Advances in Environmental Biology, 8(21) October 2014, Pages: 140-146

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Using Imperialist Competitive Algorithm for Optimal Radiative Properties of Nano Scale Metal Coatings

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ARTICLE INFO

Article history:
Received 4 September 2014
Received in revised form 24 November 2014
Accepted 8 December 2014
Available online 16 December 2014

Keywords:
Radiation properties, Thin films, Imperialist Competitive Algorithm (ICA), Reflectance coefficient, Emissivity.

ABSTRACT

This work uses transfer-matrix method for calculating the radiative properties. Light doped silicon is used and Coherent Formulation is applied. Imperialist Competitive Algorithm (ICA) can be used to obtain suitable cover relevant to industry needs. The results showed that the silicon whit coating of gold, silver and copper such as anti-transmission and this leads to an increase in the reflectance coefficient than silicon substrate. In The metallic coatings due to the influence of electromagnetic waves is negligible, therefore the change thickness has not effect on the reflection coefficient. The considered wavelengths are 0.65 for visible range and 0.8 for infrared wavelength. In wavelength 0.65, Metal-coated silicon has higher increases reflectance coefficient than wavelength 0.8.

To Cite This Article: Somayyeh Amiri Rad, Seyyed Amir Abbas Oloomi, Seyyed Ali Agha Mirjalily, Using Imperialist Competitive Algorithm for Optimal Radiative Properties of Nano Scale Metal Coatings. ***Adv. Environ. Biol., 8(21),*** *140-146, 2014*

INTRODUCTION

Understanding the radiative properties of semiconductors is essential for the advancement of manufacturing technology, such as rapid thermal processing [1]. Because the major heating source in rapid thermal processing is lamp radiation, knowledge of radiative properties is important for temperature control during the process. Silicon is semiconductor that plays a vital role in integrated circuits and MEMS/NEMS [2]. Semitransparent crystalline silicon solar cells can improve the efficiency of solar power generation [3].

Accurate radiometric temperature measurements of silicon wafers and heat transfer analysis of rapid thermal processing furnaces require a thorough understanding of the radiative properties of the silicon wafer, whose surface may be coated with dielectric or absorbing films [1]. In fact, surface modification by coatings can significantly affect the radiative properties of a material [4].

For lightly doped silicon that metal coating has higher reflectance than silicon nitride coating for visible wavelengths. In visible wavelengths the reflectance increases as the temperature increases, because of decreasing emittance but in infrared wavelengths the reflectance and transmittance decrease as the temperature increases [2, 5].

Metal-coated silicon act as anti-Transmission, these coatings reduce emittance toward bare silicon. If thickness of metal coating increases, reflectance of multilayer increases and transmittance decreases. Cover with metal material has a lot of space and military applications. Space applications such as satellites and spacecraft covered with a thin layer of the radiation is to prevent damage to equipment.

MATERIALS AND METHODS

Coherent Formulation:

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 (Figure. A.1).

By assuming that the electromagnetic field in the j_{th} medium is a summation of forward and backward waves in the *z*-direction, the electric field in each layer can be expressed by [6,7]

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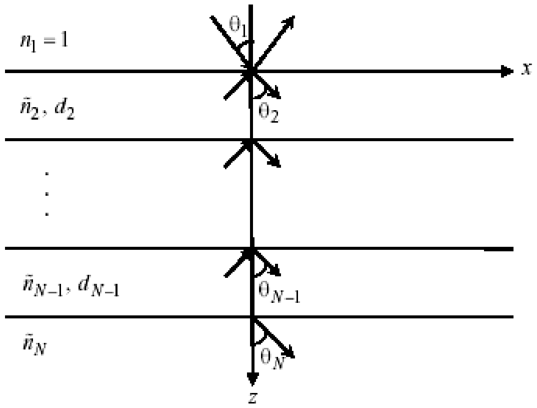

Fig. A.1: The geometry for calculating the radiative properties of a multilayer structure [1]

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

Where A_j and B_j are the amplitudes of forward and backward waves in the j_{th} layer. Detailed descriptions of how to solve for A_j and B_j is given in [8].

Consequently, the radiative properties of the N-layer system are given by [7, 8]

$$\rho = \frac{B_1 B_1^*}{A_1^2} \qquad \text{Eq. (A.2)}$$

$$\tau = \frac{\mathrm{Re}(n_N \cos\theta_N)}{n_1} \frac{A_N A_N^*}{A_1^2} \qquad \text{Eq. (A.3)}$$

$$\varepsilon = 1 - \varepsilon - \rho \qquad \text{Eq. (A.4)}$$

Incoherent Formulation:

When the thickness of silicon substrate is much greater than the coherent length, and the considered wavelength falls in the semitransparent region of silicon, interferences in the substrate are generally not observable from the measurements. In this case, the incoherent formulation or geometric optics should be used to predict the radiative properties of the silicon substrate. Two ways to get around this problem are to use the fringe-averaged radiative properties and to treat thin-film coatings as coherent but the substrate as incoherent [8]. (Fig. A.2)

Consequently, the radiative properties of the silicon wafer with thin-film coatings in the semitransparent region can be expressed as [8, 7]

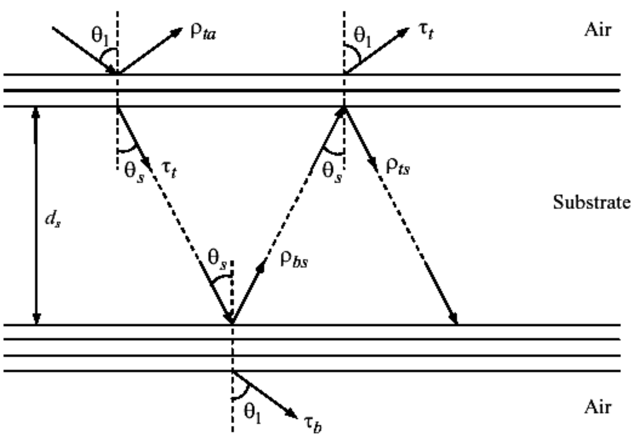

Fig. A.2 (2):

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Optical Constants:

The Jellison and Modine (J-M) expression of optical constants of silicon for a wavelength between 0.4 µm and 0.84 µm is given in [9]. Li developed a functional relation, for optical constants of silicon that covers the wavelength region between 1.2 µm and 14 µm [10]. The J-M expression is used in this study to calculate the optical constants of silicon for the wavelength region from 0.5 µm to 0.84 µm but Li's expression is employed for wavelengths above 1.2 µm. For a wavelength range of 0.84 µm to 1.2 µm, we use a weighted average based on the extrapolation of the two expressions. The optical constants of silicon dioxide, silicon nitride and gold are mainly based on the data collected in Palik [11].

Imperialist Competitive Algorithm:

Imperialist Competitive Algorithm (ICA) is a new socio-politically motivated global search strategy that has recently been introduced for dealing with different optimization tasks (Atashpaz-Gargari and Lucas, 2007). This evolutionary optimization strategy has shown great performance in both convergence rate and better global optima achievement. Like other evolutionary algorithms, it starts with an initial population which is called country and is divided into two types of colonies and imperialists which together form empires. Imperialistic competition among these empires forms the proposed evolutionary algorithm. During this competition, weak empires collapse and powerful ones take possession of their colonies. Imperialistic competition converges to a state in which there exists only one empire and colonies have the same cost function value as the imperialist [12].

Creation of Initial Empires:

The goal of optimization is to find an optimal solution in terms of the variables of the problem. We form an array of variable values to be optimized. In the GA terminology, this array is called "chromosome", but in ICA the term "country" is used for this array. In a N_{var} dimensional optimization problem, a country is an $1\times N_{\text{var}}$ array. This array is defined as following

$$country = [p_1, p_{2,}, p_3, ..., p_{N_{\text{var}}}] \qquad \text{Eq. (B.1)}$$

Where $p_i s$ are the variables to be optimized the variable values in the country are represented as floating point numbers. Each variable in the country can be interpreted as a socio-political characteristic of a country. The cost of a country is found by evaluation of the cost function f at variables $(p_1, p_{2,}, p_3, ..., p_{N_{\text{var}}})$ so we have

$$Cost_i = f(country) = f(p_1, p_2, p_3, ..., p_{N_{\text{var}}}) \qquad \text{Eq. (B.2)}$$

To start the optimization algorithm, initial countries of size $N_{country}$ is produced. We select N_{imp} of the most powerful countries to form the empires. The remaining N_{col} of the initial co`1untries will be the colonies each of which belongs to an empire.

To form the initial empires, the colonies are divided among imperialists based on their power. That is, the initial number of colonies of an empire should be directly proportionate to its power.

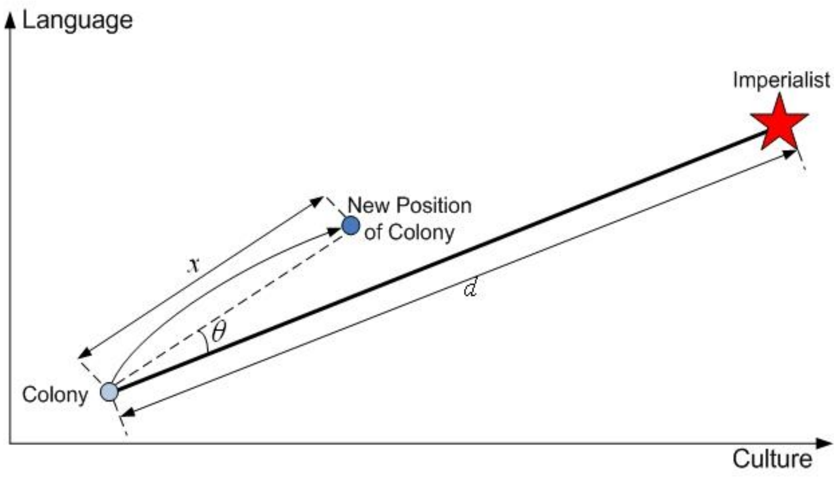

Fig. B.1: [12]

Assimilation: Movement of Colonies toward the Imperialist:

Pursuing assimilation policy, the imperialist states tried to absorb their colonies and make them a part of themselves. More precisely, the imperialist states made their colonies to move toward themselves along different socio-political axis such as culture, language and religion. In the ICA, this process is modeled by moving all of the colonies toward the imperialist along different optimization axis. Fig. (B.1) shows this movement. Considering a 2-dimensional optimization problem, in this figure the colony is absorbed by the imperialist in the culture and language axes [12].

Revolution: A sudden change in socio-political characteristics of a country:

Revolution is a fundamental change in power or organizational structures that takes place in a relatively short period of time. . In the terminology of ICA, revolution causes a country to suddenly change its socio-political characteristics.

The revolution increases the exploration of the algorithm and prevents the early convergence of countries to local minimums. The revolution rate in the algorithm indicates the percentage of colonies in each colony which will randomly change their position.

Exchanging Positions of the Imperialist and a Colony:

While moving toward the imperialist, a colony might reach to a position with lower cost than the imperialist. In this case, the imperialist and the colony change their positions. Then the algorithm will continue by the imperialist in the new position and the colonies will be assimilated by the imperialist in its new position.

Total Power of an Empire:

Total power of an empire is mainly affected by the power of imperialist country. However the power of the colonies of an empire has an effect, albeit negligible, on the total power of that empire. This fact is modeled by defining the total cost of an empire by

$$T.C._n = Cost(imperialist_n) + \xi meam\{Cost(colonies \quad of \quad empire)\} \qquad \text{Eq. (B.3)}$$

$T.C._n$ is the total cost of the n^{th} empire and ξ is a positive small number. A little value for ξ causes the total power of the empire to be determined by just the imperialist and increasing it will increase to the role of the colonies in determining the total power of an empire. The value of 0.1 for ξ has shown good results in most of the implementations.

Imperialistic Competition:

In imperialistic competition, all empires try to take the possession of colonies of other empires and control them. The imperialistic competition gradually brings about a decrease in the power of weaker empires and an increase in the power of more powerful ones. The imperialistic competition is modeled by just picking some (usually one) of the weakest colonies of the weakest empire and making a competition among all empires to possess these (this) colonies. Fig. (B.2) shows a big picture of the modeled imperialistic competition. Based on their total power, in this competition, each of empires will have a likelihood of taking possession of the mentioned colonies. In other words, these colonies will not definitely be possessed by the most powerful empires, but these empires will be more likely to possess them.

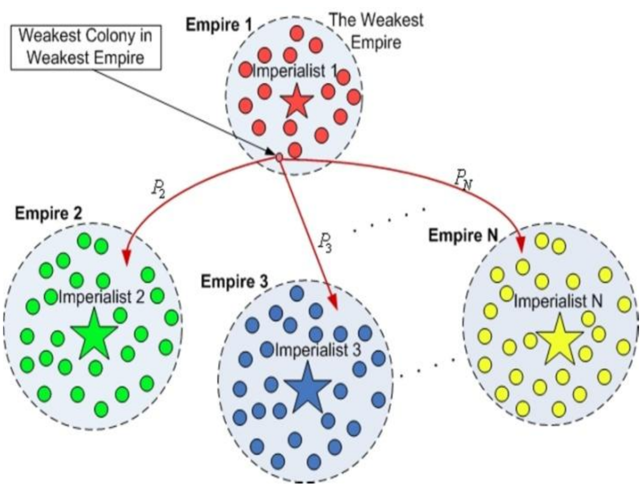

Fig .B.2: [12].

ICA is a new evolutionary method which is used in several applications, such as designing PID controller, characterizing materials properties, error rate beam forming, designing vehicle fuzzy controller, etc. In this paper, we have applied this algorithm for obtain the radioactive properties.

Results:

Figure C.1 compare the reflectance and transmittance of thick silicon substrate with $700\mu m$ thickness and coated by silicon dioxide thin film with $300nm$ thickness in two different coating cases and two different temperatures with the results in [13]. The Electromagnetic waves are incident at $\theta = 0^{\circ}$. The calculated results are in good agreement with results in [13].

Because the refractive index of silicon dioxide (around 1.45) is smaller than that of silicon, the reflectance with a coating is always lower than that of bare silicon.

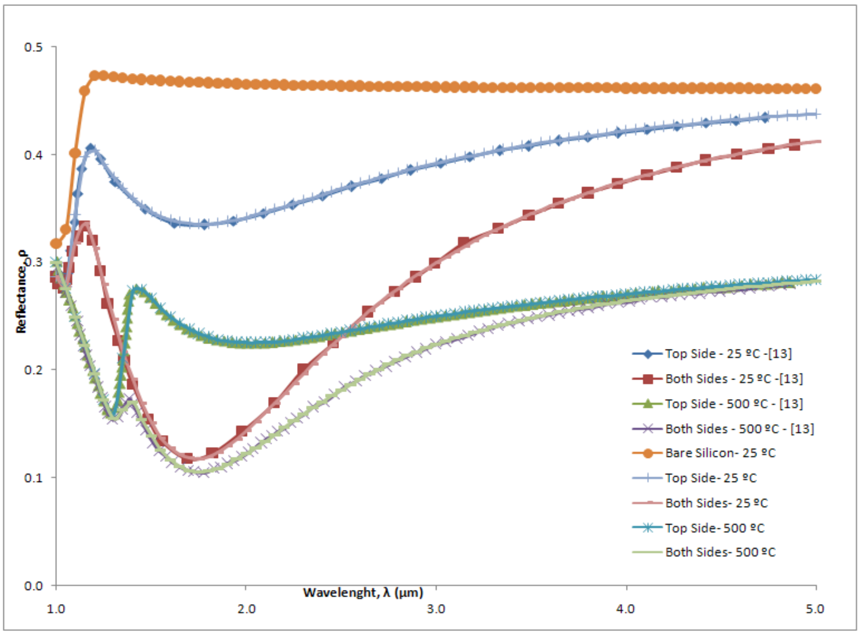

Fig. C.1:

It is possible to choose the suitable coating for minimum emittance, minimum transmittance and or minimum reflectance. It depends on industrial usages.

Thin films play an important role in the semiconductor industry and micro electromechanical and nano electromechanical equipment. Knowledge of the radiation properties of silicon and metal multilayered structures such as gold, silver and copper with different parameters is essential for small system applications.

This paper considered the radiative properties of silicon coated with gold, silver and copper at room temperature for 9 layers with different coating procedures and coherent formulation is used. The division of layer's materials and the thickness of each layer (according as micrometer) the outcome of optimization of Imperialist competitive Algorithm (ICA) for maximum reflection coefficient in the tables , No (A.1) and (A.2) and for maximum emiision factor in two wavelength sample 0.65 μm and 0.8 μm in the tables No (B.1) and (B.2) are mentioned.

Table A.1: Distribution Gender layers for maximum reflectance coefficient

0.8 μm	0.65 μm	Wavelength(λ)
5	9	The number of layers
1	1	Layer Genus 1
2	4	Layer Genus 2
4	1	Layer Genus 3
1	1	Layer Genus 4
1	3	Layer Genus 5
-	2	Layer Genus 6
-	3	Layer Genus 7
-	2	Layer Genus 8
-	3	Layer Genus 9
0.9988	0.8875	Maximum reflection coefficient

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Table A.2: Layers thickness for maximum reflectance coefficient

0.8 μm	0.65 μm	Wavelength(λ)
500	500	Layer thickness 1
0.2982	0.0120	Layer thickness 2
0.2789	0.1181	Layer thickness 3
0.1491	0.0384	Layer thickness 4
0.1263	0.2500	Layer thickness 5
-	0.0603	Layer thickness 6
-	0.2033	Layer thickness 7
-	0.2970	Layer thickness 8
-	0.1026	Layer thickness 9
0.8525	1.5811	Total thickness of the coating

Table B.1: Distribution Gender layers for maximum emittance.

0.8 μm	0.65 μm	Wavelength(λ)
8	7	The number of layers
1	1	Layer Genus 1
3	1	Layer Genus 2
2	4	Layer Genus 3
2	3	Layer Genus 4
3	3	Layer Genus 5
2	3	Layer Genus 6
1	1	Layer Genus 7
3	-	Layer Genus 8
-	-	Layer Genus 9
0.6810	0.6666	Maximum emittance

Table B.2: layers thickness for maximum emittance

0.8 μm	0.65 μm	Wavelength(λ)
500	500	Layer thickness 1
0.3186	0.4000	Layer thickness 2
0.1610	0.0566	Layer thickness 3
0.1778	0.0944	Layer thickness 4
0.0620	0.1259	Layer thickness 5
0.1028	0.2124	Layer thickness 6
0.1609	0.2330	Layer thickness 7
0.0693	-	Layer thickness 8
-	-	Layer thickness 9
1.0578	1.1223	Total thickness of the coating

Conclusion:

By selecting the appropriate coverage, It can be seen the growth of 10.031 times in the 0.65 μm wavelength, and the growth of 6.51 times in the 0.8 μm wavelength for the reflection coefficient (Tables A1 and A3). For Metallic coatings, thickness increases to a certain value, cause rapid growth in reflection coefficient, and significant decrease in the transmission coefficient, and afterward, I t is almost going to be stable. The smallness of the penetration of gold (Au), copper (Cu) and silver (Ag) to the silicon substrate ratio, cause that the transmission coefficient by increasing the thickness of the gold would be faster closes to Zero.

The upper wavelengths had been chosen in form of sample, due to the usage requirements of the industry, you can analyze the specified wavelength and by the Imperialist competitive Algorithm (ICA) you can choose the appropriate structure with the appropriate number of layers, appropriate type and combination of coverage.

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