Optik 166 (2018) 127–131

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Solar cell with multilayer structure based on nanoparticles composite

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ARTICLE INFO

Article history:
Received 3 March 2018
Accepted 3 April 2018

Keywords:
Nanoparticles
Antireflection coating
Reflectance
Solar energy
Solar cell

ABSTRACT

In this study, a four-layer waveguide structure has been investigated as a solar cell model. In the proposed structure, a nanoparticle composite layer is added to enhance the efficiency of the solar cell due to their ability of controlling the light transmission and reflection. The nanoparticles are taken to be a mixture of Ag and Au embedded in a dielectric media consists of polyacrylic acid laid above a SiNx antireflection coating layer. Both layers are sandwiched between glass substrate and air cladding. The average reflectance for TE and TM fields are calculated using Maple. Results show that the reflectance depends on the ratio of the nanoparticle in the dielectric media, refractive index of SiNx layer and the angle of incidence. Thus, the performance of solar cell has been optimized by tuning and adjusting the above-mentioned parameters.

1. Introduction

Solar cells are widely used as a building block for solar systems. Solar cells, which is also known as photovoltaic (PV) cells, convert absorbed sun light to electrical energy. Recently, solar cell models based on nanoparticles have been extensively investigated in order to enhance solar cell efficiencies [1–3]. Particularly, they may be used to obtain zero reflection due to their ability to absorb light if they used at a specified ratio. Materials such as SiNx are used like antireflection coating layer for high refractive index, which can be easily varied by varying the deposition parameters [4–7]. For this reason, they are used intensively to improve the efficiency of solar cells as single or double antireflection coating layer [4,7,8].

Oh et al. [5] investigated the features that affect potential-induced degradation of the shunting type. Among these features are the parts of refractive index of SiNx antireflection coating in addition to emitter sheet resistance. Hsu et al. [6]) were able to apply the hydrogenated amorphous silicon nitride (a-SiNx:H) as a refractive index (n) equivalent deposits in the middle of glass ($n = 1.5$) and the transparent conducting oxide ($n = 2$). It is shown that the solar cell performance is enhanced by changing the refractive index and thickness of the a-SiNx:H deposits.

El-Amassi et al. [2] reported that PV cell efficiency could be improved by using metamaterial (MTM) and SiNx layers surrounded by glass and by air. El-Khozondar et al. [1] considered dissipative MTM for the same structure to measure the

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https://doi.org/10.1016/j.ijleo.2018.04.014

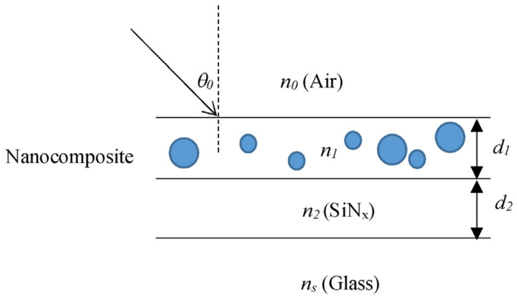

Fig. 1. Proposed solar cell structure.

effect of dissipation. In other work, nanoparticles embedded in a dielectric media is used to further control the efficiency of the solar cell [3].

In this study, we employed a composite nanoparticle made of Ag-Au embedded in a dielectric media between SiNx layer from bottom and air from top. In the following section, the theory will be developed. Section 3 is dedicated to exhibit the results and discussions followed by conclusion.

2. Theory

The simple schematic proposed structure is a four-layer solar cell as shown in Fig. 1. The SiNx antireflection coating layer is placed on a glass substrate. The nanoparticle-composite sheet is sandwiched between SiNx antireflection coating layer from below and air layer from above. The nanoparticle-composite layer is taken to be Ag-Au embeded in polyacrylic acid host media with thickness d_1 and effective refractive index n_1. SiNx layer has a thickness d_2 and refractive index n_2. Glass layer has refractive index n_s and air has refractive index n_0.

The effective permittivity for the nanocomposite layer (ε_1) is calculated using Dynamical Maxwell-Garnett theory (Eq. (1)) which is an extended version of Maxwell-Garnett theory [9]. The theory assumes that the host (in our case is polyacrylic acid) is the majority and the metal nanoparticles (Au and Ag) are the annexation materials with chosen metal fraction in the composite [9–11].

$$\frac{\varepsilon_1-\varepsilon_h}{\varepsilon_1+2\varepsilon_h}=f_{Ag}\frac{\varepsilon_{Ag}-\varepsilon_h}{\varepsilon_{Ag}+2\varepsilon_h+\left(\varepsilon_h-\varepsilon_{Ag}\right)\left(1-f_{Ag}\right)\alpha}+f_{Au}\frac{\varepsilon_{Au}-\varepsilon_h}{\varepsilon_{Au}+2\varepsilon_h+(\varepsilon_h-\varepsilon_{Au})(1-f_{Au})\alpha} \tag{1}$$

where ε_{Ag} is the permittivity of silver nanometal, ε_{Au} is the permittivity of gold nanometal, ε_h is the permittivity of polyacrylic acid, f_{Ag} and f_{Au} are the silver nanoparticle and gold nanoparticle volume fractions. The particle size effect is introduced via α [9,10] as follows

$$\alpha=x^2+i\left(\frac{2}{3}\right)x^3 \tag{2}$$

where $x=\varepsilon_h\sqrt{(\omega a)/c}$, ω is the angular frequency, a is the radius of the metal nanoparticle, and c is the speed of light. The value of a is assumed to be an average value which equals to 20 nm. Once ε_1 is calculated, the value of effective refractive index n_1 is obtained by taking square root of ε_1.

To understand the performance of the proposed structure, the light assumed to strike the solar cell air-nanocompsite interface at oblique incidence with an incidence angle (θ_0) that can adopt different values. For oblique incidence, the optical admittance for the k_{th} layer is derived in the paper of [12,13] for both transverse electric field polarization (TE) and transvers magnetic field polarization (TM) as follows

$$\gamma_k^{TE}=\frac{1}{\eta_0\mu_k}n_k\cos\theta_k \tag{3}$$

$$\gamma_k^{TM}=\frac{1}{\eta_0\mu_k}\frac{n_k}{\cos\theta_k} \tag{4}$$

where $\eta_0=\sqrt{\mu_0/\varepsilon_0}$ is the air intrinsic impedance. The angle θ_k is related to θ_0 by Snell's law:

$$n_0\sin\theta_0=n_k\sin\theta_k;k=1,2,...m \tag{5}$$