Numerical analysis of Absorption Enhancement in Solar cells with Si Nanoconical-Frustum Arrays

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Abstract

To investigate the enhancement of absorption in solar cells with antireflective Si nanoconical-frustum (NCF) arrays, we used finite-difference time-domain (FDTD) method for the analysis over the range of 300~900nm. The short circuit current density (J_{sc}) of the solar cell with Si NCF arrays increases about 46% compared to the solar cell without Si NCF arrays.

1. Introduction

In order to improve the conversion efficiency of solar cells, it is important to suppress the light reflection at the surface of device in the broadband wavelength range. In recent years, there have been several research efforts to increase the light absorption in the solar cells integrating with nanostructures such as moth-eye structure with anti-reflective coating [1], Si nanowire (NW) [2], metal nanoparticle [3] and dielectric nanosphere arrays. [4]

In this paper, we fabricated the structure of Si nanoconical-frustum (NCF) arrays and numerically investigated the light absorption enhancement caused by the nanostructure. We designed and calculated simulation model of solar cell with and without nanostructures to compare both cases. And we predict performance of two models by estimating increment of short circuit current density.

2. Design and Results

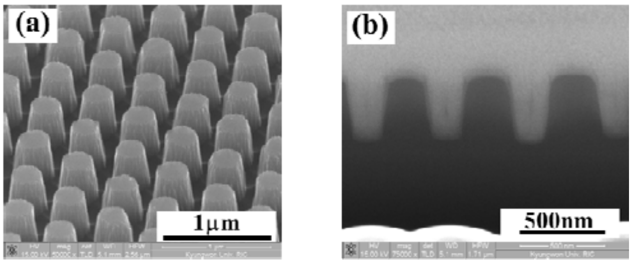

Fig. 1: (a) SEM image of Si NCF arrays fabricated by DRIE with colloidal lithography and (b) Cross section of Si NCF arrays milled by FIB.

To make silicon NCF arrays we employed surface texturing technique based on single-step deep reactive ion etching (DRIE) with colloidal lithography. The diameter of polystyrene (PS) nanosphere is

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500nm and two reactive plasma gases (SF_6 and C_4F_8) were used for DRIE. The detailed fabrication procedures have been presented and discussed in our previous paper. [1] Figure 1(a) displays SEM image of silicon NCF arrays. Figure 1(b) represents the cross sectional profile of silicon NCF arrays measured by the dual beam focused ion beam (FIB).

In order to investigate the influence of anti-reflective nanostructures, we carry out the numerical simulation of the solar cell structure with and without the Si NCF arrays by employing finite-difference time-domain (FDTD) tools. Figure 2(a) shows geometry of solar cell structure with and without Si NCF arrays. Each Si NCF with heights of 500nm has the top diameter (dtop) of 300nm, base diameter (dbase) of 500nm.

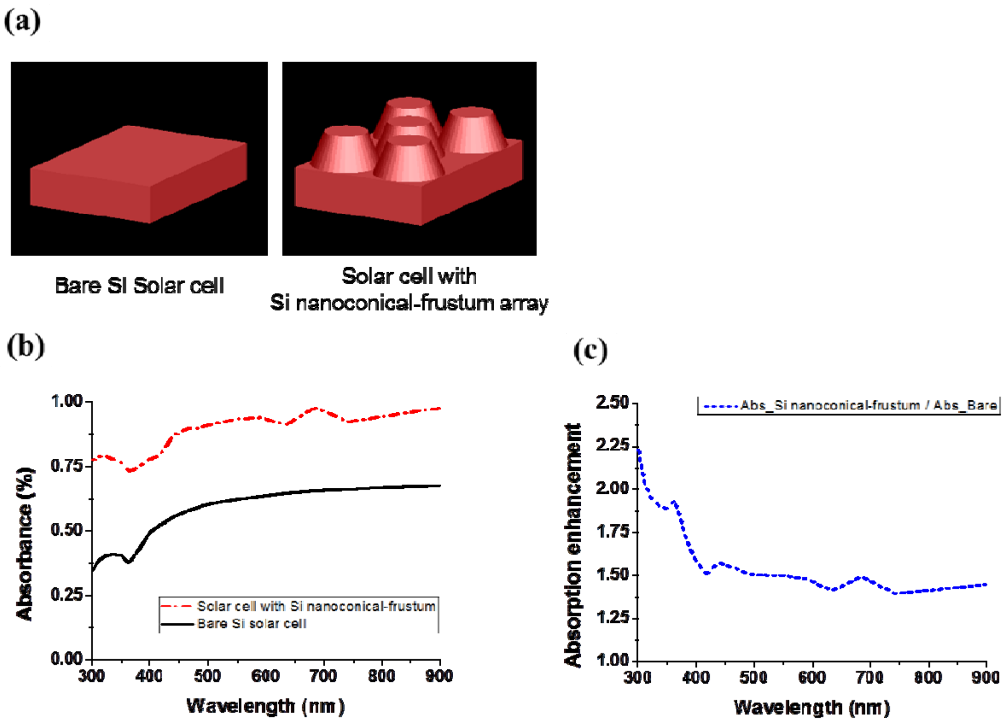

Fig. 2: (a) Schematic diagram of bare Si solar cell and solar cell with Si NCF. (b) Absorbance spectra for solar cell with Si NCF and Bare Si solar cell calculated by FDTD simulation. (c) Spectrally resolved absorption enhancements of solar cell with Si NCF compared to bare Si solar cell.

The absorbance spectra of simulated solar cells with a flat surface and textured surface over the spectral ranges of 300nm-900nm are shown in Fig. 2(a). Spectrally resolved absorption enhancement of solar cell with Si NCF arrays compared to bare Si solar cell is calculated and shown in Fig. 2(b). Enhancement factors have different values from 1.39 to 2.23 according to the wavelength of light. By employing solar irradiance ($W/m^2/nm$) from sun light spectrum, we calculated the short circuit current density (mA/cm^2) by integrating photocurrent over the wavelength range (300nm-900nm). The short circuit current density (J_{sc}) is defined as follows,

$$J_{sc} = q\int \frac{\lambda}{hc}\cdot QE(\lambda)\cdot I_{AM1.5}(\lambda)d\lambda \tag{1}$$

where q is charge on electron, h is Planck's constant, c is speed of light, and $I_{AM1.5}$ (λ) is the spectral irradiance from the sun. [5, 6] By assuming that all charge carriers caused by photogeneration will contributes to photocurrent, we can predict short circuit current density (J_{sc})

Model	J_{sc} (mA/cm^2)
Bare Si solar cell	21.22
Solar cell with Si NCF arrays	31.19

3. Conclusion

Solar cells integrated with Si NCF arrays are a promising approach to a simple, low-cost and highly efficient photovoltaic devices. We have numerically investigated influence of Si NCF arrays on the solar cell by employing FDTD simulation. Based on our 3D simulation results, Si NCF arrays can enhance the absorption of solar cell and increase the efficiency of device for broad spectral ranges of 300nm to 900nm. The short circuit current density (J_{sc}) of the solar cell with Si NCF arrays was increased about 46% compared to solar cell without Si NCF arrays.

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