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DIRECTING THE ABSORPTION PEAKS OF PLASMOINC SOLAR CELL

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ABSTRACT

In this paper, a plasmonic solar cell using silver nanoparticles is presented. The unit cell structure composes of two layers, each containing a silver nanoparticle deposited on the absorber layer and covered with an indium tin oxide layer. Nanoparticle structure has been used for light-trapping to increase the absorption of plasmonic solar cells. By various light trapping techniques, light can be concentrated in a thin absorber layer. As it will be clarified, through varying the geometry of these nanoparticle structures, the absorption peaks can be directed. All simulation data are obtained using the finite element method. The proposed model achieves two absorption peaks existing at 1.07 μm and 1.17 μm, each with absorptions of around 50%. The parameters of optimized performance have been specified. The results indicate that this model shows an absorption full width at half maximum, reaching 122 nm. Moreover, it can be noticed that the absorption peak can be increased to reach 0.5. The proposed structure has potential applications in the absorption of the infra-red part of the solar spectrum.

Keywords: *Absorption enhancement, Light Trapping, Nanoparticles, Plasmonic Solar cell.*

1. INTRODUCTION

The energy trouble can be reduced through the conversion of sunlight into electricity [1]. Although the plasmonic solar cells low cost, it suffers from poor absorption of the infrared portion of the solar spectrum [2, 3]. Recently light-trapping structures have been utilized in different ways to increase the absorption of plasmonic solar cells. Several structures including surface texturing [4-6], anti-reflection coatings [7, 8], photonic crystals [9], nanogratings [10, 11], and metallic nanoparticles [12-13] have been presented to enhance the absorption of plasmonic solar cells. Solar cells are generally classified into four generations [14-18]. By various techniques of nanostructures, light can be concentrated in a thin absorber layer through scattering, enhanced near-field, or surface plasmon polariton phenomenon [1, 2]. The absorption enhancement of the absorber layer in plasmonic solar cells using nanoparticles has been studied by many researchers in [19-34]. Nanoparticle structures have been used for light-trapping to enhance the absorption of plasmonic solar cells [1]. In 2014, Novitsky et al. [12] demonstrated an effective mechanism for expanding the photon bsorption below the semiconductor bandgab in the infrared range. In 2017, Aboul-Dahab et al. [13] presented techniques to enhance the infrared absorption coefficients and directing the absorption peak of plasmonic solar cells. In this study, a plasmonic solar cell is proposed. The unit cell structure composes of two layers, each

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containing a silver nanoparticle deposited on the absorber layer and covered with indium tin oxide (ITO) layer. In this structure two absorption peaks can be directing. The geometry influence of the nanoparticles on the absorption magnitude and bandwidth has been presented. Numerical investigations of the light absorption response of the proposed solar cell using the finite element method (FEM) have been introduced.

2. STRUCTURE AND DESIGN

The structure of a single layer is illustrated in Figure.1. The unit cell structure composes of two layers, each containing a silver nanoparticle deposited on the absorber layer and covered with ITO layer. Each nanoparticle consists of cylindrical silver nanoparticle of thickness, *h* and an elliptical cross-section with a semi-minor axis, *Rs*, equals half the semi-major axis, R_L.

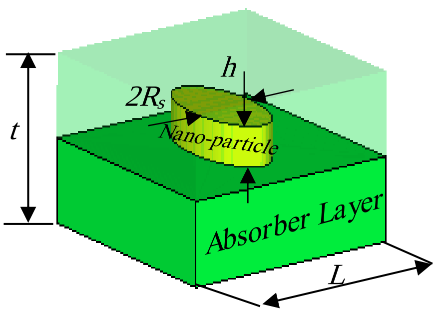

Figure.1. Structure of a single layer.

The size of the unit cell is 80 × 80 nm^2. The thickness of each layer is of 50 nm. The permittivity of absorber layer and ITO are assumed equal 12.86 and 4.67, respectively. The dispersive properties of the silver nanoparticles are determined using the Drude model [35]. Throughout the analysis, a R_L-polarized plane wave is used as an incident wave. All the simulation data are obtained using the FEM method.

3. RESULTS AND DISCUSSION

Figure 2 shows the reliance of the absorption spectra on the semi-minor axis, R_s, when it varies from 10 nm to 12 nm. Other nanoparticle parameters are h = 10 nm and L = 80 nm, and t = 50 nm. The silver nanoparticle unit cell is illuminated by incident light polarized along the major axis. It is clear that the proposed plasmonic solar cell appears two separate absorption peaks. The Low-frequency absorption peak is approximately the same for different semi-minor axes while the High-frequency absorption peak decreases with the increase of R_s. The High-frequency absorption peak for R_s = 10 nm was found at λ = 1.07 µm with the maximum absorptivity of 0.49 compared to 0.37 at λ = 1.12 µm for R_s = 12 nm. Enhancing performance occurs at higher values of absorption. Full width at half maximum (FWHM) increases with the increase of R_s, which referred to a wide absorption range of the solar spectrum. The FWHM of the High-frequency absorption peak is 69 nm for R_s = 10 nm compared to 106 nm for R_s = 12 nm while the FWHM of the Low-frequency absorption peak is 35 nm for R_s = 10 nm compared to 41 nm for R_s = 12 nm. Frequencies of both absorption peaks shift to lower frequencies with an increase of the semi-minor axis, R_s. Enhancing performance occurs at higher frequencies. At these high frequencies, the photons have higher energies. The results indicate that the performance enhances by decreasing the nanoparticle radii.

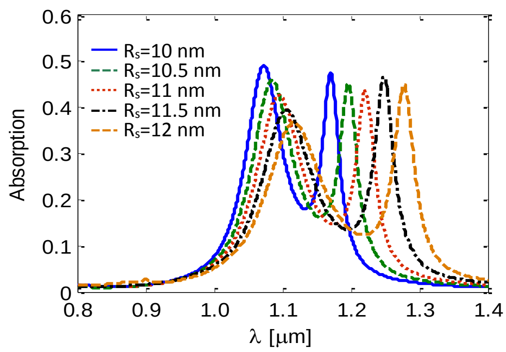

Figure.2. Absorption spectra of the model with various nanoparticle semi-minor axes

Figure.3 shows the absorption spectra of the model with various thicknesses, *h*. Other nanoparticle parameters are R_s = 12 nm, *L* = 80 nm, and *t* = 50 nm. It can be observed that the proposed plasmonic solar cell has two discrete absorption peaks for all different values of nanoparticle thickness, *h*. The High-frequency absorption peaks are approximately the same of 0.37 compared to 0.45 for the Low-frequency absorption peaks. Frequencies of both absorption peaks shift to higher frequencies with an increase of the nanoparticle thickness, *h*. The FWHM decreases with the increase of *h*. The FWHM of the High-frequency absorption peak is 120 nm for *h* = 8 nm compared to 97 nm for *h* = 12 nm while the FWHM of the Low-frequency absorption peak is slightly decreased from 43 nm for *h* = 8 nm compared to 41 nm for *h* = 12 nm. The results indicate that the performance enhances by increasing the nanoparticle thickness.

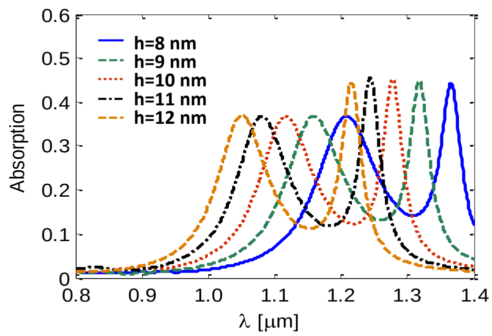

Figure.3. Absorption spectra of the model for several nanoparticle thicknesses *h*

Figure.4 discusses the dependence of the absorption spectra on several periods *L* when it varies from 80 nm to 100 nm. Other nanoparticle parameters are *h* = 10 nm, R_s = 12 nm, and *t* = 50 nm. It can be seen that two absorption peaks were found. It can be noticed that when the period *L* increases, the Low-frequency absorption peak decreases, and the High-frequency absorption peak increases. The FWHM of the High-frequency absorption peak is 106 nm for *L* = 80 nm compared to 76 nm for *L* = 100 nm while the FWHM of the Low-frequency absorption peak is 41 nm for *L* = 80 nm compared to 37 nm for *L* = 100 nm. It can be seen that when the period *L* increases, The FWHM of the High-frequency absorption peak decreases, and the FWHM of the Low-frequency absorption peak slightly decreases. As illustrated in Figure.4, when the period *L* increases, the Low-frequency absorption peak slightly shifts to higher frequencies, and the High-frequency absorption peak slightly shifts to lower frequencies. Increasing the nanoparticle periodicity reduces the cost and achieves a good performance.

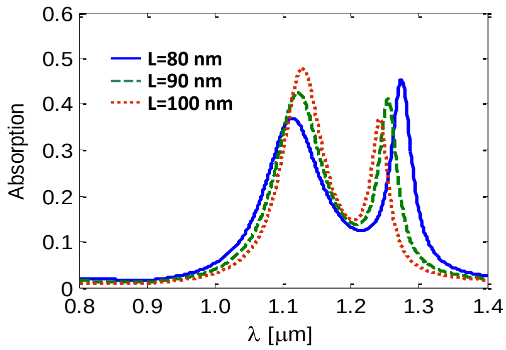

Figure.4. Absorption spectra of the model for several nanoparticle periodicities *L*

Figure.5 shows the dependence of the absorption spectra on layer thickness *t* when it varies from 42 nm to 50 nm. Other nanoparticle parameters are *h* = 10 nm, R_s = 12 nm, and *L* = 80 nm. It can be noticed that when the layer thickness *t* increases, both absorption peaks increase. The FWHM of the High-frequency absorption peak is 122 nm for *t* = 42 nm compared to 106 nm for *t* = 50 nm while the FWHM of the Low-frequency absorption peak is 37 nm for *t* = 42 nm compared to 41 nm for *t* = 50 nm. It can be seen that when the layer thickness *t* increases, The FWHM of the High-frequency absorption peak decreases and the FWHM of the Low-frequency absorption peak slightly increases. As illustrated in Figure.5, when the layer thickness *t* increases, both absorption peaks shift to lower frequencies. The results indicate that the performance enhances by increasing the thickness *t* but this increases the cost.

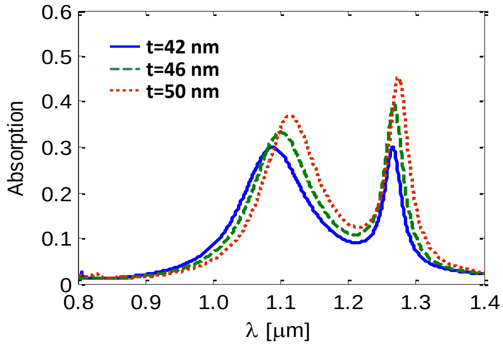

Figure.5. Absorption spectra of the model with variable layer thickness

As shown in the results, the optimized performance achieved using the parameters: R_s = 10 nm, h = 10 nm, L = 80 nm, and t = 50 nm. The enhancing performance occurs at higher values of absorption and frequencies. All absorption peaks considered here exist at wavelengths longer than λ_g = 0.87 μm, which corresponds to the absorber layer bandgap E_g = 1.43 eV. The enhanced photon absorption below the semiconductor bandgap results from the photoemission of electrons by nanoparticles.

4. CONCLUSIONS

In conclusion, a plasmonic solar cell formed by two layers of silver nanoparticle deposited on the absorber layer and covered with ITO layers is presented. It is found that the proposed structure shows two separate absorption peaks. The absorption peaks can be directed through varying the geometry of the silver nanoparticle. As shown in the results, the proposed plasmonic solar cell achieves a full width at half maximum, reaching 122 nm. It can be noticed that by changing the nanoparticle dimensions, the absorption peak can be increased to reach 0.5. The proposed structure has potential applications in the absorption of the infra-red part of the solar spectrum.

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