International Journal of Engineering Works
ISSN-p: 2521-2419
ISSN-e: 2409-2770
Vol. 7, Issue 11, PP. 390-393, November 2020
https://www.ijew.io/
https://doi.org/10.34259/ijew.20.711390393

Optimization of Shape, Size and Material of Plasmonic Nano Particles in Thin Film Solar Cell

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Received: 19 October, Revised: 27 October, Accepted: 04 November

***Abstract*—** In this study we present optimized shape, size and material of plasmonic nanoparticles in thin film solar cell. For this purpose, we chose silicon active layer solar cell, on the top of active layer another layer of silicon dioxide was used as antireflection coating. Thickness of ARC layer was kept 71nm. On the top of ARC layer metallic nanoparticles were placed. Parameters of NP's such as shape, size and material were varied. Respective variations in the absorption of light in the active silicon layer were observed respectively. Absorption patterns were plotted against wavelength range of 400nm to 1400nm of incident light radiation using Finite Element Method (FEM).

Results revealed the most optimized size and shape of nanoparticles that can contribute to the absorption of light in the active layer of the solar cell. Results also distinguished the best material for nanoparticle.

***Keywords*—** Nanoparticles, Array, Absorption, Wavelength Renewable Energy.

I. Introduction

On the basis of advancement in technology solar cells can be divided into three generations namely first generation, second generation and third generation. First generation solar cells are known for their high-cost and high efficiency [8]. But production of first generation solar cells is a laboured task which is one of the major factor that are responsible for its high cost. second generation solar cells also called thin film solar cells emerged in 1990's as a mean to reduce the material costs. But because of thin active layer they cannot absorb sufficient amount of light and most of the light transmit through the cell. An alternative way to enhance capability of photo-catalyst or photo-electrode to absorb more light is the use of photosensitizer for e.g. certain inorganic quantum dots and organic dyes. Unluckily organic dyes can absorb only a narrow band of visible spectrum, and are less stable when exposed to solar radiation. The transfer rate of electron to the active semiconductor layer from quantum dots is slower and relatively inefficient. Moreover, most of the inorganic quantum dots produce toxic effects under sunlight and are highly unstable [21]. Plasmonic metal nanoparticles on the other hand have ability to absorb broad light absorption band and provide larger absorption cross-section, which results excellent photosensitization in semiconductor material.

Furthermore, plasmonic metal nanoparticles can also be used for scattering and trapping of radiation [22].

Recently, verity of nanostructures has been used in thin film solar cells to improve the absorption efficiency, such as Park experementally presented the performance enhancement of organic photovoltaic by using plasmonic gold nanoparticle clusters [29], Cheng Sun reported on silver nanoparticles based structural design of thin film solar cell, in which they used silicon as absorbing layer [17], P.H.Wang used hydrogenated amorphous silicon as an active absorbing layer, silver nanoparticles of random size and with different fixed periodic inter–particle placement, a silver mirror as back reflector [30], ZhixiaoWang et al reported a study of front surface modification of silicon solar cell [32], Knight et al used metallic nano antennas to enhance light absorption. Among these all surface plasmons resonances structure of metals have drawn much attention due to enhanced solar radiation absorption in thin active layer. The simultaneous excitation of the free electrons in nanoparticles and the energy incident light, through the excitation of surface plasmon resonances (SPR), strong near field enhancement and high scattering cross-sections of light absorption can be attained. Till date many studies exist regarding surface plasmon enhances light absorption using metals mostly silver and gold NP's.

In this study, Optical simulations were used to examine and compare the effect of three different kinds of nanoparticles namely gold, aluminum and silver.

II. Methodology

The Different techniques and tools are used word wide for the purpose of simulation, these techniques include Finite Difference Time Domain (FDTD), Integral Equation (IE), and Finite Element Method (FEM). Various tools are used that can carry out results by using any of the above mentioned techniques, among these tools, COMSOL is one the frequently used and detailed to study the nature and behavior of the nanoparticles.

Therefore, for the current study we preferred COMSOL over all other tools. This tool is based upon the Finite Element Method (FEM), which is one the most efficient techniques for solving electromagnetic problems and produce results that are nearest to the real ones.

We used COMSOL to study the absorption of radiation in the thin film solar cell. nanoparticles sprinkled over the active silicon layer were subjected to light radiation. Transmission T(ω) through solar cell and Reflection R(ω) from the top surface of the assembly were calculated directly during the simulation. The parameter of interest i.e. Absorption A(ω) was calculated from the following equation.

$$A(\omega) = 1 - R(\omega) - T(\omega)$$

Where 'I' is the total incident light falling on the surface of solar cell. All three parameters Transmission, Reflection, Absorption are treated as a function of frequency of light. The structure is composed of mainly three layers, top layer is composed of nanoparticles, in this case we used three different types of metals i.e. gold, silver and aluminum, second layer is antireflection layer, in which Silicon dioxide (SiO2) is used as an anti-reflecting material. The bottom layer is active silicon layer. All parameters and dimension of the model and the cuboidal box are studied on nanoscale. The data obtained from COMSOL multiphysics and was furthered analyzed in MATLAB.

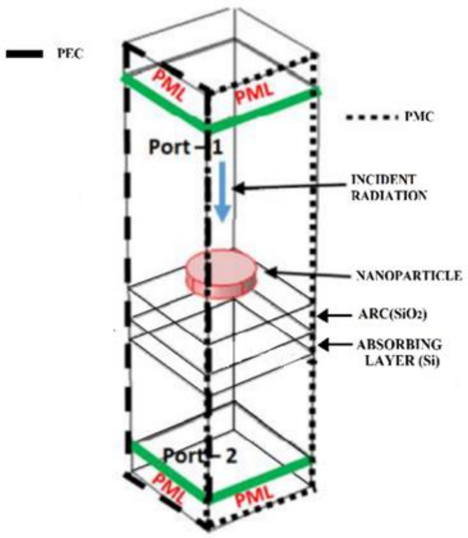

Figure 1 Model of Three layered thin film solar cell

III. Results and Discussion

A. Impact of Material of Nanoparticle on Absorption

Material of nanoparticles plays an important role in the enhancement of photocurrent density in thin-film solar cells. In this work we used nanoparticles made of three different kinds of material i.e. gold (Au), silver(Ag) and aluminum(Al) these three material were selected on the basis of their good conducting properties [1, 2]. Both optical and electrical properties were observed for all three materials under identical circumstances, and were compared at the end. The comparison is shown in figure 2. Results revealed that all material exhibit almost similar impact on absorption of light, except a few distinguished peak by each material [3]. Beside this other physical parameter were also considered such as cost effectiveness, availability, stability etc. By further investigation we explore that as compare to Aluminum; Gold and Silver have more conduction losses, moreover, these materials are costlier than Aluminum [4]. On the other way around Aluminum is one of the most available element on the earth crest and is less costly as compare to gold and silver. Further Aluminum is stable to outer environment.

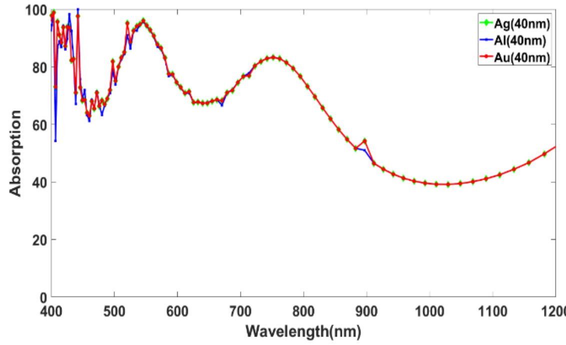

Figure 2 Comparison Among Three Different Types Of Materials

B. Impact of Shape of Nanoparticle

Shape is another crucial parameter that plays an important role in the absorption of light. Keeping in view previous works, process of fabrication and impact on light absorption, we selected five different shapes for nanoparticles i.e. circular disc, sphere, pyramid, rectangle, and square. Nanoparticles were placed in XY plane on the top surface of thin film solar cell [5]. The light beam was directed on the NP's from above in the negative Z-direction. Nanoparticles of all shapes were subjected radiation under similar conditions. The absorption pattern of radiation was obtained and was plotted for all shapes against wavelength ranging from 400nm to 1200nm. All the results obtained were compared and plotted in one graph shown in figure 3.

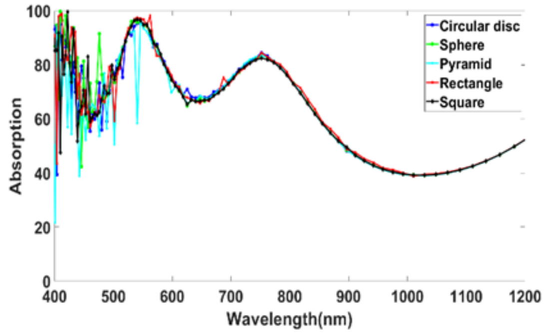

Figure 3. Absorption of light with respect to wavelengths of incident light by using different nanoparticles shapes: circular discs, sphere, pyramid, rectangular and Square

C. Impact of Size of Nanoparticle on Absorption

After optimizing the shape, size of nanoparticle is an important parameter that cannot be ignored. Size of nanoparticles contribute a vital role in the absorption of light radiation and in turn the photocurrent density in the active layer of solar cell. For the purpose of optimization of size, the size of nanoparticle was governed by varying it under unchanged circumstances [6]. Five sizes (radii) were tested on the top surface of solar cell i.e. 20nm, 40nm, 60nm, 80nm and 100nm. Sizes of nanoparticles were varied under similar condition [7]. Results of each size was plotted against wavelength at the end all absorption patterns were analyzed, compared and were plotted in single graph as shown in figure 4.

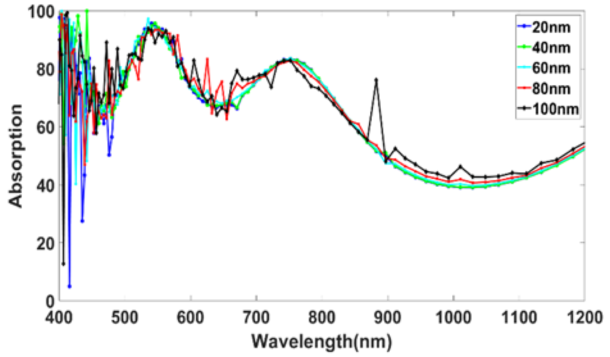

Figure 4. Optimization of size of nanoparticles: Absorption curves for 20nm, 40nm, 60nm, 80nm and 100nm

CONCLUSION

Considering both optical and electrical properties of nanoparticles, three types of nanoparticles were used in current work i.e. Aluminum, Gold, and Silver. Nanoparticles of all three were deposited on the top surface of solar cell, and subjected to light radiation under identical condition.

Almost all three types of nanoparticles showed similar results, except with some of the exceptional peaks by each type. Considering the impact of types of nanoparticles along with other parameters such as stability, radial availability of raw material, and cost effectiveness, we found that gold and silver exhibit electrical losses as compare to Aluminum. Further gold and silver possess more cost than aluminum. On the other hand, aluminum is available radially, and is more stable in open environment. We concluded from the above discussion and simulation results that, Aluminum is the best choice among all three types of nanoparticles.

To study the impact of shape of nanoparticles on the current density in the active layer of solar cells, we established a rational relationship between light absorption and shape of the nanoparticles. Five different types of nanoparticles were used for this purpose namely, circular disc, sphere, square, and rectangular. Among all experimented shape, we observed that sphere shape is the most optimized size of nanoparticle as shown in the figure. Beside the impact on absorption of light, sphere nanoparticles are capable of producing high, surface plasmons, polaritron, strong near field enhancement and larger scattering angle [8, 9]. These are the most important parameters for enhanced current density.

Optimization of size of nanoparticles was governed by varying the size of sphere nanoparticles as 20nm, 40nm, 60nm, 80nm and 100nm. All size nanoparticles were exposed to light under similar condition. Results for each size were plotted against the range of wavelengths. As the size of nanoparticles went on increasing, the current density/absorption increased accordingly. Selecting the optimized size of nanoparticles was a crucial step then.

We found that nanoparticle of 40nm showed dominant curve in the range of lower visible wavelength i.e. 400 to 450nm. In wavelength 450 to 550nm, nanoparticles of all radii produce almost similar curves, except 100nm showing dominancy towards the end. Nanoparticles of 80nm showed dominant curve in the wavelength range of 550 to 680nm. From 680 to 850nm all nanoparticles showed better and almost similar behavior except 100nm nanoparticles. Nanoparticles of 100nm dominated in the wavelength range 850 and onward.

Analysis of simulations revealed that nanoparticles of 80nm and 100nm have more peaks as compare to other radii. Considering other parameters, process of fabrication and specially cost effectiveness we realized that nanoparticles of radius 40nm can overcome the lower current density by its lower cost. The efficiency to cost ratio of 40nm is far more than others sizes.

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His research interests include optoelectronic modeling of photovoltaic devices, photonics nano-technology for light management in third generation solar cell, renewable energy materials & technology modeling, smart grid and power electronics.

How to cite this article:

Asadullah, Fazal E Hilal, Optimization of Shape, Size and Material of Plasmonic Nano Particles in Thin Film Solar Cell, International Journal of Engineering Works, Vol. 7, Issue 11, PP. 390-393, November 2020, https://doi.org/10.34259/ijew.20.711390393.