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Research Article

GLOBAL OPTIMIZATION OF METAL COATING AT VISIBLE SPECTRUM

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ABSTRACT

Global optimization is a branch of applied mathematics and numerical analysis that deals with the global optimization of a function or a set of functions according to some criteria. This paper, optimize the directional, spectral, and temperature dependence of the radiative properties for the thin films consisting of silicon and related materials such as Silver, and Aluminum. In this study the layers at 25°C has been investigated. The electromagnetic wave with an angle of 45° to the multi-layered structure is applied. The wavelength 0.72 μm is considered.

***Keywords:** Simulated Annealing, Metallic, Thin Films*

INTRODUCTION

Doped silicon (D-Si) has been shown to support surface modes in the infrared spectrum and can enhance near-field radioactive transfer (Fu *et al.*, 2005; Wang *et al.*, 2009; Basu *et al.*, 2010; Rousseau *et al.*, 2010) to similar magnitude as those for SiC and SiO2 based on narrowband phonon modes (Biehs *et al.*, 2010). Furthermore, the doping level can be varied to tune the far-field radiative properties (Liu *et al.*, 2013) or near-field heat transfer (Shi *et al.*, 2013).

Another method to obtain higher radiative heat flux is to broaden the super-Planckian radiation band with the help of the resonance-free hyperbolic modes (Biehs *et al*., 2012; Guo *et al*., 2010). Hyperbolic dispersion or hyperbolic modes may exist in natural or artificial anisotropic materials in certain frequency regions, where the electromagnetic waves with large transverse wave vector can propagate inside the hyperbolic met materials, unlike surface modes where the electromagnetic waves propagate only along the interface and decay into both media. Hyperbolic met materials, no matter whether they exist in nature (such as graphite) or are artificially synthesized, exhibit hyperbolic dispersion only in certain frequency ranges and are not ideally lossless (Biehs *et al*., 2013; Liu *et al*., 2013). Therefore, achieving a great enhancement of near-field radioactive thermal transport beyond bulks for more efficient thermal transport or heat dissipation is still a challenge. The calculation of the radiative properties of thin films can be performed by two different approaches: wave optics and geometric optics. Wave optics is based on superposition of the amplitudes of the electromagnetic fields, including interference phenomena (Heavens, 2012; Phelan *et al*., 2013). Geometric optics is based on intensity superposition, excluding interference (Siegel *et al*., 1981; Tang *et al*., 1999). No quantitative criterion has been presented to characterize the range of applications for the two methods; the choice depends on the thickness of the film and of the degree of coherence (Chen *et al*., 1992). Recently, the net-radiation method was employed to study the lower chamber of the RTP furnace at the National Institute of Standards and Technology (Tsai *et al*., 1999; Rosa *et al*., 1999).

The division of layer's materials and the thickness of each layer (according as micrometer) the outcome of optimization of Simulated Annealing Algorithm in wavelengths 0.65 μm is of optimization of Simulated Annealing Algorithm Equal to 0.333 (Mirjalili *et al.*, 2015). By selecting the appropriate coating, It can be seen the reduction of 10.031 times in the 0.65 wavelength, and the reduction of 6.51 times in the 0.8 wavelength for the transmittance (Mirjalili *et al*., 2014).

MATERIALS AND METHODS

The transfer-matrix method provides a convenient way to calculate the radiative properties of multilayer structures of thin films (Figure 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 (Fu *et al*., 2003; Oloomi *et al*., 2009).

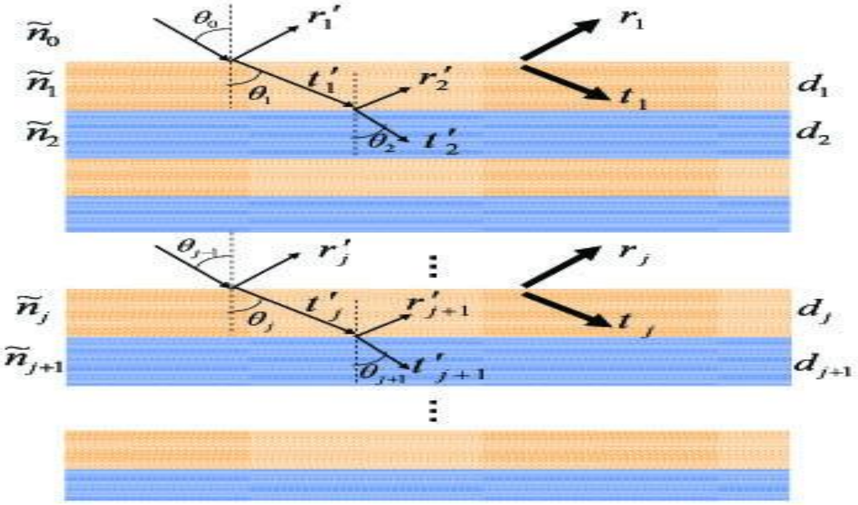

Figure 1: The geometry for calculating the radiative properties of a multilayer structure

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

The optical constants, including the refractive index (*n*) and the extinction coefficient (k), of a material are complicated functions of the wavelength and temperature. 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 (Jellison *et al*., 1994):

$$n_{JM}(\lambda, T) = n_0(\lambda) + \beta(\lambda)T \quad (2)$$

$$n_0 = \sqrt{4.565 + \frac{97.3}{3.648^2 - (1.24/\lambda)^2}} \quad (3)$$

$$\beta(\lambda) = -1.864 \times 10^{-4} + \frac{5.394 \times 10^{-3}}{3.648^2 - (1.24/\lambda)^2} \quad (4)$$

The optical constants of silicon dioxide and silicon nitride are mainly based on the data collected in Palik (Palik, 1998).

Simulated Annealing

The word Simulated Annealing means molten the substance but in expression is a physical process to increase substance temperature up to molten point and then cool it during certain situation, that in this process substance energy became minimum. In 1953 Metro Police, presented an algorithm to evaluate solid substance temperature changes. First his increase substance temperature until it becomes melted, and then in order to reduce substance internal energy, replaces its atoms. This replacement is done between two atoms. Then, in vicinity of this atom, select another atom and replace with that one, atom selection for replacement is completely randomly and there is no order for this issue. In this temperature, several replacements are done, and whenever there is no change in energy, substance temperature decreased. Before decrease substance temperature, a balancing test is done. If due to placement, substance energy decreased, placement is accepted but if substance energy didn't decrease, placement is acceptable with a probability. Later in 1983, Crack Patrick, by equaling this algorithm, between minimizing cost function of a problem and cooling substance to reach basic energy state used to solve optimization problems. Through this substitution, he and his peers introduced an algorithm called Simulated Annealing to solve integrated optimization problems (Metropolis *et al*., 1953; Kirkpatrick *et al*., 1983).

RESULTS AND DISCUSSION

Results

This paper considered the radiative properties of silicon coated with Silver, and Aluminum at room temperature for 9 layers with different coating procedures. Coherent formulation is used. The division of layer's materials and the thickness of each layer (according as micrometer) are the results of optimization of SA. The Maximum and Minimum Emittance , Reflectance and Transmittance at the wavelength 0.72 μm are shown in the tables No (1) to (6). In this Article, Maximum thickness of each layer was considered equal to 800 nm and the incidence angle of 45 ° is considered. The results are compared in Table (7) with colonial competitive algorithm (Teymoorzadi *et al*., 2014), Also in Table (8) with another optimization of Simulated Annealing Algorithm (Mirjalili *et al*., 2014).

Table 1: Distribution Gender layers for Minimum Emittance

Wavelength(λ)	The number of layers	Layer Genus 1	Layer Genus 2	Layer Genus 3	Layer Genus 4	Layer Genus 5	Layer Genus 6	Layer Genus 7	Layer Genus 8	Layer Genus 9	Minimum Emittance
0.72 μm	9	Ag	Ag	Ag	Si	Ag	Ag	Si	Si	AL	0.136

Table 2: Distribution Gender layers for Maximum Eemittance

Wavelength(λ)	The number of layers	Layer Genus 1	Layer Genus 2	Layer Genus 3	Layer Genus 4	Layer Genus 5	Layer Genus 6	Layer Genus 7	Layer Genus 8	Layer Genus 9	Maximum Emittance
0.72 μm	9	AL	Si	AL	Si	Ag	Ag	Si	Ag	Si	0.933

Table 3: Distribution Gender layers for Minimum Reflectance Coefficient

Wavelength(λ)	The number of layers	Layer Genus 1	Layer Genus 2	Layer Genus 3	Layer Genus 4	Layer Genus 5	Layer Genus 6	Layer Genus 7	Layer Genus 8	Layer Genus 9	Minimum Reflectance
0.72 μm	9	Si	AL	Ag	Ag	Si	Ag	AL	Ag	Ag	0.325

Table 4: Distribution Gender layers for Maximum Reflectance Coefficient

Wavelength(λ)	The number of layers	Layer Genus 1	Layer Genus 2	Layer Genus 3	Layer Genus 4	Layer Genus 5	Layer Genus 6	Layer Genus 7	Layer Genus 8	Layer Genus 9	Maximum Reflectance
0.72 μm	9	AL	AL	AL	Si	AL	AL	Si	Si	Ag	0.897

Table 5: Distribution Gender layers for Minimum Transmittance

Wavelength(λ)	The number of layers	Layer Genus 1	Layer Genus 2	Layer Genus 3	Layer Genus 4	Layer Genus 5	Layer Genus 6	Layer Genus 7	Layer Genus 8	Layer Genus 9	Minimum Transmittance
0.72 μm	9	Si	Ag	Si	Si	Si	AL	Si	Ag	Ag	$4.36*10^{-35}$

Table 6: Distribution Gender layers for Maximum Transmittance

Wavelength(λ)	The number of layers	Layer Genus 1	Layer Genus 2	Layer Genus 3	Layer Genus 4	Layer Genus 5	Layer Genus 6	Layer Genus 7	Layer Genus 8	Layer Genus 9	Maximum Transmittance
0.72 μm	9	Ag	Ag	AL	Ag	AL	AL	Si	Ag	Ag	$1.63*10^{-9}$

Table 7: Comparison of the colonial competitive algorithm (Teymoorzadi *et al.*, 2014) with an algorithm simulated annealing

Wavelength(λ)	The number of layers	Layer Genus 1	Layer Genus 2	Layer Genus 3	Layer Genus 4	Layer Genus 5	Layer Genus 6	Layer Genus 7	Layer Genus 8	Layer Genus 9	Minimum Reflection Coefficient
0.72 μm	9	Si	AL	Ag	Ag	Si	Ag	AL	Ag	Ag	0.325
0.65 μm (Teymoorzadi *et al*., 2014)	9	Si_3N_4	SiO_2	Si	SiO_2	Si_3N_4	Si_3N_4	SiO_2	Si	Si_3N_4	0.31

Table 8: Distribution Gender layers for Minimum emittance (Mirjalili *et al*., 2014) with maximum emittance algorithm simulated annealing.

Wavelength(λ)	The number of layers	Layer Genus 1	Layer Genus 2	Layer Genus 3	Layer Genus 4	Layer Genus 5	Layer Genus 6	Layer Genus 7	Layer Genus 8	Layer Genus 9	Minimum Emittance
0.72 μm	9	Ag	Ag	Ag	Si	Ag	Ag	Si	Si	AL	0.136
0.8 μm (Mirjalili *et al*., 2014)	9	Si	SiO_2	SiO_2	SiO_2	Si_3N_4	Si	Si_3N_4	Si_3N_4	Si_3N_4	0.68

Results of SA from Matlab Software are shown at figures 2, 3 and 4.

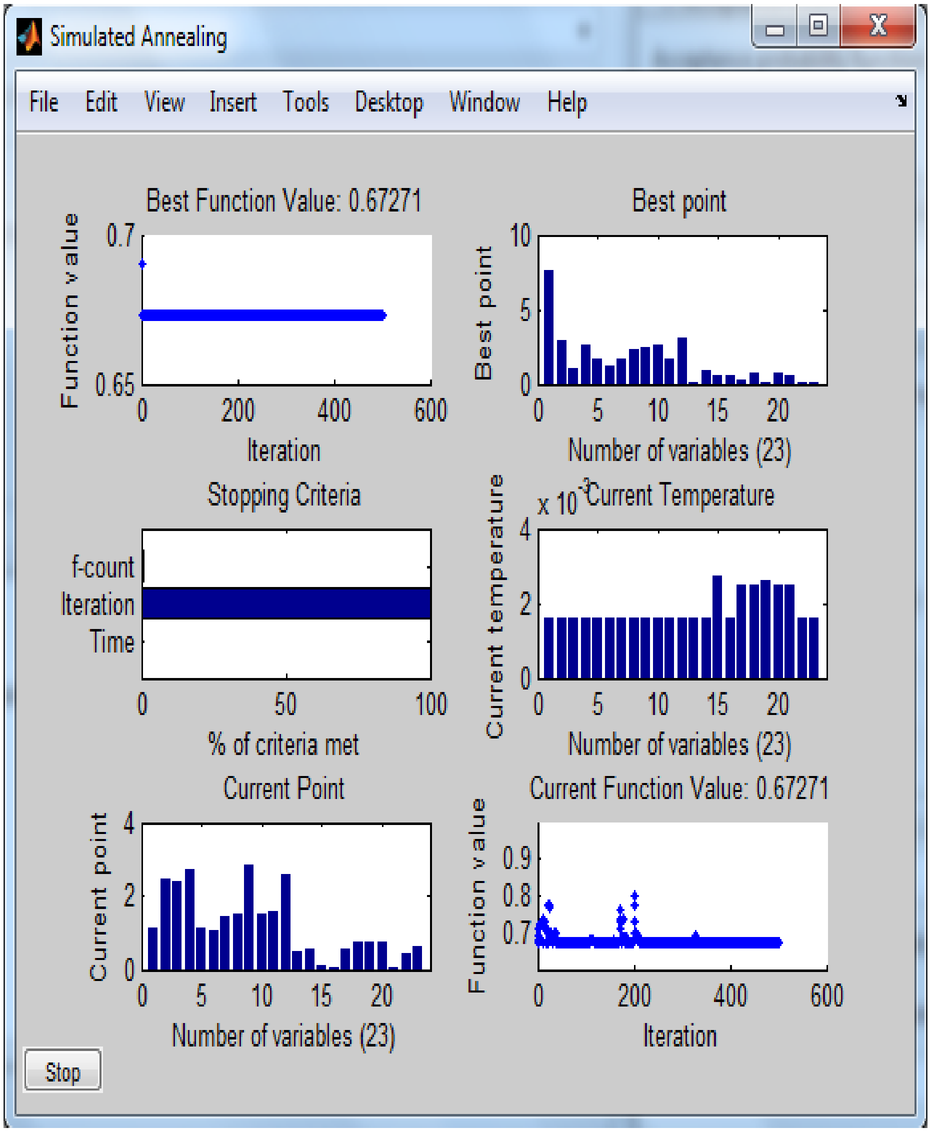

Figure 2: Distribution Gender layers for Emittance

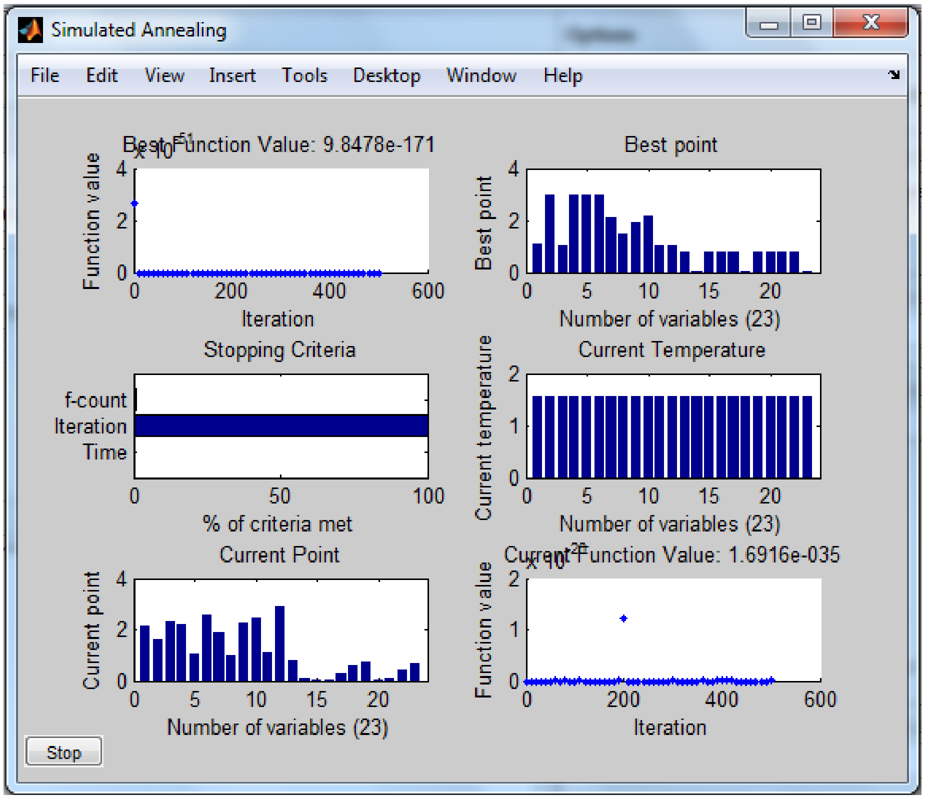

Figure 3: Distribution Gender layers for Transmittance

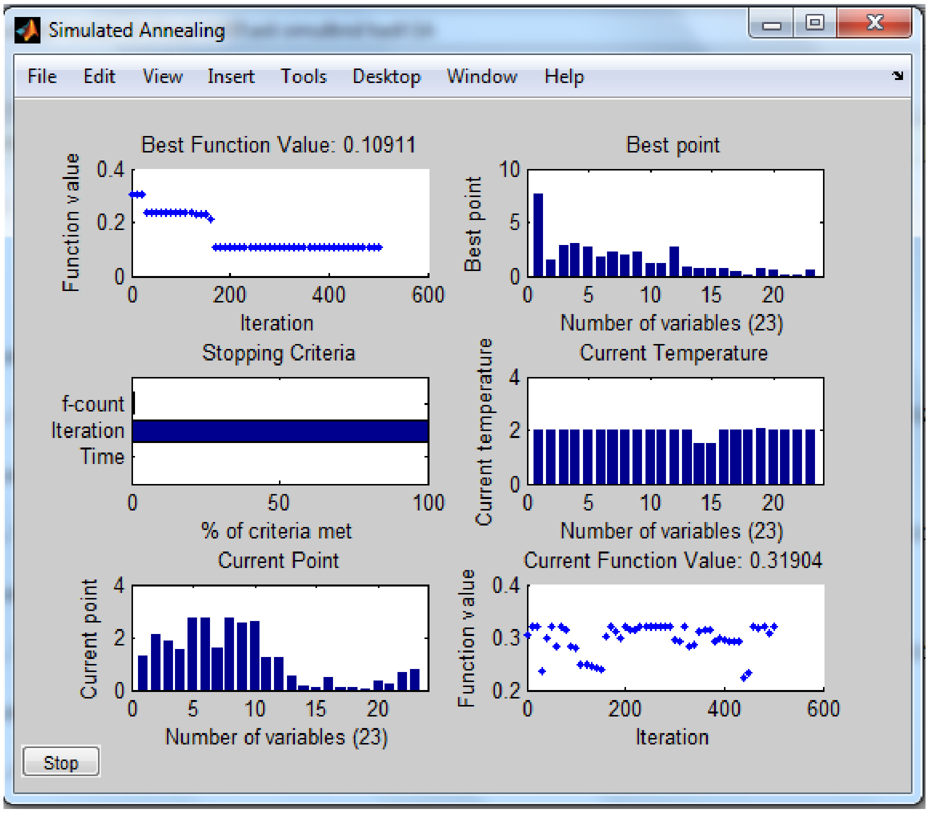

Figure 4: Distribution Gender layers for Reflectance Coefficient

Conclusion

SA is a generic probabilistic metaheuristic for the global optimization problem of locating a good approximation to the global optimum of a given function in a large search space. The emiitance of metal thin film changed from 0.136 to 0.933. It is very useful for many industrials. The maximum of reflectance is 2.76 greater than the minimum of it. The transmittance is negligible, because the sub layer is thick.

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