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Improving the Efficiency of Thin Film Amorphous Silicon Solar Cell by Changing the Location and Material of Plasmonic Metallic Nanostructures

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Abstract

In this work we present a 3D-finite difference time domain (FDTD) simulation of ultra thin amorphous silicon solar cell. The optical generation rate and plasmonic resonance enhance absorption in thin film cell in which silver nanoparticles are imbedded inside the depletion region of p-n junction. Here, the operation of thin film solar cell has been analyzed. Here, by inserting the metal nanoparticles within the active layer in the depletion region of the p-n junction, a new structure has been introduced. We have utilized three different materials, gold, silver and aluminium and the efficiencies of 5.27%, 5.3% and 3.74% have been obtained respectively. The results indicate a significant increase in the efficiency of proposed solar cell with silver nanoparticles.

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Keywords: solar cell, amorphous silicon, plasmonic, silver nanoparticles, efficiency;

1. Introduction

In recent years, replacement of fossil fuels with renewable energies have attracted extensive researches; meanwhile the photovoltaic, because of the non toxic and abundant material resources, has become one of the important alternatives. There are 4 different generations of solar cells [1]. The second generation (thin-film cells) was introduced with the aim of reducing construction costs, however reducing the active layer thickness leads to efficiency reduction [2]. Conventional light trapping methods, such as creating gratings on the surface of solar cells

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are not functional in thin film cells due to very low thickness. Recently, to solve this problem metallic nanoparticles and their plasmonic features are used for light trapping [3-5]. The plasma is a state of matter which is composed of electrons and charged and neutral particles and its overall charge is neutral. Plasma used in this field and in most of plasmonic structures are noble metals (gold, silver, aluminum, etc.). Since in the metal structures, even with a radius of a few nanometers there are very large numbers of electrons, high density of electrons will not allow discretization of energy levels. So plasmonic is based on classical physics of Maxwell's equations [6]. In total there are three types of plasmons: surface plasmons, localized surface plasmons and balk plasmons. The surface plasmon resonance wavelength can be tuned by changing the size and shape of the nanoparticles [7,8]. Plasmonic structures can increase the efficiency of thin film solar cells in two ways [3]; A) enhanced near field within a radius of a few nanometers due to the plasmon resonances of metallic nanoparticles.B) Management of light scattering by engineering the shape and size of metallic nanoparticles that will lead light in the desired lateral direction. This in turn leads to an increase in the path of light in the active layer and the absorption cell will increase. So far a wide variety of designs and creative strategies have been proposed to increase the efficiency of solar cells by using metallic nanoparticles. One of these designs has been putting nanoparticles on the surface of solar cells, and also on the rear of the solar cell [9-11]. In this paper, the potential of increasing absorption in the active layer of amorphous silicon thin-film solar cell by placing metallic nanoparticles within the active layer, inside the depletion region of a p-n junction, is investigated. Therefore in this work we use finite difference time domain (FDTD) numerical modeling method to simulate the optical response of metallic nanoparticles. Finally, by adjusting the radius and density of metallic nanoparticles within the active layer, we will find a balance for maximum efficiency.

2. Mathematical Background

The proposed solar cell architecture (Fig. 1) has an amorphous silicon active layer with the following structure: ITO (50 nm)/ a-Si (500 nm)/ Aluminium (50 nm). For incident plane wave, we consider AM1.5 irradiance. The FDTD method was used for optical analysis. The solar cell structure was simulated by defining a unit cell and applying periodic boundary conditions in the x and y directions, and the perfectly-matched-layer (PML) in the z-direction. For specified incident wave, the output will be the spatial distribution of electric field intensity $|E(x,y,z,\lambda)|^2$. The absorption per unit volume is calculated by:

$$Q_{abs}(\mathrm{r},\lambda) = \frac{\omega\varepsilon_0}{2}\mathrm{Im}[\varepsilon(\mathrm{r},\lambda)]\,|\,\mathrm{E}(\mathrm{r},\lambda)\,|^2 \tag{1}$$

Where Q_{abs} is absorbed power per unit volume at wavelength λ and ε is frequency dependent relative permittivity and ε_0 is the permittivity of free space, ω is angular frequency and E is the electric field. The generation rate is calculated using the following relation,

$$G(r) = \int Q(r,\lambda)\left(\frac{\lambda}{hc}\right)d\lambda \tag{2}$$

In this relation, h is the Planck's constant and c is the speed of light. If the absorbed photons in the active layer contribute perfectly to the photocurrent and if all of them generate electron hole pairs EHPs and all of these EHPs be collected at the contacts, the ideal short circuit current density can be expressed as,

$$J_{sc} = \frac{q\int G(r)dV}{S} \tag{3}$$

Where, q represents electron charge, dV is the element volume and S is the solar cell surface. In the following, with the optical stimulus imported from the optical FDTD simulation the electrical modeling of the device is carried out and the coupled Poisson and charge carrier continuity equations are solved. Silicon doping concentration is applied in Poisson equation. For bulk silicon, radiative and Auger recombination processes are taken into account. The back and front contact regions are p and n-type diffusion doped regions, respectively, with a surface doping concentration of $1\mathrm{x}10^{19}\mathrm{cm}^{-3}$. Surface recombination at the interface of silicon material with Silver, Aluminum and ITO is simulated assuming a carrier recombination velocity of 10^7cm/s.