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Technical Note

High Efficiency of Solar Cell Model Based on Two Types of Nanoparticles

Kholoud Kh. Abushaar[a], **Mohammed M. Shabat**[a], **Dena M. El-Amassi**[a] and **Daniel M. Schaadt**[b]

[a] *Departement of Physics, Islamic University of Gaza, P.O. Box 108, Gaza Strip, Palestine..*

[b] *Institute of Energy Research and Physical Technologies, Clausthal University of Technology, Leibnizstr. 4, 38678 Clausthal-Zellerfeld, Germany..*

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Abstract: Novel solar cell structure based on multi-type nanoparticles layer has been investigated. The transmission and reflection of the incident light have been computed by the Transfer Matrix Method for different physical parameters of the structure and the numerical results are obtained by Maple program software. We found that the types of nanoparticles on the proposed anti-reflective (AR) structure have effectively enhanced transmission and minimized reflection.

Keywords: Anti-reflective, Metallic, Nanoparticles, Reflection, Solar cell, Transmission.

Introduction

Photovoltaic or solar cells are among of the key elements of renewable energy sources which convert sunlight into electrical power. This technology may meet the demand of the increasing need for energy. Absorption, reflection and transmissions are very important parameters which influence photovoltaic solar cell efficiency. Solar cells have attracted the attention of researchers and industry worldwide through research on both raw materials and the fabrication process in order to reduce the processing cost and solar cell size to meet the worldwide demand on energy [1-6].

The basic key concept of effective solar cells depends on increasing the transmitted light and decreasing the reflected light, taking into account the concept of surface plasmons. Surface plasmons (SPs) are two-dimensional (2D) electromagnetic waves confined at the metal–dielectric interface [7-15], resulting from the coupling of the electromagnetic field to the collective plasma excitation. SPs show promise as a possible tool to control light at a subwavelength scale [9-15], which has prospective uses in many practical applications, such as optical biosensing, waveguide devices and emitters [9-15]. SPs have been investigated in a large variety of metal-based systems as crystalline solar cells. Various solar cell structure models have been extensively investigated containing different materials as nanoparticles. One of the most approaches meeting the requirements of the concept of solar cell is the anti-reflected coating (ARC) by minimizing the reflected light [5-9]. Recently, there have been growing interests in using nanoparticles for designing solar cell models [5-21].

In this communication, we propose theoretically and numerically a novel solar cell model based on two types of nanoparticles.

Simulation Model and Theory

The solar cell model under investigation is a four-layered structure containing one film with nanoparticle materials. We examine the proposed structure for three cases: the first case

Corresponding Author: Kholoud Kh. Abushaar **Email**: abushaar_kh@hotmail.com

is with two nanoparticle materials (Ag and Au), the second case is with one type of nanoparticle either (Ag or Au) as shown in Fig. 1. The nanoparticle film is deposited on SiN and covered by an air layer. The refractive indices are denoted as n_0, n_1, n_2 and n_s for air, (Ag-Au or Ag, Au), SiN and Si, respectively. The nanoparticle layer thickness is d_1 and the SiN layer thickness is d_2.

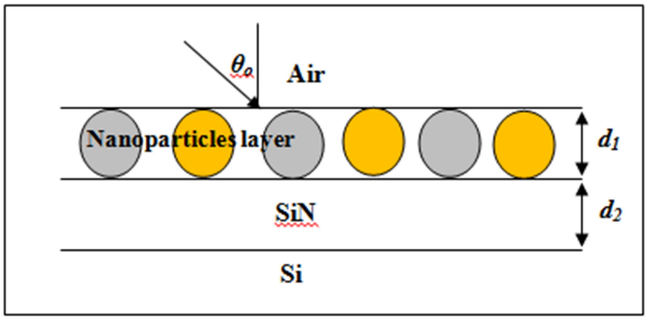

FIG. 1. Sketch of the Air–Nps–SiN –Si multilayer structure (solar cell model). The Np layer with the thickness d_1 and the SiN layer with the thickness d_2 are deposited on the Si substrate.

The effective permittivity of the nanoparticle-film with two types of nanoparticles is described by the Maxwell-Garnett mixing rule as [4]:

$$\varepsilon_{eff} = \varepsilon_o + 3\varepsilon_o \frac{f_1\left(\frac{\varepsilon_1 - \varepsilon_o}{\varepsilon_1 + 2\varepsilon_o}\right) + f_2\left(\frac{\varepsilon_2 - \varepsilon_o}{\varepsilon_2 + 2\varepsilon_o}\right)}{1 - \left[f_1\left(\frac{\varepsilon_1 - \varepsilon_o}{\varepsilon_1 + 2\varepsilon_o}\right) + f_2\left(\frac{\varepsilon_2 - \varepsilon_o}{\varepsilon_2 + 2\varepsilon_o}\right)\right]} \tag{1}$$

where ε_o is the permittivity of the host (base) material which equals 1, $\varepsilon_1=(0.13455\text{-}3.98651i)^2$ is the permittivity of the silver nanoparticles, $\varepsilon_2 = (0.19715\text{-}3.0899i)^2$ is the permittivity of the gold nanoparticles and f_1 and f_2 are the volume fractions of Ag and Au nanoparticles in the host medium, respectively.

Following the notations and approaches used in [10, 21], both transmission and reflection can easily be derived.

Results and Discussion

The structure under consideration has a film consisting of two types of nanoparticles, (Ag-Au) with n_{Ag}= 0.13455-3.98651i, n_{Au}=0.19715-3.0899i on SiN (n_2=2.24) and covered by air with n_0=1 and the Si substrate with n_s=3.5. The thicknesses $d_1$and d_2 are taken to be equal to a quarter of wavelength at each medium ($d_i = \lambda_i/4$), where $\lambda_i = \lambda_i/n_i$ and n_i is the refractive index for each medium. The wavelength λ is chosen close to the peak of the solar spectrum (λ=600nm), as well noticed at the spectral response in the range (300-1200 nm). This range is taken to limit the spectrum of incident light. Also, it is worth mentioning that for Si technology, the infrared region is less important due to the gap of Si. The variation of the percentage of the transmitted and reflected light *versus* the wavelength of the incident light was computed and illustrated for different values of light incidence angle. The values of the volume fractions of the two nanoparticles (f_1=0.15, f_2=0.05) for Ag and Au, respectively, in the host medium are used in the computations.

Fig. 2 displays the effects of the solar cell model structure based on two types of nanoparticles (Ag-Au) through the concept of transmission. It has been noticed that the transmission coefficients are almost reaching 100% when incidence angle is equal to zero.

Moreover, an enhancement of the results has been observed over a good range, as we saw that the transmission coefficient is above 95% over the wavelength range term 450nm to 1100nm.

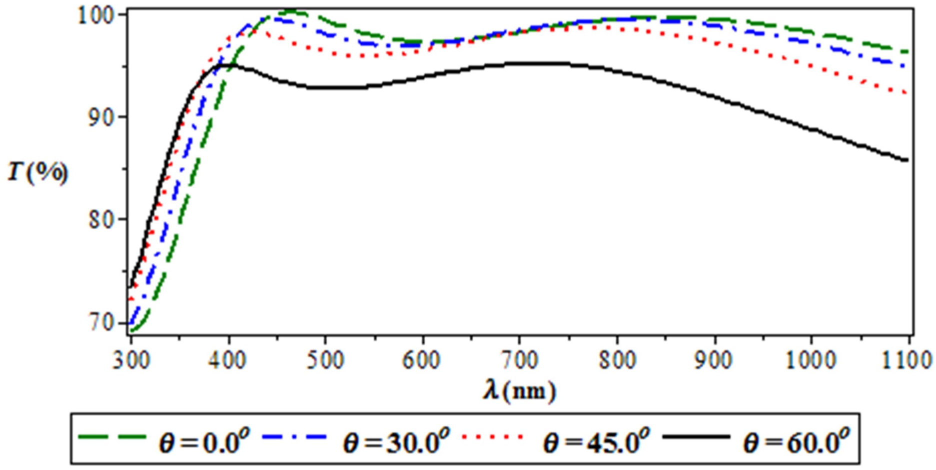

FIG. 2. Percentage of transmitted light *versus* incident light wavelength for different values of light incidence angle, where $d_1 = 600/4n_1$, $d_2 = 600/4n_2$, $\theta = 0.0^o$, $f_1 = 0.15$ and $f_2 = 0.05$.

Fig. 3 illustrates the reflection coefficients of the two types of nanoparticles (Ag and Au) *versus* the operating of light incident leading to minimum values. The reflection coefficients almost equal zero or the minimum values for a long range of light wavelengths leading to remarkable solar enhancement.

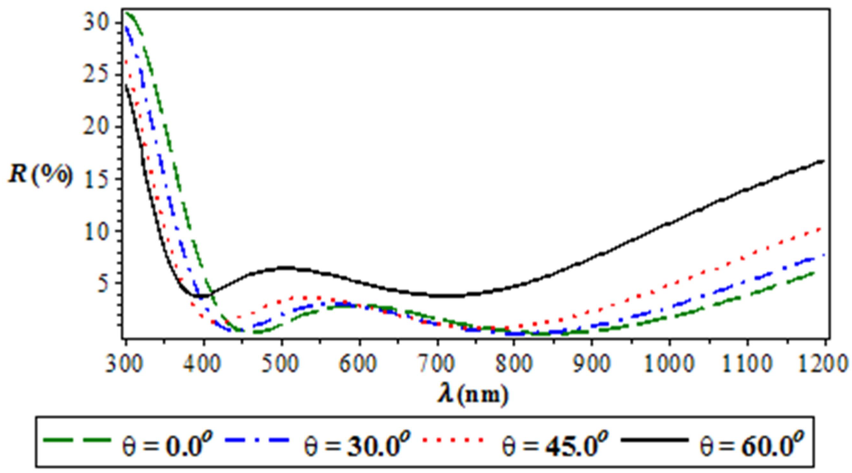

FIG. 3. Percentage of reflected light *versus* incident light wavelength for different values of light incidence angle, where $d_1 = 600/4n_1$ and $d_2 = 600/4n_2$.

Fig. 4 illustrates the effects of the fractions of the two types of nanoparticles (Ag-Au) on the efficiency of solar cell model structure. The percentage of the transmitted light *versus* the incident light wavelength for different values of volume of fraction shows equal fractions of the two types of nanoparticles or quantities of the two nanoparticles as $f_1 = 0.25$, $f_2 = 0.25$. It has been noticed that the mixture of the two equal quantities of nanoparticles as f1 = f2 = 0.25 is the best state to achieve higher efficiency by getting lower reflection and higher transmission. Other nice views of the transmission of the proposed structure have been clearly noticed for different values of the nanoparticles of the two recommended types, Au and Ag. So, transmission can be controlled and adjusted by tuning or adopting the fractions of nanoparticles in the manufacturing process.

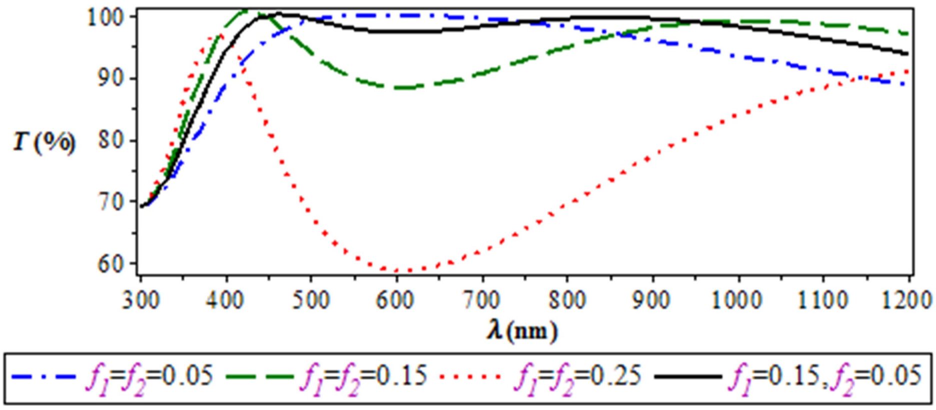

FIG. 4. Percentage of transmitted light *versus* incident light wavelength for different values of volume of fraction, where $d_1 = 600/4n_1$, $d_2 = 600/4n_2$, $\theta = 0.0^o$, $f_1 = 0.15$ and $f_2 = 0.05$.

Fig. 5 shows the percentage of the reflected light *versus* incident light wavelength for different values of volume of fraction of the two types of nanoparticles with the same data of the above figures of transmission. This figure demonstrates a good picture of the high efficiency of solar cells.

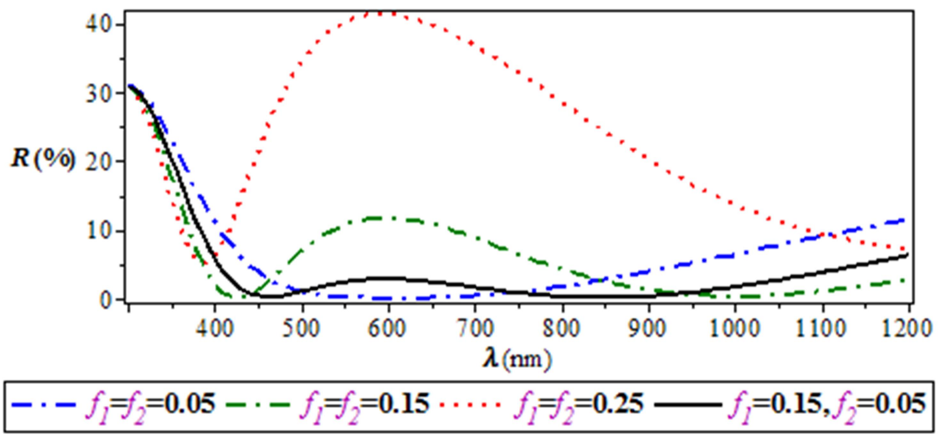

FIG. 5. Percentage of reflected light *versus* incident light wavelength for different values of volume of fraction, where $d_1 = 600/4n_1$, $d_2 = 600/4n_2$ and $\theta = 0.0^o$.

Figs. 6 and 7 shoe the effect of a new physical parameter of the proposed solar cells; thickness of the layer of SiN d_2 has been implemented to compute the percentage of transmitted light *versus* the incident light wavelength and the percentage of reflected light *versus* the incident light wavelength for various values of the thickness d_2.

Widening the SiN layer leads to minimum percentage of reflected light *versus* the incident light wavelength at d_2 = 60 nm and d_2 = 80nm, which confirms the concept that minimum reflected light occurs at the thickness equal to a quarter of the wavelength.

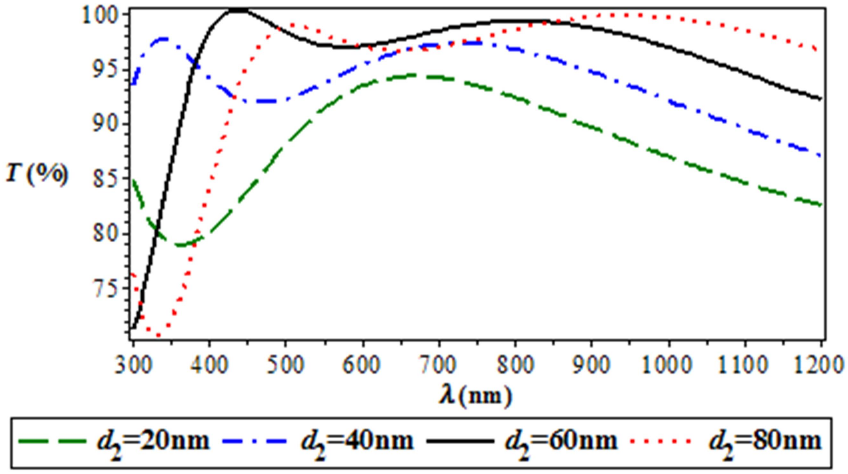

FIG. 6. Percentage of transmitted light *versus* incident light wavelength for various values of the thickness d_2, $d_1 = 600/4n_1$, $f_1 = 0.15$, $f_2 = 0.05$ and $\theta = 0.0^o$.

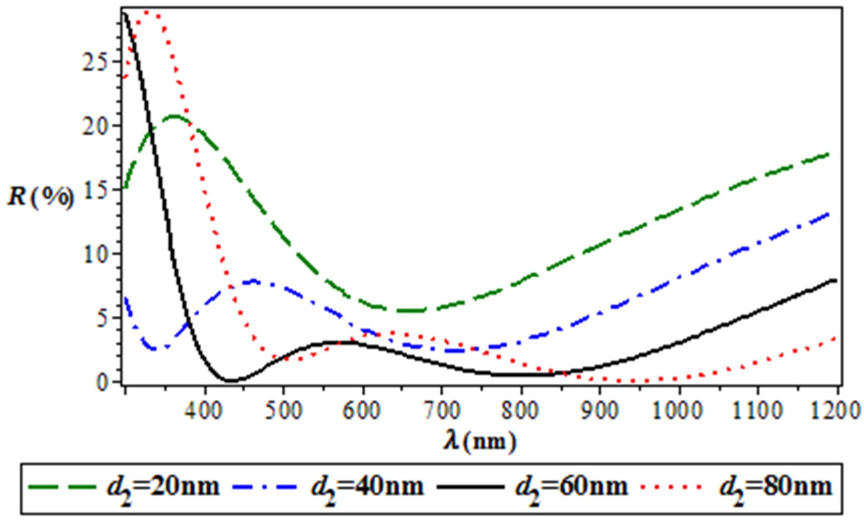

FIG. 7. Percentage of reflected light *versus* incident light wavelength for various values of the thickness d_2, $d_1 = 600/4n_1$, $f_1 = 0.15$, $f_2 = 0.05$ and $\theta = 0.0^o$.

Conclusions

We have numerically investigated a novel proposed solar cell structure model based on two types of nanoparticles. Maximum transmission and minimum reflection have been achieved leading to higher solar cell efficiency. Higher efficiency can be obtained by adjusting the physical parameter of volume fraction of nanoparticles, the film thickness and the incident light angle in the proposed structure. The obtained promising results of the structure model based on two types of nanoparticles could be used in designing future solar cells.

Acknowledgements

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