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# Antireflection and absorption properties of silicon parabolic-shaped nanocone arrays

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ABSTRACT

Adding antireflection and light trapping structures to the solar cell can decrease the optical losses and increase the efficiency of the cell effectively, the nanocone antireflection structure was paid lots of attention because of its simple manufacture processes and low reflectance. In this work, the effect of the height and diameter of the periodic unit on the reflectance, transmittance and absorptance of the parabolic-shaped nanocone (PSNC) arrays was calculated using finite-difference time-domain method. It was found that the average reflectance decreased and the average absorptance increased with the increase of height in our calculation range. The average reflectance could be decreased to 0.13% by optimizing the diameter even when the height decreased to 1 μm, thus the PSNC arrays had good antireflection character. The average absorptance could reach 81.16% by optimizing the diameter when the height increased to 7 μm.



## 1. Introduction

Photovoltaic is becoming more and more important as a kind of renewable energy, and crystalline silicon solar cell has the largest share in worldwide photovoltaic market now. However the cost of photovoltaic is still high compared to traditional energy, and the cost could be decreased effectively by increasing the conversion efficiency of solar cell. Adding antireflection and light trapping structures to the solar cell can decrease the light reflection and increase the light absorption of the cell effectively, thus the efficiency of the cell could be increased. Plenty of antireflection and light trapping structures have been made, such as random pyramids, inverted pyramids, nanorods, nanowires, nanocones, nanoholes and nanospheres and so on [1–6], and lots of experiment and simulation work has been done to research the optical reflectance, transmittance and absorptance properties of above structures. The nanocone antireflection structure was paid lots of attention, because the manufacture process of this structure was simple, and the reflectivity of this structure was low. Wang et al. used the reactive ion etching process to make the nanocone structure on silicon wafer with polystyrene sphere masks, the reflectance was decreased to less than 0.7% in the wavelength between 400 nm and 1050 nm [7]. Zhou et al. used the $Ar^+$ ion bombardment

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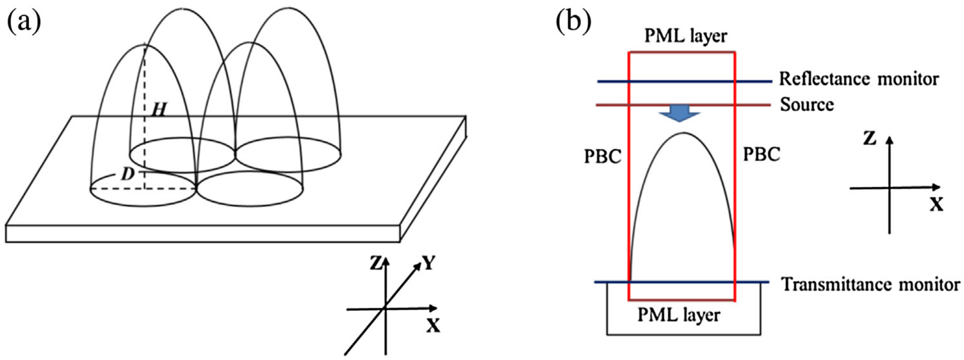


**Fig. 1.** Schematic of the parabolic-shaped nanocone (PSNC) arrays (a) and cross section of the simulated periodic unit (b).

process to make the nanocone structure, the reflectance was decreased to less than 11% in the wavelength between 350 nm and 2000 nm [8]. Kim et al. used the nanoimprint process to make the nanocone structure on the 8 inch silicon wafer, and they used the finite-difference time-domain (FDTD) method to calculate the reflectance of the structure, the reflectance was decreased to less than 10% in the wavelength of visible light, and the Mie resonance in the nanocones was found [9]. Wang et al. used the $Ar^{+}$ ion sputtering process to make the nanocone structure, and they used the transfer matrix method to calculate the reflectance and absorpance of the structure, the absorptance of the structure was higher than 95% in the wavelength between 300 nm and 2000 nm, and they found that the Wood-Rayleigh anomaly effect also affected the absorptance besides the Mie resonance [10].

In this work, the effect of the height and diameter of the periodic unit of the bioinspired parabolic-shaped nanocone (PSNC) arrays on the reflectance, transmittance and absorptance of the structure was calculated using FDTD method. The calculation results showed that the PSNC structure had good antireflection character.

## 2. Simulation model

The schematic of the parabolic-shaped nanocone (PSNC) arrays were shown in Fig. 1(a), the units were placed periodically in the X and Y directions, the height $H$ of the unit had the following relationship with the diameter $D$ of the unit:

$$H = \frac{1}{2Rc} \times \left(\frac{D}{2}\right)^2 \tag{1}$$

where $R_C$ was the curvature radius of the unit. The FDTD method was used to calculate the optical reflectance, transmittance and absorptance of the PSNC arrays, and only one periodic unit was calculated according to the symmetry of the PSNC arrays [11]. The optical parameters of crystalline silicon were used, two perfectly matched layers (PML) were placed above and below the simulated unit, and the period boundary condition (PBC) was used in the $X$ and $Y$ directions as shown in Fig. 1(b). A reflectance monitor was placed above the unit to get the reflectance of the unit, and a transmittance monitor was placed below the unit to get the transmittance of the unit. The light source of plane wave was placed above the unit, and the wavelength was set from 0.3 μm to 1.1 μm according to the solar spectrum and the absorbed wavelength of crystalline silicon. The absorptance of the unit was calculated as follows:

$$\alpha = 1 - R - T \tag{2}$$

where $R$ was the reflectance of the unit, and $T$ was the transmittance of the unit. The average reflectance $R_a$ was calculated as follows:

$$Ra = \frac{\int R(\lambda)I(\lambda)d\lambda}{\int I(\lambda)d\lambda} \tag{3}$$

where $I(\lambda)$ was the light intensity distribution of the AM1.5G spectrum. The average transmittance $T_a$ was calculated as follows:

$$Ta = \frac{\int T(\lambda)I(\lambda)d\lambda}{\int I(\lambda)d\lambda} \tag{4}$$

The average absorptance $\alpha_a$ was calculated according to Formula (2).