Antireflection of Nano-sized SiO Sphere Arrays on Crystalline Silicon Solar Cells

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Abstract — **Optical properties of dielectric nano-sized sphere, embedded sphere and hemisphere arrays on SiN coated Si texture wafer were studied using the three dimensional finite-difference time-domain method. These arrays increase the photon currents each with an appropriate radius range. The spheres with a radius of 60 nm shows the strongest enhancement at normal incidence. The spheres can be seen as an additional antireflection coating by effective medium theory, because the sphere radius is smaller than the wavelengths of AM1.5G spectrum. It also shows the properties of omnidirectional antireflection due to the coupling of light through nano-sized spheres into Si with oblique incidence. For the angle of incidence from 0° to 75°, the sphere arrays on SiN coated Si texture shows the lowest averaged weighted reflectance.**

I. Introduction

The optical properties of nano-sized sphere and hemisphere arrays on SiN coated Si texture are studied in this work by using the finite-difference time-domain method (FDTD) method. [1] A SiN layer also functions as a passivation layer on poly- and crystalline Si solar cells traditionally due to its high fixed charge density.

II. Structures and Simulation Method

The surface of Si wafer is periodic square-based pyramids covered by a SiN ARC. A plane wave light source was project to the Si wafer with the angle of incidence ranging from 0° to 75°. The reflectance spectra with oblique incidence was the average of reflectance spectra from TE and TM waves. (Fig. 1(a)) The radius (r) of the SiO spheres, hemispheres or partial spheres is determined by $r = w/[2(n_{sphere} - 1 + \sqrt{2})]$ where n_{sphere} is the number of spheres or partial spheres at the lowest level. (Fig. 1(b)) The sphere or hemisphere arrays are hexagonally close packed (HCP) on outer surfaces of the pyramid. (Fig. 1(c)) Fig. 1(d) illustrates the perspective view of the SiN coated Si texture covered with hemisphere arrays. The positions of spheres, embedded spheres and hemispheres are depicted in Fig. 2. Note that the partial spheres are hemispheres except the partial-spheres at the lowest level. The semi-infinite textured Si wafer is simulated to avoid reflected waves form back side.

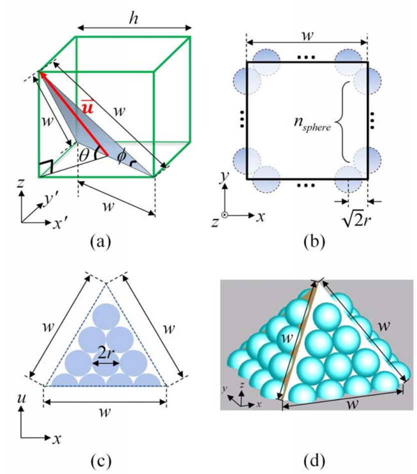

Fig. 1. Schematics of the simulated structures. (a) The outer surface of the pyramid is shown by the shaded region (a regular triangle). w and h are 1 and 0.7 μm, respectively. θ and ϕ are 54.7° and 60°, respectively. (b) The arrangement of the sphere embedded-sphere or partial-sphere arrays at the lowest level. n_{sphere} is the number of spheres or partial spheres. The bases of the four regular triangles in (a) form the square. (c) The sphere or partial-sphere arrays are HCP on the outer surface of the pyramid. (d) A perspective view of the SiN coated Si texture covered with partial-sphere arrays.

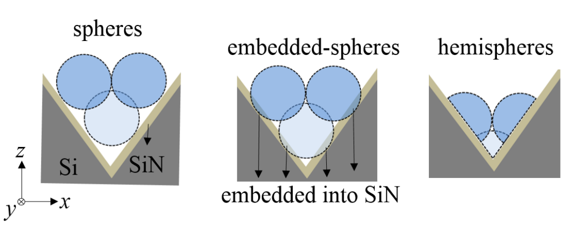

Fig. 2. Schematics of the relative positions of spheres, embedded spheres and partial spheres on the SiN coated Si texture.

III. Results and Discussion

Fig. 3 shows the photon currents J_{ph} of different structures. J_{ph} is defined as the optical generation current density without any

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carrier loss by $J_{ph} = q\int_{\lambda_1}^{\lambda_2} F(\lambda)(1-R(\lambda))\,d\lambda$ where R(λ) is the reflectance spectrum, and F(λ) is the photon flux of AM1.5G spectrum. λ_1 and λ_2 are set to 0.3 and 1.1 μm, respectively. When considering semi-infinite Si wafer, the absorption of Si is 1-R.

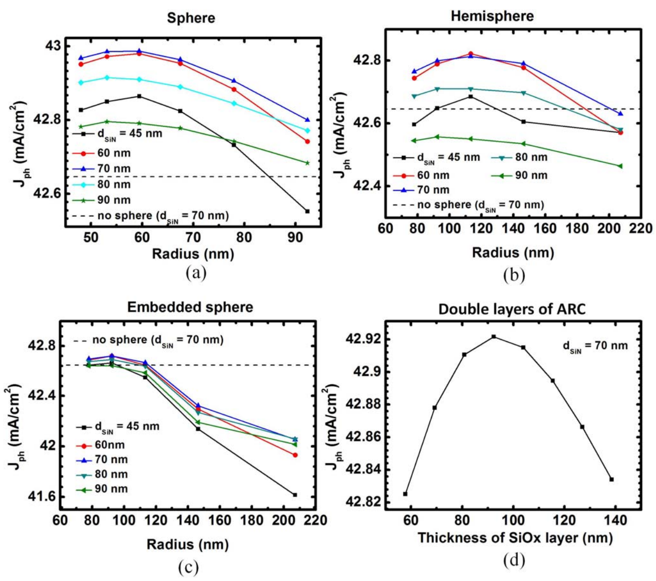

Fig 3. The Jph of different structures (a) sphere (b) hemisphere (c) embedded sphere arrays, and (d) double layers of ARCs.

Note that the refractive indices of SiN and SiO are set to 2 and 1.46, respectively. The thickness of SiN layer and the radius of the spheres are varied to maximize the J_{ph}. The case with sphere arrays show the best J_{ph} with a radius of 60 nm when the thickness of the SiN layer is 70 nm seen from the surface normal. (Fig. 3(a)) The dashed line is the J_{ph} without sphere arrays and with an optimized thickness of 70 nm of the SiN layer. The optimal diameter of the sphere arrays is near the optimal radius of the hemisphere arrays and this can be explained by the effective index theory [2]. Because the sphere size is smaller than the wavelength, the dielectric sphere or hemisphere arrays can be seen as an additional ARC on top of the SiN coated textured Si wafer. If we simulate the double-layer ARCs consist of SiO and SiN on textured Si wafer, the optimal thickness of the SiO is 90 nm. (Fig. 3(d)) We choose the best condition of sphere, embedded-sphere and hemisphere arrays at normal incidence and calculated their angle of incidence dependent R_w which clearly shows the enhancement of the omnidirectional property of these arrays. (Fig. 4 (a)) The weighted reflectance is defined as $R_w = \int_{\lambda_1}^{\lambda_2} R(\lambda)I(\lambda)\,d\lambda \,/ \int_{\lambda_1}^{\lambda_2} I(\lambda)\,d\lambda$ where I(λ) is the photon flux of AM1.5G spectrum.

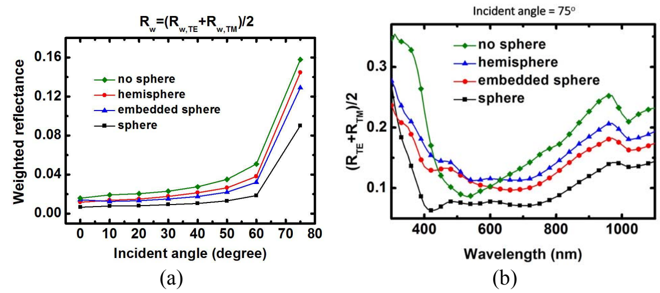

Fig 4. (a) The angle of incidence dependent R_w of different structures. (b) The reflectance spectra of different structures with an angle of incidence of 75°.

Sphere, embedded-sphere and hemisphere arrays all decrease the R_w. The sphere arrays show the lowest R_w at incident angles range from 0° to 75°. In addition, the reduction of the R_w increases with increasing incident angles. Fig. 4 (b) shows the reflectance spectra with the 75° angle of incidence. In addition, the significant reflectance at short wavelength (< 400 nm) is due to the large imaginary part of the refractive index of Si. For all wavelengths, the reflectance of sphere arrays is smaller than the reflectance without any sphere arrays. It is a broadband omnidirectional light trapping mechanism by coupling of light into absorbing layer through the nano-sized SiO spheres.

CONCLUSION

The SiN coated semi-infinite textured Si wafer with sphere arrays HCP on top has the highest Jph when the diameter is 120 nm. The optimal diameter of the sphere arrays is near the optimal radius (110 nm) of the hemisphere arrays and this can be explained by the effective index theory. For the angle of incidence ranges from 0° to 75°, the addition of sphere arrays shows lowest R_w compared with the SiN coated Si texture without sphere arrays due to the coupling of the light through nano-sized SiO spheres.

ACKNOWLEDGEMENT

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