Rear Located Hemispherical Silver Nanoparticles for Light Trapping in Thin Film Solar Cells

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***Abstract-* In this work, we investigate the scattering and coupling efficiencies of the rear located hemispherical silver nanoparticles by using finite difference time domain simulations. The results indicate that the placement and diameters of silver nanoparticles have a strong impact on scattering efficiency. This finding could lead to improved light trapping within a thin silicon solar cell device.**

I. INTRODUCTION

In order to reducing the cost of solar energy, thin-film silicon solar cells are one of the most promising approaches by reducing the material costs[1]. As cells become thinner, light trapping becomes more important due to the thin active layer compared with larger absorption length of silicon[2]. Light scattering by metal nanoparticles due to excitation of plasmons is a promising technique for tapping light[3].

When metal nanoparticles are located on the front of a solar cell, 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.

In this work, two configurations of hemispherical silver nanoparticle are considered as depicted in Fig. 1. In both configurations the Ag nanoparticle is at the rear interface between the air and silicon, where light is scattered after propagating through the silicon. In the first case the nanoparticle extends into the air whilst for the second case it extends back into the silicon. In each case we calculate the scattering properties of the metal nanoparticles with varying diameters.

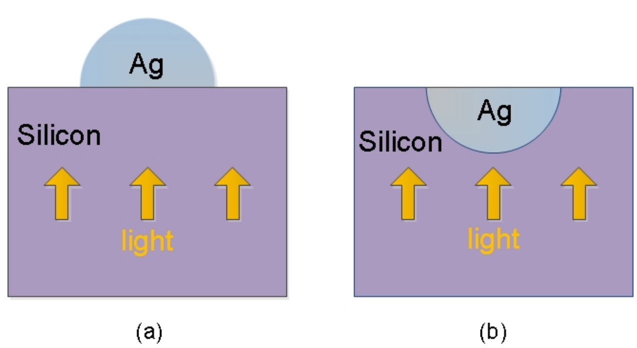

Fig.1 Schematic of the FDTD simulation model. (a) nanoparticle extending into air and (b) nanoparticle extending into silicon.

II. SIMULATION MODELS

To investigate the scattering behaviour of plasmonic nanoparticles that locate rear interface of Si substrates, finite-difference time-domain (FDTD) numerical simulations were performed[4]. The boundaries of the computational domain are terminated using perfectly matched layers (PMLs) to prevent any non-physical reflections. Linearly polarised radiation from the normally incident source was propagated from the substrate to air. The source is incident 60 nm from the Si interface, to minimise the amount of light absorbed in the Si before reaching the particle. The dielectric function of the silver nanoparticles was modelled using a Lorentz-Drude model and the dielectric constants of the Si were taken from Ref. 5.

The total power absorbed by the nanoparticle, P_{abs}, was calculated by integrating the Poynting vector of the total field (incident plus scattered) over a closed surface surrounding the particle. The normalised absorption cross section is then calculated by $Q_{abs}=P_{abs}/(P_{inc}\cdot A_{xs})$, where P_{inc} is the incident source power, and A_{xs} is the cross sectional area of the particle. Similarly, the scattered power was calculated from the integrated Poynting vector of the scattered field. This was evaluated separately in the air, $P_{scat,air}$, and in the substrate, $P_{scat,subs}$. The fraction of scattered light coupled into the substrate, also referred to as the coupling efficiency, was calculated as $F_{subs} = P_{scat,subs}/(P_{scat,air}+P_{scat,subs})$. The normalised scattering cross-section, Q_{scat}, is then determined from the total scattered power in the same manner as Q_{abs}. From these cross sections we can define the scattering efficiency of the particle as $\eta_{scat}= Q_{scat}/(Q_{scat} + Q_{abs})$.

III. RESULT AND DISCUSSION

Fig. 2 (a) and (b) show the calculated values of Q_{scat} and Q_{abs} for the particle with different diameter in air and in the silicon,

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respectively. It can be seen from Fig. 2(a) that the scattering cross section of small diameter nanoparticle is very low and increase with increasing diameter. It is clear that the resonance wavelength is red-shifted when the diameter becomes larger. We attribute these shifts to the nature of the geometrical resonances of surface plasmon polaritons (SPPs) at the Ag/Si interface, confined to the area of the particle. Since the resonant SPP occurs at the Ag/Si interface, the resonance wavelength is determined by the diameter of the area in contact substrate.
The average scattering and coupling efficiency, as shown in Fig. 3, are calculated over the light trapping spectral region (500 nm to 1200 nm) for a Si substrate.

It can be seen from Fig. 2 and Fig. 3 that the particle extending into silicon leads to scattering being dominant and the averaging coupling efficiency into the semiconductor ($\eta \times F_{subs}$) of better than 50% for diameters above 40 nm, much higher than when the dome of the hemisphere is in air. It is also interesting to note that the scattering efficiency does not change significantly for larger particles as the diameter is changed, but decreases sharply for small particles when the hemispherical silver nanoparticles protrude into silicon. The change in diameter does not affect F_{subs} significantly as the overlap of the near field is the same for all values of diameter.

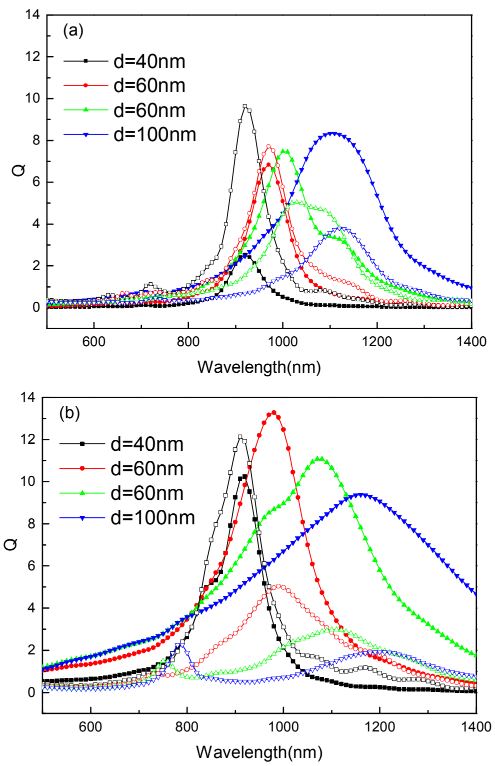

Fig.2 Calculated normalised scattering cross-section (Qscat, solid symbol line) and normalised absorption cross-section (Qabs, open symbol line) for rear located Ag nanoparticles directly on a Si substrate, Data is shown for hemispherical nanoparticles (a) extending into air and (b) extending into silicon, with diameters of 40 nm (black square), 60 nm (red circle), 80 nm (green up triangle).and 100 nm (blue down triangle)

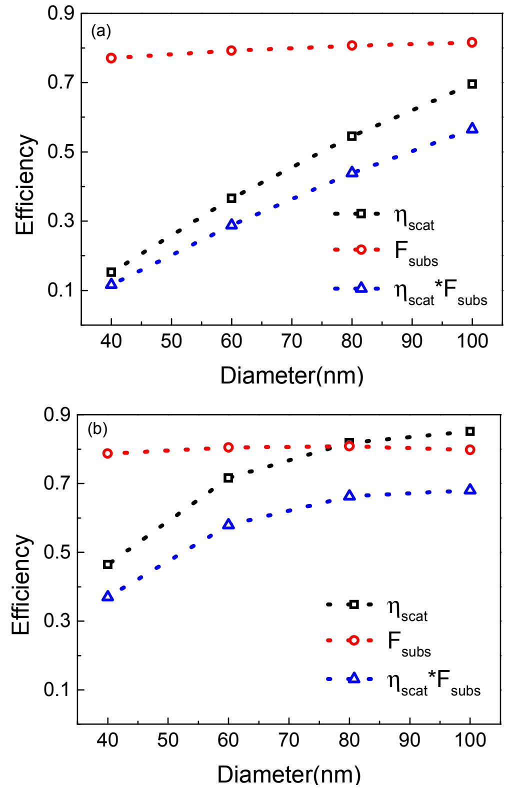

Fig.3 Average scattering and coupling efficiency calculated over the light trapping spectral region for a Si substrate (500 nm to 1200 nm) for rear located particles, varying diameter from 80 to 100 nm.

IV. Conclusion

The scattering from a hemispherical Ag particle situated at the silicon-air interface have been simulated based on two cases, one where the Ag nanoparticle dome protrudes into air and the other where it protrudes into the silicon. For the case where the Ag particle extends into the silicon the results indicate that scattering from the particle is dominant and that there is good coupling efficiency of the incident energy into the semiconductor.

Acknowledgment

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