International Journal of Engineering & Technology, 7 (4.30) (2018) 269-270

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Optical Absorption of Plasmonic Cylindrical Gold Nanoparticle in Hexagonal Geometry

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Abstract

A high quality solar cell depends on how good the design of the solar cell can absorb light. In this study, cylindrical gold nanoparticles were embedded into indium tin oxide (ITO) layer and silicon layer arranged in hexagonal geometry on plasmonic solar cell simulation design. The aim is to investigate the optical absorption percentage in terms of wavelength and angle of incidence for the solar cell design. The numerical results showed that the highest absorption has occurred in 480 nm in the range of visible spectrum. In this wavelength, the highest absorption occurred at the incidence angle of 48 degree.

Keywords: *Gold Nanoparticle, Optical Absorption, Plasmonic Nanostructure, Numerical Simulation, Solar Cell*

1. Introduction

Many solar applications arising in connection with plasmonic that use metal nanoparticles like gold and silver [1-3] is the result of the unique properties of surface plasmon [1]. These unique properties include manipulation and transport of light at nanometer scale due to their highly localized electromagnetic fields [4]. When using the surface plasmon properties, geometrical dimensions of the nanostructure can be controlled. It is possible to enhance the optical absorption because the light could enter the structure with various angles of incidence at certain wavelengths [5-6]. However, there are still exists the limited absorption of light effect at geometry structure for optical absorption efficiency. Recently, several numerical simulations have been investigated on metal nanostructures [7]. Simulations are used as a method to understand fundamental of plasmonic and investigated the effective factors of plasmon properties on nanoparticles. Finally, more plasmonic device can be designed to become a commercial product in industry [7]. Simulation of plasmons in nanostructure usually used as a method to solved the Maxwell's equations for nanoparticles with several geometry, size and dielectric function [7]. In this paper, nanoscale plasmonic structures are explored for performance improvement. These structures used as a ways to guide and trap light for absorption and the overall performance in solar applications and optical properties [8]. Plasmonic structure in hexagonal geometry of cylindrical nanoparticle gold is modelled using COMSOL Multiphysics in electromagnetic wave propagation of frequency domain.

2. Theory and methodology

The interaction of light with Au nanostructures simulations were carried out with COMSOL Multiphysics which applies Finite Element Method to discretize Maxwell's equations as follows:

$$\nabla \times E = -\mu \, \partial H / \partial t \quad (1)$$

$$\nabla \times H = \varepsilon \, \partial E / \partial t + \sigma E \quad (2)$$

where, electric field E, magnetic field H, permeability μ , permittivity ε, and conductivity σ [9]. Maxwell's equations are indispensable to accurately predicting the interaction of matter in nanostructures as full-wave electromagnetic solvers [10]. Absorption were calculated using Beer-Lambert Laws that expressed as

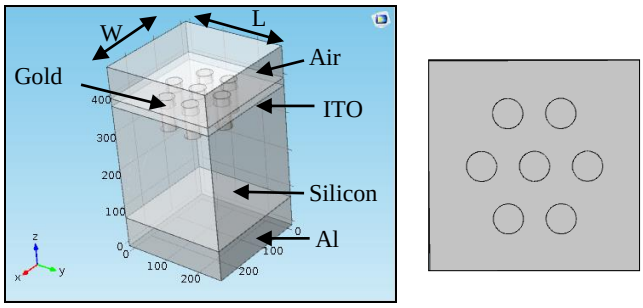
$$A = \log_{10}(I/I_o) \quad (3)$$

where A is absorption, I is the intensities of incident light and I_0 is transmitted light after passing through the structure [11].

3. Simulation Model

The design of plasmonic gold nanoparticles in hexagonal geometry structure is adapted from [8] as shown in Figure 1 (a) and Figure 1 (b). The cylindrical gold nanoparticles of the hexagonal geometry structure have height, 80nm and the radius, 20 nm. The thickness of Al and ITO layers are taken as 80nm and 20nm while the silicon layer thickness is 300nm. The width, W and length, L of the structure are equal which is 280nm. Finite Element Method (FEM) was used in this work to analyses the absorption on plasmonic structure in hexagonal geometry of cylindrical nanoparticle gold. The absorption was calculated in the wavelength range 100 nm - 1000 nm.

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(a) **(b)**

Fig. 1: (a) Schematic of the plasmonic gold nanoparticle in hexagonal geometry structure **(b)** 2D hexagonal geometry of gold nanoparticle viewed from top.

4. Results and Discussion

In this section, the simulation results were shown in terms of absorption versus of wavelength and angle of incident. The wavelengths used were in the range of 100 to 1000 nm while the angles of incident were taken in the range of 0 degree to 90 degree.

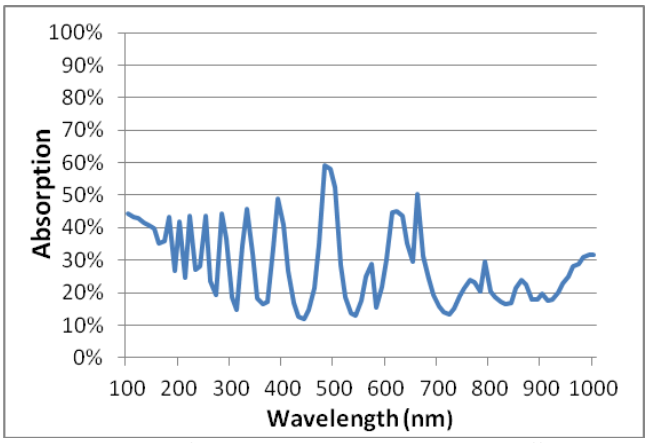


Fig. 2: Absorption of cylindrical gold nanoparticles with different wavelength.

Figure 2 shows the absorption with different wavelength of plasmonic gold nanoparticle in hexagonal geometry structure. The maximum absorption is 59% at a wavelength of 480 nm which is the highest peaks value in absorption. The second highest peaks happened at 660 nm at about 50%. This highest peak occurs in frequency range of visible spectrum from 400 nm to 800 nm which give benefit to improve absorption and trapping the light in solar application. If compared to the result of Aluminium nanoparticle in [8], the maximum absorption rate is too low. Aluminium performed much better than gold with the same geometry. Further study need to be done in term of the arrangement of distance between cylindrical gold nanoparticles itself and also with different radius and height of cylindrical gold nanoparticles.

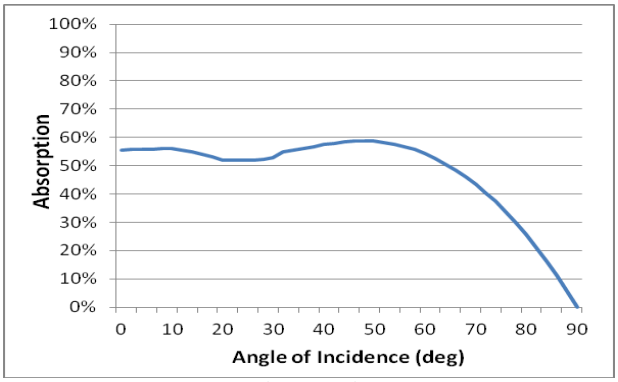


Fig. 3: Absorption as a function of incidence angle in 480 nm

Wavelength at 480 nm was taken to analyses due to their highest peaks value in absorption as shown in Figure 2. The effect of absorption in the wavelength of 480 nm was showed in Figure 3 with different angle of incidence of optical light. The simulation results started with absorption value at about 56% when light directly on top of the surface at 0 degree. The value of absorption is high until it achieves a maximum absorption at 48 degree which about 59% and then it started to decreased at 50 degree until 90 degree. These means that there are exist the high limits as a function of angle of incidence of optical light for the absorption.

5. Conclusion

This paper has presented the absorption of light based on plasmonic gold nanoparticle in hexagonal geometry as function of wavelength and angle of incidence. Results showed that the highest absorption has occurred in the range of visible spectrum. Surface plasmonic proved their efficiency using gold nanoparticle in hexagonal geometry in trapping more light or photon in solar applications although the absorption rate is lower than aluminium nanoparticles.

Acknowledgement

This research work was fully sponsored by Universiti Tun Hussein Onn Malaysia under GPPS 2017 vot U973 and TIER 1 phase 1/2017 vot U901. We extend our special thanks to I-Math Sdn Bhd in providing the Comsol Multiphysics 5.3a software trial for the simulation.

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