برای ساختار چند لایه خیلی نازک بهینه می‌شوند. بطوریکه می‌توان برحسب نیاز در صنعت با بررسی و تحلیل تأثیر زاویه و تواتذ طول موج که به سلول اعمال می‌شود می‌توان شرایط بهینه را انتخاب کرد. نتایج نشان می‌دهد که برای تمام حالات ضریب عبور در حد صفر باقی می‌ماند و دو ضریب دیگر بصورت منحنی‌هاس سینوسی رفتار

واژه‌های کلیدی: سلول‌های خورشیدی نازک Cd Te/Cd S ، الگوریتم ژنتیک ، ضریب عبور ، ضریب جذب و ضریب بازتابش.

1. Introduction

CdTe solar cells have been demonstrated as one of the most promising technologies for large scale fabrication and production of energy due to their high scalability, low energy consumption in fabrication, low pay back time, and high efficiency [1]. However, it has been reported that a large scale production in the order of terawatts could be limited by tellurium scarcity as this is a rare element and generally mined as a by-product [2]. There are number of papers theoretically focused on detailed investigation of the dependence of the efficiency of CdS/CdTe thin film solar cells on some properties such as [3–7]: the thickness of front contact layer, thickness of window layer, thickness of absorber layer, the width of the space-charge region and other parameters.

Numerical models have become important tools for the design of any kind of efficient solar cells. Analytic models of solar cells have been used since the earliest days to improve understanding of the operation and to provide guidance for their design [8, 9]. Recently search-based methods have received much attention for their outstanding characteristics, for instance, less dependence on initial value and no need for gradient information, especially in nonlinear or multiparameter problems. Among others, genetic algorithm (GA) has been applied to various optimization and parameter estimation problems [10]. P. Suresh et al. used genetic algorithm for optimization of Intervening Variables in Micro EDM.[11]Application of GAs to radiation analysis was conducted by Li and Yang for estimating the scattering albedo, optical thickness, and phase function in parallel planes [12] , while Kim et al. improved the GA by combining a local optimization technique for estimating wall emissivity's in two-dimensional irregular geometry [13] .

This work is focused on radiative properties and structural thickness of CdTe/Cds thin film solar cell optimized with genetic algorithm in Matlab by using transfer matrix method and then analyzing the effect of angle of incident, wavelength of incident in un- polarize condition.

The main purpose is to determine the optimum conditions that lead to enhance the performance of CdTe/Cds solar cells.

2. Main parameters and optical constants of the materials used

Fig. 1 shows the schematic cross-section of a typical Cdte/Cds solar cell.When the thickness of each layer is comparable or less than the wavelength of electromagnetic waves, the wave interference effects inside each layer become important to correctly predict the radiative properties of multilayer structure of thin films. The transfer-matrix method provides a convenient way to calculate the radiative properties of multilayer structures of thin films (Fig.1 [14]). By assuming that the electromagnetic field in the medium is a summation of forward and backward waves in the z-direction, the electric field in each layer can be expressed by [15, 16]:

$$E_j = \begin{cases} \left[A_1 e^{iq_{1z}z} + B_1 e^{-iq_{1z}z}\right] e^{(iq_x x - i\omega t)}, j = 1 \\ \left[A_j e^{iq_{jz}(z-z_{j-1})} + B_j e^{-iq_{jz}(z-z_{j-1})}\right] e^{(iq_x x - i\omega t)}, j = 2,3,...N \end{cases} \quad (1)$$

Where and are the amplitudes of forward and backward waves in the layer. Detailed descriptions of how to solve for and is given in [17]. By applying the boundary conditions Aj and Bj can relate to the next layer with the below equation:

$$\begin{pmatrix} A_j \\ B_j \end{pmatrix} = P_j D_j^{-1} D_{j+1} \begin{pmatrix} A_{j+1} \\ B_{j+1} \end{pmatrix}, (j = 1,2,3,...,N-1) \quad (2)$$

In the above equation Pj is the propagating matrix with equation (3), Dj is the transfer matrix that in the case of applying perpendicular electromagnetic wave to electrical field is calculate with equation (4) that named s-polarized, parallel to electrical field with equation (5) that named p-polarized and none of them is named un-polarize.

$$P_j = \begin{pmatrix} e^{-iq_{jz}d_j} & 0 \\ 0 & e^{+iq_{jz}d_j} \end{pmatrix}, (j = 2,3,...,N-1) \quad (3)$$

$$D_j = \begin{pmatrix} 1 & 1 \\ \tilde{n}_j \cos\tilde{\theta}_j & -\tilde{n}_j \cos\tilde{\theta}_j \end{pmatrix}, (j = 1,2,3,...,N-1) \quad (4)$$

$$D_j = \begin{pmatrix} \cos\tilde{\theta}_j & \cos\tilde{\theta}_j \\ \tilde{n}_j & -\tilde{n}_j \end{pmatrix}, (j = 1,2,3,...,N-1) \quad (5)$$

$$M = \prod_{j=1}^{N-1} P_j D_j^{-1} D_{j+1} \quad (6)$$

Consequently, the radiative properties of the N-layer system are given by [16, 17]:

$$\rho_{\lambda,\theta} = \frac{B_1 B_1^*}{A_1^2} \quad (7)$$

$$\tau_{\lambda,\theta} = \frac{\mathrm{Re}(\tilde{n}_N \cos\tilde{\theta}_N)}{n_1 \cos\theta_1} \frac{A_N A_N^*}{A_1^2} \quad (8)$$

$$\varepsilon_{\lambda,\theta} = 1 - \rho_{\lambda,\theta} - \tau_{\lambda,\theta} \quad (9)$$

Eqs. (7) to (9) are reflection, transmission and absorption coefficients, respectively. Optical constant of silicon is extracted by Jellison and Modine (J-M) expression [16] and other optical constant is used from Palik handbook [18] for the 0.8 micrometer wavelength in the room temperature.

3. Results

For validating of our model calculating reflectance coefficient of silicon substrate with 700 micrometre thickness and coated by silicon dioxide thin film with 300 nanometre thickness in two different coating cases and two different temperature is chosen [19] (fig.2).

Investigating the model shown that it is in good agreement with result in [19].By coding genetic algorithm in MATLAB Software the optimized radiative coefficients and thickness of the solar cell structure at 25°C with an angle of incident 45° at the wavelength 800 nanometer are calculated that they are listed in table1 and table2.

The results in the wavelength range and angle of incident for reflection coefficient, absorption coefficient and transmission coefficient in the figures of (4-9) are shown. Due to wave interferences in thin films, fluctuations in results can be seen where those fluctuations are in the form of sinusoidal curves that are obvious in the equations of (3), (4) and (5).

By increasing the number of layers the product of increases and thus more fluctuations and greater dependence on the radiation properties are seen. These results obtained in this paper, both physically and mathematically are justified.

With increasing the wavelength, amplitude and distances between the peaks of the sinusoidal oscillation increases. The distance between the fluctuations can be calculated from equation [19]:

$$\Delta\lambda / \lambda^2 = (2n_j d_j)^{-1} \quad (10)$$

Therefore increasing the thickness leads to greater fluctuations in results due to reduced distance between the peaks. With increasing the wavelength less fluctuation occurs because the distance between the peaks is increased.

Transmission coefficient at shorter wavelengths due to electromagnetic wave absorption in the multi-layer structures is zero, but with increasing wavelength suddenly transmission coefficient increases and reaches its maximum. There is a steep slope around wavelength of 0.4 micrometr in the transmission coefficient (fig.3). The slope is due to the absorption edge and with increasing wavelength, transmission coefficient is influenced by impurities and defects, free carrier absorption, transfer in the strips with electrons and holes, absorption by lattice vibrations, etc are considered.

4. Conclusion

Sequentially processed thin film solar cells based on Cdte/Cds material have a great potential for achieving high efficiency. An electro-optical modelling of the device characteristics is a promising approach to identify and analyse optical performance. Based on this, a multilayer structure simulation enables virtual modifications of the device layer sequence and allows analysing expected device characteristics without need for resource-consuming structure manufacturing. Thus, optimization potentials can be quickly assessed and modifications of the device manufacturing process may be focused on most promising simulation results. In this work the effects of the thickness of multilayer structure, wave impact angle and wave frequency impact is studied. By studying the angle of incoming radiation and electromagnetic wavelength we conclude radiation parameters is a function of wavelength, angle of incoming radiation and polarization of electromagnetic wave that by applying the intended conditions the favourite coefficients is extracted. It was seen that for all cases transmission coefficient is approximately zero and other of triple coefficients behave oppositely.

5. Nomenclature

A	Amplitude of forward field
B	Amplitude of backward field
D	Transfer matrix
d	Thickness of layer
E	Electromagnetic field
i	Complex index number
j	Index of layer
N	Number of layers
n	Refractive index
P	Propagating matrix
q	Wave vector
t	Time
x	Parallel direction to layer
z	Perpendicular direction to layer
ε	Absorption coefficient
θ	Wave impact angle
λ	Wavelength
ρ	Reflection coefficient
τ	Transmission coefficient
ω	Wavelength frequency

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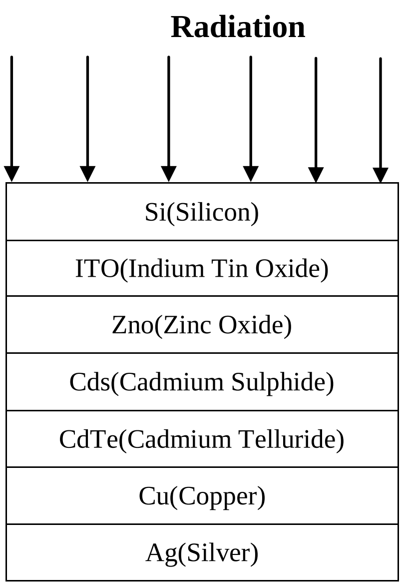

Fig. (1): Cross-section of a typical Cdte/Cds solar cell.

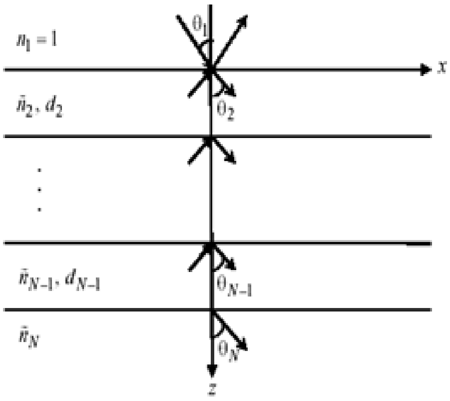

Fig. (2): The geometry for calculating the radiative properties of a multilayer structure [13]

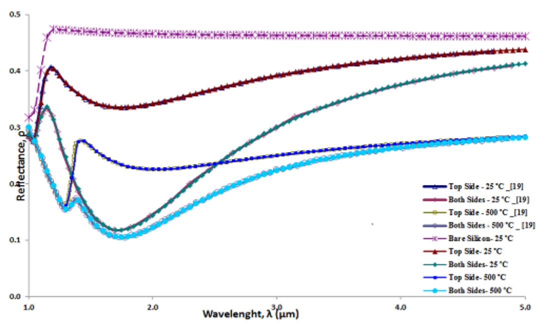

Fig. (3): A comparison of the calculated reflectance with results of [19]

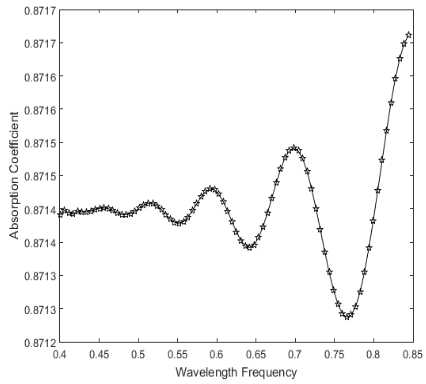

Fig. (4): Absorption coefficient versus wavelength frequency

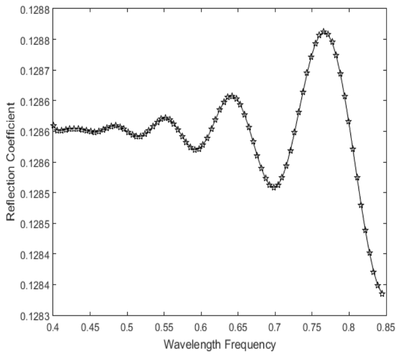

Fig.(5): Reflection coefficient versus wavelength frequency

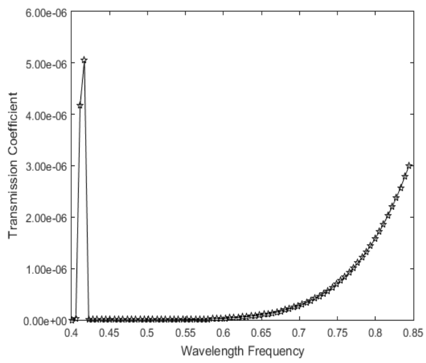

Fig. (6):Transmition coefficient versus wavelength frequency

Table 1 . The optimum thickness of layers in un-polarize condition

layer title	Layer thickness(μm)
Si	1.00
ITO	0.01
Zno	0.01
Cds	0.01
Cdte	2.76
Ag	0.01
Total tickness	3.81

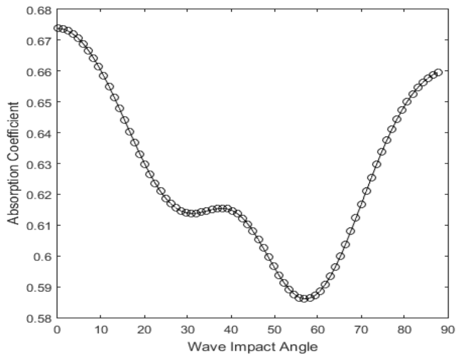

Fig. (7): Absorption coefficient versus wave impact angle

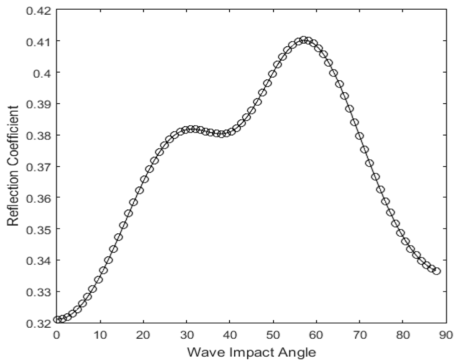

Fig. (8): Reflection coefficient versus wave impact angle

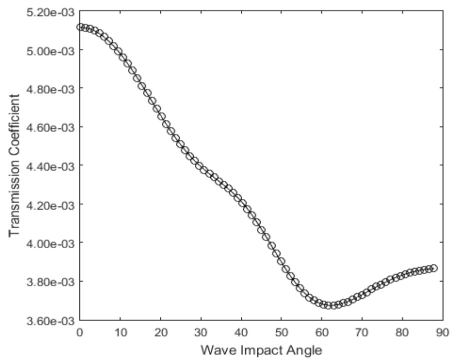

Fig. (9): Transmit ion coefficient versus wave impact angle

Table 2 . The optimized radiative coefficient

Radiative coefficient	Optimized radiative coefficient
Absorption	7.388e-01
Reflection	2.603e-01
Transmission	8.451e-04