Absorption Enhancement in Hexagonal Plasmonic Solar Cell

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***Abstract* – In this paper, a novel design of hexagonal cylindrical plasmonic solar cell (HC-PSC) is investigated and analysed by using 3D finite difference time domain method. The aim of our work is to get maximum absorption of thin film solar cell by scattering the light from metal nanoparticles. Therefore the effects of the structure geometrical parameters on the absorption are investigated. The numerical results show around 35% absorption improvement compared to the conventional thin film solar cell without metal nanoparticles.**

Index Terms–Photovoltaic, plasmonic, absorption enhancement, finite difference time domain.

I. Introduction

In the last few years, the development of low cost, and environmentally friendly energy sources has attracted the attention of many researchers all over the world. The search for clean sources of energy that can face the population and economic growth becomes mandatory. The photovoltaic solar cell (SC) can be considered as a clean energy source instead of fossils fuel. However bringing photovoltaic SC to the market is limited due to its high cost. The bulk material cost of photovoltaic devices can be reduced by using thin film SC technology which paves the road to a new generation of SCs. However, the absorption of thin film SCs is quite weak. So we should find promising alternatives to improve the absorption in optically thin semiconducting films by using surface texturing, etched diffracting grating or distributed Bragg reflector [1, 2]. These alternatives can be used to improve the absorption of light in the active layer by scattering the light from the surface or the bottom boundaries of the SC. However, these strategies are incompatible well with thin film SC due to the high minority carrier recombination texture. In addition, the necessary texture dimension is nearly equal to 1.0 μm that can easily exceed the film thickness.

The metallic nanoparticles (NPs) can improve the absorption of the active region of thin film solar cells. Moreover, the NPs have special optical properties that are different than those of bulk materials. In this regard, strong optical scattering and strongly enhanced optical near-field occur around the NPs due to their localized surface plasmon resonance [3]. In this paper, a novel design of thin film plasmonic solar cell is reported and studied. The suggested solar cell has cylindrical metallic NPs arranged in hexagonal periodic array. The effects of the structure geometrical parameters such as cylinders diameter and height on the performance of the proposed SC are investigated. The numerical results reveal that the metallic NPs improve the absorption of the conventional thin film SC by 35%.

II. Design and Numerical Method

Figure 1 shows cross section of the suggested hexagonal cylindrical plasmonic solar cell (HC-PSC). Our proposed structure is based on hydrogenated amorphous silicon (a-Si:H) as an active material of thickness T. The active material is placed over Al layer and is coated by ITO layer. The top surface of the ITO coating is uniformly covered by cylindrical aluminium NPs arranged in hexagonal periodic array. The central cylinder has a radius R_c and the cladding cylinders have radius R. In addition, the distance between two neighbouring cylinders is Λ. Moreover X and Y are the length and width of the structure, respectively.

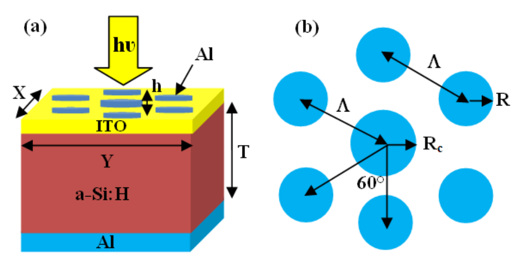

Fig.1 (a) Schematic diagram of the proposed HC-PSC, (b) Arrangement of Al NPs

The 3D finite difference time domain method (FDTD) is applied by using Lumerical FDTD solutions package to simulate the light absorption in the reported structure. The simulation results are obtained with periodic boundary condition in x and y directions and perfect matching layer in z-direction. In order to obtain accurate results, non-uniform meshing capabilities are used. The boundary conditions are employed to account the multiple scattering caused by nanoparticle-nanoparticle, nanoparticle substrate, and nanoparticle-substrate-nanoparticle interactions. All the major effects of the metallic nanoparticles deposited on top of the cell are taken into account through the performed simulations.

III. Numerical Results

In the proposed structure, all the cylindrical NPs of the hexagonal structure of height h=80nm have the same distance from the central cylinder centre Λ=100nm. The photoactive layer thickness is T=300nm while the thickness of ITO and Al layers are taken as 20nm, 80nm, respectively. Moreover the

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length and width of the structure are equal to X=Y=280nm. Figure 2 shows the wavelength dependent absorption percentage of the photoactive layer a-Si:H at different cylinder radii with height h=80nm. In this study, the central cylinder radius R_c is equal to the cladding cylinder radius R. In addition, the absorption percentage variation for conventional thin film solar cell without NPs is also shown in Fig.2. It is revealed from Fig.2 that the absorption increases by increasing the central cylinder and the cladding cylinders radii. However, this will be on expense of decreasing the absorption bandwidth. As the cylinder radius increases, the metal surface area and its absorption will be increased. Therefore the active layer absorption bandwidth decreases as shown in Fig.2.

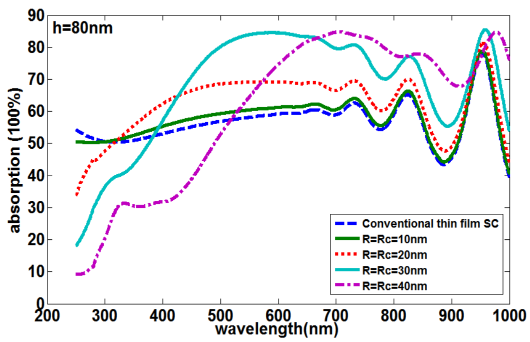

Fig.2 Spectral absorption of the a-Si:H photoactive layer as a function of wavelength

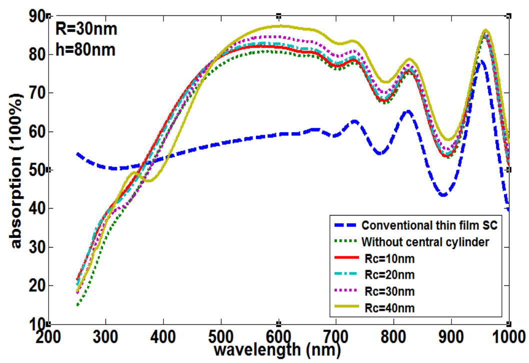

Fig.3 Spectral absorption of the a-Si:H photoactive layer as a function of wavelength

Figure 3 shows the variation of the absorption % of the photoactive layer at different central cylinder radii R_c=10, 20, 30 and 40nm while the radius of the cladding cylinders is fixed to R=30nm and the height is taken as h=80nm. It is revealed from Fig.3 that the absorption increases by increasing the radius of the central cylinder. This is due to the good confinement of the field around the central cylinder as shown in Fig.4 (a). Fig.4 (a) shows the absorbed field along x-y plane in the active layer for TE mode when R=30nm, R_c=40nm and h=80nm. In addition, the absorbed field in conventional solar cell without NPs is shown in Fig.4 (b). It is revealed from Fig.3, and Fig.4 that the absorption of the active layer of the proposed design is higher than that of the conventional solar cell.

Figure 5 shows the variation of the absorption % of the photoactive layer of the proposed HC-PSC at different cylinders height h=40, 60, 80, 100 and 120nm with R_c=40nm and R=30nm. It is revealed from Fig.5 that as the height of the cylinders increases the bandwidth of the absorption decreases.

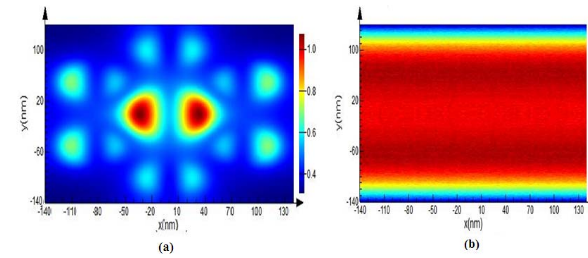

Fig.4 Absorbed field along x- y plane for TE mode in (a) HC-PSC and **(b)** conventional solar cell without NPs

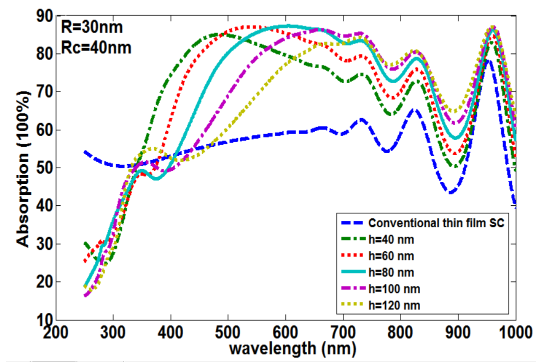

Fig.5 Spectral absorption of the a-Si:H photoactive layer as a function of wavelength

To perform optimization of the optical absorption, one needs to investigate the influence of the radius R, central cylinder radius R_c and the height h on the total absorbed light power. The total absorbed power, P_{tot}, has been calculated by integration of the absorption rate of the photoactive layer over the AM1.5 global spectrum for a wide range of the array parameters R, R_c and h. In addition, the dependence of the plasmon enhancement on the R, R_c and h are calculated from:

$$F_{(R, Rc, h)} = \frac{P_{tot}(R, Rc, h)}{P_{tot}(0,0,0)} - 1 \qquad (1)$$

where $P_{tot}(0,0,0)$ is the total absorbed power by the plain cell without NPs. It is found that an optimum absorption enhancement of 35% over the conventional thin film SC can be obtained at R_c=40nm and R=30nm and h=80nm. In addition, the suggested design has an enhancement of 20% over the spherical NPs SC [3].

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