Plasmon-enhanced Light Absorption of Silicon Solar Cells Using Al Nanoparticles

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***Abstract*- The absorption enhancements of silicon layer in silicon solar cells with Al sphere nanoparticles are studied by the finite difference time domain (FDTD) method. The results show that the light absorption of silicon is significantly improved due to the localized surface plasmon (LSP) resonance. The relations of the absorption enhancement with the parameters of nanoparticles are thoroughly analyzed. The optimal absorption enhancement can be achieved by adjusting the relevant parameters. Specially, the silicon with the 140nm Al nanoparticles shows the most efficient absorption enhancement at optimal conditions and its maximum absorption enhancement factor is 1.4.**

I. INTRODUCTION

The surface plasmon resonances of nanostructured metals have attracted much attention because of their contribution to the absorption enhancement of light in thin-film solar cells [1]. Through the excitation of the surface plasmon resonances, which are the coupled excitation of the energy of incident light and the free electrons in nanoparticles (NPs), the high scattering cross-sections and strong near-field enhancement of light can be achieved. At present there are many studies of the surface plasmon-enhanced absorption of solar cells using noble metals, particularly silver and gold particles [2]. Hence, understanding the effects of low cost aluminum NPs arrays using numerical calculations is critically needed for plasmonic solar cells.

In this study, we use optical simulations to examine the influence of nano aluminum spherical parameters and their distribution periods on the light-absorption enhancement of thin solar cells.

II. SIMULATION MODELS

Periodically ordered 3×3 arrays of aluminum spherical nanoparticles was placed on the surface of a planar semi-infinite Si slab and illuminated under a 400-1100 nm plane wave source weighted against the air mass 1.5 solar spectrum. Perfectly matched layer boundary conditions were used in the incident direction to prevent interference effect, and periodic boundary conditions were used in the lateral direction to simulate an ordered array of nanoparticles, as shown in Fig. 1. The dielectric constants of the metal nanoparticles and Si were taken from Ref. 3. As a semi-infinite Si slab was used, any light travelling into the Si substrate would be absorbed. Spherical nanoparticles of a range of sizes were initially placed on the surface of the bare Si slab in an ordered periodic array with a range of particle densities investigated.

The efficiency of the solar cell were estimated through our numerical computation results in terms of standard solar cell optical performance parameters, such as quantum efficiency (QE), integrated quantum efficiency (IQE), which are defined by

$$QE(\lambda) = \frac{P_{abs}(\lambda)}{P_{inc}(\lambda)} \tag{1}$$

where $P_{abs}(\lambda)$ and $P_{inc}(\lambda)$ are the power of the absorbed light and incident light within the Si solar cell, respectively, at a wavelength λ. Using the QE, IQE is written as

$$IQE = \frac{\int \frac{\lambda}{hc} QE(\lambda) I_{AM1.5}(\lambda) d\lambda}{\int \frac{\lambda}{hc} I_{AM1.5}(\lambda) d\lambda} \tag{2}$$

where h is the Planck's constant, c the speed of light in the free space, and $IAM1.5$ is the $AM\ 1.5$ solar spectrum [4]. In Eq. (2), the numerator and denominator means the number of photons absorbed by the solar cell and that falling onto the solar cell. Equations (1) and (2) can be modified further to see how the light-absorption efficiency of solar cells with metal particles is enhanced compared to bare solar cells and the absorption enhancement $g(\lambda)$ and G can be written as:

$$g(\lambda) = \frac{QE_{nps}(\lambda)}{QE_{bare}(\lambda)} \tag{3}$$

$$G = \frac{IQE_{nps}(\lambda)}{IQE_{bare}} \tag{4}$$

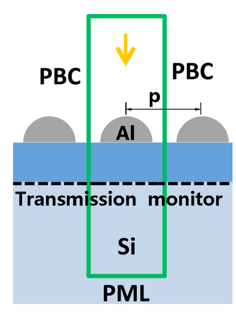


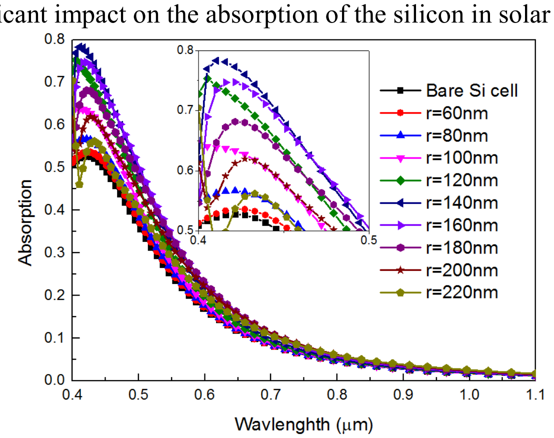
Fig.1 Schematic of the FDTD simulation model. Al: aluminum nanoparticle; PML:perfectly matched layer; PBC: periodic boundary condition.

III. Result and discussion

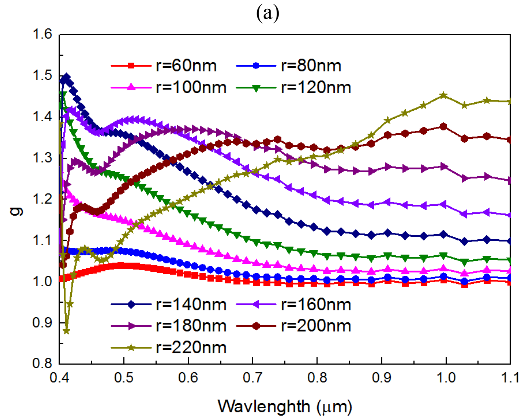
As shown in Fig. 2 (a), the wavelength position of the absorption peak and the peak value both change with radius of spherical Al NPs. The largest peak value is nearly 0.8 at the wavelength of 415 nm and the radius of 140 nm. Meanwhile, the absorption peak red-shifts when the radius is increased from 60 nm to 220 nm, while the absorption peak value is reduced after the first growth with radius from 60 nm to 140 nm. It also can be found that the absorption ratio of all the silicon thin film with spherical nanoparticles with different radius from 60 nm to 220 nm is larger than that of bare silicon in visible light wavelength range. Fig. 2(b) shows the absorption enhancement spectrum g(λ) with different radii and fixed period, and there is a considerable absorption enhancement in 400-1100nm region by the enhanced forward scattering due to the LSP resonance.

Fig.3 left shows that the Al particles mainly increase the forward scattering due to the surface plasmon resonance and enhance the absorption of the photoactivated Si cell.

Fig.4 shows that the enhancement factor G tends to 1 (no enhancement) with the further increase of period. The enhancement factor G reaches the optimal value 1.4 at p=150 nm, r=100 nm. It can be seen that both radius and period have a significant impact on the absorption of the silicon in solar cell.



(a)



(b)

Fig.2 (a) The absorption spectra and (b) the absorption enhancement g(λ) of silicon in solar cells with spherical Al nanoparticles, where p=400 nm

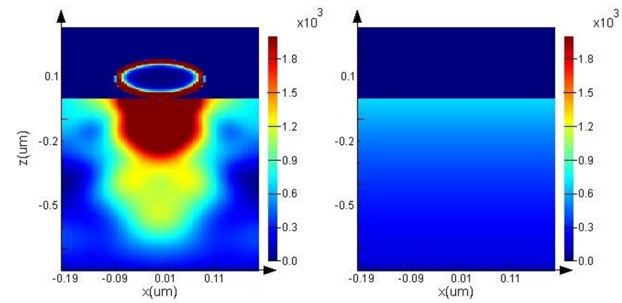


Fig.3 Visible light absorption profile of x-z cross-section at a wavelength of 500 nm in solar cells with (left) and without (right) aluminum NPs, for radius 180 nm, period 400 nm,

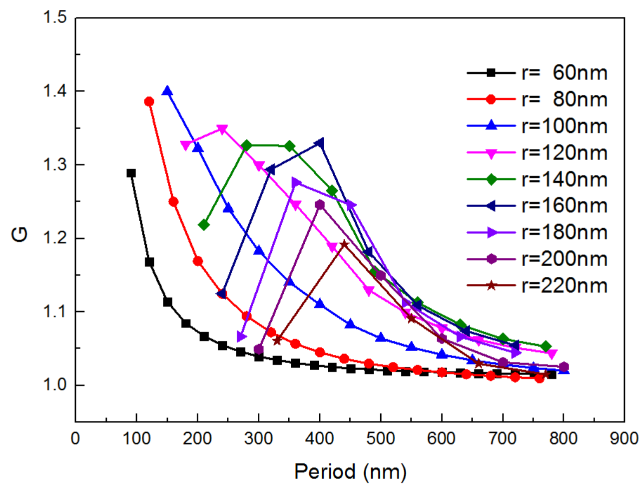


Fig.4 The relation of enhancement factor G with period at different radii of nanoparticles

IV. CONCLUSION

The absorption enhancements of silicon layer in silicon solar cells with Al nanoparticles have been simulated using the FDTD method. The absorption enhancement factor G rises as the period increases, until reaches the maximum, and then it begins to decrease. The absorption enhancement peak can be tuned to the desired position of solar spectrum by modulating the appropriate parameters of Ag nanoparticle. In general, our work is useful for the further theoretical study and the optimization of the plasmonic thin-film solar cell.

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