Light Absorption Enhancement by Embedding Aluminum Nanodisk Arrays in Rear Dielectric of Ultra-thin Film Solar Cells

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***Abstract*- In this work, in order to enhance the light absorption in one micron thick crystalline silicon solar cells, a back reflecting and plasmonic nanodisk scheme is proposed. We investigate the scattering properties of aluminum nanostructures located at the back side and optimize them for enhancing absorption in the silicon layer by using finite difference time domain simulations. The results indicate that the period and diameters nanoparticles, spacer layer have a strong impact on short circuit current enhancements. This finding could lead to improved light trapping within a thin silicon solar cell device.**

I. INTRODUCTION

The low absorption coefficient in silicon thin-film solar cells for light results in poor efficiencies. Plasmonic metal nanoparticles are of great practical interest in the field of thin film photovoltaics due to their special scattering abilities of localized surface-plasmon resonances (LSPRs) [1], as a means to increase coupling of light into silicon.

Extensive work by various groups has been put forth to investigate light enhancement using Ag metal particles on the front surface or back side of thin-film Si solar cells [2]. Earlier studies [2] suggested that using plasmonic nanostructures at the front side of the solar cell results in a decrease in its energy conversion efficiency, attributed to the fact that the destructive interference between the incident and scattered light leads to suppressed absorption in the cell below the resonance wavelength of the particles. Therefore, the plasmons of the metal nanoparticles on the rear would be excited by only light that is not absorbed by the cell (transmitted light). Even thin film Si cells normally absorb the short wavelength light strongly, hence any likely absorption in the metals or suppression of below resonance wavelengths can be avoided. Aluminum, on the other hand, also supports a strong plasmon resonance, which has been shown to be tunable from the infrared to the ultraviolet by varying the shape and size of the particle.

In this work, we propose a back reflecting and plasmonic nanodisk scheme and optimize the architecture by employing Al metallic nanostructures with varied geometry parameters, so as to maximize scattering light back into silicon. The configurations of the cell and the simulation set up are depicted in Fig. 1.

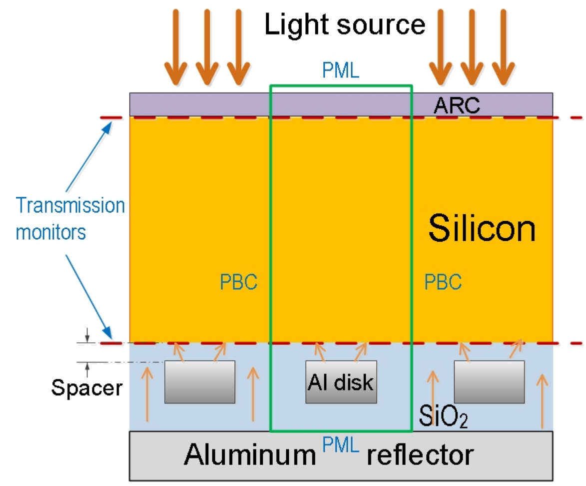

Fig.1 Structure setup for the cell and FDTD simulations

II. SIMULATION MODELS

Finite-difference time-domain (FDTD) numerical simulations [3] were performed to simulate the absorption in the active layer of the cell, from which we calculate the absorption enhancement factor G and the expected short circuit current density (J_{sc}) output in the wavelength range from 300 nm to 1200 nm. The cell structure consists of a 1 μm thick crystalline silicon absorber with 70 nm of silicon nitride for anti-reflection. Figure 1 illustrates a cross-section of the simulated geometry, with the Al nanodisk arrays on the rear of the cell, and a 100 nm thick Al mirror separated by a SiO_2 gap. The light source is located upon anti-reflecting coating. The dielectric parameters used for the silicon, aluminum, SiO_2 and Si_3N_4 layers were taken from the literature [4].

For the FDTD simulations, the x and y axis boundary conditions are periodic and the z axis boundaries are defined by perfectly matched layers (PML). Power monitors are placed on each side of the silicon layer and the absorption within the silicon is calculated as the difference in power flux between the two monitors. It is assumed that all absorption within the silicon leads to generated electron-hole pairs that are then collected in the external circuit. The J_{sc} is calculated by integrating the external quantum efficiency (EQE) response over the wavelength range from 300 nm to 1200 nm multiplied by the corresponding spectral photon flux and the electronic charge.

III. Result and Discussion

A first rough scan was performed to get the optimum values for period and diameter of nanodisk, as shown in Fig.2. 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 d=220 nm, p=330 nm. It can be seen that both diameter and period have a significant impact on the absorption of the silicon in solar cell.

The thickness of the spacer was kept constant at 10 nm while the distance between silicon and reflector, i.e. SiO_2 layer thickness, was scanned form 110 to 570 nm, with a step of 20 nm. From the J_{sc} curve shown in Figure 3(a), 180 nm of SiO_2 layer scatters the light into silicon most effectively and gives a J_{sc} value of 25.93 mA/cm^2.

The effect of silicon on the scattering properties of the plasmonic nanostructures will be modified due to the presence of the layered substrate [2]. The closer the structure is to the high index medium, the higher is the effect on the homogeneity of its surrounding and hence on the preferential scattering properties. The effect of the spacer thickness was studied on the structure from 0 nm to 60 nm, for every 1 nm. A 6-10 nm of spacer layer results in the highest enhancement in the silicon layer with J_{sc} value about 26.2 mA/cm^2. After increasing the spacer thickness, silicon's ability to modify the surrounding environment around the plasmonic particle starts decreasing and keeps on decreasing as the plasmonic nanostructure moves away from silicon. Another reason is the evanescent nature of the surface Plasmon field, which decreases very rapidly from the surface of the nanoparticle. Thus, the further the nanoparticle is from silicon, the weaker is the coupling of the enhanced field into the silicon.

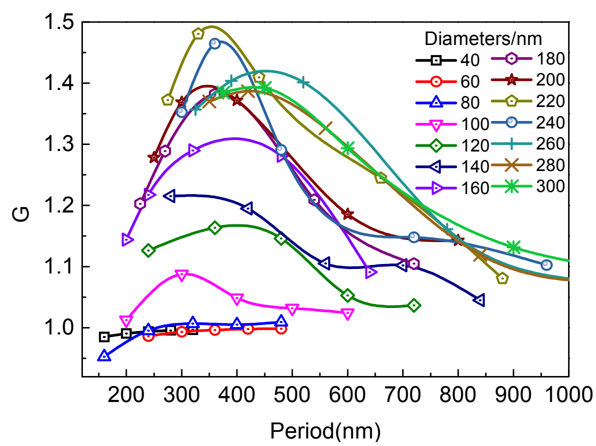

Fig.2 The relation of absorption enhancement factor G with period at different radii of nanodisks

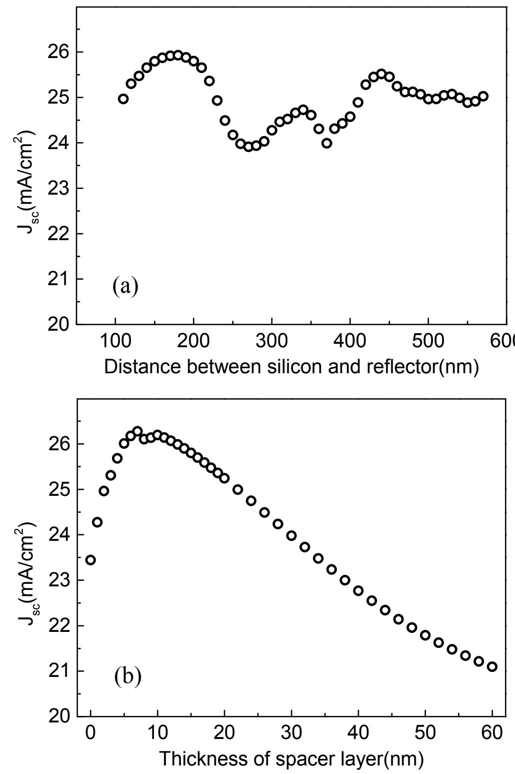

Fig.3 The dependence of J_{sc}. on various parameters: (a) distance between silicon and reflector, (b) thickness of spacer.

IV. Conclusion

In summary, we have studied numerically aluminum nanodisk arrays embedded in dielectric for light trapping on the rear of 1 μm thin film silicon solar cells with a reflector. We have optimized the geometrical properties of the arrays to maximize the scattering and reflection into cell. The optimized Al nanoparticle arrays combined with the rear reflector enhance J_{sc} with an increase of 70% from the non-plasmonic case of 15.4 mA/cm^2 to 26.2 mA/cm^2. The results clearly demonstrates the advantages offered by aluminum nanoparticles for rear surface light trapping on thin film solar cells with back reflector.

Acknowledgment

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